Food and Agriculture Organization of the United Nations

COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

ISSN 2412-5474

THE SECOND REPORT ON THE STATE OF THE WORLD'S

ANIMAL GENETIC RESOURCES FOR FOOD AND AGRICULTURE

FAO COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE
ASSESSMENTS • 2015

FAO COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE
ASSESSMENTS • 2015

THE SECOND REPORT ON THE STATE OF THE WORLD's **ANIMAL GENETIC RESOURCES FOR FOOD AND AGRICULTURE**

COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Rome, 2015

Recommended citation:
FAO. 2015. *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B.D. Scherf & D. Pilling. FAO Commission on Genetic Resources for Food and Agriculture Assessments. Rome (available at http://www.fao.org/3/a-i4787e/index.html).

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations (FAO) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The mention of specific companies or products of manufacturers, whether or not these have been patented, does not imply that these have been endorsed or recommended by FAO in preference to others of a similar nature that are not mentioned.

The designations employed and the presentation of material in the map(s) do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal or constitutional status of any country, territory or sea area, or concerning the delimitation of frontiers.

ISBN 978-92-5-108820-3

© FAO, 2015

FAO encourages the use, reproduction and dissemination of material in this information product. Except where otherwise indicated, material may be copied, downloaded and printed for private study, research and teaching purposes, or for use in non-commercial products or services, provided that appropriate acknowledgement of FAO as the source and copyright holder is given and that FAO's endorsement of users' views, products or services is not implied in any way.

All requests for translation and adaptation rights, and for resale and other commercial use rights should be made via www.fao.org/contact-us/licence-request or addressed to copyright@fao.org.

FAO information products are available on the FAO website (www.fao.org/publications) and can be purchased through publications-sales@fao.org.

Contents

Foreword xxi
Acknowledgements xiii
Abbreviations and acronyms xxvii
About this publication xxix
Summary xxxvii

Part 1 The state of livestock diversity

Introduction

SECTION A: ORIGIN AND HISTORY OF LIVESTOCK DIVERSITY 5
1 Introduction 5
2 The domestication process 5
3 Dispersal of domesticated animals 10
4 Introgression from related species 12
5 Adaptation of livestock following domestication 12
6 The recent history of livestock diversity 13
7 Conclusions 15
References 16

SECTION B: STATUS AND TRENDS OF ANIMAL GENETIC RESOURCES 25
1 Introduction 25
2 The state of reporting 25
3 Species diversity and distribution 26
4 Breed diversity and distribution 30
5 Conclusions 41
References 42

SECTION C: FLOWS OF ANIMAL GENETIC RESOURCES 43
1 Introduction 43
2 Status and trends of global gene flows 45
3 Drivers of gene flow in the twenty-first century 57
4 Effects of gene flows 60
5 Conclusions 62
References 62

SECTION D: ROLES, USES AND VALUES OF ANIMAL GENETIC RESOURCES 65
1 Introduction 65
2 Contributions to food production, livelihoods and economic output 66
3 Sociocultural roles 72

4 Ecological roles – the provision of regulating and habitat ecosystem services 73
5 Roles in poverty alleviation and livelihood development 75
6 Conclusions and research priorities 78
References 79

SECTION E: ANIMAL GENETIC RESOURCES AND ADAPTATION 83
1 Introduction 83
2 Global information on adaptations 83
3 Adaptation to non-disease stressors 85
4 Disease resistance and tolerance 89
5 Conclusions and research priorities 100
References 101

SECTION F: THREATS TO LIVESTOCK GENETIC DIVERSITY 109
1 Introduction 109
2 Livestock sector trends 110
3 Disasters and emergencies 126
4 Animal disease epidemics 133
5 Conclusions 135
References 137

SECTION G: LIVESTOCK DIVERSITY AND HUMAN NUTRITION 143
1 Introduction 143
2 Growing interest in food biodiversity 143
3 Filling the knowledge gap 145
4 Potential significance for human nutrition 146
5 Research priorities 149
References 150

Part 2 Livestock sector trends

Introduction
SECTION A: DRIVERS OF CHANGE IN THE LIVESTOCK SECTOR 157
1 Introduction 157
2 Changes in demand 157
3 Changes in trade and retailing 162
4 Changing natural environment 166
5 Advances in technology 170
6 Policy environment 171
References 174

SECTION B: THE LIVESTOCK SECTOR'S RESPONSE 179
1 Landless industrialized production systems 180
2 Small-scale landless systems 184
3 Grassland-based systems 185
4 Mixed farming systems 187
References 189

SECTION C: EFFECTS OF CHANGES IN THE LIVESTOCK SECTOR ON ANIMAL GENETIC RESOURCES AND THEIR MANAGEMENT 193
1 Overview and regional analysis 193
2 Specific effects on animal genetic resources management – examples at country level 199
References 205

SECTION D: LIVESTOCK SECTOR TRENDS AND ANIMAL GENETIC RESOURCES MANAGEMENT – CONCLUSIONS 207
References 208

Part 3 The state of capacities

Introduction
SECTION A: INSTITUTIONS AND STAKEHOLDERS 213
1 Introduction 213
2 Institutional capacities at country level 214
3 Institutional frameworks at subregional and regional levels 226
4 Institutional frameworks and stakeholders at international level 228
5 Changes since 2005 230
6 Conclusions and priorities 235
References 235

SECTION B: CHARACTERIZATION, INVENTORY AND MONITORING 237
1 Introduction 237
2 Development of national breed inventories 237
3 Baseline surveys and monitoring of population sizes 238
4 Phenotypic and molecular genetic characterization 240
5 Constraints to characterization, surveying and monitoring 246
6 Conclusions and priorities 249
References 250

SECTION C: BREEDING PROGRAMMES 251
1 Introduction 251
2 Global overview 251
3 Stakeholder involvement 253
4 Educational, research and organizational capacities 257
5 Breeding methods and activities 259
6 Breeding policies 265
7 Regional overviews 265
8 Changes since 2005 274
9 Conclusions and priorities 274
References 276

SECTION D: CONSERVATION PROGRAMMES 277
1 Introduction 277
2 Global overview 277
3 *In situ* conservation programmes – elements 281
4 *In situ* conservation programmes – the roles of the public and private sectors 291
5 *Ex situ in vitro* conservation programmes 295
6 Regional overviews 297
7 Changes since 2007 306
8 Conclusions and priorities 307
References 307

SECTION E: REPRODUCTIVE AND MOLECULAR BIOTECHNOLOGIES 309
1 Introduction 309
2 Global overview 310
3 Stakeholders involved in service provision and research 316
4 Regional overviews 317
5 Changes since 2005 326
6 Conclusions and priorities 327
References 328

SECTION F: LEGAL AND POLICY FRAMEWORKS 329
1 Introduction 329
2 International frameworks 329
3 Regional frameworks 340
4 National frameworks 355
5 Changes since 2005 403
6 Gaps and needs 404
References 405

Part 4 The state of the art

Introduction

SECTION A: **CHARACTERIZATION, INVENTORY AND MONITORING** **415**

1 Introduction 415
2 Characterization as the basis for decision-making 416
3 Tools for characterization, surveying and monitoring 419
4 Information systems 423
5 Changes since 2005 426
6 Conclusions and research priorities 427
References 429

SECTION B: **MOLECULAR TOOLS FOR EXPLORING GENETIC DIVERSITY** **431**

1 Introduction 431
2 Developments in the use of DNA markers 433
3 Characterization of within-population diversity 435
4 Characterization of between-population diversity 436
5 Molecular tools for targeting functional variation 437
6 The role of bioinformatics 440
7 Conclusions and research priorities 441
References 442

SECTION C: **BREEDING STRATEGIES AND PROGRAMMES** **451**

1 Introduction 451
2 Scientific and technological advances 452
3 The elements of a breeding programme 457
4 Breeding programmes in high-input systems 459
5 Breeding programmes in low-input systems 474
6 Conclusions and research priorities 482
References 485

SECTION D: **CONSERVATION** **497**

1 Introduction 497
2 Planning a conservation strategy 501
3 Identifying breeds at risk 501
4 Determining the conservation value of a breed 503
5 *In vivo* conservation 504
6 Cryoconservation 511
7 Conclusions and research priorities 522
References 523

SECTION E: ECONOMICS OF ANIMAL GENETIC RESOURCES USE AND CONSERVATION **529**
1 Introduction 529
2 Developments in animal genetic resources economics 531
3 Challenges and opportunities 539
References 541

Part 5 Needs and challenges

Introduction
SECTION A: CHALLENGES POSED BY LIVESTOCK SECTOR TRENDS **553**

SECTION B: CHARACTERIZATION AND MONITORING **555**

SECTION C: SUSTAINABLE USE AND DEVELOPMENT **557**

SECTION D: CONSERVATION **559**

SECTION E: POLICIES, INSTITUTIONS AND CAPACITY-BUILDING **561**

Annexes **(on CD-ROM and on the web at http://www.fao.org/3/a-i4787e/index.html)**

Country reports
Survey responses – national legal and policy frameworks
Reports from regional focal points and networks
Reports from international organizations
Thematic studies
Supplementary tables for Part 3
List of references reviewed for Part 4 Section E – Economics of animal genetic resources use and conservation
List of authors, reviewers and their affiliations

BOXES

1 The first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (2007) xxix
2 The Commission on Genetic Resources for Food and Agriculture xxx

PART 1

1A1 How the history of livestock is reconstructed: archaeology and DNA 6
1A2 Livestock diversity as revealed by molecular studies 15

1B1 Developments since the publication of the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* 26
1B2 Glossary: populations, breeds, breed classification systems and regions 27
1B3 Glossary: risk-status classification 34

1C1 Trends in gene flows into and out of Kenya 50
1C2 Gene flows into and out of Thailand 50
1C3 Gene flows into Senegal 51
1C4 Gene flows into and out of South Africa 52
1C5 Gene flows between Uganda and other developing countries 54
1C6 Brazil's role as an exporter of genetic resources 55
1C7 Influence of policies on gene flows into Cameroon 58
1C8 Effect of a disease outbreak on inward gene flow – an example from the Republic of Korea 59

1D1 Categories of ecosystem services 74
1D2 The use of livestock in the provision of ecosystem services – examples from the United States of America 75
1D3 A special sheep breed helps to preserve centuries-old grassland in the Alps 76
1D4 The use of livestock in the provision of ecosystem services – examples from Poland 77

1E1 Yakutian cattle – a breed well adapted to subarctic climatic conditions 88

1F1 Production system changes as threats to animal genetic resources – a view from Africa 112
1F2 The potential impact of climate change on breed distribution – an example from Kenya 114
1F3 Animal genetic resources and access to grazing land – an example from India 115
1F4 Indiscriminate cross-breeding as a threat to animal genetic resources in Egypt 116
1F5 Lessons from history? Breed extinctions and near extinctions during the nineteenth century 118

1F6 The near extinction of the Cleveland Bay horse of the United Kingdom 119
1F7 The near extinction of the Lleyn sheep of the United Kingdom 119
1F8 Threats to animal genetic resources in Ethiopia 120
1F9 Threats to animal genetic resources in Mozambique 123
1F10 Shifting consumer demand as a threat to animal genetic resources – examples from around the world 123
1F11 Threats to animal genetic resources in the United States of America 124
1F12 Threats to animal genetic resources in Peru 124
1F13 Threats to animal genetic resources in Botswana 125
1F14 Effects of predation on sheep production in Norway 125
1F15 Projections for the risk of climatic disasters 130
1F16 The European Livestock Breeds Ark and Rescue Net 135

PART 2

2A1 Demand for animal-source foods from minority species and breeds 165
2A2 Development of the poultry sector in Thailand 167

2C1 Efficiency and multifunctionality in extensive livestock systems 197
2C2 Shift of livestock species as a result of climate change: an example from Ethiopia 197
2C3 Animal genetic resources management in Iceland: will exotic breeds substitute locally adapted breeds? 200
2C4 The potential influence of genomics on the utilization of at-risk breeds 204

PART 3

3A1 Strategic Priority Area 4 of the Global Plan of Action for Animal Genetic Resources 213
3A2 Elements of the recommended national institutional framework for the management of animal genetic resources 214
3A3 The role of the National Coordinator for the Management of Animal Genetic Resources 215
3A4 Facilitating the establishment of institutional frameworks for animal genetic resources management – lessons from a project in Bulgaria 229
3A5 FAO's role in the management of animal genetic resources 230
3A6 The Domestic Animal Diversity Network (DAD-Net) 231
3A7 Livestock Keepers' Rights 233

3B1 Characterization – definitions of terms 238
3B2 China's second national animal genetic resources survey 247
3B3 BushaLive – a collaborative project to characterize the Busha cattle of the Balkans 248

3C1 Sheep breeding in Tunisia 267
3C2 Kazakhstan's plan for the development of the beef-cattle industry 269

3C3	Using exotic genetics in the dairy sector – experiences from Poland	270
3C4	Beef cattle breeding in Brazil	272
3C5	Sheep breeding in Jordan	273
3D1	Implementing a conservation programme – experiences from China	290
3D2	Dyeing sheep wool naturally in 35 colours: indigenous production systems and associated traditional knowledge – a case from Argentina	291
3D3	The conservation network for the Finnish Landrace chicken	292
3D4	Iberian pigs in Spain – sustained through product labelling	293
3D5	Reconstituting a research pig line	301
3D6	Conservation of the Gembrong goat of Bali (Indonesia): a breed brought close to extinction by nylon fishing line	302
3D7	Switzerland's virtual national gene bank – building on the work of the commercial sector	303
3D8	Development of the European Gene Bank Network for Animal Genetic Resources	305
3E1	Glossary: biotechnologies	309
3E2	Glossary: production systems	314
3E3	The use of reproductive technologies in South Africa	321
3E4	The use of reproductive technologies in Botswana	321
3E5	Artificial insemination in sheep and goats – an Indian experience	323
3E6	Biotechnologies for livestock production in Brazil – use and research	325
3E7	Use of biotechnologies in livestock production in the United States of America	326
3F1	Findings of a patent landscape report on animal genetic resources	338
3F2	Viet Nam's legal framework for animal genetic resources management	364
3F3	Albania's Law No. 9426 on Livestock Breeding	365
3F4	The Punjab Livestock Breeding Act 2014 (Pakistan)	366
3F5	The legal basis for Turkey's animal genetic resources management programme	367
3F6	Official recognition of livestock breeds in Brazil	371
3F7	Registration of livestock breeds in Indonesia	372
3F8	The legal and policy framework for breeding programmes in Bhutan	376
3F9	The legal framework for the use of reproductive biotechnologies in Brazil	377
3F10	The legal basis for animal genetic resources conservation in Poland	381
3F11	The regulatory framework for the use of genetically modified organisms in Australia	385
3F12	Animal genetic resources management in Kenya's National Livestock Policy	398

PART 4

4A1	Phenotypic and molecular characterization	416
4A2	Elements of a country-based early warning and response system	417
4A3	Surveying and monitoring methods – a toolbox	421
4A4	A digital enumeration method for collecting phenotypic data for genome association	424
4A5	Biogeoinformatics for the management of animal genetic resources	426
4A6	Rumen microbes: small but significant	428
4B1	From DNA to phenotype	432
4B2	Glossary: genetic markers	434
4B3	How genetic tools helped to solve the mystery of the origin of the Booroola gene	438
4B4	What are the promises of the post-genomic era?	441
4B5	The reality and promises of epigenetics for animal production	442
4C1	Reduction of genetic variability and its consequences in cattle breeds	452
4C2	Genetically modified animals in agriculture	456
4C3	Adoption of genomic selection in French dairy sheep breeds	465
4C4	Improving the system of sheep breeding in Ireland	466
4C5	GENECOC – the breeding programme for meat goats and sheep in Brazil	478
4C6	Establishing a cross-breeding scheme for dairy goats in the United Republic of Tanzania	479
4C7	Community-driven breeding programmes for locally adapted pig breeds in Viet Nam	480
4C8	Genetic selection for reduced methane production – a future tool for climate change mitigation	484
4D1	Glossary: *in vivo* and *in vitro* conservation	497
4D2	Analysis of strengths, weaknesses, opportunities and threats (SWOT analysis) of Groningen White Headed cattle in the Netherlands	500
4D3	Biocultural community protocols	506
4D4	Identifying keys to success in breed conservation and development in France: the VARAPE project	510
4D5	Indigenous people and scientists team up to conserve Pantaneiro cattle in Brazil	512
4D6	A study of the comparative costs of *in vivo* and cryoconservation programmes for chickens	519
4D7	Use of induced pluripotent stem cells in *in vitro* conservation	520
4D8	Bilateral agreement on sanitary issues in germplasm exchange – an example	521
4E1	Biodiversity valuation, ecosystem services and animal genetic resources	533
4E2	Environmental valuation methods	534

TABLES

1	Regional overview of country reporting	xxxiii
2	List of country reports	xxxiii

PART 1

1A1	Domestication, disperal and sources of introgresssion	8
1A2	Examples of genes or loci involved in selected traits	14
1B1	Status of information recorded in the Global Databank for Animal Genetic Resources	27
1B2	Number of reported mammalian local breeds	32
1B3	Number of reported avian local breeds	32
1B4	Number of reported mammalian transboundary breeds	33
1B5	Number of reported avian transboundary breeds	33
1B6	Number of extinct mammalian breeds reported	40
1B7	Number of extinct avian breeds reported	40
1B8	Breed extinction over time	41
1C1	Regional shares of germplasm exports and imports in the twenty-first century	48
1D1	Global output of animal-source foods (2004 and 2012)	67
1E1	Adaptations in cattle breeds as recorded in DAD-IS	84
1E2	Adaptations in sheep breeds as recorded in DAD-IS	84
1E3	Adaptations in equine breeds as recorded in DAD-IS	85
1E4	Examples of studies indicating breed differences in resistance, tolerance or immune response to specific diseases	91
1E5	Number of mammalian breed populations recorded in DAD-IS as having resistance or tolerance to specific diseases or parasites	92
1E6	Breeds recorded in DAD-IS as showing resistance or tolerance to trypanosomosis	93
1E7	Breeds recorded in DAD-IS as showing resistance or tolerance to tick burden	94
1E8	Breeds recorded in DAD-IS as showing resistance or tolerance to tick-borne diseases	94
1E9	Breeds recorded in DAD-IS as showing resistance or tolerance to internal parasites	95
1E10	Cattle breeds recorded in DAD-IS as showing resistance or tolerance to leukosis	96
1E11	Breeds recorded in DAD-IS as showing resistance or tolerance to foot rot	97
1E12	Avian breeds recorded in DAD-IS as showing resistance to diseases	99

1F1 Estimates of effective population size in transboundary breeds based on genealogical or molecular data 111
1F2 Factors reported in the country reports as causes of genetic erosion 122

1G1 Nutrient composition of selected animal-source foods 144
1G2 Selected nutrient composition ranges for milk from buffalo, horse and dromedary breeds 147
1G3 Selected nutrient composition ranges for beef (longissimus muscle) from different cattle breeds 148
1G4 Mineral content of milk from various species in relation to recommended nutrient intake 149

PART 2

2A1 Previous and projected trends in meat consumption 158
2A2 Previous and projected trends in milk consumption 159
2A3 Growth in per capita demand for livestock products from 2000 to 2030 160
2A4 Direct and indirect effects of climate change on livestock production systems 168
2A5 Change in area of arable and pasture land (2000 to 2010) 169
2A6 A policy framework for inclusive growth of the livestock sector 173

2B1 Livestock production systems classification 179

2C1 Drivers of change explored in the country-report questionnaire 194
2C2 Past and predicted future impacts of livestock sector trends and drivers on animal genetic resources and their management 198

PART 3

3A1 Reported extent of collaboration in the management of the various subsectors of genetic resources for food and agriculture 225
3A2 Organizations supporting animal genetic resources management at regional and international levels 232
3A3 Institutions and stakeholders – changes 2005 to 2014 234

3B1 Coverage of baseline surveys and monitoring programmes for the big five species 239
3B2 Coverage of baseline surveys and monitoring programmes for cattle 241
3B3 Coverage of baseline surveys and monitoring programmes for sheep, goats, pigs and chickens 242
3B4 Characterization activities for the big five species – average scores 245

3C1 Proportion of countries reporting the existence of breeding programmes – regional breakdown 252

3C2	Proportion of countries reporting the existence of breeding programmes – species breakdown	253
3C3	Extent of involvement of different stakeholder groups as operators of breeding programmes	254
3C4	Level of organization of livestock keepers with respect to animal breeding activities	261
3C5	Level of implementation of breeding-programme elements and techniques – regional breakdown	262
3C6	Level of implementation of breeding-programme elements and techniques – species breakdown	263
3C7	Proportion of breeds reported to be subject to breeding programmes applying straight/pure-breeding and cross-breeding	264
3D1	Proportion of countries reporting conservation activities	278
3D2	Breed coverage in conservation activities for the big five species – average scores	281
3D3	Proportion of countries reporting *in situ* conservation programmes	282
3D4	Proportion of countries reporting *ex situ in vivo* conservation programmes	283
3D5	Proportion of countries reporting *ex situ in vitro* conservation programmes	284
3D6	Level of breed coverage in conservation programmes for "minor" species	285
3D7	Proportion of countries reporting the use of elements of *in situ* conservation – species breakdown	287
3D8	Proportion of countries reporting the use of elements of *in situ* conservation – regional breakdown	288
3D9	Proportion of countries reporting the presence of *in vitro* gene banks, the storage of different types of genetic material, and plans for international collaboration in gene banking	296
3D10	Breed coverage of the big five species in gene banks	298
3D11	Breed coverage of "minor" species in gene banks	299
3D12	Characteristics and functions of national gene banks	300
3E1	Use of reproductive and molecular biotechnologies – regional breakdown	310
3E2	Use of advanced reproductive and molecular biotechnologies – regional breakdown	311
3E3	Level of availability of reproductive and molecular technologies for use in livestock production – big five species	312
3E4	Level of use of artificial insemination and sources of semen	315
3E5	Use of reproductive and molecular technologies – selected "minor" species	316
3E6	Stakeholder involvement in the provision of artificial insemination and embryo transfer services	318
3E7	Proportion of countries reporting research on reproductive biotechnologies	319
3E8	Proportion of countries reporting research on molecular biotechnologies	320
3E9	Changes in the level of use of reproductive biotechnologies since 2005	327

3F1 Priority levels of implementation of the strategic priorities of the Global Plan of Action for Animal Genetic Resources 331
3F2 Indicator scores for the implementation of the strategic priority areas of the Global Plan of Action for Animal Genetic Resources 332
3F3 Progress in the development of legal and policy frameworks 404

PART 4

4A1 Usefulness of different surveying and monitoring tools to address different survey questions 423

4B1 Examples of non-disease phenotypes specific to one or more livestock breeds 439

4C1 Selection criteria in dairy cattle 461
4C2 Selection criteria in beef cattle 461
4C3 Recessive haplotypes tracked in the genomic evaluation system in the United States of America 462
4C4 Selection criteria in sheep 464
4C5 Selection criteria in goats 466
4C6 Selection criteria in pigs 468
4C7 Cross-breeding scheme and relative numbers in a typical broiler breeding programme 469
4C8 Selection criteria in poultry 471
4C9 Selection criteria in rabbits 473
4C10 Characteristics of conventional and community-based livestock breeding programmes 477
4C11 Selected community-based breeding programmes 477

4D1 Conservation methods and their potential to contribute to various objectives 499
4D2 Risk categories for species with high reproductive capacity 502
4D3 Risk categories for species with low reproductive capacity 502
4D4 Relative importance of population management objectives according to risk status 503

4E1 Overview of livestock breed and trait valuation studies by region (2006 to 2014) 535

FIGURES

1 Assignment of countries to regions and subregions in this report xxxv

PART 1

1A1 Three pathways of domestication 7
1A2 Major centres of livestock domestication as inferred from archaeological and molecular genetic evidence 10

1B1 Proportion of national breed populations for which population figures have been reported 28
1B2 Regional distribution of livestock species in 2012 29
1B3 Number of local and transboundary breeds at global level 31
1B4 Number of local and transboundary breeds at regional level 31
1B5 Proportion of the world's breeds by risk status category 35
1B6 Risk status of the world's mammalian breeds in June 2014 – species breakdown 36
1B7 Risk status of the world's avian breeds in June 2014 – species breakdown 37
1B8 Risk status of the world's mammalian breeds in June 2014 – regional breakdown 38
1B9 Risk status of the world's avian breeds June 2014 – regional breakdown 39
1B10 Changes in breed risk status between 2006 and 2014 41

1C1 Trends in the value of global exports of live animals and bovine semen 45
1C2 Do gene flows into and out of your country correspond to the pattern of North–North and/or North–South exchanges? 46
1C3 Trade in pig and bovine genetic resources between OECD and non-OECD countries (2005 to 2012) 47
1C4 Net exporters and importers of bovine semen (2006 to 2012) 49
1C5 South Africa's trade in live pure-bred cattle and bovine semen 56
1C6 Brazil's trade in live pure-bred cattle and bovine semen 57

PART 2

2A1 Demand growth for poultry meat in China and India (2000 to 2030) 162
2A2 Net meat trade of major importer and exporter country groups 163

2B1 Distribution of livestock production systems 180
2B2 Production from the main livestock production systems 181
2B3 Meat production trends in developing and developed countries (1981 to 2050) 182
2B4 Proportion of pigs and poultry raised in intensive systems in 2005 183
2B5 Agricultural land available per person economically active in agriculture 188

2C1 Past and predicted future impacts of the drivers of change on animal genetic resources and their management 195

PART 3

3A1	Submission of country reports and nomination of National Coordinators for the Management of Animal Genetic Resources	216
3A2	Employment affiliations of National Coordinators for the Management of Animal Genetic Resources	217
3A3	Status of National Advisory Committees for Animal Genetic Resources	217
3A4	Overview of the state of institutions in animal genetic resources management	218
3A5	State of institutions in animal genetic resources management – Africa	219
3A6	State of institutions in animal genetic resources management – Asia	219
3A7	State of institutions in animal genetic resources management – Latin America and the Caribbean	220
3A8	Indicators for the implementation of Strategic Priority Area 4 of the Global Plan of Action for Animal Genetic Resources	220
3A9	State of infrastructure and stakeholder participation	221
3A10	State of education, research and knowledge	221
3A11	State of policy development	222
3B1	Progress in the establishment of national breed inventories	240
3B2	Characterization activities for the big five species – frequency of responses	243
3B3	Characterization activities for "minor" species	244
3C1	Stakeholder involvement in breeding-related activities in ruminants and monogastrics – global averages	256
3C2	Involvement of breeders' associations in breeding programmes and elements of breeding programmes	257
3C3	State of training in the field of animal breeding	258
3C4	State of implementation of training and technical support programmes for the breeding activities of livestock-keeping communities	259
3C5	State of research in the field of animal breeding	260
3C6	Proportion of countries reporting breeding programmes and policies supporting breeding programmes	266
3C7	Implementation of breeding tools in cattle (2005 and 2014)	275
3D1	Coverage of *in situ* conservation programmes for the big five livestock species	279
3D2	Breed coverage in conservation activities for the big five species – frequency of responses	280
3D3	Involvement of public and private institutions in the implementation of *in situ* conservation programme elements	294
3D4	State of development of *in vitro* gene banks for animal genetic resources	297
3D5	State of conservation programmes and policies at country level and progress since 2007	306

3E1 Level of availability of reproductive technologies 313

3F1 The status of national strategy and action plans for animal genetic resources 360
3F2 State of development of legal and policy instruments 362
3F3 Types of conservation targeted by legal and policy instruments 379
3F4 Inclusion of animal genetic resources issues in national biodiversity strategies and action plans 400

PART 4

4A1 Management of breed populations – flow chart of decisions 418
4A2 Descriptor system for production environments 419

4B1 Change in cost per genome sequenced in humans 431

4C1 Structure of the poultry breeding industry 470

4D1 Interactions among the potential stakeholders of a community-based conservation programme 505

4D2 A decentralized *ex situ* conservation programme involving institutional herds and private breeders 507

4E1 Breed production functions, public-good values and replacement opportunity costs 532

Foreword

Domesticated animals contribute directly to the livelihoods of millions of people, including an estimated 70 percent of the world's rural poor. In 2007, through the adoption of the Global Plan of Action for Animal Genetic Resources, the international community recognized the vital importance of the world's livestock biodiversity for agriculture, rural development and food and nutrition security.

Eight years later, the conservation and sustainable management of animal genetic resources remains a vital and challenging task. The global livestock sector is continuously evolving, with new centres of growth emerging and rapid technological developments. The challenges posed by population growth and climate change are ever more present.

The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture – another milestone in the work of FAO's Commission on Genetic Resources for Food and Agriculture – provides a comprehensive and updated assessment of current livestock biodiversity. It draws on information provided by 129 countries, 15 international organizations, 4 networks and regional focal points and inputs from 150 authors and reviewers.

The preparation of *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture* offered an opportunity to review progress made in the implementation of the Global Plan of Action. It was a chance to re-evaluate the opportunities and challenges facing national authorities, livestock keepers, breeders and scientists and to identify future priorities for action.

Many countries have made progress in the establishment of the policies, programmes and institutional frameworks needed to promote the sustainable management of livestock diversity. Many weaknesses still need to be addressed, particularly in developing countries. Smallholder and pastoralist production systems that are home to much of the world's livestock diversity continue to be under a range of pressures.

A substantial proportion of the world's livestock breeds remain at risk of extinction. The characteristics of many of them have not been adequately studied, and this genetic wealth could be lost before it can be used for helping farmers, pastoralists and animal breeders to meet current and future production challenges.

Knowledge gaps are still a major concern. Monitoring of trends in the size and structure of breed populations is often inadequate, which impedes the estimation of risk status. Threats have been broadly identified, but the detailed information that could be used to prioritize and plan action at the national level is often lacking.

The priorities set out in the Global Plan of Action for Animal Genetic Resources remain broadly relevant today. Many countries have prepared national strategies and action plans for animal genetic resources, or are in the process of doing so, as a means to translate the provisions of the Global Plan of Action into targeted activities at country level. Nevertheless, constraints to implementation remain. The Global Plan of Action emphasizes the importance of international collaboration as a means of

strengthening capacity in developing countries, and recognizes the need for substantial additional financial resources for animal genetic resource management. While there have been positive developments, both collaboration and the provision of funding still need to be strengthened.

Genetic diversity is a mainstay of resilience and a prerequisite for adaptation in the face of future challenges. I trust that this report will help underpin renewed efforts to ensure that animal genetic resources are used and developed to promote global food security, and remain available for future generations.

José Graziano da Silva
FAO Director-General

Acknowledgements

This report could not have been prepared without the assistance of the many individuals who generously contributed their time, energy and expertise, and the collaboration and support of governments. FAO would like to take this opportunity to acknowledge these contributions.

The core of the information used in the preparation of *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture* was provided by the 129 governments that submitted country reports; the first and most important acknowledgement therefore goes to these governments and to all the individuals at country level who contributed to these reports and to the updating of breed-related data in the Domestic Animal Diversity Information System (DAD-IS), in particular National Coordinators for the Management of Animal Genetic Resources and their colleagues. The African Union – Interafrican Bureau for Animal Resources (AU-IBAR) was instrumental in mobilizing African National Coordinators and supported their training in the preparation of country reports. Thanks are also due to everyone who contributed to the preparation of the reports submitted by international organizations and regional focal points and networks for animal genetic resources. The preparation of the report would not have been possible without the financial and in-kind support provided by the Governments of France, Germany, Norway and Spain.

The report was prepared by FAO's Animal Genetic Resources Branch, Animal Production and Health Division. The reporting process and the preparation of the report were coordinated by Beate Scherf with the assistance of Dafydd Pilling. The work was facilitated and supported by the Chief of Animal Genetic Resources Branch, Irene Hoffmann, and all officers of the Branch: Roswitha Baumung, Badi Besbes, Paul Boettcher, Mateusz Wieczorek and Grégoire Leroy (seconded by the French Government). The work was further supported by a number of interns: Bendik Elstad (Norway), Tatiana From (Russian Federation), Katherine Hall (United Kingdom), Claire-Marie Luitaud (France) and Jessica Miller (United States of America).

The database of country-report data was designed, created, loaded and pre-analysed by a team from FAOs Information Technology Division led by Gianluca Franceschini and Karl Morteo. Daniel Martin-Collado undertook much of the database analysis for Part 3 of the report. Peter Deupmann of FAO's Legal Office provided support to the organization of the survey on legal and policy measures and related work. David Steane contributed to the reviewing of draft country reports. Oliver Mundy contributed to the communication strategy for the launch of the report. Administrative and secretarial support was provided by Kafia Fassi-Fihri and Umberto Ciniglio.

Throughout the preparation process, support and encouragement were received from the Secretariat of the Commission on Genetic Resources for Food and Agriculture, as well as from the Director of FAO's Animal Production and Health Division, Berhe G. Tekola.

150 individuals from more than 40 countries contributed to the preparation of the report as authors or reviewers. Details are provided below, section by section. An alphabetical list of authors and reviewers and their contact details is provided in the annex to the report (on CD-ROM and at http://www.fao.org/3/a-i4787e/i4787e195.pdf).

Authors and reviewers[1]

Part 1 THE STATE OF LIVESTOCK DIVERSITY

Section A: Origin and history of livestock diversity
Author: Johannes Lenstra
Reviewers: Gus Cothran, Charles Moses Liymo, Steffen Weigend, Pam Wiener

Section B: Status and trends of animal genetic resources
Authors: Roswitha Baumung, Mateusz Wieczorek
Reviewer: Mary Mbole-Kariuki

Section C: Flows of animal genetic resources
Authors: Claire-Marie Luitaud, Dafydd Pilling
Reviewers: Arthur Da Silva Mariante, Keith Ramsay

Section D: Roles, uses and values of animal genetic resources
Author: Dafydd Pilling
Reviewers: Ilse Köhler-Rollefson, Chanda Bonbehari Nimbkar

Section E: Animal genetic resources and adaptation
Authors: Paul Boettcher, Aynalem Haile, Katherine Hall, Jessica Louise Miller, Tadele Mirkena, Beate Scherf, Maria Wurzinger
Reviewers (Subsection 4): Donagh Berry, Stephen Bishop, Larry Kuehn, Marie-Hélène Pinard-van der Laan

Section F: Threats to livestock genetic diversity
Author: Dafydd Pilling
Reviewers: Kefyalew Alemayehu, Siboniso Moyo

Section G: Livestock diversity and human nutrition
Author: Doris Rittenschober
Reviewers: Ruth Charrondiere, Dominique Gruffat, Jean-François Hocquette, Ramani Wijesinha-Bettoni

Part 2 LIVESTOCK SECTOR TRENDS

Section A: Drivers of change in the livestock sector
Authors: Claire-Marie Luitaud, Anni McLeod

Section B: The livestock sector's response
Authors: Claire-Marie Luitaud, Anni McLeod

Section C: Effects of changes in the livestock sector on animal genetic resources and their management
Authors: Grégoire Leroy, Claire-Marie Luitaud, Dafydd Pilling

Section D: Livestock sector trends and animal genetic resources management – conclusions
Author: Dafydd Pilling
Reviewers of Part 2: Alejandro Acosta, Harinder Makkar

Part 3 THE STATE OF CAPACITIES

Section A: Institutions and stakeholders
Authors: Katherine Hall, Dafydd Pilling
Reviewers: Vera Matlova, Joseph L.N. Sikosana

[1] Listed in alphabetical order within each section.

Section B: Characterization, inventory and monitoring
Author: Daniel Martin-Collado, Dafydd Pilling
Reviewers: Workneh Ayalew, Kathiravan Periasamy, Michèle Tixier-Boichard

Section C: Breeding programmes
Author: Daniel Martin-Collado
Reviewers: Vlatka Cubric Curik, Olaf Thieme

Section D: Conservation programmes
Author: Daniel Martin-Collado
Reviewer: Kor Oldenbroek

Section E: Reproductive and molecular biotechnologies
Author: Daniel Martin-Collado
Reviewer: Oswin Perera

Section F: Legal and policy frameworks
Authors: Dafydd Pilling, with contributions from Bendik Elstad, Dan Leskien, Irene Kitsara, Brittney Martin and Elżbieta Martyniuk
Reviewers: Harvey Blackburn, Olivier Diana, Dan Leskien, Oliver Lewis, Sipke Joost Hiemstra, Gigi Manicad, Arthur da Silva Mariante, Sergio Pavon

Part 4 THE STATE OF THE ART

Section A: Surveying, monitoring and characterization
Authors: Paul Boettcher, Beate Scherf,
Reviewers: Workneh Ayalew, Xavier Rognon

Section B: Molecular tools for exploring genetic diversity
Authors: Mike Bruford, Grégoire Leroy, Pablo Orozco-terWengel, Andrea Rau, Henner Simianer
Reviewers: Bertrand Bed'Hom, Christine Flury, Catarina Ginja, Johannes Lenstra, Michael Stear

Section C: Breeding strategies and programmes
Authors: Peter Amer, Daniel Allain, Santiago Avendano, Manuel Baselga, Paul Boettcher, João Dürr, Hervé Garreau, Elisha Gootwine, Gustavo Gutierrez, Pieter Knap, Eduardo Manfredi, Victor Olori, Rudolf Preisinger, Juan Manuel Serradilla, Miriam Piles, Bruno Santos, Kenneth Stalder
Reviewers: Hélène Larroque, Tadele Mirkena, Joaquin Pablo Mueller, Julie M.F. Ojango, Mauricio Valencia Posadas

Section D: Conservation
Authors: Harvey Blackburn, Paul Boettcher, Kor Oldenbroek
Reviewers: Andréa Alves do Egito, Jesús Fernández Martín, Sipke Joost Hiemstra, Samuel Rezende Paiva, Geoff Simm

Section E: Economics of animal genetic resources use and conservation
Authors: Workneh Ayalew, Adam Drucker, Kerstin Zander
Reviewer: Giovanni Signorello

Part 5 NEEDS AND CHALLENGES
Author: Beate Scherf

The manuscript was further reviewed by Stuart Barker (Parts 1 and 2), David Notter (Parts 1, 2, 4 and 5), David Steane and Akke J. Van der Zijpp (Parts 1, 2 and 5). All the officers of FAO's Animal Genetic Resources Branch also contributed to the reviewing process.

Text boxes were prepared by Aron Batubara, Harvey Blackburn, Elli Broxham, Tobias Bühlmann, Adrian Cookson, Christèle Couzy, Yvette De Haas, Sebastián de la Rosa, Solange Duruz, Gemma Henderson, Sipke Joost Hiemstra, Erika Hiltbrunner, Mervi Honkatukia, Heather J. Huson, Peter Janssen, Stéphane Joost, Talgat Karymsakov, Bill Kelly, Sajjad Khan, Jason K. Kinser, Eirini Kitsara, Ilse Köhler-Rollefson, Christian Körner, Kristaq Kume, Sinead Leahy, Johannes Lenstra, I Made Londra, Catherine Marguerat, Arthur Da Silva Mariante, Lucie Markey, Elżbieta Martyniuk, Evelyn Mathias, Yakobo Msanga, Philipp Muth, Chanda Bonbehari Nimbkar, Raimundo Nonato Braga Lôbo, Cleopas Okore, Bertrand Pain, Boulbaba Rekik, Fred Silversides, Tad S. Sonstegard, Johann (Hans) Sölkner, Sylvie Stucki, Thi Thuy Le, Bess Tiesnamurti, Sergio Ulhoa Dani, Anne Valle Zárate, Curtis P. Van Tassell, Iosif I. Vaisman, Marcus Vinicius de Oliveira, Klaus Wimmers, Jennifer Woodward-Greene, Hongjie Yang and Tobias Zehnder.

The thematic study *Ecosystem services provided by livestock species and breeds with special consideration to the contributions of small-scale livestock keepers and pastoralists* was prepared by Irene Hoffmann, Tatiana From and David Boerma. The study *Patent landscape report on animal genetic resources* was prepared by Paul Oldham, Stephen Hall and Colin Barnes, with contributions from Irene Hoffmann and Paul Boettcher.

The draft report was made available for review by members and observers of the Commission on Genetic Resources for Food and Agriculture. Comments, submitted by the respective National Coordinators for the Management of Animal Genetic Resources, were received from the Governments of Brazil, Indonesia, Mongolia, the Netherlands, Slovakia, Turkey and the United States of America and from a review group established by the European Regional Focal Point for Animal Genetic Resources.

The layout was designed by Simona Capocaccia and implemented by Enrico Masci under the supervision of Claudia Ciarlantini.

Listing every person by name is not easy and carries with it the risk that someone may be overlooked. Apologies are conveyed to anyone who provided assistance but whose name has been omitted.

Abbreviations and acronyms

AI	artificial insemination
AnGR	animal genetic resources for food and agriculture
BLUP	best linear unbiased prediction
CBD	Convention on Biological Diversity (https://www.cbd.int)
CGIAR	Consultative Group on International Agricultural Research (http://www.cgiar.org)
CGRFA	Commission on Genetic Resources for Food and Agriculture (http://www.fao.org/nr/cgrfa)
DAD-IS	Domestic Animal Diversity Information System (http://www.fao.org/dad-is)
DNA	deoxyribonucleic acid
EBV	estimated breeding value
EU	European Union (http://europa.eu)
GEBV	genomic estimated breeding value
ICAR	International Committee for Animal Recording (http://www.icar.org)
MAS	marker-assisted selection
MOET	multiple ovulation and embryo transfer
OIE	World Organisation for Animal Health (Office International des Epizooties) (http://www.oie.int)
QTL	quantitative trait locus
SNP	single nucleotide polymorphism
TEV	total economic value
WIPO	World Intellectual Property Organization (http://www.wipo.int)
WTO	World Trade Organization (http://www.wto.org)

First SoW-AnGR	(first report on) *The State of the World's Animal Genetic Resources for Food and Agriculture*
Second SoW-AnGR	*The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture*

About this publication

Background

This report serves as an update of the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (see Box 1), published in 2007,[1] which provided the basis for the development of the Global Plan of Action for Animal Genetic Resources,[2] adopted in 2007 as the first internationally agreed framework specifically targeting the management of livestock biodiversity.

Box 1

The first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (2007)

The State of the World's Animal Genetic Resources for Food and Agriculture,[1] the first comprehensive global assessment of livestock biodiversity and its management, was published by FAO in 2007. The report was the outcome of an extensive reporting and preparatory process initiated by the Commission on Genetic Resources for Food and Agriculture in 1999. In March 2001, FAO invited 188 countries to submit country reports on their animal genetic resources. The intention was that the preparation of these reports (in addition to providing the basis for a global assessment) would help countries to identify national priorities for action in the sustainable use, development and conservation of animal genetic resources. While countries were provided with guidelines and a proposed structure for their reports, the process was not based on a standardized questionnaire.

Between 2002 and 2005, FAO received 169 country reports. These were complemented by 9 reports from international organizations[2] and 12 thematic studies[3] commissioned to address specific aspects of animal genetic resources management. More than 90 authors and reviewers were involved in the preparation of the main report. The country reports, reports from international organizations and thematic studies, along with subregional and regional reports on animal genetic resources, were provided on the CD-ROM that accompanied the report. This material is also all available on the web site of FAO's Animal Production and Health Division.[4]

The report was published in seven languages and an "in brief" version in more than ten languages. The report was launched at the first International Technical Conference on Animal Genetic Resources for Food and Agriculture,[5] held in Interlaken, Switzerland, in September 2007. The conference also adopted the Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration on Animal Genetic Resources.

[1] FAO. 2007a. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at www.fao.org/3/a-a1250e.pdf).

[2] ftp://ftp.fao.org/docrep/fao/010/a1250e/annexes/Reports from International Organizations/IntOrganisationReports.pdf

[3] ftp://ftp.fao.org/docrep/fao/010/a1250e/annexes/Thematic Studies/ThematicStudies.pdf

[4] http://www.fao.org/ag/againfo/programmes/en/genetics/first_state.html

[5] http://www.fao.org/ag/againfo/programmes/en/genetics/angrvent2007.html

[1] FAO. 2007a. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at www.fao.org/3/a-a1250e.pdf).

[2] FAO. 2007b. *The Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration*. Rome (available at http://www.fao.org/docrep/010/a1404e/a1404e00.htm).

Box 2

The Commission on Genetic Resources for Food and Agriculture

With its 178 member countries, the Commission on Genetic Resources for Food and Agriculture offers an intergovernmental forum where global consensus can be reached on policies relevant to biodiversity for food and agriculture. The main objective of the Commission is to ensure the conservation and sustainable use of genetic resources for food and agriculture and the fair and equitable sharing of benefits derived from their use, for present and future generations. Its work focuses on developing and overseeing the implementation of policies and supporting initiatives that raise awareness and seek to solve emerging problems. It guides the preparation of periodic global assessments of the status and trends of genetic diversity, the threats facing genetic diversity and the measures being taken to promote its conservation and sustainable use. The Commission also negotiates global action plans, codes of conduct and other instruments relevant to the conservation and sustainable use of genetic resources for food and agriculture.

FAO's reports on the state of the world's genetic resources are prepared under the guidance of the Commission on Genetic Resources for Food and Agriculture[3] (see Box 2). To date, in addition to the first SoW-AnGR, two reports have been published on plant genetic resources for food and agriculture (1998 and 2010)[4] and one on forest genetic resources (2014).[5]

Scope and contents of the report

This report addresses the sustainable use, development and conservation of animal genetic resources for food and agriculture (AnGR) worldwide. The term AnGR here refers to the genetic resources of mammalian and avian species used or potentially used for food and agriculture. The report consists of the following five parts.

Part 1 provides a broad overview of livestock diversity, including the origins and history of AnGR, the status and trends of AnGR (the state of genetic diversity as indicated by the risk status of breed populations), the state of gene flows (movements of AnGR around the world), the uses, roles and values of AnGR, the adaptedness of AnGR to environmental stressors, threats to AnGR, and the influence of genetic diversity on the composition of animal-source food products.

Part 2 discusses livestock-sector trends and how they are affecting AnGR and their management.

Part 3 discusses the state of capacity to manage AnGR, including institutional frameworks, programmes for inventory, characterization and monitoring, breeding strategies and programmes, conservation programmes, the use of reproductive and molecular biotechnologies, and legal and policy frameworks.

Part 4 discusses the "state of the art" in the management of AnGR, including methods, tools and strategies used in inventory, characterization and monitoring, breeding programmes, conservation programmes and economic valuation of AnGR.

Part 5 draws on the material presented in the other parts of the report to provide an assessment of gaps and needs in the management of AnGR and how they can be addressed.

---

[3] http://www.fao.org/nr/cgrfa/en/

[4] FAO. 1998. *The State of the World's Plant Genetic Resources for Food and Agriculture.* Rome (http://www.fao.org/agriculture/crops/core-themes/theme/seeds-pgr/sow/en/); FAO. 2010. *The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture.* Rome (http://www.fao.org/docrep/013/i1500e/i1500e00.htm).

[5] FAO 2014. *The State of the World's Forest Genetic Resources.* Rome (available at http://www.fao.org/forestry/fgr/64582/en/).

The report serves as basis for a review and potential update of the Global Plan of Action for Animal Genetic Resources.

The reporting and preparatory process

In April 2013, the Commission on Genetic Resources for Food and Agriculture requested FAO to coordinate the preparation of *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture* (second SoW-AnGR), focusing particularly on changes that had occurred since the preparation of the first SoW-AnGR.[6]

The first draft of the report was prepared between January and October 2014. In November 2014, it was submitted to the Eighth Session of the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture (a subsidiary body of the Commission charged with addressing issues relevant to the management of animal genetic resources)[7] for review. The first draft included Parts 1, 2, 3 and 5 of the report. At the request of the Fifteenth Regular Session of the Commission (January 2015), a revised draft, including all five parts, was made available for comments by members and observers of the Commission in May 2015. The report was finalized, taking comments received into account.

Inputs to the report

The main sources used to prepare the second SoW-AnGR were as follows:

Country reports

In August 2013, FAO invited its 191 member nations, as well as non-member nations, to submit country reports on the management of their AnGR, using a standardized electronic questionnaire[8] that had been endorsed by the Commission and finalized by the Bureau[9] of the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture. Government-appointed National Coordinators for the Management of Animal Genetic Resources led the preparation of the reports in their respective countries.

The country-report questionnaire[10] consisted of four sections:

I. Executive summary
II. Data for updating the parts and sections of *The State of the World's Animal Genetic Resources for Food and Agriculture*
    - Flows of animal genetic resources
    - Livestock sector trends
    - Overview of animal genetic resources
    - Characterization
    - Institutions and stakeholders
    - Breeding programmes
    - Conservation
    - Reproductive and molecular biotechnologies

[6] CGRFA-14/13/Report, paragraph 71 (http://www.fao.org/docrep/meeting/028/mg538e.pdf).
[7] http://www.fao.org/ag/againfo/programmes/en/genetics/angrvent-1st-docs.html
[8] http://www.fao.org/Ag/AGAInfo/programmes/en/genetics/Second_state.html
[9] http://www.fao.org/Ag/AGAInfo/programmes/en/genetics/angrvent-bureau.html
[10] http://www.fao.org/ag/againfo/programmes/en/genetics/documents/SoW2_CR_E.pdf

III. Data contributing to the preparation of *The State of the World's Biodiversity for Food and Agriculture*[11]
   - Integration of the management of animal genetic resources with the management of plant, forest and aquatic genetic resources
   - Animal genetic resources management and the provision of regulating and supporting ecosystem services

IV. Progress report on the implementation of the Global Plan of Action for Animal Genetic Resources – 2007 to 2013[12]
   - Strategic Priority Area 1: Characterization, Inventory and Monitoring of Trends and Associated Risks
   - Strategic Priority Area 2: Sustainable Use and Development
   - Strategic Priority Area 3: Conservation
   - Strategic Priority Area 4: Policies, Institutions and Capacity-building
   - Implementation and financing of the Global Plan of Action for Animal Genetic Resources

Country reports were received between 31 January 2014 and 22 May 2014. Comments on the completeness and internal consistency of the reports were provided to National Coordinators. Based on these comments, final versions of the country reports were submitted. The data provided in the country reports were loaded into a database for analysis.

One hundred and twenty-eight country reports[13] were received in the standardized format – 30 from OECD countries (88 percent of OECD countries) and 98 from non-OECD countries (61 percent of non-OECD countries). The regional breakdown of the reporting is summarized in the Table 1. The full list of reporting countries is shown in Table 2.

Survey responses on policy and legal frameworks

Detailed questions on national-level legal and policy frameworks affecting the management of AnGR were not included in the country-report questionnaire. In order to enable the respective section of the report (Part 3 Section F) to be updated, FAO conducted a separate survey on this issue. In September 2013, National Coordinators for the Management of Animal Genetic Resources were requested to complete an electronic questionnaire[14] on the legal and policy frameworks in their respective countries. The following 46 countries provided responses: Australia, Austria, Bhutan, Brazil, Bulgaria, Burundi, Costa Rica, Croatia, Cyprus, the Czech Republic, the Democratic Republic of the Congo, Ecuador, Ethiopia, Finland, France, Germany, Ghana, Guatemala, Hungary, Iraq, Italy, Jordan, Latvia, Luxembourg, Malaysia, Mauritius, Montenegro, Namibia, Nepal, the Netherlands, Norway, the Republic of Korea, Serbia, Slovenia, Spain, Sri Lanka, Sudan, Suriname, Sweden, Switzerland, the United Republic of Tanzania, Thailand, the United States of America, Uruguay, Viet Nam and Zimbabwe.[15]

---

[11] In 2013, the Commission requested FAO to prepare *The State of the World's Biodiversity for Food and Agriculture*, a report focusing on interactions between the different subsectors of genetic resources for food and agriculture and on cross-sectoral matters (CGRFA-14/13/Report) (http://www.fao.org/docrep/meeting/028/mg538e.pdf).

[12] In 2009, the Commission agreed to a timetable and format for reporting on progress made in the implementation of the Global Plan of Action for Animal Genetic Resources at national level (CGRFA-12/09/Report) (ftp://ftp.fao.org/docrep/fao/meeting/017/k6536e.pdf). The first round of reporting took place in 2012 (CGRFA/WG-AnGR-7/12/Inf.3) (http://www.fao.org/docrep/meeting/026/me636e.pdf). A second round of reporting was incorporated into the country-reporting process for the second SoW-AnGR.

[13] http://www.fao.org/3/a-i4787e/i4787e01.htm

[14] http://www.fao.org/Ag/AGAInfo/programmes/en/genetics/Second_state.html

[15] http://www.fao.org/3/a-i4787e/i4787e02.htm

TABLE 1

Regional overview of country reporting

Region	Number of countries in the region*	Number of country reports (second SoW-AnGR)	Number of country reports (first SoW-AnGR)	Coverage (second SoW-AnGR) (%)
Africa	52	41	49	79
Asia	31	20	26	65
Europe and the Caucasus	49	35	41	71
Latin America and the Caribbean	33	18	30	55
Near and Middle East	14	7	9	50
North America	2	1	2	50
Southwest Pacific	15	7	12	47
Total	**196**	**129**	**169**	**66**

*The number of countries refers to the number of countries in 2014. Between 2005 (when the country reporting for the first SoW-AnGR was completed) and 2014, Montenegro and Serbia and South Sudan and Sudan became separate countries. For the purposes of the first SoW-AnGR, Sudan was part of the Near and Middle East region. For the purposes of the second SoW-AnGR, Sudan is part of the Near and Middle East region and South Sudan is part of the Africa region.

TABLE 2

List of country reports

Region[1]	Countries
Africa (41)	Algeria, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Comoros, Côte d'Ivoire, Democratic Republic of the Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco,[2] Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Swaziland, Togo, Uganda, United Republic of Tanzania, Zambia, Zimbabwe
Asia (20)	Bangladesh, Bhutan, China, India, Indonesia, Iran (Islamic Republic of), Japan, Kazakhstan, Kyrgyzstan, Malaysia, Maldives, Mongolia, Nepal, Philippines, Republic of Korea, Sri Lanka, Tajikistan, Thailand, Timor-Leste, Viet Nam
Europe and the Caucasus (35)	Albania, Austria, Azerbaijan, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, Lithuania, Luxembourg, Montenegro, Netherlands, Norway, Poland, Portugal, Russian Federation, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom
Latin America and the Caribbean (18)	Argentina, Barbados, Bolivia (Plurinational State of), Brazil, Chile, Costa Rica, Cuba, Dominican Republic, Ecuador, Guatemala, Jamaica, Mexico, Paraguay, Peru, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay
Near and Middle East (7)	Bahrain, Egypt, Iraq, Jordan, Kuwait, Oman, Sudan
North America (1)	United States of America
Southwest Pacific (7)	Cook Islands, Kiribati, New Zealand, Niue, Samoa, Solomon Islands, Tonga

[1] Note that these regions do not correspond to the usual FAO regions; see below for further explanation.

[2] The country report was not prepared in the standardized format and thus could not be included in the quantitative analysis.

Reports from regional focal points and networks

In February 2014, regional focal points and networks for the management of AnGR were invited to provide reports (based on a standardized electronic questionnaire)[16] on activities related to the implementation of the Global Plan of Action in their respective regions. In accordance with the reporting framework agreed by the Commission, the regional focal points and networks were requested to highlight collaborative efforts at regional level and indicate regional priorities for capacity-building in relation to the implementation of the Global Plan of Action, rather than to provide a summary of national-level activities in the region. Reports[17] were received from the following regional focal points and networks:

1. the European Regional Focal Point for Animal Genetic Resources;
2. the Regional Focal Point for Latin America and the Caribbean;
3. the Animal Genetic Resources Network – Southwest Pacific; and
4. the Asian Animal Genetic Resources Network.

Reports from international organizations

In February 2014, 209 international organizations were invited to report (based on a standardized electronic questionnaire)[18] on their contributions to the implementation of the Global Plan of Action for Animal Genetic Resources, in particular on any activities, programmes or projects undertaken or supported by the respective organization. Reports[19] were received from the following fifteen organizations: the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD); the African Union – Interafrican Bureau for Animal Resources (AU-IBAR); Bioversity International; the Secretariat of the Convention on Biological Diversity (CBD); the European Federation of Animal Science (EAAP); Heifer International; the International Atomic Energy Agency (IAEA); the International Committee for Animal Recording (ICAR); the International Center for Agriculture Research in the Dry Areas (ICARDA); the International Livestock Research Institute (ILRI); the League for Pastoral Peoples and Endogenous Livestock Development (LPP); the Nordic Genetic Resource Centre (NordGen); Rare Breeds International (RBI); Safeguard for Agricultural Varieties in Europe (SAVE Foundation); and the World Intellectual Property Organization (WIPO).

Thematic studies

Two thematic studies providing in-depth analysis of specific topics relevant to the management of AnGR were prepared as part of the second SoW-AnGR reporting process:

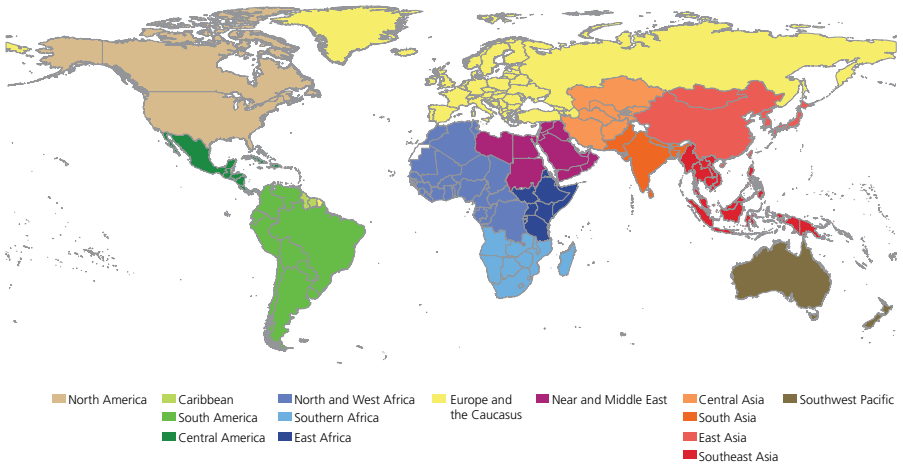
- *Ecosystem services provided by livestock species and breeds, with special consideration to the contributions of small-scale livestock keepers and pastoralists*;[20]
- *The patent landscape for animal genetic resources*.[21]

Other sources

In addition to the sources mentioned above, the second SoW-AnGR draws on a range of literature and data sources. The latter include the Domestic Animal Diversity Information System (DAD-IS),[22] FAO's legal database FAOLEX,[23] FAO's statistical database FAOSTAT,[24] the

[16] http://www.fao.org/Ag/AGAInfo/programmes/en/genetics/Second_state.html
[17] http://www.fao.org/3/a-i4787e/i4787e03.htm
[18] http://www.fao.org/Ag/AGAInfo/programmes/en/genetics/Second_state.html
[19] http://www.fao.org/3/a-i4787e/i4787e03.htm
[20] http://www.fao.org/3/a-at598e.pdf
[21] http://www.wipo.int/edocs/pubdocs/en/wipo_pub_947_3.pdf
[22] http://fao.org/dad-is
[23] http://faolex.fao.org/
[24] http://faostat.fao.org/

FIGURE 1
Assignment of countries to regions and subregions in this report



FAO/INFOODS Food Composition Database for Biodiversity (BioFoodComp)[25] and the UN Comtrade Database.[26] The analysis of DAD-IS data for Part 1 Section B of the report (Status and trends of AnGR) was carried out in July 2014.

Regional classification of countries

The assignment of countries to regions and subregions for the purposes of the second SoW-AnGR follows the assignment used in the first SoW-AnGR (see Figure 1). This assignment was based on a number of considerations, including production environments, cultural factors and the distribution of shared AnGR. Because of these various considerations, the regional groupings do not correspond exactly to the standard FAO regions used in FAO statistics and for FAO election purposes (although for most countries the assignment does not differ from the standard classification).

Seven regions are distinguished, three of which are further subdivided into subregions:

- Africa (East Africa, North and West Africa, Southern Africa);
- Asia (Central Asia, East Asia, Southeast Asia, South Asia);
- Europe and the Caucasus;
- Latin America and the Caribbean (Caribbean, Central America, South America);
- the Near and Middle East;
- North America; and
- the Southwest Pacific.

[25] http://www.fao.org/infoods/infoods/tables-and-databases/faoinfoods-databases/en/
[26] http://comtrade.un.org

Summary

About this report

The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture provides a comprehensive assessment of the state of livestock biodiversity and its management. It sets out the latest available information on the origin and history of animal genetic resources (AnGR), trends in the status of AnGR, the uses, roles and values of AnGR, the adaptive characteristics of AnGR and threats to AnGR diversity. It presents an overview of livestock-sector trends and their effects on AnGR and their management. It describes the state of capacity to manage AnGR and the state of the art in methods and strategies for their management. It reviews progress made in the implementation of the Global Plan of Action for Animal Genetic Resources, adopted in 2007 as the first internationally agreed framework for the management of livestock biodiversity. It ends with an assessment of gaps and needs in AnGR management.

The report draws on information provided in 129 country reports, 15 reports from international organizations, 4 reports from regional focal points and networks for AnGR management and inputs from 150 authors and reviewers. It is intended to serve as an update of the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture*, published in 2007, and focuses particularly on developments since the first report was prepared.

Key findings

Livestock diversity facilitates the adaptation of production systems to future challenges and is a source of resilience in the face of greater climatic variability

Livestock production systems face many challenges. The precise demands that will be placed on the livestock of the future are difficult to predict. However, coping with climate change, new disease challenges, restrictions on the availability of natural resources and changing market demands will require a diverse range of AnGR. Adaptedness to harsh conditions and resilience in the face of extreme climatic events and other shocks are likely to be important. Potential synergies in efforts to promote sustainable AnGR management, improve livelihoods and achieve environmental objectives need to be exploited. Appropriate management strategies require better knowledge of the roles, uses and values of AnGR, particularly in the livelihoods of poor people, and better knowledge of the effects of livestock on ecosystem functions.

The roles and values of animal genetic resources remain diverse, particularly in the livelihoods of poor people

While livestock's roles in the provision of some products and services are gradually being replaced as alternative sources become more widely available, the use of livestock remains very diverse. There is a need to understand these diverse roles and how they are changing. This will help ensure that AnGR are well matched to the needs of livestock keepers and society. It will also help identify potential threats to AnGR diversity arising because particular breeds are no longer valued for their former functions and may therefore face an increased risk of extinction. Livestock's roles in the provision of ecosystem services related to the regulation of ecological functions, landscape management and the provision of wildlife habitats remain under-researched and undervalued. Interest in the connection between genetic diversity and the nutritional contents of animal-source foods for human consumption is increasing, but this field has not yet received much research attention.

The adaptations of specific species and breeds to specific environmental challenges need to be better understood

The adaptive characteristics of individual breeds (e.g. ability to cope well with extremes of temperature, restricted water supply, poor-quality feed, rough terrain, high elevations and other challenging aspects of the production environment) have generally not been studied in great depth. Some progress has been made over recent years in terms of expanding our understanding of the genetics of disease resistance and tolerance, including the relative susceptibilities of specific breeds to specific diseases. However, many reported instances of resistance or tolerance remain anecdotal (i.e. have not been evaluated in scientific studies). Lack of information remains the major constraint to the integration of genetic approaches into disease-control strategies.

The world's livestock diversity remains at risk

The proportion of livestock breeds classified as being at risk of extinction increased from 15 percent to 17 percent between 2005 and 2014. A further 58 percent of breeds are classified as being of unknown risk status because no recent population data (from the last ten years) have been reported to FAO. The number of breeds at risk is therefore likely to be underestimated. Monitoring of population trends is a prerequisite for prompt and effective action to protect breeds from extinction. Erosion of within-breed diversity can be a problem even in breeds whose total population size remains very large.

The assessment of threats to animal genetic resources needs to be improved

Action to prevent the loss of livestock diversity will be more effective if the factors that drive genetic erosion and extinction risk are well understood. While there is considerable agreement among stakeholders regarding the range of factors that can be considered potential threats to AnGR diversity, the magnitude of these threats and the ways in which they combine to affect particular breeds in particular circumstances are often unclear. Information provided in the country reports suggests that indiscriminate cross-breeding, economic drivers and changing market demands, weaknesses in AnGR management programmes, policies and institutions, degradation of natural resources (or problems with access to such resources), climate change and disease epidemics are major threats.

Institutional frameworks for the management of AnGR need to be strengthened

While progress has been made in terms of improving the basic prerequisites for effective AnGR management at national level (adequate physical infrastructure, effective mechanisms for stakeholder participation, high-quality education and research programmes, good knowledge and awareness of AnGR-related issues, and appropriate legal and policy frameworks and capacity to implement them) many weaknesses remain, particularly in developing countries. While a number of examples of international cooperation in research and other aspects of AnGR management are described in the country reports, international collaboration remains a relatively underdeveloped element of the implementation of the Global Plan of Action.

Establishing and sustaining effective livestock breeding programmes remains challenging in many countries, particularly in the low-input production systems of the developing world

Implementing a livestock breeding programme is a challenging task that involves a number of different elements. Over recent years, a number of countries have made progress in terms of putting some of these elements in place (e.g. the establishment of animal identification and registration schemes). However, the country reports indicate that, in developing regions

in particular, these elements do not always form part of coherent genetic improvement programmes for the breeds concerned. Even where programmes exist, they are often of a rudimentary nature and operate on a limited scale. A lack of adequate organizational structures for the involvement of livestock keepers and breeders in the planning and implementation of breeding schemes often inhibits the establishment of more effective programmes.

Conservation programmes for animal genetic resources have become more widespread, but their coverage remains patchy

Most countries that participated in the reporting process indicate that they now have at least some AnGR conservation activities in place. *In vitro* gene banks have been established by 64 countries and a further 41 countries are planning to do so. Many of these gene banks are in the early stages of development and the collections often have many gaps in their coverage of relevant breeds and populations. The coverage of *in situ* conservation activities (actions that support the maintenance of livestock populations in their usual production environments) is also incomplete. However, a diverse range of different activities are reported. For example, countries increasingly report the development of niche markets for speciality products as a means of increasing the profitability of potentially threatened breeds.

Emerging technologies are creating new opportunities and challenges in animal genetic resources management

Substantial advances have been made in genomic technologies over recent years. These technologies have improved understanding of the genetic basis of heritable traits and have increased the efficacy of some breeding programmes. However, in global terms, the impact of these technologies has been largely limited to certain international transboundary breeds kept in high-input systems. Although various circumstances influence the applicability of these tools, a primary facilitating factor is the availability of phenotypic and pedigree data. Increasing the collection of these data is of critical importance, not only for the effective use of genomics, but for any type of genetic improvement or conservation programme.

The impact of many livestock sector trends on animal genetic resources and their management is increasing

The major changes that have affected the global livestock sector over recent decades – including the rapid expansion of large-scale high-input production systems in parts of the developing world, growing pressures on natural resources, the partial replacement of some of livestock's roles as alternative sources of provision become available, and changes in the livelihood and lifestyle opportunities available to rural people – have had a substantial impact on AnGR and their management. Countries generally report that they expect such effects to be even greater in the coming years than they have been in the recent past. Growth in demand for animal-source food continues to create major challenges for the sustainable use of AnGR. South Asia and Africa are projected to become the main centres of growth in meat and milk consumption. These are very resource-constrained regions that are home to many small-scale livestock keepers and pastoralists and to a diverse range of AnGR. Other drivers of change predicted to have a major effect on AnGR management in the coming years include climate change, technological developments and policy factors. Keeping track of trends of this kind and identifying their potential effects on demand for particular species and breeds and on capacity to maintain a diverse portfolio of livestock diversity is an important part of planning the long-term sustainable management of AnGR, both at national level and globally.

Livestock diversity and the sustainable management of animal genetic resources are acquiring a greater foothold on policy agendas

Despite the limited amount of time available for reporting, 129 countries submitted country reports for use in the preparation of this report. As of May 2015, 177 countries had nominated National Coordinators for the Management of AnGR and 112 report that they have prepared, are in the process of preparing or are planning to prepare national strategies and action plans for AnGR. Many countries report that they have developed legal instruments or policies targeting improvements to the management of AnGR. At international level, the importance of genetic resources for food and agriculture, including AnGR, has been highlighted in several major initiatives and agreements (e.g. the Convention on Biological Diversity's Strategic Plan for Biodiversity 2011–2020 and Aichi Targets, and the draft post-2015 development goals).

What needs to be done?

Strategic priorities for action in the management of AnGR are set out in the Global Plan of Action for Animal Genetic Resources. The analysis presented in this report suggests that these strategic priorities remain relevant.

Efforts still need to be made to strengthen the main elements of sustainable AnGR management. Priorities include:

- improving knowledge of the characteristics of different types of AnGR, the production systems in which they are kept and the trends affecting these production systems;
- developing stronger institutional frameworks for AnGR management, including mechanisms that allow for better communications among stakeholders and facilitate the participation of livestock keepers in the planning and implementation of AnGR-related policies and programmes;
- improving awareness, education, training and research in all areas of AnGR management, including in the emerging fields of access and benefit sharing, ecosystem services and climate change adaptation and mitigation;
- strengthening breeding strategies and programmes so as to enable full advantage to be taken of available genetic diversity and ensure that AnGR are well matched to their production environments and to societal needs; and
- expanding and diversifying conservation programmes, where possible combining approaches that provide for ongoing use of livestock breeds in their usual production environments with those that provide for backup storage of genetic material.

National strategies and action plans for AnGR provide a means of translating the provisions of the Global Plan of Action into well-targeted activities that meet specific needs at country level. Countries that have not yet developed a national strategy and action plan should consider doing so. Countries that have already developed such instruments should ensure that they are implemented. In many cases, improving AnGR management at national level will also require strengthening National Focal Points for the Management of Animal Genetic Resources.

In addition to individual strategic priorities, the Global Plan of Action also addresses the question of implementation and funding, emphasizing the need for long-term commitment and the need to devote substantial and additional financial resources to improving the sustainable management of AnGR. Many country reports stress that lack of funding is a major constraint to the improvement of many aspects of AnGR management. These funding gaps need to be addressed.

The Global Plan of Action also emphasizes the importance of international cooperation in AnGR management. There is a need to strengthen global- and regional-level activities related both to the management of shared resources (transboundary breeds) and to the transfer of technologies and knowledge that facilitate the sustainable use, development and conservation of AnGR.

Part 1

THE STATE OF LIVESTOCK DIVERSITY

Introduction

Part 1 of the report begins by describing advances in research on the origin of the diversity of today's animal genetic resources for food and agriculture (AnGR) – the domestication and history of livestock species. This is followed by a description of the current status and trends of AnGR diversity and the extent to which this diversity is threatened by genetic erosion. The next section describes patterns of international exchange of AnGR. The roles and values of AnGR, including their direct and indirect contributions to livelihoods and economic output, are then described. This is followed by a discussion of the various adaptive characteristics, including genetic resistance and tolerance to specific diseases and parasites, that enable livestock breeds to survive and produce in a range of different production environments. The next section addresses threats to the diversity of the world's AnGR. In the final section of Part 1, livestock diversity is discussed in relation to human nutrition. All sections highlight, in particular, changes that have occurred since the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007)[1] was prepared.

AnGR are here taken to include those animal species that are used, or may be used, for food production and agriculture,[2] and the populations within each. Distinct populations within species are usually referred to as breeds. FAO (1999)[3] defines a breed as:

> *"either a subspecific group of domestic livestock with definable and identifiable external characteristics that enable it to be separated by visual appraisal from other similarly defined groups within the same species or a group for which geographical and/or cultural separation from phenotypically similar groups has led to acceptance of its separate identity."*

The broad definition of the term "breed" is a reflection of the difficulties involved in establishing a strict definition of the term. Further information on the development of the breed concept is provided in the first SoW-AnGR.[4]

---

[1] FAO. 2007. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

[2] Fish are excluded as management requirements and breeding techniques are very different.

[3] FAO. 1999. *The Global Strategy for the Management of Farm Animal Genetic Resources*. Executive brief. Rome (available at http://dad.fao.org/cgi-bin/getblob.cgi?sid=-1,50006152).

[4] FAO, 2007, pages 339–340.

Section A

Origin and history of livestock diversity

1 Introduction

Genetic diversity provides the raw material for breed improvement and for the adaptation of livestock populations to changing environments and changing demands. Information on the origin and history of animal genetic resources (AnGR) is essential to the design of strategies for their sustainable management (Ajmone-Marsan *et al.*, 2010; Felius *et al.*, 2014). The first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007) provided a review of the state of knowledge of the domestication of livestock species and their subsequent dispersal around the world.[1] Since the time the first SoW-AnGR was prepared, a considerable amount of research work has been undertaken in this field. In particular, further development of genomic tools (see Box 1A1) has allowed the use of genome-wide information in the investigation of various aspects of the history of livestock species. This section provides an updated overview of the state of knowledge in this field, focusing particularly on recent advances. It describes, in turn, the initial domestication process, subsequent introgression[2] of wild species into domesticated species, adaptations that occurred after domestication and, finally, relatively recent breed formation.

[1] FAO, 2007, Part 1 Section A (pages 5–22).

[2] Reproductive contacts that have left traces of DNA from one population in another population.

2 The domestication process

Theories about the process of livestock domestication have continued to develop since the time the first SoW-AnGR was prepared (Larson and Burger, 2013; Larson and Fuller, 2014). Animals can be considered domesticated if they are bred in captivity and (after several generations) have become adapted to being kept by humans. Once animals have been domesticated, their reproduction is controlled by their human keepers, who provide them with shelter and feed and protect them against predators (Diamond, 2002; Mignon-Grasteau *et al.*, 2005). Only 15 out of 148 non-carnivore terrestrial mammalian species weighing more than 45 kg have been domesticated (Table 1A1). From the 10 000 avian species, only very few (chicken, turkey, pheasant, guinea fowl, duck, Muscovy duck, goose, pigeon, quail and ostrich) have been domesticated as a source of food. According to Diamond (2002), successful domestication depends on the presence of several traits in the target species:

- behavioural traits that facilitate management by humans (e.g. a lack of aggression towards humans, a tendency not to panic when disturbed and strong social instincts);
- reproductive traits, such as the ability to breed in captivity, short intervals between births and (preferably) large litter sizes; and
- physiological traits, such as rapid growth and a non-carnivorous diet.

Domestication may have been triggered by climatic changes at the end of the Pleistocene (12000 to 14000 BP) that led to localized expansion of human populations and the emergence of crop farming (Larson and Burger, 2013). Domestication

Box 1A1

How the history of livestock is reconstructed: archaeology and DNA

Archaeologists use various means to distinguish the skeletal remains of domestic animals from those of wild animals, including studying morphological changes to the teeth, cranium and skeleton to estimate body size and shape and determine growth patterns (Zeder *et al.*, 2006a). The age of organic material can be determined by radiocarbon dating. Isotope analysis of organic residues on pottery may identify milk fatty acids (Evershed *et al.*, 2008). Nitrogen isotope ratios in the teeth of calves may reveal early weaning and thus the use of cattle for dairying (Balasse and Tresset, 2002).

Different categories of polymorphic DNA markers reveal different aspects of the history of livestock (see Part 4 Section B for further information on different types of markers).

- Mitochondrial DNA (mtDNA) is transmitted maternally and has been instrumental in identifying ancestor species, estimating the number of female founders (Bollongino *et al.*, 2012), identifying the geographic regions of domestication (Naderi *et al.*, 2008) and reconstructing migration routes (Groeneveld *et al.*, 2010; Lenstra *et al.*, 2012). Most mtDNA studies target the hypervariable control region of the mitochondrial genome, but complete mtDNA genomes are needed to establish relations between major mtDNA types (the haplogroups[1]) (Achilli *et al.*, 2009). It is no longer believed that the presence of a given number of different haplogroups always indicates the equivalent number of separate domestication events; a single ancestral wild population may harbour more than one haplogroup (Naderi *et al.*, 2008; Cieslak *et al.*, 2010; Bollongino *et al.*, 2012). Because regional haplogroup distributions tend to be stable, mitochondrial DNA often tells us about the earliest migrations (Cieslak *et al.*, 2010; Miao *et al.*, 2013; Lenstra *et al.*, 2014). In the case of cattle, these migrations have been shown to have involved severe population bottlenecks (Lenstra *et al.*, 2014).
- Mammalian Y-chromosomal variation is transmitted via the paternal line and is a powerful tool for tracing gene flow by male introgression, whether in the distant past or more recently (Edwards *et al.*, 2011).
- Autosomal variation is transmitted via both parents. Microsatellite markers have been widely used for analysing autosomal variation and are still useful (FAO, 2011). However, they are being replaced by high-density SNP (single nucleotide polymorphism) analysis (Kijas *et al.*, 2012; Goedbloed *et al.*, 2013; Petersen *et al.*, 2013a; Decker *et al.*, 2014) or whole-genome sequencing (Groenen *et al.*, 2012). Autosomal loci are commonly used for population diversity estimations, detection of the subdivision and differentiation of populations, calculation of genetic distances and quantification of genetic admixture.

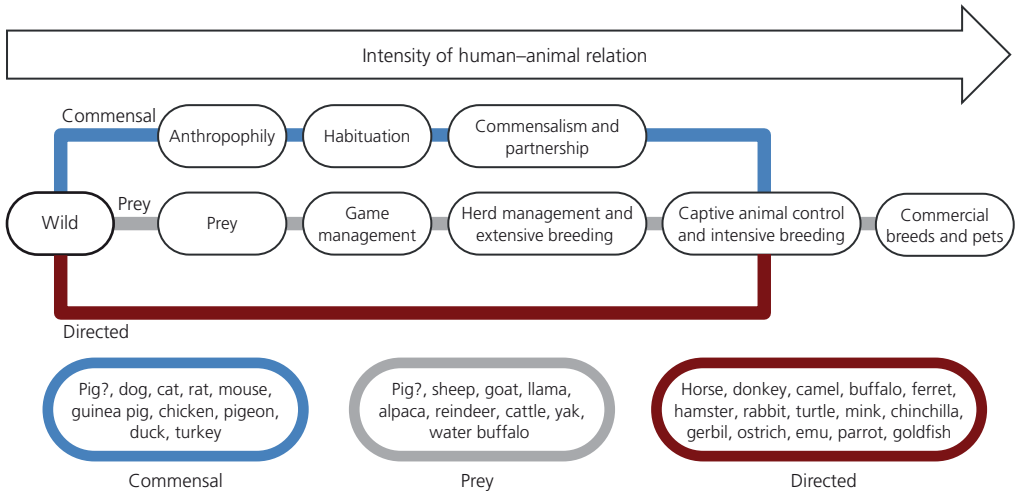
An important recent development is the use of Bayesian computations for the analysis of large datasets, which allows detailed reconstruction of prehistoric genetic events (Bollongino *et al.*, 2012; Larson and Burger, 2013; Gerbault *et al.*, 2014).

[1] A haplogroup is a group of similar haplotypes that share one or more mutations indicative of descent from a common ancestor. Haplogroups most commonly pertain to mitochondrial and Y-chromosome DNA. Haplotype is the combination of alleles from two or more polymorphic sites in a mitochondrial, Y-chromosomal or autosomal DNA segment.

scenarios remain uncertain. However, it is clear that they varied from species to species. Three plausible pathways –"commensal", "prey" and "directed"– have recently been proposed (Larson and Burger, 2013) (see Figure 1A1). The first of these pathways involved animals being attracted to human settlements and then becoming captive as a source of food. The second involved the capture of artiodactyl[3]

[3] Even-toed hoofed animals (cattle, sheep, goats, pigs, camels, etc.).

FIGURE 1A1
Three pathways of domestication



Note: The figure includes some species not included in the scope of the SoW-AnGR.
Source: Larson and Burger, 2013, with permission from Elsevier.

prey animals as a means of securing a supply of meat. Once domesticated, these species also provided other products, such as milk, wool and leather. Later, some were also used for ploughing. The third pathway, which came into play later in history, involved deliberate efforts to exploit the specific capabilities of the target species (e.g. their potential as pack, riding or draught animals).

There is now consensus about which wild species were the ancestors of the various domesticated livestock species (Table 1A1). Livestock domestication is thought to have occurred in at least 15 areas of the world (Figure 1A2). Inferences regarding the dates of domestication events (Table 1A1) remain approximations. Skeletal remains identified as belonging to domesticated species on the basis of their morphology are never as old as the first domesticates. Close genetic relationships between domestic and wild populations in other parts of the world (i.e. outside the recognized domestication centres) are considered to indicate introgression (Larson and Burger, 2013). Views on the location of domestication centres have evolved since the time the first SoW-AnGR was prepared (Larson *et al.*, 2014). For example, evidence indicating pig domestication in Europe and in Indonesia is now considered to be a result of introgression. Similarly, it is now accepted that Africa was not a centre of cattle domestication and that the river buffalo originated in India rather than in Mesopotamia (although the evidence for the latter conclusion is not abundant). Recent studies have indicated an African origin for the donkey and distinct origins for Chinese and European geese.

Recently, Wilkins *et al.* (2014) proposed, as a general mechanism of domestication, that selection for tameness induced a mild neural crest cell deficit during embryonic development, which attenuated behaviour and also modified several morphological and physiological traits related to domestication (e.g. smaller brain and depigmentation).

TABLE 1A1
Domestication, disperal and sources of introgresssion

Domestic species	Wild ancestor[1]	Date	Domestication site	Domestic range	Sources of introgression	References
Taurine cattle *Bos taurus*	Aurochs *Bos primigenius*[a]	10250 BP	Southwest Asia[2]	Global	- African aurochs bulls - European aurochs bulls?[3] - Zebu in African Sanga	Stock and Gifford-Gonzalez, 2013; Decker *et al.*, 2014; Freeman *et al.*, 2006; Decker *et al.*, 2014
Zebu cattle *Bos indicus*	Aurochs *Bos primigenius*[a]	8000 BP	Indus Valley[2]	Subtropical and tropical	- 2-way taurindicine hybrids in China - Taurine maternal lineage in nearly all non-Asian zebus and taurindicines - Banteng in southern China - Yak cows in Nepal and Qinghai, China - Banteng cows in Indonesian zebu breeds	Ajmone-Marsan *et al.*, 2010; Decker *et al.*, 2014; Lenstra *et al.*, 2014
Bali cattle *Bos javanicus*	Banteng *Bos javanicus*[c]	5500 BP	Indonesia	Indonesia, Malaysia, feral in Australia	Zebu in Malaysia	Mason, 1984; Nijman *et al.*, 2003
Mithun *Bos frontalis*	Gaur *Bos gaurus*[d]			India–Myanmar border region	Zebu cows in Dulong cattle (Yunnan, China)	Mason, 1984; Lenstra *et al.*, 2014
Yak *Bos grunniens*	Wild yak *Bos mutus*[d]	5000 BP	Quinghai- Tibetan Plateau	Quinghai–Tibetan Plateau, adjacent Asian highlands		Wiener *et al.*, 2003
River buffalo *Bubalus bubalis*	Wild water buffalo *Bubalus arnee*[b]	4500 BP	India	Italy, Balkans, Southwest Asia, Egypt, India, Brazil, Australia		Kumar *et al.*, 2007
Swamp buffalo *B. bubalis carabensis*	Wild water buffalo *Bubalus arnee*[b]	5000 BP	Southern China	South China, Indochina, Philippines, Brazil, Australia	River buffalo in China and Bangladesh	Zhang *et al.*, 2012
Sheep *Ovis aries*	Asiatic mouflon *Ovis orientalis*[d]	9750 BP	Southwest Asia	Global	Argali and urial ewes	Demirci *et al.*, 2013
Goat *Capra hircus*	Bezoar *Capra aegagrus*[d]	9750 BP	Southwest Asia	Global	Possibly other goat species	Naderi *et al.*, 2008
Reindeer *Rangifer tarandus*	Reindeer *Rangifer tarandus*[f]	2500 BP	North Siberia	Northern Eurasia		Mason, 1984
Dromedary *Camelus dromedarius*	Wild dromedary[a]	6000 BP?	Arabia?	North and East Africa, Southwest Asia, Australia	Bactrian males	Spassov *et al.*, 2004; Pott, 2004
Bactrian camel *Camelus bactrianus*	Wild Bactrian camel *C. bactrianus ferus*[b]	5500 BP	Turkmenistan, Iran	From Black Sea to Manchuria		Larson *et al.*, 2014
Llama *Lama glama*	Guanaco *Lama guanicoe*[f]	6000 BP	Central–southern Andes	Central–southern Andes	Alpaca	Kadwell *et al.*, 2001
Alpaca *Vicugna pacos*	Vicuna *Vicugna vicugna*[f]	5000 BP	Central–southern Andes	Central–southern Andes	Llama	Kadwell *et al.*, 2001

(Cont.)

TABLE 1A1 *(Cont.)*

Domestication, disperal and sources of introgresssion

Domestic species	Wild ancestor[1]	Year	Domestication site	Domestic range	Sources of introgression	References
Pig *Sus scrofa*	Wild boar *Sus scrofa*[f]	10000 BP 8500 BP	Southwest Asia China	Global	Males and females from several wild boar populations; Chinese pigs in Europe in nineteenth century	Larson *et al.*, 2005; Fang *et al.*, 2006
Horse *Equus caballus*	Wild horse *Equus ferus*[a]	5500 BP	Kazakhstan	Global	Wild mares during dispersal, Iberian horses	Warmuth *et al.*, 2012; Cieslak *et al.*, 2012
Donkey *Equus asinus*	African wild ass *Equus africanus*[b]	5500 BP	Sudan	Global (relatively rare in Europe and North America)		Rosenbom *et al.*, 2015
Rabbit *Oryctolagus cuniculus*	Wild rabbit *Oryctolagus cuniculus*[e]	1400 BP	Southern France	Global		Carneiro *et al.*, 2014
Chicken *Gallus domesticus*	Red jungle fowl *Gallus gallus*[f]	4500 BP 8000 BP	India Indochina	Global	Grey jungle fowl (*Gallus sonneratii*) in India	Tixier-Boichard *et al.*, 2011
Turkey *Meleagris gallopavo*	Mexican turkey *Meleagris gallopavo*[f]	2000 BP	Mexico	Global		Thornton *et al.*, 2012
Guinea fowl *Numida meleagris*	Helmeted guinea fowl *Numida meleagris*[f]	2000 BP	Africa	Global		Larson *et al.*, 2014
Domestic duck *Anas platyrhynchos*	Mallard *Anas platyrhynchos*[f]	1000 BP	Southern China	Global	Wild population, permanently	Larson *et al.*, 2014
Muscovy duck *Cairina moschata*	Muscovy duck *Cairina moschata*[f]	4000 BP	South America	Global	Wild population, permanently	Stahl *et al.*, 2006
Goose *Anser anser* Chinese goose	Greylag goose *Anser anser*[f] Swan goose *Anser cygnoides*[f]			Global	Wild populations, permanently	Shi *et al.*, 2006; Wang *et al.*, 2010

[1] Superscipt letters next to the species names indicate their risk status according to the IUCN Red List of Threatened Species (http://www.iucnredlist.org) as of October 2014: a = Extinct; b = Critically endangered; c = Endangered; d = Vulnerable; e = Near threatened; f = Least concern.

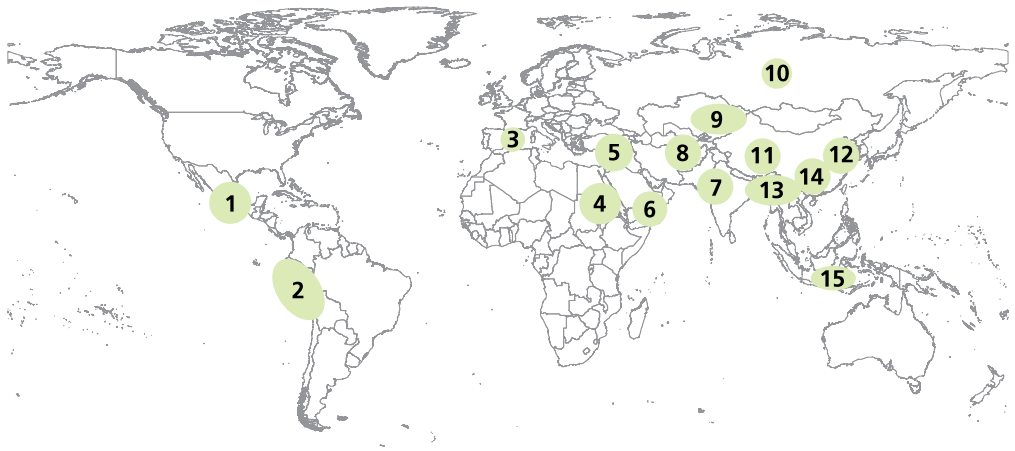
[2] Taurine and zebu cattle are commonly considered to have been domesticated separately. Alternatively, zebus may have emerged as a result of wild male and female introgression in taurine cattle introduced from the west (Larson and Burger, 2013).

[3] Female introgression rare (Achilli *et al.*, 2008; Stock *et al.*, 2009); role of male introgression and of the Mediterrean aurochs unclear (Lari *et al.*, 2011).

In addition to the references cited in the table, see Mason (1984), Mignon-Grasteau et al. (2005) and Larson *et al.* (2014).

FIGURE 1A2

Major centres of livestock domestication as inferred from archaeological and molecular genetic evidence



Note: (1) turkey; (2) guinea pig, llama, alpaca, Muscovy duck; (3) rabbit; (4) donkey; (5) taurine cattle, pig, goat, sheep; (6) dromedary, (7) zebu cattle, river buffalo; (8) Bactrian camel; (9) horse; (10) reindeer; (11) yak; (12) pig; (13) chicken; (14) swamp buffalo; (15) Bali cattle.
Sources: Mignon-Grasteau *et al.*, 2005; Larson *et al.*, 2014; references in Table 1A1.

3 Dispersal of domesticated animals

Knowledge of the dispersal of livestock species from their centres of domestication during the prehistoric period is based on a synergic combination of archaeology and molecular genetics. For later periods, written and pictorial documentation is also available. More information is available on cattle (followed by sheep) than on other livestock species, and migrations within Europe are better documented than those in other regions. Zebu cattle and water buffalo only migrated within tropical and subtropical climate zones, while the distributions of dromedaries, Bactrian camels, llamas, alpacas, reindeer, yaks, Bali cattle and mithun are even more restricted. Since the first SoW-AnGR was prepared, molecular studies have filled several gaps in our knowledge of the dispersal of livestock species.

In Europe, the introduction of crops and livestock from Southwest Asia occurred around 8500 BP. Domesticated livestock followed two major routes into Europe, the first along the Mediterranean coast and the second along the Danube, arriving in the British Isles around 6500 BP (Gkiasta *et al.*, 2003). A detailed archaeological study in Anatolia that reconstructed the westward movements of sheep, goats, cattle and pigs (Arbuckle and Makarewicz, 2009) suggested that these species migrated independently of each other. The occurrence of the T1 mitochondrial haplotype from African cattle in Spain indicates that gene flow also occurred across the Strait of Gibraltar (Bonfiglio *et al.*, 2012). Short-horn cattle emerged around 5000 BP in southwest Asia and gradually replaced the original long-horn cattle in most parts of Europe (Mason, 1984). The introduction of the horse was associated with the spread of the Indo-European language around 4500 BP and was probably accompanied by migrations of people and other livestock (Balter and Gibbons, 2015).

During the Roman Era, cattle and sheep were exported from Italy to other parts of the Empire. From the fourth to the eighth century, the Germanic migrations also led to large-scale movements of livestock. Presumably, these migrations preceded the paternal founder effects that are believed to have led to the north–south contrast detected in the Y-chromosomal variation of cattle in Europe (Edwards *et al.*, 2011). A Y-chromosomal haplotype in sheep of British or Nordic origin (Niemi *et al.*, 2013) and the fixation of a goat Y-chromosomal haplogroup in central and northern Europe (Lenstra, 2005) indicate similar paternal founder effects.

In Asia, sheep, goats and taurine cattle migrated to China before 4500 BP (Jing *et al.*, 2008). Cattle arrived in Japan around 2500 BP (Minezawa, 2003). Further to the south, zebu cattle were introduced around 3000 BP (Payne and Hodges, 1997). The introduction of the domestic swamp buffalo, which is more suitable than cattle for ploughing rice paddies, followed the spread of wet rice cultivation in China, Indochina, the Philippines and Indonesia. The river buffalo, domesticated in India, arrived around 900 to 1000 AD in Egypt, the Balkans and southern Italy.

Taurine cattle and other livestock species arrived in Africa around 7000 BP from southwest Asia (Brass, 2012). As in Europe, the original long-horn cattle were replaced by short-horns, although long-horns still exist in some parts of Africa. There are pictures of zebus in Egypt dating from around 4000 BP, but substantial zebu populations were not established at that time (Payne and Hodges, 1997). Import of zebu bulls into Africa was probably stimulated by the Arabian invasions after 700 AD. Cross-breeding to taurine cattle generated taurindicine populations, such as the sanga, which remained mainly taurine and 500 years ago was the dominant type of cattle in central and eastern Africa. Gene flow into western African taurine populations was stimulated by nomadic Fulani pastoralists. The Bantu expansion southwards from the Great Lakes region led to the introduction of sheep into southern Africa around 2000 BP and sanga cattle around 1500 BP (Payne and Hodges, 1997). At the end of the nineteenth century, a rinderpest epidemic led to the spread of zebu cattle with little taurine ancestry in East and West Africa.

Domestic chickens appeared around 8000 BP in Southeast Asia and were introduced around 4500 BP into India and Oceania, around 3000 BP into Europe and around 2300 BP into Africa. It is thought that Polynesians had already brought chickens to South America via the Pacific before 1492 (Storey *et al.*, 2012).

The European colonization of America after 1492 introduced cattle, sheep, goats, pigs, horses, donkeys and chickens. South and Central America and the southern part of North America initially received Iberian livestock, including horses, which transformed the sedentary indigenous societies of the prairies. Further to the north, English-speaking settlers imported northwest-European livestock. In the nineteenth century, cattle of Iberian descent were largely replaced by, or crossbred with, zebus from South Asia.

As well as accompanying human migrations into new areas, the dispersal of livestock populations was also stimulated by the need to import animals from neighbouring regions following major losses caused by epidemics, famines or plundering. Gene flow was further stimulated by trading, the use of horses and dromedaries for transport, the nomadic lifestyles of cattle-herding peoples and the seasonal transhumant movements of cattle and sheep in several parts of the Old World.

The wide dispersal of the major livestock species had the following effects:

- genetic "isolation by distance", which led to the development of many regional types, many of which already existed in the eighteenth century, when livestock diversity started to be documented;
- a decrease in molecular genetic diversity correlating with distance from centres of origin, caused by founder effects; this effect has been observed in European goats (Canon *et al.*, 2006), African and European cattle (Cymbron *et al.*, 2005; Freeman *et al.*, 2006), the mtDNA

of cattle worldwide (Lenstra *et al.*, 2014) and Arabian horses (Khansour *et al.*, 2013); however, founder effects were often counteracted by cross-breeding with wild or other domestic populations (see Subsections 4 and 6 below); among sheep, the spread of the Merino breed from the the sixteenth century onwards anticipated the spread of other successful livestock breeds in the nineteenth and twentieth centuries;

- so-called "diversity enhancing gene flow" (FAO, 2007), the development of additional diversity as a result of adaptations to diverse environments (see Subsection 5 below).

4 Introgression from related species

The genetics of several livestock populations were enriched after the initial split from the wild ancestral species (Table 1A1). Plausible scenarios include capture of wild animals to replenish domestic populations and introgression from wild males.

Taurine and zebu cattle descend from different aurochs populations. A major contribution from African aurochs bulls is plausible (Decker *et al.*, 2014). However, it is not clear whether there was substantial input from European wild bulls (Beja-Pereira *et al.*, 2006; Lari *et al.*, 2011). Local populations in Asia have received maternal input from other *Bos* species (Lenstra *et al.*, 2014). In several tropical and subtropical regions, taurine and zebu cattle introduced during different periods along different routes formed taurindicine populations when brought into contact. Chinese yellow cattle populations harbour both taurine and zebu Y-chromosomes and mtDNA and the African sanga combines both Y-chromosomal types with taurine mtDNA (Hanotte *et al.*, 2000; Li *et al.*, 2013). Other taurindicine cattle carry a zebu Y-chromosome and taurine mtDNA (Ajmone-Marsan *et al.*, 2010).

The origins of domestic sheep and goats are relatively uncomplicated because of the narrow geographical ranges of their wild ancestors. However, possible introgression from other sheep and goat species has not been investigated. The European mouflon is a feral descendant of the first domestic immigrants and has been shown to breed with domestic sheep in Sardinia (Ciani *et al.*, 2014).

In Europe, the first domestic pigs were immigrants from southwest Asia. As a result of continuous introgression, these populations came to be closely related to the European wild boar (Larson and Burger, 2013). In the case of horses, it has been also proposed that the first domesticates were crossed with wild animals, but the relative homogeneity of the horse Y-chromosome suggests that only wild females were added to the domestic population (Warmuth *et al.*, 2012). A similar scenario has been suggested for chickens, in which mtDNA patterns suggest post-domestication introgression from various Asian red jungle fowl populations (Miao *et al.*, 2013). Introgression from the grey jungle fowl of India introduced a *BCDO2* gene variant, which confers yellow skin colour and has reached a high frequency in domestic chicken (Eriksson *et al.*, 2008).

5 Adaptation of livestock following domestication

After domestication, livestock species adapted to being kept by humans via changes to their behaviour, morphology, appearance, physiology and performance (Mignon-Grasteau *et al.*, 2005). Species that spread beyond their centres of domestication also had to adapt to new physical environments (new climates, feeds, diseases, etc.).

An obvious, if superficial, difference between most domestic species and their wild ancestors is in the colour of their coats, plumage or skins. Driven by human aesthetic sense rather than the need for camouflage or signal display, several colours and patterns emerged in domestic animals that are not observed in wild species (Ludwig *et al.*, 2009; Linderholm and

Larson, 2013). In several species, domestication was accompanied by a reduction in size, which made the animals easier to handle (Zeder *et al.*, 2006b). In addition, sexual dimorphism in bovine species was greatly reduced, because males no longer had to fight for dominance. In Europe, taurine cattle gradually decreased in size between the Neolithic and the end of the Middle Ages, with a temporary preference for large animals in the Roman Empire (Lenstra *et al.*, 2014; Felius *et al.*, 2011). In the post-Medieval period, a shift from subsistence farming to market production, together with improvements in animal husbandry, led to larger cattle again being preferred. Similar changes occurred in goats, sheep and pigs. Another aspect of the adaptation of cattle, sheep and goats to the domestic environment was a reduction in horn length. A step further, the complete loss of horns, occurred in several breeds of cattle and sheep (Medugorac *et al.*, 2012).

In several livestock species, adaptation led, at an early stage, to the development of different conformational types:

- the humpless taurine and humped indicine cattle ecotypes, resulting from independent domestications (see Subsection 2);
- the thin-tailed, fat-tailed and fat-rumped sheep ecotypes, the latter two adapted to desert environments (Wang *et al.*, 2014); and
- warmblood, coldblood and pony horses.

Molecular genetic studies, especially genome-wide association studies and whole-genome sequencing, allow adaptive traits to be linked to genomic regions, genes or even mutations. Several examples are listed in Table 1A2. Several traits have been subject to selection within breeds (see Table 4B1 in Part 4, Section B), but the corresponding mutation may have predated breed formation. For instance, the breed distribution of the derived *DGAT1* allele in cattle, which was identified as a result of efforts to localize milk quantitative trait loci (QTLs) in the Holstein, reveals an old origin and an early role in the development of dairy cattle (Kaupe *et al.*, 2004).

6 The recent history of livestock diversity

The last 250 years have seen changes on a scale unprecedented in the history of livestock diversity. From the earliest times, livestock keepers had influenced the characteristics of their animals through selective breeding. However, developments in England during the late eighteenth century marked the beginning of a new era and had major consequences for the future of livestock diversity throughout the world. Systematic performance recording, identification of animals and pedigree recording, managed by breeders' associations and documented in herd books, led to the development of more homogenous breeds. Explicit breeding objectives accentuated the existing differences between geographically separated populations. This led not only to the fixation of breed-specific traits, with coat colour being the easiest target (Linderholm and Larson, 2013), but also to an increase in production. Within half a century, the new breeding practices had been widely adopted in Europe and North America. The degree of genetic isolation varied from one breed to another. Island and fancy breeds were often isolated and became inbred, but most breeds continued to interact with others as a result of upgrading, intentional cross-breeding or unintended introgression. Not all newly formed breeds were equally successful. Even before the end of the nineteenth century several had been absorbed by other populations (Felius *et al.*, 2014; 2015).

Other developments also had a major effect on the geographic distribution of livestock diversity. In the nineteenth century, railways increased mobility and facilitated the long-distance transportation of livestock. Steamships enabled the transportation of large numbers of animals across the oceans. These developments initiated what is referred to in the first SoW-AnGR as the "second phase of global gene flow", which lasted from the nineteenth to the mid-twentieth century and saw a large expansion in the geographical distribution of several successful breeds (Valle Zárate

TABLE 1A2

Examples of genes or loci involved in selected traits

Trait	Locus, gene	Reference
Most mammalian livestock		
Coat colour	Several genes	Ludwig *et al.*, 2009; Linderholm and Larson, 2013; Switonski *et al.*, 2013
Cattle		
Production traits	Multiple loci	Bovine HapMap Consortium, 2009; Druet *et al.*, 2013; Qanbari *et al.*, 2014; Randhawa *et al.*, 2014; Xu *et al.*, 2015
Prenatal growth	*NCAPG*	Eberlein *et al.*, 2009
Polledness	Intergenic deletions, *BTA1*	Allais-Bonnet *et al.*, 2013; Rothammer *et al.*, 2014; Wiedemar *et al.*, 2014
Slick-hair coat for thermoregulation	*SLICK* locus	Huson *et al.*, 2014
Trypanotolerance in African cattle	Multiple loci	Dayo *et al.*, 2012
Fat content of milk	*DGAT1*, multiple loci	Kaupe *et al.*, 2004; Stella *et al.*, 2010
Sheep		
Production traits	Multiple loci	Kijas *et al.*, 2012; Fariello *et al.*, 2014; Randhawa *et al.*, 2014
Horn size	*RLXN1*	Johnston *et al.*, 2013
Milk traits	Multiple loci	Gutierrez-Gil *et al.*, 2014
Pig		
Domestication, production traits	Multiple loci	Rubin *et al.*, 2012; Ramos-Onsin *et al.*, 2014; Herrero-Medrano *et al.*, 2014; Yang *et al.*, 2014
Adaptation	Multiple loci	Ai *et al.*, 2015
Back elongation	*NR6A1, PLAG1, LCORL*	Rubin *et al.*, 2012
Meat quality	*PRKAG3*	Galve *et al.*, 2013
Fecundity	*AHR, ESR1, PRM1, PRM2, TNP2, GPR149, JMJD1C*	Bosse *et al.*, 2014; Wang *et al.*, 2015
Horse		
Domestication	Multiple loci	Schubert *et al.*, 2014
Performance	Multiple loci	Petersen *et al.*, 2013b; Metzger *et al.*, 2014
Adult size	*NCAPG/LCORL, HMGA2, ZFAT, LASP1*	Makvandi-Nejad *et al.*, 2012
Gait	*DMRT3*	Andersson *et al.*, 2012; Petersen *et al.*, 2013b; Promerova *et al.*, 2014
Rabbit		
Domestication, behaviour	Multiple loci	Carneiro *et al.*, 2014
Chicken		
Comb form	*HAO1, BMP2*	Johnsson *et al.*, 2012
Domestication	Multiple loci	Rubin *et al.*, 2010
Yellow skin colour	*BCDO2*	Eriksson *et al.*, 2008
Fecundity	*TSRH*	Rubin *et al.*, 2010

Note: For further information see Braunschweig (2010) and Nicholas and Hobbs (2012) in addition to the references cited in the table. Also note that Table 4B1 in Part 4, Section B lists several traits and associated genes/loci that have been identified as being specific to one or more breeds.

et al., 2006; Felius, 2015). Most of these breeds were of European origin, but (as noted above) Indian zebus were exported to the Americas and Chinese pigs were crossed with European pig populations (Bosse, 2014; Felius, 2015).

During the period following the Second World War, artificial insemination became common in cattle and pig breeding. This helped to break down genetic isolation by distance, and catalysed the "third phase of global gene flow",[4] which is still continuing. As a result of these developments, a limited number of transboundary breeds (see Part 1 Sections B and C) have become very widespread and increasingly dominate livestock production throughout the world. This has tended to lead to the decline of locally adapted breeds (see Part 1 Sections B and F). At the same time, crossing of breeds from different parts of the world has added to the breed repertoire, for instance, through the development of synthetic taurine and taurindicine cattle breeds in the United States of America and Australia (Felius, 2015) and the Assaf sheep in Israel.

The genetic diversity harboured in today's breeds is being actively researched (FAO, 2011), to date mainly using neutral markers (i.e. markers that have no known effect on the phenotype) (Groeneveld *et al.*, 2010). As described above (see in particular Box 1A1), diversity studies are instrumental to the reconstruction of genetic events that have shaped the present diversity patterns of livestock species, including ancestry, prehistoric and historical migrations, admixture and genetic isolation. Some general conclusions about the current state of livestock diversity drawn from molecular studies are summarized in Box 1A2. See Part 4 Section B for a detailed discussion of the use of molecular tools in the characterization of livestock diversity.

Box 1A2
Livestock diversity as revealed by molecular studies

- Individual breeds carry a substantial part (typically 80 percent) of the total molecular variation of the respective livestock species; only a small part of the total diversity is accounted for by variation among breeds.
- Breeds vary in their molecular genetic diversity, with the lowest diversity generally being found in breeds that are isolated by geography or management and the highest diversity in breeds located near sites of domestication, panmictic populations (those in which there is random mating) and cross-bred populations (Groeneveld *et al.*, 2010; Herrero-Medrano *et al.*, 2014).
- Well-defined breeds with unique and appreciated traits tend to be inbred and have low molecular genetic diversity, while non-descript local populations tend to have high molecular genetic diversity (Groeneveld *et al.*, 2010).
- Breeds from the same region, or from nearby regions, tend to be closely related.

7 Conclusions

Over recent years, the latest molecular tools have contributed to a better understanding of the genetic basis of domestication and have helped in the identification of a growing list of genes involved in adaptation. Four sources of the genetic diversity present in today's livestock populations can be distinguished:

1. sequestration of part of the genetic repertoire of the wild ancestral species;
2. acquisition of additional diversity as a result of contact with other populations or related species during the dispersal of domesticated species;
3. selection of gene variants conferring adaptation to a variety of environments and capacity to serve a variety of different purposes; and
4. breed formation and systematic breeding, which accentuated differences between populations and increased productivity while decreasing overall molecular genetic diversity.

[4] FAO, 2007, pages 53–55.

Conservation efforts have tended to focus on the fourth, and most recent, source of diversity, i.e. on diversity generated by breed formation. However, diversity derived from the third source, environmental adaptation, is likely to be old in origin and is highly relevant to the maintenance of future breeding options.

The genetic constitution of livestock species and breeds will probably be as dynamic in the future as it has been in the past. Moreover, our growing knowledge of the molecular characteristics of current livestock populations may very well be used to direct the ongoing domestication of other species, such as various types of deer and ratites.

References

Achilli, A., Olivieri, A., Pellecchia, M., Uboldi, C., Colli, L., Al-Zahery, N., Accetturo, M., Pala, M., Hooshiar Kashani, B., Perego, U.A., Battaglia, V., Fornarino, S., Kalamati, J., Houshmand, M., Negrini, R., Semino, O., Richards, M., Macaulay, V., Ferretti, L., Bandelt, H.J., Ajmone-Marsan, P. & Torroni A. 2008. Mitochondrial genomes of extinct aurochs survive in domestic cattle. *Current Biology*, 18: R157–R158.

Achilli, A., Bonfiglio, S., Olivieri, A., Malusa, A., Pala, M., Hooshiar Kashani, B., Perego, U.A., Ajmone-Marsan, P., Liotta, L., Semino, O., Bandelt, H.J., Ferretti, L. & Torroni, A. 2009. The multifaceted origin of taurine cattle reflected by the mitochondrial genome. *PLoS ONE*, 4: e5753.

Ai, H., Fang, X., Yang, B., Huang, Z., Chen, H., Mao, L., Zhang, F., Zhang, L., Cui, L., He, W., Yang, J., Yao, X., Zhou, L., Han, L., Li, J., Sun, S., Xie, X., Lai, B., Su, Y., Lu, Y., Yang, H., Huang, T., Deng, W., Nielsen, R., Ren, J. & Huang, L. 2015. Adaptation and possible ancient interspecies introgression in pigs identified by whole-genome sequencing. *Nature Genetics,* 47: 217–225.

Ajmone-Marsan, P., Garcia, J.F. & Lenstra, J.A. 2010. On the origin of cattle: How aurochs became cattle and colonized the world. *Evolutionary Anthropology*, 19: 148–157.

Allais-Bonnet, A., Grohs, C., Medugorac, I., Krebs, S., Djari, A., Graf, A., Fritz, S., Seichter, D., Baur, A., Russ, I., Bouet, S., Rothammer, S., Wahlberg, P., Esquerré, D., Hoze, C., Boussaha, M., Weiss, B., Thépot, D., Fouilloux, M-N., Rossignol, M-N., van Marle-Köster, E., Hreiðarsdóttir, G. E., Barbey, S., Dozias, D., Cobo, E., *et al.*, 2013. Novel insights into the bovine polled phenotype and horn ontogenesis in Bovidae. *PLoS ONE*, 8: e63512.

Andersson, L.S., Larhammar, L., Memic, F., Wootz, H., Schwochow, D., Rubin, C-J., Patra, K., Arnason, T., Wellbring, L., Hjälm, G., Imsland, F., Petersen, J.L., McCue, M.E., Mickelson, J.R., Cothran, G., Ahituv, N., Roepstorff, L., Mikko, S., Vallstedt, A., Lindgren, G., Andersson, L. & Kullander, K. 2012. Mutations in *DMRT3* affect locomotion in horses and spinal circuit function in mice. *Nature*, 488: 642–646.

Arbuckle, B.S. & Makarewicz, C.A. 2009. The early management of cattle (*Bos taurus*) in neolithic central Anatolia. *Antiquity*, 83: 669–686.

Balasse, M. & Tresset, A. 2002. Early weaning of neolithic domestic cattle (Bercy, France) revealed by intra-tooth variation in nitrogen isotope ratios. *Journal of Archaeological Science*, 29: 853–859.

Balter, M. & Gibbons, A. 2015. Ancient DNA. Indo-European languages tied to herders. *Science*, 347: 814-815.

Beja-Pereira, A., Caramelli, D., Lalueza-Fox, C., Vernesi, C., Ferrand, N., Casoli, A., Goyache, F., Royo, L.J., Conti, S., Lari, M., Martini, A., Ouragh, L., Magid, A., Atash, A., Zsolnai, A., Boscato, P., Triantaphylidis, C., Ploumi, K., Sineo, L., Mallegni, F., Taberlet, P., Erhardt, G., Sampietro, L., Bertranpetit, J., Barbujani, G., Luikart, G. & Bertorelle, G. 2006. The origin of European cattle: evidence from modern and ancient DNA. *Proceedings of the National Academy of Sciences of the United States of America*, 103: 8113–8118.

Bollongino, R., Burger, J., Powell, A., Mashkour, M., Vigne, J.D. & Thomas, M.G. 2012. Modern taurine cattle descended from small number of Near-Eastern founders. *Molecular Biology and Evolution*, 29: 2101–2104.

Bonfiglio, S., Ginja, C., De Gaetano, A., Achilli, A., Olivieri, A., Colli, L., Tesfaye, K., Agha, S.H., Gama, L.T., Cattonaro, F., Penedo, M.C.T., Ajmone-Marsan, P. Torroni, A. & Ferreti, L. 2012. Origin and spread of *Bos taurus*: New clues from mitochondrial genomes belonging to haplogroup T1. *PLoS ONE*, 7: e38601.

Bosse, M., Megens, H.J., Frantz, L.A., Madsen, O., Larson, G., Paudel, Y., Duijvesteijn, N., Harlizius, B., Hagemeijer, Y., Crooijmans, R.P.M.A. & Groenen, M.A.M. 2014. Genomic analysis reveals selection for Asian genes in European pigs following human-mediated introgression. *Nature Communications*, 5: 4392.

Bovine HapMap Consortium 2009. Genome-wide survey of SNP variation uncovers the genetic structure of cattle breeds. *Science*, 324: 528–532.

Brass, M. 2012. Revisiting a hoary chestnut: the nature of early cattle domestication in north-east Africa. *Sahara*, 24: 7–12.

Braunschweig, M.H. 2010. Mutations in the bovine ABCG2 and the ovine MSTN gene added to the few quantitative trait nucleotides identified in farm animals: A mini-review. *Journal of Applied Genetics*, 51: 289–297.

Canon, J., Garcia, D., Garcia-Atance, M.A., Obexer-Ruff, G., Lenstra, J.A., Ajmone-Marsan, P., Dunner, S. & ECONOGENE Consortium. 2006. Geographical partitioning of goat diversity in Europe and the Middle East. *Animal Genetics*, 37: 327–334.

Carneiro, M., Rubin, C.J., Di Palma, F., Albert, F.W., Alfoldi, J., Barrio, A.M., Pielberg, G., Rafati, N., Sayyab, S., Turner-Maier, J., Younis, S., Afonso, S., Aken, B., Alves, J.M., Barrell D., Bolet, G., Boucher, S., Burbano, H.A., Campos, R., Chang, J.L., Duranthon, V., Fontanesi, L., Garreau, H., Heiman, D., Johnson, J., *et al.*, 2014. Rabbit genome analysis reveals a polygenic basis for phenotypic change during domestication. *Science*, 345: 1074–1079.

Ciani, E., Crepaldi, P., Nicoloso, L., Lasagna, E., Sarti, F.M., Moioli, B., Napolitano, F., Carta, A., Usai, G., D'Andrea, M. ,Marletta, D., Ciampolini, R., Riggio, V., Occidente, M., Matassino, D., Kompan, D., Modesto, P., Macciotta, N., Ajmone-Marsan, P. & Pilla, F. 2014. Genome-wide analysis of Italian sheep diversity reveals a strong geographic pattern and cryptic relationships between breeds. *Animal Genetics*, 45: 256–266.

Cieslak, M., Pruvost, M., Benecke, N., Hofreiter, M., Morales, A., Reissmann, M. & Ludwig, A. 2010. Origin and history of mitochondrial DNA lineages in domestic horses. *PLoS One*, 5: e15311.

Cymbron, T., Freeman, A., Malheiro, M.I., Vigne, J.D. & Bradley, D. 2005. Microsatellite diversity suggests different histories for Mediterranean and northern European cattle populations. *Proceedings of the Royal Society B: Biological Sciences*, 272: 1837–1843.

Dayo, G.K., Gautier, M., Berthier, D., Poivey, J.P., Sidibe, I., Bengaly, Z., Eggen, A., Boichard, D. & Thevenon, S. 2012. Association studies in QTL regions linked to bovine trypanotolerance in a West African crossbred population. *Animal Genetics*, 43: 123–132.

Decker, J.E., McKay, S.D., Rolf, M.M., Kim, J., Molina Alcala, A., Sonstegard, T.S., Hanotte, O., Gotherstrom, A., Seabury, C.M., Praharani, L., Babar, M.E., Correia de Almeida Regitano, L., Yildiz, M.A., Heaton, M.P., Liu, W.S., Lei, C.Z., Reecy, J.M., Saif-Ur-Rehman, M., Schnabel, R.D. & Taylor, J.F. 2014. Worldwide patterns of ancestry, divergence, and admixture in domesticated cattle. *PLoS Genetics*, 10: e1004254.

Demirci, S., Koban Bastanlar, E., Dagtas, N.D., Piskin, E., Engin, A., Ozer, F., Yuncu, E., Dogan, S.A. & Togan, I. 2013. Mitochondrial DNA diversity of modern, ancient and wild sheep (*Ovis gmelinii anatolica*) from Turkey: new insights on the evolutionary history of sheep. *PLoS One*, 8: e81952.

Diamond, J. 2002. Evolution, consequences and future of plant and animal domestication. *Nature*, 418: 700–707.

Druet, T., Perez-Pardal, L., Charlier, C. & Gautier, M. 2013. Identification of large selective sweeps associated with major genes in cattle. *Animal Genetics*, 44: 758–762.

Eberlein, A., Takasuga, A., Setoguchi, K., Pfuhl, R., Flisikowski, K., Fries, R., Klopp, N., Furbass, R., Weikard, R. & Kuhn, C. 2009. Dissection of genetic factors modulating fetal growth in cattle indicates a substantial role of the non-SMC condensin I

complex, subunit G (NCAPG) gene. *Genetics*, 183: 951–964.

Edwards, C.J., Ginja, C., Kantanen, J., Pérez-Pardal, L., Tresset, A., Stock, F., Gama, L.T., European Cattle Genetic Diversity Consortium, Gama, L.T., Penedo, M.C.T., Bradley, D.G., Lenstra, J.A. & Nijman, I. 2011. Dual origins of dairy cattle farming – evidence from a comprehensive survey of European Ychromosomal variation. *PLoS ONE*, 6: e15922.

Eriksson, J., Larson, G., Gunnarsson, U., Bed'hom, B., Tixier-Boichard, M., Stromstedt, L., Wright, D., Jungerius, A., Vereijken, A., Randi, E., Jensen, P & Andersson, L. 2008. Identification of the yellow skin gene reveals a hybrid origin of the domestic chicken. *PLoS Genetics*, 4: e1000010.

Evershed, R.P., Payne, S., Sherratt, A.G., Copley, M.S., Coolidge, J., Urem-Kotsu, D., Kotsakis, K., Ozdogan, M., Ozdogan, A.E., Nieuwenhuyse, O., Akkermans, P.M.M.G., Bailey, D., Andeescu, R-R., Campbell, S., Farid, S., Hodder, I., Yalman, N., Özbasaran, M., Bıçakçı, E., Garfinkel, Y., Levy, T & Burton, M.M. 2008. Earliest date for milk use in the Near East and Southeastern Europe linked to cattle herding. *Nature*, 455: 528–531.

Fang, M. & Andersson, L. 2006. Mitochondrial diversity in European and Chinese pigs is consistent with population expansions that occurred prior to domestication. *Proceedings Biological Sciences,* 273: 1803–10.

FAO. 2007. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2011. *Molecular genetic characterization of animal genetic resources*. FAO Animal Production and Health Guidelines. No. 9. Rome. (available at http://www.fao.org/docrep/014/i2413e/i2413e00.pdf).

Fariello, M.I., Servin, B., Tosser-Klopp, G., Rupp, R., Moreno, C., International Sheep Genomics Consortium, San Cristobal, M. & Boitard, S. 2014. Selection signatures in worldwide sheep populations. *PLoS One*, 9: e103813.

Felius, M., Koolmees, P.A., Theunissen, B., European Cattle Genetic Diversity Consortium & Lenstra, J.A. 2011. On the breeds of cattle – historic and current classifications. *Diversity*, 3: 660–692 (available at http://www.mdpi.com/1424-2818/3/4/660).

Felius, M., Theunissen, B. & Lenstra, J.A. 2015. On the conservation of cattle – the role of breeds. *Journal of Agricultural Science*, 153: 152–162.

Freeman, A.R., Bradley, D.G., Nagda, S., Gibson, J.P. & Hanotte, O. 2006. Combination of multiple microsatellite data sets to investigate genetic diversity and admixture of domestic cattle. *Animal Genetics*, 37: 1–9.

Galve, A., Burgos, C., Varona, L., Carrodeguas, J.A., Canovas, A. & Lopez-Buesa, P. 2013. Allelic frequencies of PRKAG3 in several pig breeds and its technological consequences on a Duroc x Landrace-Large White cross. *Journal of Animal Breeding and Genetics*, 130: 382–393.

Gerbault, P., Allaby, R.G., Boivin, N., Rudzinski, A., Grimaldi, I.M., Pires, J.C., Climer Vigueira, C., Dobney, K., Gremillion, K.J., Barton, L.,Arroyo-Kalin, M., Purugganan, M.D., Rubio de Casas, R., Bollongino, R., Burger, J., Fuller, D.Q., Bradley, D.G., Balding, D.J., Richerson, P.J., Thomas M., Gilbert, P., Larson, G. & Thomas, M.G. 2014. Storytelling and story testing in domestication. *Proceedings of the National Academy of Sciences of the United States of America*, 111: 6159–6164.

Gkiasta, M., Russell, T., Shennan, S. & Steele, J. 2003. Neolithic transition in Europe: the radiocarbon record revisited. *Antiquity*, 77: 45–62.

Goedbloed, D.J., Megens, H.J., Van Hooft, P., Herrero-Medrano, J.M., Lutz, W., Alexandri, P., Crooijmans, R.P., Groenen, M., Van Wieren, S.E., Ydenberg, R.C. & Prins, H.T. 2013. Genome-wide single nucleotide polymorphism analysis reveals recent genetic introgression from domestic pigs into northwest European wild boar populations. *Molecular Ecology*, 22: 856–866.

Groenen, M.A., Archibald, A.L., Uenishi, H., Tuggle, C.K., Takeuchi, Y., Rothschild, M.F., Rogel-Gaillard, C., Park, C., Milan, D., Megens, H.J., Li, S., Larkin, D.M., Kim, H., Frantz, L.A., Caccamo, M., Ahn, H., Aken, B.L., Anselmo, A., Anthon, C., Auvil, L., Badaoui, B., Beattie, C.W., Bendixen, C., Berman, D., Blecha, F., *et al.*, 2012. Analyses of pig genomes provide insight into porcine demography and evolution. *Nature*, 491: 393–398.

Groeneveld, L.F., Lenstra, J.A., Eding, H., Toro, M.A., Scherf, B., Pilling, D., Negrini, R., Finlay, E.K.,

Jianlin, H., Groeneveld, E., Weigend, S. & the GOBALDIV Consortium. 2010. Genetic diversity in farm animals: A review. *Animal Genetics*, 41: 6–31.

Gutierrez-Gil, B., Arranz, J.J., Pong-Wong, R., Garcia-Gamez, E., Kijas, J. & Wiener, P. 2014. Application of selection mapping to identify genomic regions associated with dairy production in sheep. *PLoS One*, 9: e94623.

Hanotte, O., Tawah, C.L., Bradley, D.G., Okomo, M., Verjee, Y., Ochieng, J. & Rege, J.E. 2000. Geographic distribution and frequency of a taurine *Bos taurus* and an indicine *Bos indicus* Y specific allele amongst sub-Saharan African cattle breeds. *Molecular Ecology*, 9: 387–396.

Herrero-Medrano, J.M., Megens, H.J., Groenen, M.A., Bosse, M., Perez-Enciso, M. & Crooijmans, R.P. 2014. Whole-genome sequence analysis reveals differences in population management and selection of European low-input pig breeds. *BMC Genomics*, 15: 601-2164-15-601.

Huson, H.J., Kim, E.S., Godfrey, R.W., Olson, T.A., McClure, M., Chase, C.C., Rizzi, R., O'Brien-Perez, A.M., Van Tassell, C., Garcia, J.F. & Sonstegard, T.S. 2014. Genome-wide association study and ancestral origins of the slick-hair coat in tropically adapted cattle. *Frontiers in Genetics*, 5: 101.

Jing, Y., Han, J. & Blench, R. 2008. Livestock in ancient China: An archaeozoological perspective. *In* A. Sanchez-Mazas, R. Blench, M.D. Ross, I. Peiros & M. Lin, eds. *Past human migrations in East Africa: Matching archaeology, linguistics and genetics*. pp. 427–442. London, Taylor and Francis.

Johnsson, M., Gustafson, I., Rubin, C.J., Sahlqvist, A.S., Jonsson, K.B., Kerje, S., Ekwall, O., Kampe, O., Andersson, L., Jensen, P. & Wright, D. 2012. A sexual ornament in chickens is affected by pleiotropic alleles at HAO1 and BMP2, selected during domestication. *PLoS Genetics*, 8: e1002914.

Johnston, S.E., Gratten, J., Berenos, C., Pilkington, J.G., Clutton-Brock, T.H., Pemberton, J.M. & Slate, J. 2013. Life history trade-offs at a single locus maintain sexually selected genetic variation. *Nature*, 502: 93–95.

Kadwell, M., Fernandez, M., Stanley, H.F., Baldi, R., Wheeler, J.C., Rosadio, R. & Bruford, M.W. 2001. Genetic analysis reveals the wild ancestors of the llama and the alpaca. *Proceedings Biological Sciences*, 268: 2575–2584.

Kaupe, B., Winter, A., Fries, R. & Erhardt, G. 2004. DGAT1 polymorphism in *Bos indicus* and *Bos taurus* cattle breeds. *The Journal of Dairy Research*, 71: 182–187.

Khanshour, A., Conant, E. Juras, R. & Cothran. E.G. 2013. Microsatellite analysis of genetic diversity and population structure of Arabian horse populations. *Journal of Heredity*, 104: 386–398.

Kijas, J.W., Lenstra, J.A., Hayes, B., Boitard, S., Porto Neto, L.R., San Cristobal, M., Servin, B., McCulloch, R., Whan, V., Gietzen, K., Paiva, S., Barendse, W., Ciani, E., Raadsma, H., McEwan, J., Dalrymple, B. & International Sheep Genomics Consortium Members. 2012. Genome-wide analysis of the world's sheep breeds reveals high levels of historic mixture and strong recent selection. *PLoS Biology*, 10: e1001258.

Kumar, S., Nagarajan, M., Sandhu, J.S., Kumar, N. & Behl, V. 2007. Phylogeography and domestication of Indian river buffalo. *BMC Evolutionary Biology*, 7: 186–193.

Lari, M., Rizzi, E., Mona, S., Corti, G., Catalano, G., Chen, K., Vernesi, C., Larson, G., Boscato, P., De Bellis, G., Cooper, A., Caramelli, D. & Bertorelle, G. 2011. The complete mitochondrial genome of an 11, 450-year-old aurochsen (*Bos primigenius*) from central Italy. *BMC Evolutionary Biology*, 11: 32.

Larson, G. & Burger, J. 2013. A population genetics view of animal domestication. *Trends in Genetics*, 29: 197-205.

Larson, G., Dobney, K., Albarella, U., Fang, M., Matisoo-Smith, E., Robins, J., Lowden, S., Finlayson, H., Brand, T., Willerslev, E., Rowley-Conwy, P., Andersoon, L. & Cooper, A. 2005. Worldwide phylogeography of wild boar reveals multiple centers of pig domestication. *Science (New York, N.Y.)*, 307: 1618–1621.

Larson, G. & Fuller, D.Q. 2014. The evolution of animal domestication. *The Annual Review of Ecology, Evolution, and Systematics*, 45: 115136 (available at http://www.sv.uio.no/sai/english/research/projects/anthropos-and-the-material/Intranet/domestication-practices/reading-group/texts/larson-and-fuller-the-evolution-of-animal-domestication.pdf).

Larson, G., Piperno, D.R., Allaby, R.G., Purugganan, M.D., Andersson, L., Arroyo-Kalin, M., Barton, L., Climer Vigueira, C., Denham, T., Dobney, K., Doust, A.N., Gepts, P., Gilbert, M.T.P., Gremillion, K.J., Lucas, L., Lukens, L., Marshall, F.B., Olsen, K.M., Pires, J.C., Richerson, P.J., de Casas, R.R., Sanjur, O.I., Thomas, M.G. & Fuller, D.Q. 2014. Current perspectives and the future of domestication studies. *Proceedings of the National Academy of Sciences of the United States of America*, 111: 6139–6146.

Lenstra, J.A. 2005. Evolutionary and demographic history of sheep and goats suggested by nuclear, mtDNA and Ychromosomal markers. *Proceedings of the international workshop The Role of Biotechnology for the Characterization of Crop, Forestry, Animal and Fishery Genetic Resources, Turin, Italy, 5–7 March 2005.*

Lenstra, J.A., Ajmone-Marsan, P., Beja-Pereira, A., Bollongino, R., Bradley, D.G., Colli, L., De Gaetano, A., Edwards, C.J., Felius, M., Ferretti, L., Ginja, C., Hristov, P., Kantanen, J., Lirón, J.P., Magee, D.A., Negrini, R. & Radoslavov, G.A. 2014. Meta-analysis of mitochondrial DNA reveals several population bottlenecks during worldwide migrations of cattle. *Diversity*, 6: 178–187.

Lenstra, J.A., Groeneveld, L.F., Eding, H., Kantanen, J., Williams, J.L., Taberlet, P., Nicolazzi, E.L., Sölkner, J., Simianer, H., Ciani, E., Garcia, J.F., Bruford, M.W., Ajmone-Marsan P. & Weigend, S. 2012. Molecular tools and analytical approaches for the characterization of farm animal diversity. *Animal Genetics*, 43: 483–502.

Li, R., Zhang, X.M., Campana, M.G., Huang, J.P., Chang, Z.H., Qi, X.B., Shi, H., Su, B., Zhang, R.F., Lan, X.Y., Chen, H. & Lei, C.Z. 2013. Paternal origins of Chinese cattle. *Animal Genetics*, 44: 446–449.

Linderholm, A. & Larson, G. 2013. The role of humans in facilitating and sustaining coat colour variation in domestic animals. *Seminars in Cell & Developmental Biology*, 24: 587–593.

Ludwig, A., Pruvost, M., Reissmann, M., Benecke, N., Brockmann, G.A., Castanos, P., Cieslak, M., Lippold, S., Llorente, L., Malaspinas, A.S., Slatkin, M., Hofreiter, M. 2009. Coat colour variation at the beginning of horse domestication. *Science*, 324: 485.

Makvandi-Nejad, S., Hoffman, G.E., Allen, J.J., Chu, E., Gu, E., Chandler, A.M., Loredo, A.I., Bellone, R.R., Mezey, J.G., Brooks, S.A. & Sutter, N.B. 2012. Four loci explain 83% of size variation in the horse. *PLoS One*, 7: e39929.

Mason, I.L. 1984. *Evolution of domesticated animals*. London and New York. Longman.

Medugorac, I., Seichter, D., Graf, A., Russ, I., Blum, H., Gopel, K.H., Rothammer, S., Forster, M. & Krebs, S. 2012. Bovine polledness - an autosomal dominant trait with allelic heterogeneity. *PLoS ONE*, 7: e39477.

Metzger, J., Tonda, R., Beltran, S., Agueda, L., Gut, M. & Distl, O. 2014. Next generation sequencing gives an insight into the characteristics of highly selected breeds versus non-breed horses in the course of domestication. *BMC Genomics*, 15: 562-2164-15-562.

Miao, Y.W., Peng, M.S., Wu, G.S., Ouyang, Y.N., Yang, Z.Y., Yu, N., Liang, J.P., Pianchou, G., Beja-Pereira, A., Mitra, B., Palanichamy, M.G., Baig, M., Chaudhuri, T.K., Shen, Y.Y., Kong Q.P., Murphy, R.W., Yao Y.G. & Zhang Y.P. 2013. Chicken domestication: An updated perspective based on mitochondrial genomes. *Heredity*, 110: 277–282.

Mignon-Grasteau, S., Boissy, A., Bouix, J., Faure, J., Fisher, A.D., Hinch, G.N., Jensen, P., Neindre, P., Mormede, P., Prunet, P., Vandeputte, M., Beaumont, C. 2005. Genetics of adaptation and domestication in livestock. *Livestock Production Science*, 93: 3–14.

Minezawa, M. 2003. Cattle genetic resources in Japan: One successful crossbreeding story and genetic diversity erosion. *In* H. Chang & Y. Huang, eds. *The relationship between indigenous animals and human in APEC region*, pp. 71–90. Taiwan. Chinese Society of Animal Science.

Moradi, M.H., Nejati-Javaremi, A., Moradi-Shahrbabak, M., Dodds, K.G. & McEwan, J.C. 2012. Genomic scan of selective sweeps in thin and fat tail sheep breeds for identifying of candidate regions associated with fat deposition. *BMC Genetics*. 13: 10.

Naderi, S., Rezaei, H.R., Pompanon, F., Blum, M.G., Negrini, R., Naghash, H.R., Balkiz, O., Mashkour, M., Gaggiotti, O.E., Ajmone-Marsan, P., Vigne, J.D. & Taberlet P. 2008. The goat domestication process inferred from large-scale mitochondrial DNA analysis of wild and domestic individuals. *Proceedings of the National Academy of Sciences of the United States of America*, 105: 17659-17664.

Nicholas, F.W. & Hobbs, M. 2012. Mutation discovery for mendelian traits in non-laboratory animals: A review of achievements up to 2012. *Animal Genetics*, 45: 157–170.

Niemi, M., Blauer, A., Iso-Touru, T., Nystrom, V., Harjula, J., Taavitsainen, J.P., Stora, J., Liden, K. & Kantanen, J. 2013. Mitochondrial DNA and Ychromosomal diversity in ancient populations of domestic sheep (*Ovis aries*) in Finland: comparison with contemporary sheep breeds. *Genetics, Selection, Evolution*, 45: 2-9686-45-2.

Nijman, I.J., Otsen, M., Verkaar, E.L., de Ruijter, C., Hanekamp, E., Ochieng, J.W., Shamshad, S., Rege, J.E., Hanotte, O., Barwegen, M.W., Sulawati, T. & Lenstra, J.A. 2003. Hybridization of banteng (*Bos javanicus*) and zebu (*Bos indicus*) revealed by mitochondrial DNA, satellite DNA, AFLP and microsatellites. *Heredity*, 90: 10-16.

Payne, W.J.A. & Hodges, J. 1997. Tropical cattle: origin, breeding and breeding policies. Oxford, UK, Blackwell Science.

Petersen, J.L., Mickelson, J.R., Cothran, E.G., Andersson, L.S., Axelsson, J., Bailey, E., Bannasch, D., Binns, M.M., Borges, A.S., Brama, P., da Câmara Machado, A., Distl, O., Felicetti, M., Fox-Clipsham, L., Graves, K.T., Guérin, G., Haase, B., Hasegawa, T., Hemmann, K., Hill, E.W., Leeb, T., Lindgren, G., Lohi, H., Lopes, M.S., McGivney, B.A., *et al.*, 2013a. Genetic diversity in the modern horse illustrated from genome-wide SNP data. *PLoS ONE*, 8: e54997.

Potts, D.T. 2004. Camel hybridization and the role of *Camelus bactrianus* in the ancient Near East. *Journal of the Economic and Social History of the Orient*, 47: 143-165.

Promerova, M., Andersson, L.S., Juras, R., Penedo, M.C., Reissmann, M., Tozaki, T., Bellone, R., Dunner, S., Horin, P., Imsland, F., Mikko, S., Modrý, D., Roed, K.H., Schwochow, D., Vega-Pla, J.L., Mehrabani-Yeganeh, H., Yousefi-Mashouf, N., Cothran, G.E., Lindgren, G. & Andersson, L. 2014. Worldwide frequency distribution of the 'gait keeper' mutation in the DMRT3 gene. *Animal Genetics*, 45: 274–282.

Qanbari, S., Pausch, H., Jansen, S., Somel, M., Strom, T.M., Fries, R., Nielsen, R. & Simianer, H. 2014. Classic selective sweeps revealed by massive sequencing in cattle. *PLoS Genetics*, 10: e1004148.

Ramos-Onsins, S.E., Burgos-Paz, W., Manunza, A. & Amills, M. 2014. Mining the pig genome to investigate the domestication process. *Heredity*, 113: 471–484.

Randhawa, I.A., Khatkar, M.S., Thomson, P.C. & Raadsma, H.W. 2014. Composite selection signals can localize the trait specific genomic regions in multi-breed populations of cattle and sheep. *BMC Genetics,* 15: 34.

Rosenbom, S., Costa, V., Al-Araimi, N., Kefena, E., Abdel-Moneim, A.S., Abdalla, M.A., Bakhiet, A. & Beja-Pereira, A. 2015. Genetic diversity of donkey populations from the putative centers of domestication. *Animal Genetics,* 46: 30–36.

Rothammer, S., Capitan, A., Mullaart, E., Seichter, D., Russ, I. & Medugorac, I. 2014. The 80-kb DNA duplication on BTA1 is the only remaining candidate mutation for the polled phenotype of Friesian origin. *Genetics, Selection, Evolution*, 46: 44-9686-46-44.

Rubin, C.J., Zody, M.C., Eriksson, J., Meadows, J.R., Sherwood, E., Webster, M.T., Jiang, L., Ingman, M., Sharpe, T., Ka, S., Hallböök, F., Besnier, F., Carlborg, O., Bed'hom, B., Tixier-Boichard, M., Jensen, P., Siegel, P., Lindblad-Toh, K. & Andersson, L. 2010. Whole-genome resequencing reveals loci under selection during chicken domestication. *Nature*, 464: 587–591.

Rubin, C.J., Megens, H.J., Martinez Barrio, A., Maqbool, K., Sayyab, S., Schwochow, D., Wang, C., Carlborg, O., Jern, P., Jorgensen, C.B., Archibald, A.L., Fredholm, M., Groenen, M.A. & Andersson, L. 2012. Strong signatures of selection in the domestic pig genome. *Proceedings of the National Academy of Sciences of the United States of America*, 109: 19529–19536.

Schubert, M., Jónsson, H., Chang, D., Der Sarkissian, C., Ermini, L., Ginolhac, A., Albrechtsen, A., Dupanloup, I., Foucal, A., Petersen, B., Fumagalli, M., Raghavan, M., Seguin-Orlando, A., Korneliussen, T.S., Velazquez, A.M., Stenderup, J., Hoover, C.A., Rubin, C.J., Alfarhan, A.H., Alquraishi, S.A., Al-Rasheid, K.A., MacHugh, D.E., Kalbfleisch, T., MacLeod, J.N., *et al.*, 2014. Prehistoric genomes reveal the genetic foundation and cost of horse domestication. *Proceedings of the National Academy of Sciences of the United States of America*, 111(52): E5661-E5669.

Shi, X.W., Wang, J.W., Zeng, F.T. & Qiu, X.P. 2006 Mitochondrial DNA cleavage patterns distinguish independent origin of Chinese domestic geese and Western domestic geese *Biochemical Genetics* 44: 237–245.

Spassov, N. & Stroytchev, T. 2004. The dromedary domestication problem: 3000 BC rock art evidence for the existence of wild one-humped camel in Central Arabia, *Historia Naturalis Bulgarica*, 16: 151–158.

Stahl, P.W., Muse, M.C. & Delgado-Espinoza, F. 2006. New evidence for pre-Columbian muscovy duck *Cairina mos*chata from Ecuador. *Ibis*, 148: 657–663.

Stella, A., Ajmone-Marsan, P., Lazzari, B. & Boettcher, P. 2010. Identification of selection signatures in cattle breeds selected for dairy production. *Genetics,* 185: 1451–1461.

Stock, F., Edwards, C.J., Bollongino, R., Finlay, E.K., Burger, J. & Bradley, D.G. 2009. Cytochrome b sequences of ancient cattle and wild ox support phylogenetic complexity in the ancient and modern bovine populations. *Animal Genetics*, 40: 694–700.

Stock, F. & Gifford-Gonzalez, D. 2013. Genetics and African cattle domestication. *African Archaeological Review*, 30: 51–72.

Storey, A.A., Athens, J.S., Bryant, D., Carson, M., Emery, K., deFrance, S., Higham, C., Huynen, L., Intoh, M., Jones, S., Kirch, P.V., Ladefoged, T., McCoy, P., Morales-Muñiz, A., Quiroz, D., Reitz, E., Robins, J., Walter, R. & Matisoo-Smith, E. 2012, Investigating the global dispersal of chickens in prehistory using ancient mitochondrial DNA signatures. *PLoS One,* 7: e 39171.

Switonski, M., Mankowska, M. & Salamon, S. 2013. Family of melanocortin receptor (MCR) genes in mammals-mutations, polymorphisms and phenotypic effects. *Journal of Applied Genetics*, 54: 461–472.

Tixier-Boichard, M., Bed'hom, B. & Rognon, X. 2011. Chicken domestication: from archeology to genomics. *Comptes Rendus Biologies*, 334: 197–204.

Thornton, E.K., Emery, K.F., Steadman, D.W., Speller, C., Matheny, R. & Yang, D. 2012. Earliest Mexican Turkeys (*Meleagris gallopavo*) in the Maya Region: implications for pre-Hispanic animal trade and the timing of turkey domestication. *PLoS One*, 7: e42630.

Valle Zárate, A., Musavaya, K. & Schäfer, C. 2006. *Gene flow in animal genetic resources: a study on status, impact and trends*. Hohenheim, Germany, University of Hohenheim, GTZ, BMZ (available at http://tinyurl.com/pd6d82r).

Wang, C., Wang, H., Zhang, Y., Tang, Z., Li, K., Liu, B. 2015. Genome-wide analysis reveals artificial selection on coat colour and reproductive traits in Chinese domestic pigs. *Molecular Ecology Resources,* 15: 414–424.

Wang, C.M., Way, T.D., Chang, Y.C., Yen, N.T., Hu, C.L., Nien, P.C., Jea, Y.S., Chen, L.R. & Kao, J.Y. 2010. The origin of the White Roman Goose. *Biochemical Genetics*, 48: 938–943.

Wang, X., Zhou, G., Xu, X., Geng, R., Zhou, J., Yang, Y., Yang, Z. and Chen, Y. 2014. Transcriptome profile analysis of adipose tissues from fat and short-tailed sheep. *Gene,* 549: 252–257.

Warmuth, V., Eriksson, A., Bower, M.A., Barker, G., Barrett, E., Hanks, B.K., Li, S., Lomitashvili, D., Ochir-Goryaeva, M., Sizonov, G.V., Soyonov, V. & Manica, A. 2012. Reconstructing the origin and spread of horse domestication in the Eurasian steppe. *Proceedings of the National Academy of Sciences of the United States of America*, 109: 8202–8206.

Wiedemar, N., Tetens, J., Jagannathan, V., Menoud, A., Neuenschwander, S., Bruggmann, R., Thaller, G. & Drogemuller, C. 2014. Independent polled mutations leading to complex gene expression differences in cattle. *PLoS One*, 9: e93435.

Wiener, G., Han, J. & Ruijun, L. 2003. *The yak*. Second edition. Bangkok. FAO (available at http://www.fao.org/docrep/006/ad347e/ad347e00.htm).

Wilkins, A.S., Wrangham, R.W. & Fitch, W.T. 2014. The "Domestication syndrome" in mammals: a unified explanation based on neural crest cell behaviour and genetics. *Genetics,* 197: 795–808.

Xu, L., Bickhart, D.M., Cole, J.B., Schroeder, S.G., Song, J., Tassell, C.P., Sonstegard, T.S. & Liu, G.E. 2015. Genomic signatures reveal new evidences for selection of important traits in domestic cattle. *Molecular Biology and Evolution* 32: 711–725.

Yang, S., Li, X., Li, K., Fan, B. & Tang, Z. 2014. A genome-wide scan for signatures of selection in Chinese indigenous and commercial pig breeds. *BMC Genetics,* 15: 7.

Zeder, M.A., Emshwiller, E., Smith, B.D. & Bradley, D.G. 2006a. Documenting domestication: the intersection of genetics and archaeology. *Trends in Genetics*, 22: 139–155.

Zeder, M.A., Bradley, D.G., Emshwiller, E. & Smith, B.D. 2006b. *Documenting domestication. New genetic and archaeological paradigms*. Berkeley, USA. University of California Press.

Zhang, Y., Vankan, D., Zhang, Y. & Barker, J.S. 2011. Genetic differentiation of water buffalo (*Bubalus bubalis*) populations in China, Nepal and south-east Asia: inferences on the region of domestication of the swamp buffalo. *Animal Genetics* 42: 366–377.

Section B

Status and trends of animal genetic resources

1 Introduction

The monitoring system for the implementation of the Global Plan of Action for Animal Genetic Resources (FAO, 2007a) consists of two elements. One line of reporting focuses on the process of implementing the Global Plan of Action (see Part 3 and FAO, 2014a). The other focuses on animal genetic resources (AnGR) themselves, as the state of these resources constitutes a measurable indicator of the success of the Global Plan of Action (FAO, 2013a).

Data for monitoring the status and trends of AnGR on a world scale are drawn from the Global Databank for Animal Genetic Resources, a database of breed-related data that FAO began to build up in the early 1990s. Since 1995, the Global Databank has formed the backbone of the Domestic Animal Diversity Information System (DAD-IS). Data from the Global Databank were used to prepare three editions of the *World Watch List for Domestic Animal Diversity* (FAO, 1993; 1995; 2000), as well as *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007b). They have subsequently been used to prepare biennial reports on the status and trends of AnGR (FAO, 2009; 2011; 2013b; 2014b).

This section presents a global overview of the diversity and status of AnGR. The analysis is based on DAD-IS data made available by countries by June 2014. It serves as an update of the analysis presented in the first SoW-AnGR, which was based on data from 2006.[1] Box 1B1 outlines changes in the approach to reporting and data analysis that have been introduced for the second SoW-AnGR process. The section begins by describing the state of reporting on AnGR and the progress made in this respect during the period between January 2006 and June 2014. A description of the current regional distribution of livestock species and breeds is then presented, followed by an overview of the risk status of the world's livestock breeds. Trends in risk status are then described.

[1] FAO, 2007a, Part 1 Section B (pages 23–49).

2 The state of reporting

As breed population data are provided by individual countries, the basic unit from which an analysis of global status and trends has to be built is the national breed population. The number of national breed populations recorded in the Global Databank for Animal Genetic Resources increased from 2 719 in 1993 to 5 330 in 1999 and 14 017 in 2006 when the first SoW-AnGR was drafted. By June 2014, the total number of entries had risen to 14 869 (Table 1B1). While the number of national breed populations recorded rose sharply during the period preceding the preparation of the first SoW-AnGR, the percentage for which any population data had been recorded declined. These figures have improved since 2006 as a result of population data being added to the records in the Global Databank (Table 1B1). However, as shown in Figure 1B1, many gaps remain. Moreover, even where some population data have been reported, many have not been recently updated (see further discussion below). It should also not be assumed that the national breed inventories recorded in DAD-IS are complete. As

Box 1B1

Developments since the publication of the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture*

Following the publication of *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) and the adoption of the Global Plan of Action for Animal Genetic Resources in 2007, the Commission on Genetic Resources for Food and Agriculture, in 2009, agreed a schedule and a format for reporting on the status and trends of animal genetic resources (AnGR). It was agreed that a report would be prepared every two years, based on a template derived from the structure of relevant section (Part 1 Section B) of the first SoW-AnGR. It was agreed that the status and trends reports should include the Convention on Biological Diversity's headline indicator for "trends in genetic diversity of domesticated animal species of major socio-economic importance", once this indicator had been developed (a task which fell to FAO under the auspices of the Commission).

In 2013, the Commission agreed to the use of the following set of indicators:

- the number of locally adapted breeds;
- the proportion of the total population accounted for by locally adapted and exotic breeds; and
- the number of breeds classified as at risk, not at risk and unknown.

To allow the indicators to be calculated, the Commission agreed to the use of a new breed classification system, distinguishing "locally adapted" breeds from "exotic" breeds (see Box 1B2). DAD-IS was then adapted so as to allow countries to allocate their breed records to the appropriate classes (exotic or locally adapted). In June 2014, when the analysis of status and trends was performed, this allocation procedure had not been completed. A provisional indicator set, based on a provisional categorization of breeds, is presented in the status and trends report for 2014 (FAO, 2014b).

Also in 2013, the Commission agreed to additional changes to the reporting framework, with the aim of providing a more realistic picture of the state of reporting and eliminating some confounding factors that made it difficult to interpret trends in risk status. First, in order to address the potentially misleading effects of including breeds for which no recent population data are recorded in DAD-IS in the analysis of risk-status trends, a decision was taken to introduce a ten-year cut-off point after which a breed is re-assigned to the "unknown" risk-status category (see Box 1B3) if its population data are not updated. Second, it was agreed that trends in breed risk status should be calculated based on the most up-to-date current and historical data available in DAD-IS at the time of calculation, rather than by comparing current data to those presented in older reports. Historical population data recorded in DAD-IS can be updated at any time, as can countries' breed inventories (breed records can be added or deleted). The new calculation method allows any recent updates of this kind to be taken into account. The revised calculation methods were used in the preparation of the 2014 status and trends report and in the preparation of the second SoW-AnGR. One consequence is that, compared to the first SoW-AnGR (and previous status and trends reports), a higher proportion of breeds are currently classified as being of unknown risk status.

discussed in Part 3 Section B, many countries consider that they have not yet established comprehensive breed inventories at national level, and it is also likely that not all identified breeds have been entered into DAD-IS, particularly in the case of species that are not regarded as priorities in the respective countries.

3 Species diversity and distribution

DAD-IS records breed-related information on 19 mammalian species, 17 avian species and two fertile interspecies crosses (Bactrian camel × dromedary and duck × Muscovy duck). As was the case when

Box 1B2

Glossary: populations, breeds, breed classification systems and regions

Classification of populations as domesticated, wild or feral

Domestic(ated) animals: animals whose breeding and husbandry are controlled by human communities to obtain benefits or services from them. The process of domestication may take many generations of the species to be completed.

Wild populations: wild relatives of domesticated livestock, wild populations that are used for food and agriculture, or populations undergoing domestication.

Feral populations: populations whose ancestors were domesticated, but which now live independently of humans; for example, dromedaries in Australia.

Breed classification related to geographic distribution

Local breeds: breeds that occur only in one country.

Transboundary breeds: breeds that occur in more than one country.

Regional transboundary breeds: transboundary breeds that occur only in one of the seven SoW-AnGR regions.

International transboundary breeds: transboundary breeds that occur in more than one SoW-AnGR region.

Breed classification related to adaptedness

Locally adapted breeds: breeds that have been in the country for a sufficient time to be genetically adapted to one or more of the traditional production systems or environments in the country. The phrase "sufficient time" refers to time present in one or more of the country's traditional production systems or environments. Taking cultural, social and genetic aspects into account, a period of 40 years and six generations of the respective species might be considered as a guiding value for "sufficient time", subject to specific national circumstances. Indigenous breeds, also termed autochthonous or native breeds form a subset of locally adapted breeds.

Exotic breeds: breeds that are not locally adapted. Exotic breeds comprise both recently introduced breeds and continually imported breeds.

SoW-AnGR regions

Seven regions were defined for the SoW-AnGR: Africa, Asia, Europe and the Caucasus, Latin America and the Caribbean, the Near and Middle East, North America and the Southwest Pacific – see Figure 1 (preliminary pages).

TABLE 1B1

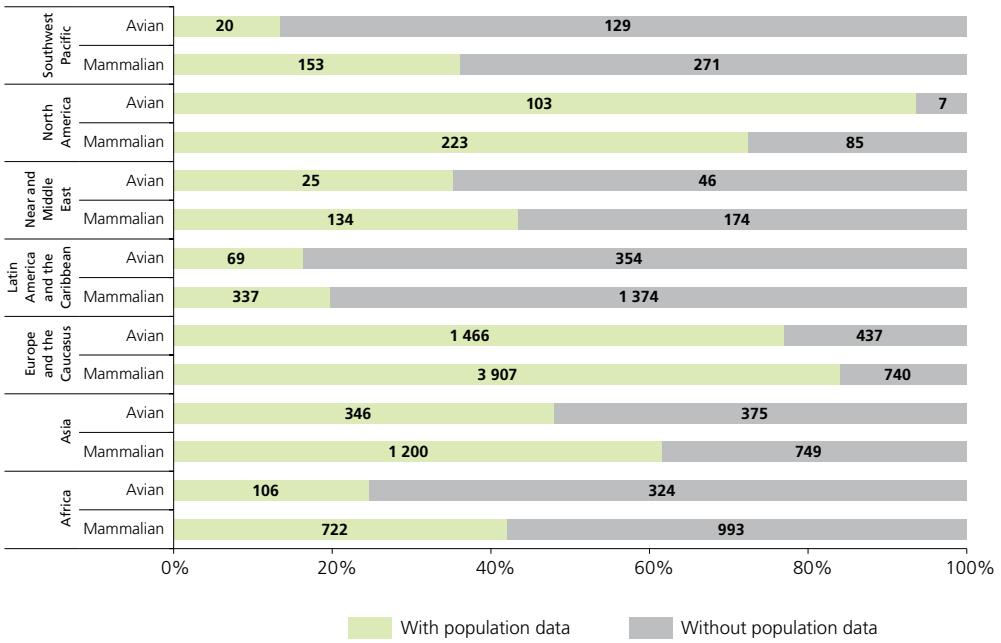
Status of information recorded in the Global Databank for Animal Genetic Resources

Year of analysis	Mammalian species		Avian species		Countries covered
	Number of national breed populations	% with population data	Number of national breed populations	% with population data	
1993	2 719	53	-	-	131
1999	5 330	63	1 049	77	172
2006	10 512	43	3 505	39	181
2014	**11 062**	**60**	**3 807**	**56**	**182**

Note: As of June 2014, no breed data had been recorded in DAD-IS from Andorra, Brunei Darussalam, Liechtenstein, Marshall Islands, Micronesia (Federated States of), Monaco, Nauru, Qatar, San Marino, Singapore, South Sudan, Timor-Leste, United Arab Emirates or Western Sahara. "With population data" figures refer to breed populations for which population data are recorded for any year up to 2014. The ten-year cut-off point (see Box 1B1) is not applied to these figures.
Source: DAD-IS (accessed July 2014).

FIGURE 1B1

Proportion of national breed populations for which population figures have been reported



Note: "With population data" figures refer to breed populations for which population data are recorded for any year up to 2014. The ten-year cut-off point (see Box 1B1) is not applied to these figures.
Source: DAD-IS (accessed July 2014).

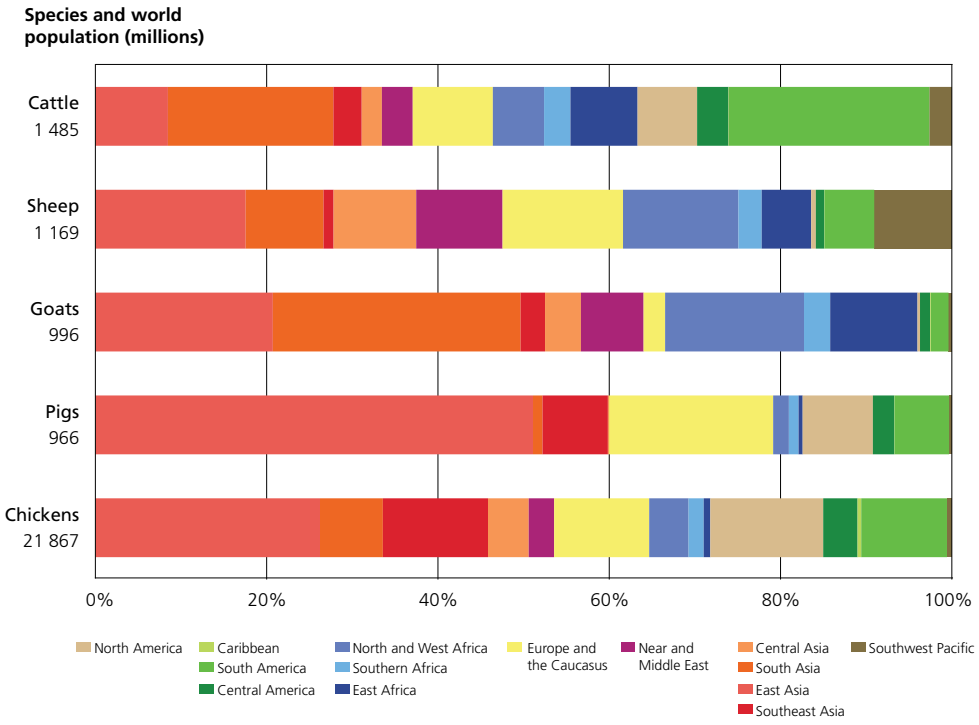
the first SoW-AnGR was published, five species – cattle, sheep, chickens, goats and pigs (the so-called "big five") – are widely distributed across the world and have particularly large global populations. The first three are the most widely distributed livestock species globally, while the latter two are less evenly spread (Figure 1B2). The total global population of each of these species increased between 2005[2] and 2012. Figures from FAO's statistical database FAOSTAT show an increase of 23 percent in the chicken population, 12 percent in the goat population, 10 percent in the pig population, 7 percent in the cattle population and 4 percent in the sheep population over this period.[3]

The world's cattle population reached almost 1.5 billion in 2012. Asia accounts for one-third of the total (highest numbers in India and China, together accounting for about 22 percent of the world total). Latin America accounts for 27 percent (highest numbers in Brazil, alone accounting for 14 percent of the global total), Africa for 17 percent (highest numbers in Ethiopia and the United Republic of Tanzania), Europe and the Caucasus for 9 percent (highest numbers in the Russian Federation and France), North America for 7 percent (highest numbers in the United States of America), the Near and Middle East for 4 percent (highest numbers in Sudan and Egypt) and the Southwest Pacific for 3 percent (highest numbers in Australia). The pattern of regional distribution has not changed greatly since 2005. Asia and Africa have increased their shares of the world total, while the shares of

[2] The analysis of species diversity and distribution presented in the first SoW-AnGR was based on FAOSTAT figures for 2005.

[3] Calculations based on FAOSTAT data accessed September 2014.

FIGURE 1B2
Regional distribution of livestock species in 2012



Source: FAOSTAT.

Latin America and the Caribbean, North America, and Europe and the Caucasus have declined. In the latter two regions, the cattle population has fallen slightly in absolute terms.

The world's sheep population reached almost 1.2 billion in 2012. Asia accounts for 37 percent of the total (highest numbers in China and India), Africa for 22 percent (highest numbers in Nigeria and Ethiopia), Europe and the Caucasus for 14 percent (highest numbers in the United Kingdom and Turkey), the Near and Middle East for 10 percent (highest numbers in Sudan and the Syrian Arab Republic), the Southwest Pacific for 9 percent (highest numbers in Australia and New Zealand), Latin America and the Caribbean for 7 percent (highest numbers in Brazil and Argentina) and North America for 1 percent. The most dramatic change in the regional distribution of the world's sheep population since 2005 has been a sharp decline in the proportion of the global population accounted for by the Southwest Pacific (share of the total falling by 4 percent; population size falling by 25 percent in absolute terms). The sheep populations of North America and Europe and the Caucasus have also declined, both in absolute size and in terms of global share. In contrast, Africa and Asia account for larger shares of the world sheep population than they did in 2005, with Africa's sheep population having risen by 19 percent in absolute terms.

The world's goat population reached approximately 1 billion in 2012. Goats are widely distributed in developing regions, but less so in developed regions. Asia (56 percent; highest numbers in China and India), Africa (30 percent; highest numbers in Nigeria and Kenya) and the Near and Middle East (7 percent; highest numbers in Sudan and Yemen) account for the vast majority of the world's goats. There are also significant populations in Latin America and the Caribbean (3 percent; highest numbers in Mexico and Brazil) and in Europe and the Caucasus (3 percent; highest numbers in Turkey and Greece). The main change since 2005 has been a large increase in Africa's goat population (share of the global total rising by 4 percent, and population size rising by 27 percent in absolute terms).

The world's pig population reached almost 1 billion in 2012. Asia accounts for 60 percent of the world total, with China alone accounting for 49 percent. Europe and the Caucasus accounts for 19 percent (highest numbers in Germany and Spain), Latin America and the Caribbean for 9 percent (highest numbers in Brazil and Mexico), North America for 8 percent (highest numbers in the United States of America) and Africa for 4 percent (highest numbers in Nigeria). The pattern of regional distribution has not changed greatly since 2005. Asia has increased its share. The shares of Europe and the Caucasus and North America have fallen, with the former region experiencing an absolute fall in the size of its pig population. From a relatively low starting point, Africa's pig population has increased by 37 percent since 2005.

The world's chicken population reached more than 21 billion in 2012. More than half the total (53 percent) is found in Asia, where the largest producers are China and Indonesia. Latin America and the Caribbean accounts for 15 percent of the total (highest numbers in Brazil and Mexico); Europe and the Caucasus for 11 percent (highest numbers in the Russian Federation and Turkey); North America for 10 percent (highest numbers in the United States of America); Africa for 7 percent (highest numbers in Nigeria and South Africa) and the Near and Middle East for 3 percent (highest numbers in Saudi Arabia and Egypt). Since 2005, the chicken population has increased in all regions except North America. Asia has increased its share of the total world population, while the shares of Europe and the Caucasus and North America have declined.

4 Breed diversity and distribution

This subsection discusses the geographical distribution of breeds belonging to the local and transboundary categories, presents a summary of the current risk status of the world's breeds and considers trends in breed risk status since the time the first SoW-AnGR was prepared.

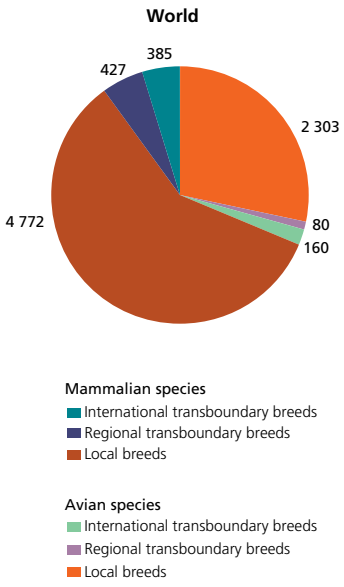
4.1 Geographical distribution of local and transboundary breeds

The Global Databank for Animal Genetic Resources currently contains data from 182 countries and 38 species. The total number of breeds recorded in the Global Databank increased from 7 616 in 2006 to 8 774 in 2014. Out of this total, 7 718 are local breeds (i.e. breeds present in only one country – see Box 1B2); the equivalent figure in 2006 was 6 536. The remaining 1 056 are transboundary breeds (i.e. breeds present in more than one country); the equivalent figure in 2006 was 1 080. Among transboundary breeds, 510 (compared to 523 in 2006) are regional transboundary breeds (occur in only one region) and 546 (compared to 557 in 2006) are international transboundary breeds (occur in more than one region). A total of 647 breeds (compared to 690 in 2006) are classified as extinct. Four of these extinct breeds (compared to nine in 2006) are transboundary breeds (three regional and one international).[4]

Figure 1B3 shows the share of local, regional transboundary and international transboundary breeds among the mammalian and avian breeds

[4] The 2006 figures presented in this paragraph are taken from the first SoW-AnGR, i.e. they do not account for corrections that countries have made to their breed inventories in DAD-IS since 2006. For example, the apparent fall in the number of extinct breeds between 2006 and 2014 is caused by corrections of this kind.

FIGURE 1B3
Number of local and transboundary breeds at global level



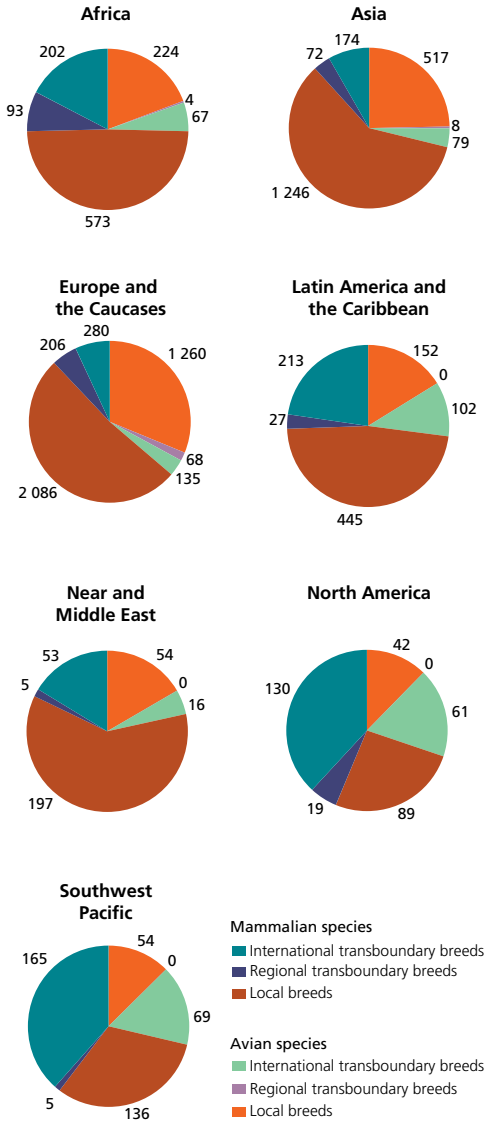
Source: DAD-IS (accessed July 2014).

of the world (excluding extinct breeds). The shares of the breed classes have remained more or less constant since 2006. Figure 1B4 presents a regional breakdown of the figures.

As in 2006, more than two-thirds of reported breeds belong to mammalian species. Mammalian breeds outnumber avian breeds in all regions of the world. The number of mammalian regional transboundary breeds is similar to the number of international transboundary breeds. In contrast, there are twice as many avian international transboundary breeds as there are avian regional transboundary breeds.

Tables 1B2 and 1B3, respectively, show the number of reported local breeds of mammalian and avian species in each region of the world. The totals in some categories have fallen since 2006 because of corrections made by some countries to their breed inventories recorded in DAD-IS.

FIGURE 1B4
Number of local and transboundary breeds at regional level



Source: DAD-IS (accessed July 2014).

TABLE 1B2

Number of reported mammalian local breeds

Species	Africa	Asia	Europe and the Caucasus	Latin America and the Caribbean	Near and Middle East	North America	Southwest Pacific	World
Asses	20	39	50	24	16	5	3	157
Bactrian camels	0	9	3	0	0	0	0	12
Buffaloes	2	90	9	11	8	1	2	123
Cattle	176	241	369	141	43	17	32	1 019
Dromedaries	46	13	1	0	23	0	2	85
Goats	96	183	218	28	34	6	11	576
Guinea pigs	4	0	0	13	0	0	0	17
Horses	40	138	371	84	14	22	25	694
Pigs	53	214	188	60	1	12	15	543
Rabbits	11	16	186	18	5	0	0	236
Sheep	117	262	613	51	53	21	38	1 155
Yaks	0	25	2	0	0	1	0	28
Others	8	16	76	15	0	4	8	127
Total	**573**	**1 246**	**2 086**	**445**	**197**	**89**	**136**	**4 772**

Note: Figures exclude extinct breeds. Figures for alpacas, American bison, deer, dogs, dromedary × Bactrian camels, guanacos, llamas and vicuñas are combined in the "others" category.
Source: DAD-IS (accessed July 2014).

TABLE 1B3

Number of reported avian local breeds

Species	Africa	Asia	Europe and the Caucasus	Latin America and the Caribbean	Near and Middle East	North America	Southwest Pacific	World
Chickens	129	305	912	88	35	15	30	1 514
Ducks	15	92	107	22	4	1	12	253
Geese	10	44	119	5	2	0	2	182
Muscovy ducks	5	9	6	1	1	0	2	24
Ostriches	6	2	3	0	0	0	1	12
Partridges	2	8	2	0	0	0	0	12
Pheasants	0	7	5	6	0	0	0	18
Pigeons	7	12	35	7	8	1	2	72
Turkeys	11	11	40	11	3	11	5	92
Others	39	27	31	12	1	14	0	124
Total	**224**	**517**	**1 260**	**152**	**54**	**42**	**54**	**2 303**

Note: Figures exclude extinct breeds. Figures for cassowaries, Chilean tinamous, duck × Muscovy ducks, emus, guinea fowl, ñandus, peacocks, quails and swallows are combined in the "others" category.
Source: DAD-IS (accessed July 2014).

TABLE 1B4

Number of reported mammalian transboundary breeds

Species	Regional transboundary							International transboundary	World
	Africa	Asia	Europe and the Caucasus	Latin America and the Caribbean	Near and Middle East	North America	Southwest Pacific		
Asses	3	3	1	1	0	0	0	5	13
Bactrian camels	0	0	0	0	0	0	0	2	2
Buffaloes	0	9	1	1	0	0	0	4	15
Cattle	36	20	30	6	1	2	1	109	205
Deer	0	1	1	0	0	0	0	10	12
Dromedaries	1	1	0	0	0	0	0	2	4
Goats	16	12	14	2	0	5	1	36	86
Guinea pigs	0	0	0	1	0	0	0	0	1
Horses	7	10	36	4	0	4	0	63	124
Pigs	3	2	17	5	0	2	0	30	59
Rabbits	3	0	32	1	0	0	0	23	59
Sheep	24	14	74	3	4	6	3	99	227
South American camelids	0	0	0	3	0	0	0	2	5
Total	**93**	**72**	**206**	**27**	**5**	**19**	**5**	**385**	**812**

Note: Figures exclude extinct breeds.
Source: DAD-IS (accessed July 2014).

TABLE 1B5

Number of reported avian transboundary breeds

Species	Regional transboundary							International transboundary	World
	Africa	Asia	Europe and the Caucasus	Latin America and the Caribbean	Near and Middle East	North America	Southwest Pacific		
Cassowaries	0	0	0	0	0	0	0	1	1
Chickens	4	3	42	0	0	0	0	106	155
Ducks	0	2	12	0	0	0	0	12	26
Emus	0	0	0	0	0	0	0	1	1
Geese	0	2	7	0	0	0	0	14	23
Guinea fowl	0	0	0	0	0	0	0	5	5
Muscovy ducks	0	0	0	0	0	0	0	1	1
Ostriches	0	0	0	0	0	0	0	3	3
Pigeons	0	0	0	0	0	0	0	1	1
Quails	0	1	0	0	0	0	0	0	1
Turkeys	0	0	7	0	0	0	0	16	23
Total	**4**	**8**	**68**	**0**	**0**	**0**	**0**	**160**	**240**

Note: Figures exclude extinct breeds.
Source: DAD-IS (accessed July 2014).

Tables 1B4 and 1B5, respectively, show the number of reported regional transboundary breeds of mammalian and avian species in each region of the world. The existence of significant numbers of regional transboundary breeds has implications for the use and conservation of AnGR, and highlights the need for cooperation at regional or subregional levels. For several mammalian species, including sheep, horses and pigs, Europe and the Caucasus, has the highest number of regional transboundary breeds. Africa has a relatively large share of regional transboundary breeds in most of the species listed and has more regional transboundary breeds of cattle and goats than any other region. Europe and the Caucasus has by far the highest number of regional transboundary breeds among avian species.

4.2 Breed risk status

As described in Box 1B1, since the publication of the first SoW-AnGR, the method for assigning breeds to risk-status categories has been amended by the introduction of a ten-year cut-off point, beyond which the risk status of a breed is considered to be unknown if no population data from more recent years have been reported. The results presented in this subsection are therefore not directly comparable to those presented in the first SoW-AnGR. Trends based on comparable figures from 2006 and 2014 are presented below (Subsection 4.3).

A total of 1 458 breeds (17 percent of all breeds, including those that are extinct) are classified as being at risk. The percentage of breeds classified as being of unknown risk status has increased from 34 percent in 2012 (as calculated for that year's status and trends report – FAO, 2013b) to 58 percent in 2014, mainly because of the above-mentioned new method of assigning risk status.

Box 1B3
Glossary: risk-status classification

Extinct: a breed in which there are no breeding males or breeding females remaining. Genetic material that would allow recreation of the breed may, however, have been cryoconserved. In reality, extinction may be realized well before the loss of the last animal or genetic material.

Critical: a breed in which the total number of breeding females is less than or equal to 100 or the total number of breeding males is less than or equal to five; or the overall population size is less than or equal to 120 and decreasing and the percentage of females being bred to males of the same breed is below 80 percent; and which is not classified as extinct.

Critical-maintained: a breed that meets the criteria for inclusion in the critical category, but for which active conservation programmes are in place or populations are maintained by commercial companies or research institutions.

Endangered: a breed in which the total number of breeding females is greater than 100 and less than or equal to 1 000 or the total number of breeding males is less than or equal to 20 and greater than 5; or the overall population size is greater than 80 and less than 100 and increasing and the percentage of females being bred to males of the same breed is above 80 percent; or the overall population size is greater than 1 000 and less than or equal to 1 200 and decreasing and the percentage of females being bred to males of the same breed is below 80 percent; and which is not classified as extinct, critical or critical-maintained.

Endangered-maintained: a breed that meets the criteria for inclusion in the endangered category, but for which active conservation programmes are in place or populations are maintained by commercial companies or research institutions.

At risk: a breed classified as either critical, critical-maintained, endangered or endangered-maintained.

Figure 1B5 shows that the proportion of mammalian breeds classified as at risk (16 percent) is lower than the proportion of avian breeds (19 percent). However, in absolute terms, the number of breeds at risk is higher among mammals (955 breeds) than among birds (503 breeds).

Figure 1B6 presents risk-status data for mammalian species. It can be seen that horses, sheep and cattle are the mammalian species with the highest number of breeds at risk. Rabbits (45 percent) followed by horses (22 percent) and asses (17 percent) are the species that have the highest proportions of breeds at risk. Figure 1B6 also shows the large number of breeds for which no risk-status data are available. The problem is particularly significant in some species – 93 percent for deer breeds, 66 percent for ass breeds and 98 percent for dromedary breeds. This lack of data is a serious constraint to effective prioritization and planning of breed conservation measures. Cattle are the species with the highest number of breeds (184) reported extinct. Large numbers of extinct breeds of sheep (160), pig (107) and horse (87) are also reported.

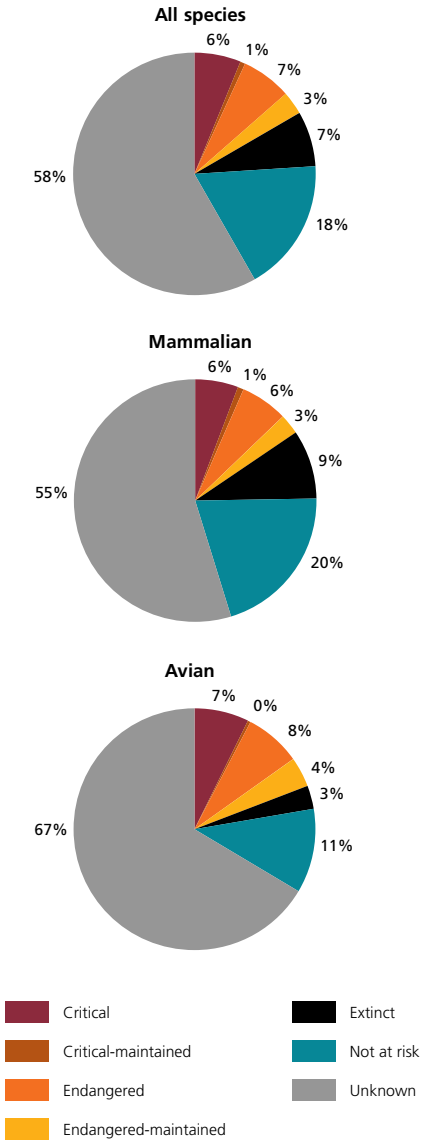
Among avian species, chickens have by far the highest number of breeds at risk (Figure 1B7). As in the case of mammals, there are a large number of avian breeds for which population figures are unavailable. Extinct breeds have mainly been reported among chickens. There are also a few reported cases among ducks, guinea fowl and turkeys.

The regions with the highest proportion of their breeds classified as at risk are Europe and the Caucasus (31 percent of mammalian breeds and 35 percent of avian breeds) and North America (16 percent of mammalian breeds). These are the regions that have the most highly specialized livestock industries, in which production is dominated by a small number of breeds. In absolute terms, Europe and the Caucasus has by far the highest number of at-risk breeds. Despite the apparent dominance of these two regions, problems in other regions may be obscured by the large number of breeds with unknown risk status (Figure 1B8).

The new method for calculating risk status (based on a ten-year cut-off point – see Box 1B1)

FIGURE 1B5

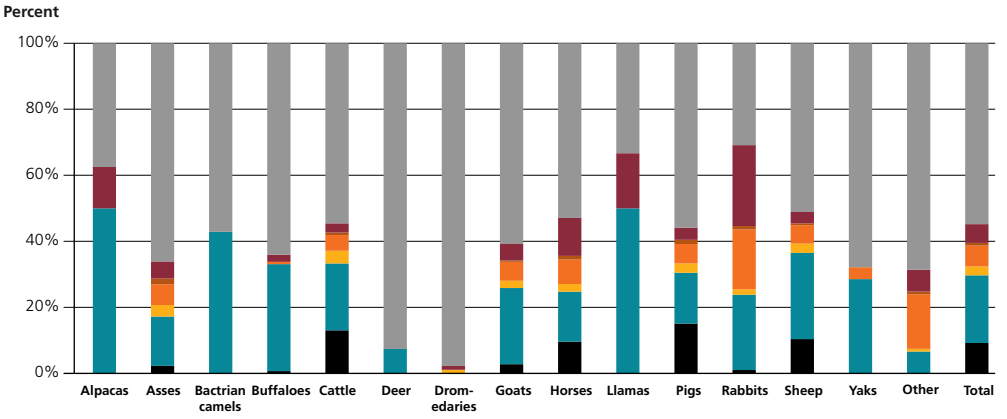
Proportion of the world's breeds by risk status category



Source: DAD-IS (accessed July 2014).

FIGURE 1B6

Risk status of the world's mammalian breeds in June 2014 – species breakdown



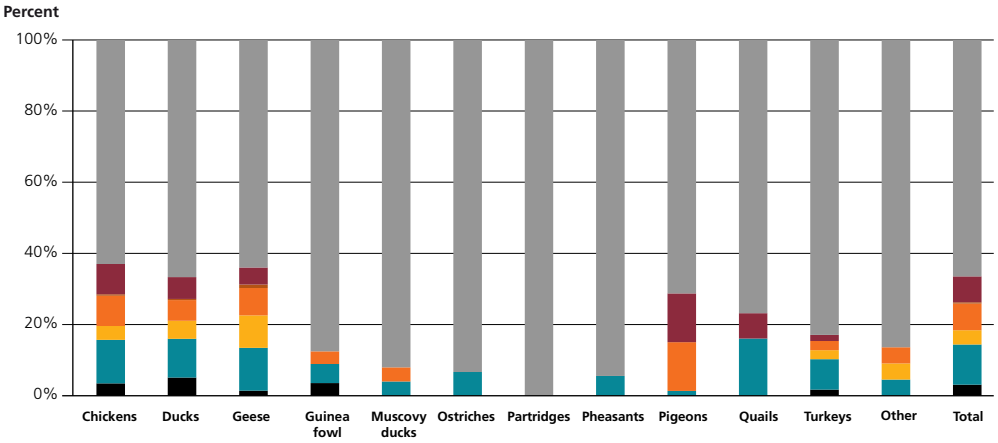
RISK STATUS

	Alpacas	Asses	Bactrian camels	Buffaloes	Cattle	Deer	Drom-edaries	Goats	Horses	Llamas	Pigs	Rabbits	Sheep	Yaks	Other	Total
Unknown	3	115	8	89	768	25	87	414	479	2	396	92	788	19	83	3 368
Critical	1	9	0	3	39	0	1	34	104	1	26	73	53	0	8	352
Critical-maintained	0	3	0	0	11	0	0	3	10	0	9	3	9	0	1	49
Endangered	0	11	0	1	67	0	0	39	67	0	42	54	86	1	20	388
Endangered-maintained	0	6	0	0	54	0	1	15	21	0	20	5	43	0	1	166
Not at risk	4	26	6	45	285	2	0	157	137	3	109	68	403	8	8	1 261
Extinct	0	4	0	1	184	0	0	19	87	0	107	3	160	0	0	565
Total	**8**	**174**	**14**	**139**	**1 408**	**27**	**89**	**681**	**905**	**6**	**709**	**298**	**1 542**	**28**	**121**	**6 149**

Note: "Other" refers to Bactrian camel × dromedary crosses, guanacos, vicuñas, guinea pigs and dogs.
Source: DAD-IS (accessed July 2014).

FIGURE 1B7

Risk status of the world's avian breeds in June 2014 – species breakdown



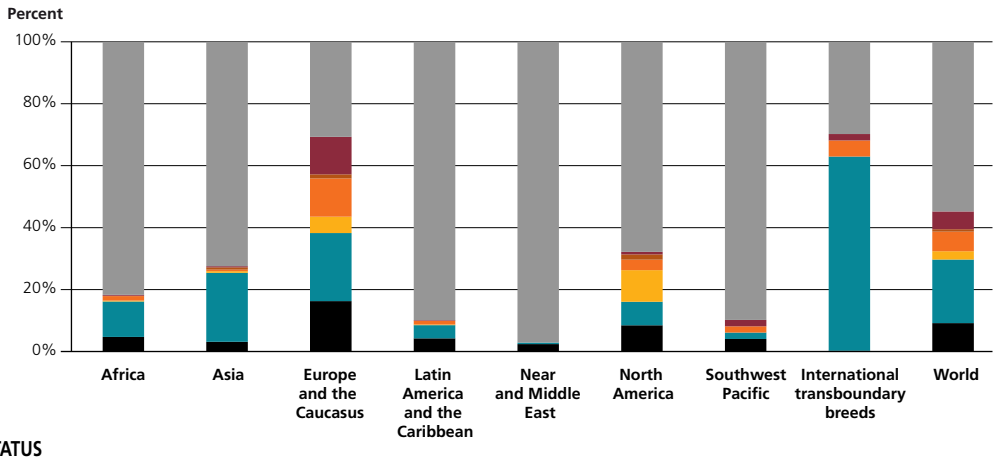
RISK STATUS

	Chickens	Ducks	Geese	Guinea fowl	Muscovy ducks	Ostriches	Partridges	Pheasants	Pigeons	Quails	Turkeys	Other	Total
Unknown	1 089	196	133	49	23	14	12	17	52	43	97	19	1 744
Critical	147	18	10	0	0	0	0	0	10	4	2	0	191
Critical-maintained	7	1	2	0	0	0	0	0	0	0	0	0	10
Endangered	147	17	16	2	1	0	0	0	10	0	3	1	197
Endangered-maintained	67	15	19	0	0	0	0	0	0	0	3	1	105
Not at risk	212	32	25	3	1	1	0	1	1	9	10	1	296
Extinct	60	15	3	2	0	0	0	0	0	0	2	0	82
Total	**1 729**	**294**	**208**	**56**	**25**	**15**	**12**	**18**	**73**	**56**	**117**	**22**	**2 625**

Note: "Other" refers to duck × Muscovy duck crosses, Chilean tinamous, cassowaries, emus, ñandus, peacocks and swallows.
Source: DAD-IS (accessed July 2014).

FIGURE 1B8

Risk status of the world's mammalian breeds in June 2014 – regional breakdown



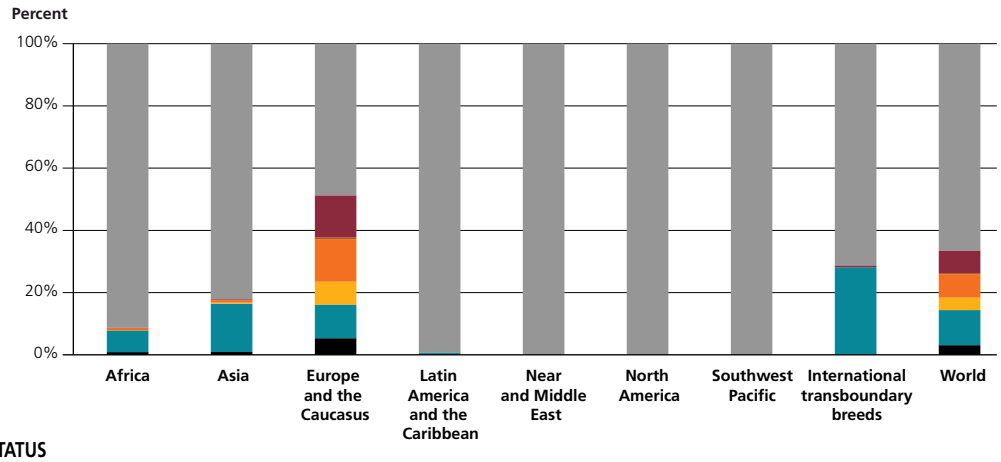
RISK STATUS

	Africa	Asia	Europe and the Caucasus	Latin America and the Caribbean	Near and Middle East	North America	Southwest Pacific	International transboundary breeds	World
Unknown	571	986	840	443	201	80	132	115	3 368
Critical	2	5	332	1	0	1	3	8	352
Critical-maintained	1	10	36	0	0	2	0	0	49
Endangered	10	7	338	6	0	4	3	20	388
Endangered-maintained	2	7	144	1	0	12	0	0	166
Not at risk	80	303	602	21	1	9	3	242	1 261
Extinct	33	43	446	21	5	10	6	1*	565
Total	**699**	**1 361**	**2 738**	**493**	**207**	**118**	**147**	**386**	**6 149**

Note: The figures for each region include local breeds and regional transboundary breeds. International transboundary breeds (breeds present in more than one region) are listed separately.
*African Aurochs, which once lived in parts of both the Africa and the Near and Middle East regions.
Source: DAD-IS (accessed July 2014).

FIGURE 1B9

Risk status of the world's avian breeds June 2014 – regional breakdown



RISK STATUS	Africa	Asia	Europe and the Caucasus	Latin America and the Caribbean	Near and Middle East	North America	Southwest Pacific	International transboundary breeds	World
Unknown	210	435	684	151	54	42	54	114	1 744
Critical	0	1	189	0	0	0	0	1	191
Critical-maintained	0	1	9	0	0	0	0	0	10
Endangered	2	4	191	0	0	0	0	0	197
Endangered-maintained	0	2	103	0	0	0	0	0	105
Not at risk	16	82	152	1	0	0	0	45	296
Extinct	2	5	75	0	0	0	0	0	82
Total	**230**	**530**	**1 403**	**152**	**54**	**42**	**54**	**160**	**2 625**

Note: The figures for each region include local breeds and regional transboundary breeds. International transboundary breeds (breeds present in more than one region) are listed separately.
Source: DAD-IS (accessed July 2014).

draws attention to the fact that during the ten years up to June 2014 countries from Latin America and the Caribbean, the Near and Middle East, North America and the Southwest Pacific reported almost no population data for any avian breeds. Almost all the avian breeds from these regions are therefore classified as being of unknown risk status. Likewise, for more than 90 percent of Africa's avian breeds and more than 80 percent of Asia's avian breeds, lack of recent population data means that no risk status can be assigned (Figure 1B9).

Tables 1B6 and 1B7 show the number of extinct mammalian and avian breeds, broken down by species and region. Europe and the Caucasus has reported far more extinct mammalian and avian

TABLE 1B6
Number of extinct mammalian breeds reported

Species	Africa	Asia	Europe and the Caucasus	Latin America and the Caribbean	Near and Middle East	North America	South-west Pacific	International transboundary	World
Asses	1	0	2	0	1	0	0	0	4
Buffaloes	0	0	1	0	0	0	0	0	1
Cattle	20	19	120	20	1	1	2	1	184
Goats	1	2	16	0	0	0	0	0	19
Horses	6	1	71	0	0	8	1	0	87
Pigs	0	15	90	1	0	0	1	0	107
Rabbits	0	0	1	0	2	0	0	0	3
Sheep	5	6	145	0	1	1	2	0	160
Total	**33**	**43**	**446**	**21**	**5**	**10**	**6**	**1**	**565**

Note: The figures for each region include local breeds and regional transboundary breeds. International transboundary breeds (breeds present in more than on region) are listed separately.
Source: DAD-IS (accessed July 2014).

TABLE 1B7
Number of extinct avian breeds reported

Species	Africa	Asia	Europe and the Caucasus	Latin America and the Caribbean	Near and Middle East	North America	Southwest Pacific	World
Chickens	0	5	55	0	0	0	0	60
Ducks	0	0	15	0	0	0	0	15
Geese	0	0	3	0	0	0	0	3
Guinea fowl	2	0	0	0	0	0	0	2
Turkeys	0	0	2	0	0	0	0	2
Total	**2**	**5**	**75**	**0**	**0**	**0**	**0**	**82**

Note: No extinct avian international transboundary breeds have been reported.
Source: DAD-IS (accessed July 2014).

breeds than any other region – 7 percent of all breeds reported from this region are extinct. The dominance of Europe and the Caucasus in terms of the number of breeds reported extinct may relate, at least in part, to the relatively advanced state of breed inventory and monitoring in this region. The year of extinction has been reported for only 33 percent of extinct breeds (214). Seven breeds are reported to have become extinct before 1900, 111 between 1900 and 1999, 66 between 2000 and 2005, and 30 after 2005 (Table 1B8).

4.3 Trends

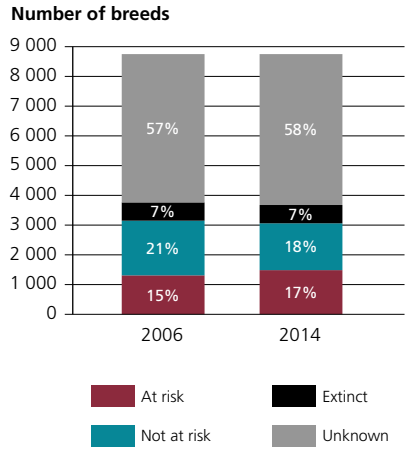
Previous attempts to summarize global trends in breed risk status have been affected by the confounding effects of ongoing corrections to breed inventories. To counter this problem, the trends in breed risk status presented in this report are calculated based on the most up-to-date current and historical data available in DAD-IS at the time of calculation, rather than by comparing current data to those presented in older reports (see Box 1B1). Figure 1B10 shows trends in breed risk status between 2006 (when the first SoW-AnGR was drafted) and 2014. The proportion of breeds classified as at risk increased from 15 percent to 17 percent; the proportion of breeds classified as not at risk decreased from 21 percent to 18 percent and the proportion of breeds reported to be extinct remained stable at 7 percent. The number of breeds for which no risk status can be calculated, either because of a complete lack of data on their population sizes or because no population data are recorded for the preceding ten years, remains very high – 58 percent in 2014 compared to 57 percent in 2006. In short, the available data indicate that genetic erosion has continued over the 2006 to 2014 period, with the proportion of breeds falling into the at-risk category increasing, relative both to the total number of recorded breeds and to the number for which population data are available. However, the full picture of the status and trends of breed risk remains to a large degree obscured by gaps in current and historical data on breed population sizes.

TABLE 1B8
Breed extinction over time

Period	Number of breeds	%
Unspecified	433	67
Before 1900	7	1
1900–1999	111	17
2000–2005	66	10
After 2005	30	5
Total	**647**	**100**

Source: DAD-IS (accessed July 2014).

FIGURE 1B10
Changes in breed risk status between 2006 and 2014



Source: DAD-IS (accessed July 2014).

5 Conclusions

Since the time the first SoW-AnGR was prepared, the number of national breed populations recorded in the Global Databank for Animal Genetic Resources has increased. However, breed-related information remains far from complete. For almost two-thirds of all reported breeds, risk status is unknown because

of a lack of population data. The problem is particularly marked in some regions. For example, in Africa, more than 80 percent of breed populations have no recorded population data for any of the last ten years. In the Southwest Pacific, the equivalent figure is 90 percent.

As a result of the introduction of the ten-year cut-off point after which breeds revert to the "unknown" risk-status category, the percentage of breeds with unknown risk status has increased significantly relative to the figures presented in the first SoW-AnGR. Because of this new calculation method, direct comparisons with the risk-status figures presented in the first SoW-AnGR are not possible. However, trends based on comparable figures – calculated using the most up to date current and historical data available in the Global Databank – indicate that erosion is ongoing.

Missing population data remains the biggest weakness of the current monitoring system, along with the non-coverage of cross-bred populations, which represent a large part of livestock populations worldwide. To arrive at a more comprehensive picture, all livestock populations, regardless of their level of cross-breeding, need to be included within one consistent monitoring system.

References

FAO. 2007a. *The Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration*. Rome (available at http://www.fao.org/docrep/010/a1404e/a1404e00.htm).

FAO. 2007b. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at www.fao.org/3/a-a1250e.pdf).

FAO. 2009. *Status and trends of animal genetic resources – 2009.* Fifth Session of the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture, Rome, 28–30 January 2009 (CGRFA/WG-AnGR-5/09/Inf. 7). Rome (available at ftp://ftp.fao.org/docrep/fao/meeting/016/ak220e.pdf).

FAO. 2011. *Status and trends of animal genetic resources – 2010.* Thirteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture, Rome, 18–22 July 2011 (CGRFA- 13/11/Inf. 17). Rome (available at http://www.fao.org/docrep/meeting/022/am649e.pdf).

FAO. 2013a. *Report of the Fourteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture, Rome, 15–19 April 2013.* CGRFA-14/13/Report. Rome (available at http://www.fao.org/docrep/meeting/028/mg538e.pdf).

FAO. 2013b. *Status and trends of animal genetic resources – 2012.* Fourteenth Session of the Commission on Genetic Resources for Food and Agriculture, Rome, 15–19 April 2013 (CGRFA-14/13/Inf.16 Rev.1). Rome (available at http://www.fao.org/docrep/meeting/027/mg046e.pdf).

FAO. 2014a. *Synthesis progress report on the implementation of the Global Plan of Action for Animal Genetic Resources – 2014.* Eighth Session of the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture, Rome, 26–28 November 2014 (CGRFA/WG-AnGR-8/14/Inf. 5). Rome (available at http://www.fao.org/3/a-at136e.pdf).

FAO. 2014b. *Status and trends of animal genetic resources – 2014.* Eighth Session of the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture, Rome, 26–28 November 2014 (CGRFA/WG-AnGR-8/14/Inf. 4). Rome (available at http://www.fao.org/3/a-at135e.pdf).

FAOSTAT. FAO statistical database (available at http://faostat.fao.org/) (accessed in June 2014).

FAO/UNEP. 1993. *World watch list for domestic animal diversity*. First edition, edited by R. Loftus & B. Scherf. Rome.

FAO/UNEP. 1995. *World watch list for domestic animal diversity*. Second edition, edited by B. Scherf. Rome (available at http://dad.fao.org/cgi-bin/getblob.cgi?sid=-1,50006347).

FAO/UNEP. 2000. *World watch list for domestic animal diversity.* Third edition, edited by B.D. Scherf. Rome (available at http://www.fao.org/docrep/009/x8750e/x8750e00.htm).

Section C

Flows of animal genetic resources

1 Introduction

The term "gene flow" is used to describe the movement and exchange of breeding animals and germplasm. Gene flow in domesticated species has been occurring for thousands of years – ever since livestock populations first began to spread from their centres of domestication (see Part 1 Section A). Throughout most of history, gene flows occurred through the movement of live animals. More recently it has become possible to move genetic material around the world in the form of frozen semen and embryos. The analysis presented below is intended to serve as an update of material presented in the equivalent section[1] of the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007), and focuses particularly on changes that have occurred since the first SoW-AnGR was prepared.

1.1 The state of knowledge in 2007

The first SoW-AnGR presented a description of the main historical phases of gene flow. To summarize: during the first of these phases, which lasted from prehistory until the eighteenth century, gene flow occurred via gradual diffusion. Livestock, including breeding animals, were moved from region to region as a result of migration, warfare, exploration, colonization and trade. During the second phase, roughly spanning the nineteenth century and the first half of the twentieth century, standardized breeds, breeding organizations and genetic improvement programmes based on pedigree and performance recording were established in Europe and North America. International gene flow occurred predominantly within these regions and to a lesser extent from these regions to other parts of the world. An exception to this pattern was the movement of cattle breeds from South Asia to tropical Latin America and parts of Africa. During this period, gene flows were affected by technological developments (e.g. improvements to transportation and communication), demand for high-producing animals and the growing commercialization of animal breeding. The third phase, which began in the mid-twentieth century, has seen an acceleration of gene flows as a result of the globalization of trade, the standardization of livestock production systems, and new technologies such as artificial insemination, embryo transplantation and genomics. Major gene flows occur between the countries of the developed "North" and from the North to the developing "South".[2] These flows have been dominated by a limited number of breeds originating from the temperate regions of the world. Some gene flows also occur between the countries of the South. South to North gene flows are limited. In addition to technological developments and demand from breeders and livestock keepers for high-output animals, gene flows during this phase have been influenced by government policies in both importing and in exporting countries, and by zoosanitary regulations.

[1] FAO, 2007, Part 1 Section C (pages 51–75).

[2] The terms "North" and "South" are frequently used when discussing gene flows to refer to developed and developing regions, respectively. This terminology is used below in this section. The categories do not fully correspond to geographical reality. For example, Australia is part of the "North".

In addition to discussing historical developments, the first SoW-AnGR also presented an overview of the global distribution of livestock species and breeds.[3] Again summarizing briefly, many breeds have spread beyond their countries of origin (1053 of these so-called transboundary breeds are now recorded in DAD-IS – see Section B). However, the number of breeds that have achieved global or near global distribution is limited, and dominated by breeds originating from the North, such as Holstein-Friesian cattle and Large White pigs. For each of the main livestock species, the first SoW-AnGR provided a description of the extent to which breeds from each region of the world had spread internationally and the significance of their roles in livestock production outside their countries of origin. This analysis again indicated the dominance of Northern breeds, but also highlighted the significance of South Asian breeds in Latin America. It also showed that some breeds originating from developing countries (e.g. Awassi sheep and Boran cattle) have acquired considerable significance within their home regions and to some extent beyond. Breeds with recent Southern ancestry are generally little used in the North, the main exceptions being certain breeds of ruminants used in grazing systems in the hotter parts of countries such as Australia. These include breeds developed in the North (e.g. Brahman cattle, developed in the United States of America, based on genetics from South Asia) and those developed in the South (e.g. South Africa's Africander cattle).

The final subsection of the first SoW-AnGR's chapter on gene flow discussed consequences for the diversity of animal genetic resources (AnGR). It noted that throughout history gene flow had provided the basis for the development of a wide range of breeds adapted to local production environments and the needs of livestock keepers and wider society. It listed the following circumstances in which gene flow can enhance diversity:

- an imported population adapts to the local environment and over time a new (locally adapted) breed or population develops;
- imported animals are crossed with those from existing locally adapted breeds to produce new composite breeds;
- imported genetics are judiciously introduced as "fresh blood" into a breed population in order to maintain the vitality of the gene pool; and
- targeted transfer of genes for specific desirable characteristics into a recipient population using marker-assisted introgression.[4]

However, it also noted that gene flow could also lead to the loss of diversity, for example if breeds are driven to extinction because they are replaced by exotic alternatives or if indiscriminate cross-breeding with exotic breeds leads to genetic dilution.

1.2 Sources of information

The country-report questionnaire[5] did not require countries to provide detailed quantitative information on current gene flows or on trends over time. However, it requested countries to indicate whether their current patterns of gene flow corresponded to the above-described pattern in which exchanges are dominated by "North–North" and "North–South" gene flows – and if not, to provide details of the exceptions. Countries were also asked to provide information on the effects that gene flows are having on their AnGR and the management of these resources. Another question asked countries to provide information on any changes in the volume, type or direction of gene flows during the last ten years, and to describe the consequences of any such changes.

Additional data on gene flows were obtained from the UN Comtrade Database,[6] which covers trade in bovines (live pure-bred and semen), horses (live pure-bred), swine (pigs) (live pure-bred, live except pure-bred weighing less than 50 kg) and fowls (live domestic weighing less than 185 grams). These data are not exhaustive. For example, they do not cover informal trade,

[3] FAO, 2007, pages 55–70.

[4] FAO, 2007, pages 73–74.

[5] For more information about the reporting process, see "About this publication" in the preliminary pages of this report.

[6] http://comtrade.un.org

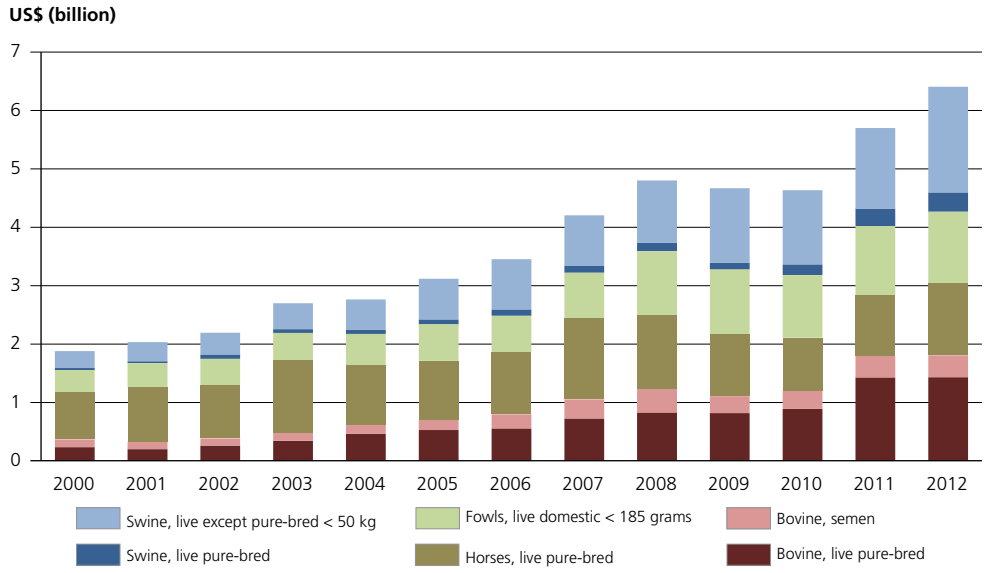
such as that associated with transhumance, cross-border migration of human populations or unofficial markets, or confidential information from private companies. It is also not always possible to distinguish breeding animals from slaughter animals.

2 Status and trends of global gene flows

While fully comprehensive data on international gene flows are not available, UN-Comtrade figures indicate that there have been substantial recent increases in the value of global exports in the various categories of live animals and genetic material covered. Between 2005 and 2012, global trade in bovine semen increased by US$0.2 billion, to reach US$0.4 billion. Reported exports of bovine semen from the United States of America exceeded US$131 million in 2012, compared to US$58 million in 2006. The data presented in Figure 1C1 seem to indicate that the rate of growth in international trade accelerated from about 2006 onwards.[7] Bovine semen exports increased at a rate of 8 percent per year during the period 2000 to 2006 and by 21 percent per year during the period 2006 to 2012.

[7] It is possible that the trend is distorted upwards by more complete reporting in recent years. However, the completeness of figures from preceding years has also been subject to ongoing improvements.

FIGURE 1C1
Trends in the value of global exports of live animals and bovine semen



Note: Referring to the categories of genetic material covered in the UN-Comtrade data, Hoffmann (2010) notes that "Assuming that 'domestic fowl < 185 g' refers to-day-old chicks, this category may represent grandparent or parent stocks, or, in the case of countries that do not have hatcheries to support multiplication, also production stock. The code 'Swine live except pure-bred breeding < 50 kg' may include female animals (mostly F1) from hybrid programmes, in addition to F2 feeder pigs traded mostly among OECD countries or [between] West and Eastern Europe." Figures are based on UN-Comtrade classification HS92.
Source: UN-Comtrade, 2015.

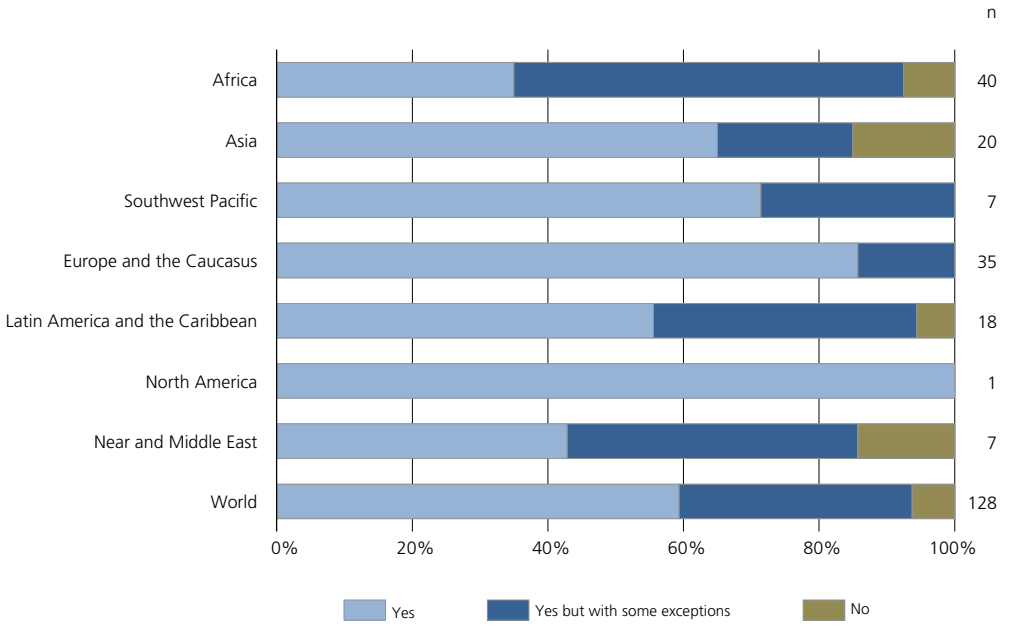
While most country reports do not include detailed quantitative data on gene flows, the descriptive answers indicate that many countries have experienced increased gene flows over recent years. Significant changes in the nature of gene flows over the preceding ten years are reported more frequently by countries from developing regions than by those from developed regions, with the most commonly mentioned changes being increases in the import of cattle and chicken genetic resources.

2.1 North–South and North–North gene flows

Both the information provided in the country reports and the UN Comtrade data indicate that the North continues to dominate global exports, and to a lesser extent global imports, of breeding animals and genetic material. Almost 60 percent of country reports state that imports and exports of genetic resources include no significant exceptions to the dominant pattern of North to North and/or North to South exchanges (Figure 1C2). As shown in Table 1C1, UN-Comtrade figures indicate that between 2000 and 2012, Europe and the Caucasus, North America and the Southwest

FIGURE 1C2

Do gene flows into and out of your country correspond to the pattern of North–North and/or North–South exchanges?



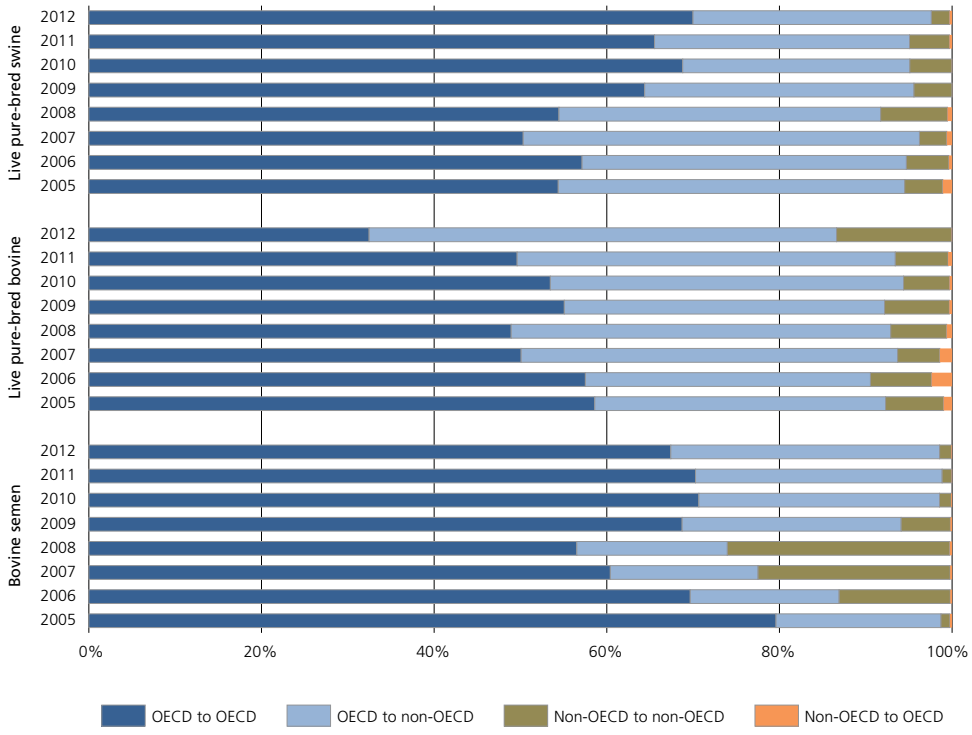
Note: The exact wording of the question in the country-report questionnaire was as follows: "Studies of gene flow in animal genetic resources have generally concluded that most gene flow occurs either between developed countries or from developed countries to developing countries. Does this correspond to the pattern of gene flow into and out of your country? (yes/no/yes but with some significant exceptions)". n = number of reporting countries.
Source: Country reports, 2014.

Pacific (together approximately representing the North) accounted for between 91 and 99 percent of the total value of global exports, and between 60 and 99 percent of the value of imports, in the various categories of breeding animals and genetic material for which data are available.

In 2012, the North, as represented by OECD countries, accounted for 98 percent of live pure-bred swine exports, 99 percent of bovine semen exports and 87 percent of live pure-bred cattle exports (Figure 1C3). Non-OECD countries have slightly increased their share of global bovine semen imports over recent years. By 2012, they accounted for about a third of global imports, the vast majority of which originated from the OECD. In the case of live pure-bred cattle, non-OECD countries accounted, by 2012, for the majority of global imports (67 percent). Latin America and the Caribbean is the main destination of North–South gene flows. For example, it has accounted for about a quarter of total global imports of bovine semen since 2000 (Table 1C1).

Most country reports do not include quantitative information on the destinations of the respective country's AnGR exports. However, Spain's report notes a substantial recent shift towards

FIGURE 1C3
Trade in pig and bovine genetic resources between OECD and non-OECD countries (2005 to 2012)



Note: Figures are based on UN-Comtrade classification HS92. The large increase in the share of non-OECD to non-OECD trade in total bovine semen trade in the years 2006 to 2009 is in large part accounted for by exports from Colombia to the Bolivarian Republic of Venezuela, which peaked at US$1 million in 2008.
Source: UN-Comtrade, 2015.

TABLE 1C1
Regional shares of germplasm exports and imports in the twenty-first century

	Type of germplasm	Africa	Asia	Southwest Pacific	Europe and the Caucasus	Latin America and the Caribbean	North America	Near and Middle East
Exports (%)	Bovine live pure-bred breeding	3	1	13	65	3	14	0
	Semen bovine	0	0	2	33	7	57	0
	Fowls live domestic < 185 grams	1	3	1	73	5	18	0
	Horses live pure-bred breeding	1	0	6	76	0	17	0
	Swine live except pure-bred breeding < 50 kg	0	1	0	78	0	21	0
	Swine live pure-bred breeding	0	3	0	79	1	16	0
Imports (%)	Bovine live pure-bred breeding	5	19	0	63	6	1	5
	Semen bovine	2	10	3	44	26	13	1
	Fowls live domestic < 185 grams	7	13	0	60	13	4	2
	Horses live pure-bred breeding	2	6	2	86	1	3	0
	Swine live except pure-bred breeding < 50 kg	0	1	0	76	0	23	0
	Swine live pure-bred breeding	0	15	0	73	10	2	0

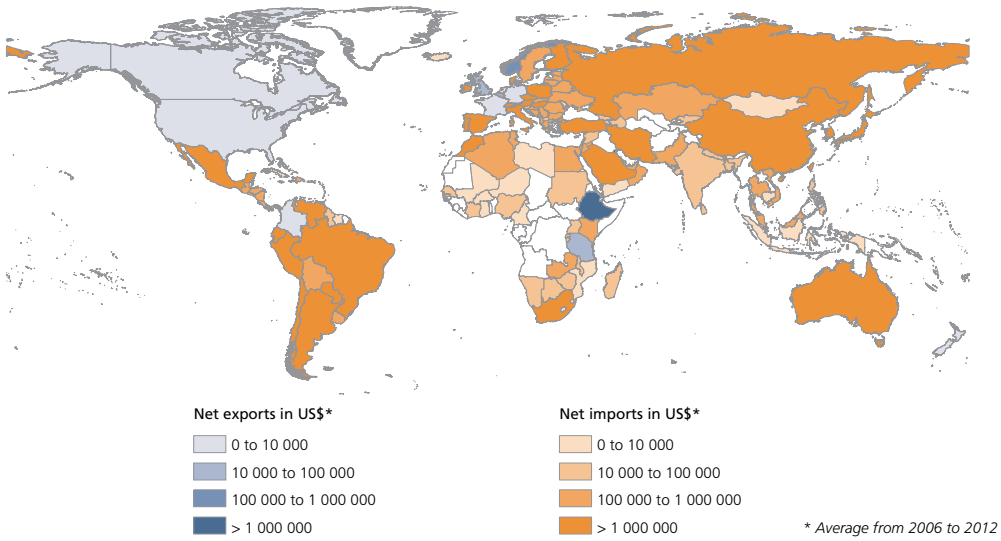
Note: Shading: no colour < 25%; light blue ≥ 25% and < 50%; mid-blue ≥ 50% and < 75%; dark blue ≥ 75%. The figures are averages for the years 2000 to 2012. The shares were calculated based on total exports reported by each country. They include exchanges both within and between regions. As a consequence, Europe and the Caucasus' share is probably increased by intraregional trade. Figures are based on UN-Comtrade classification HS92. See also notes under Figure 1C1.
Source: UN-Comtrade, 2015.

exports to the South. The share of North–North exchanges in the country's total export trade in bovine semen is reported to have fallen from 58 percent to 33 percent between 2005 and 2012. By the end of this period, South American countries accounted for 30 percent of Spain's exports and Kenya for 8 percent.

Figure 1C4 shows which of the world's countries are net exporters and which are net importers of bovine semen (based on UN-Comtrade data). It can be seen that the net exporters, apart from New Zealand and a very small number of developing countries, are clustered in North America and northwestern Europe. In interpreting these figures, it should be noted that the main net exporters of genetic resources are often also substantial importers of genetic material. For example, both the United Kingdom and the United States of America are among the world's top three importers of bovine semen.

In the pig sector, UN-Comtrade figures again indicate the dominance of exports from the North. In 2012, North–North flows, as represented by exchanges between OECD countries, accounted for 70 percent of global trade in pure-bred pigs. North–South flows accounted for 28 percent. In this sector, the share of North–North flows has increased in recent years. This is a result of increased imports of pig genetic resources into some European countries, a trend that is noted in several country reports from Europe. The report from Poland, for example, states that "enhanced import of pig breeding stock and weaners for fattening operations ... contributed to the decline of the national sow stock and overall pig numbers." In the chicken sector, the UN-Comtrade figures presented in Table 1C1 show that global exports are dominated by Europe and the Caucasus and North America. As noted above, the country reports from a number of developing countries describe increases in their imports of chicken genetic resources. Among developed countries, the country report from Japan mentions increased dependence on imported genetic resources in both the pig and the chicken sectors.

FIGURE 1C4
Net exporters and importers of bovine semen (2006 to 2012)



Note: Figures are based on UN-Comtrade classification HS92. Data from countries' dependent territories are treated separately in UN-Comtrade.
Source: UN-Comtrade, 2015.

Although global-scale import and export figures are unavailable for species other than cattle, chickens, pigs and horses, the country reports provide many examples of trade involving the export of small ruminants and several "minor" livestock species from the North. While trends are not always clear, it appears that in many developing countries such imports have increased over the last decade. Examples of North–South trade are described in Boxes 1C1, 1C2, 1C3, 1C4 and 1C6.

Despite the general trend towards greater international exchange of AnGR, a few developed countries report that in some sectors they have become more self-sufficient in breeding material. The country report from Ireland, for example, notes that

> *"a key development in Ireland has been the huge progress in genetic evaluation systems, allowing a halting of the trend in importing North American dairy genetics, and the selection of dairy sires from the Irish Holstein Friesian population."*

Referring to dairy and multipurpose cattle, the country report from Switzerland notes that

> *"the general tendency observed is that breeders and companies tend to export more material and import less material from foreign countries. Several breeders associations reported that, in comparison with 10 years ago, they rely more on the national gene pool for management of their breeds and breed improvement. For example, the population of Braunvieh cows has increased significantly during the last decades. As a consequence, breeders rely much more on indigenous material, whereas in the past there has been an important influence of US genetic material."*

Box 1C1
Trends in gene flows into and out of Kenya

In the last ten years (2003 to 2013) there has been a significant increase in the importation of germplasm into Kenya. Use of imported dairy germplasm has increased from below 2 percent to around 30 percent. Importation of goat semen has increased from zero to a substantial amount. There has been an increase in imports of cattle genetics (Ayrshire, Holstein-Friesian, Jersey, Guernsey, Brown Swiss, Fleckvieh, Gir, Charolais, Angus, etc.) in the form of semen and embryos from Europe, Australia, North America and South America. Goat genetics are imported in the form of semen (Toggenburg and Alpine from Europe) and live animals (Saanen from South Africa). Importation of sheep (Dorper) and rabbit genetics from South Africa has also increased. Kenya also imports Ankole cattle from Uganda.

Exports of Kenya Boran and Sahiwal cattle to other African countries (South Africa, Uganda and the United Republic of Tanzania) in form of live animals, semen and embryos have greatly increased. There has also been a rise in exports of Galla, Alpine and Toggenburg goats to Uganda and Rwanda.

Source: Adapted from Kenya's country report.

2.2 South–South gene flows

As shown in Figure 1C3, UN-Comtrade figures indicate that the share of South–South trade in global exchanges of AnGR remains low. Figures fluctuate considerably from year to year. In 2012, the share of South–South exchanges (as represented by exchanges among non-OECD countries) in the total value of trade in live pure-bred bovines reached 13 percent. However, figures for the preceding seven years remained in the 5 to 8 percent range. The share of South–South exchanges in global trade in bovine semen reached almost 6 percent in 2008,[8] but is usually below 2 percent.

[8] This peak is in large part accounted for by exports from Colombia to the Bolivarian Republic of Venezuela, which reached US$1 million in 2008.

Box 1C2
Gene flows into and out of Thailand

Beef cattle

Thailand imports breeding animals and frozen semen and embryos from North America, Australia and Europe. Brahman cattle are imported as replacement sires and dams. The bulls are used to improve herd genetics via both natural mating and artificial insemination. Bulls of other breeds, such as Charolais and Angus, are imported to produce semen for use in artificial insemination. Frozen Brahman embryos are imported to produce breeding animals.

Breeding animals (Thai Brahman and Kampaengsan cattle) are exported to Viet Nam, the Lao People's Democratic Republic and Cambodia. Frozen Thai Brahman semen is exported to the Lao People's Democratic Republic, Cambodia and Myanmar.

Dairy cattle

Thailand imports frozen dairy cattle semen (mostly Holstein-Friesian) from Australia, New Zealand, Canada, Europe and the United States of America. Breeding animals are exported to Viet Nam, and frozen semen to the Lao People's Democratic Republic and Myanmar.

Pigs

Thailand imports pigs from North America and Europe for use as great grandparents in cross-breeding schemes. The main breeds involved are Large White, Landrace and Duroc. There are also minor imports of Pietrain and Hampshire. Large White and Landrace pigs are exported as grandparents to Viet Nam, the Lao People's Democratic Republic and Cambodia.

Buffaloes

Thailand exports swamp buffaloes for breeding to Cambodia, Viet Nam and China.

Goats

Thailand imports dairy goat and meat goat genetics in the form of breeding animals and frozen semen.

Source: Adapted from Thailand's country report.

Box 1C3
Gene flows into Senegal

Significant gene flows into Senegal include the following (in order of importance):

1. Poultry – principally meat-producing and egg-laying chickens, imported from European countries, Morocco and Brazil in the form of hatching eggs and breeding birds, along with small quantities of duck, quail, ostrich and goose genetic resources;
2. Dairy animals – Jersey, Montbéliarde, Holstein and Normande cattle, imported from Europe as live animals and frozen semen; Guzérat and Girolando cattle, imported from Brazil; Saanen, Guerra, Alpine and Majora goats, imported from Spain;
3. Cattle, sheep and dromedaries from neighbouring West African countries – principally imported from Niger (Bali Bali sheep, Azawak cattle), Mauritania (Maure Zebu cattle, Ladoum sheep, dromedaries) and Mali (Bali Bali sheep);
4. Horses and ponies – English Thoroughbred, Arabian Thoroughbred, Anglo-Arabian Thoroughbred, Trotter, Selle français, Hafflinger Pony, Shetland Pony and Welsh Pony, imported mainly from Europe; Barb and Arab Barb imported from Morocco.

Uses of imported genetic resources include the following:

Exotic chickens are raised in intensive farms in peri-urban areas to supply urban markets. Breeding cocks (along with improvements to management practices) have been introduced into villages by non-governmental organizations and at the initiative of local populations.

Imported Ladoum and Bali Bali sheep are used to improve the meat production performance of Senegalese breeds. This constitutes a prestige form of livestock keeping – the animals do not contribute to the national food supply to the same extent as those belonging to the Maure and Peul-Peul breeds.

Exotic dairy cattle and goats (as well as Nelore beef cattle) are raised as pure breeds in closed production systems. The products of cross-breeding between these animals and locally adapted breeds are raised in semi-intensive systems.

Exotic horse breeds are used in the genetic improvement of horses for use in sports and other competitions in large towns and seaside resorts. Sale of improved horses is an important source of revenue for rural producers.

Source: Adapted from Senegal's country report.

Similarly, figures for live breeding pigs reached about 8 percent in 2008, but normally lie in the 2 to 5 percent range. Given the overall increase in the volume of international trade in these categories (Figure 1C1), the volume of South–South trade is probably increasing in absolute terms. It should also be recalled that official figures may represent underestimations of South–South gene flows. It has been estimated, for example, that informal cross-border trade may account for 80 to 90 percent of the total exports of live animals[9] from Ethiopia to Djibouti, Kenya, Somalia, South Sudan and Sudan (USAID, 2013).

A substantial proportion of country reports from all developing regions indicate that the respective country's gene flows include at least some significant exceptions to the dominant pattern of North–South exchanges (Figure 1C2). The region with the highest proportion of countries providing answers of this type is Africa (65 percent). The most commonly mentioned exception is gene flow between neighbouring countries (i.e. flows roughly at subregional level). A small number of country reports specifically mention a shift away from importing genetic

[9] These figures include animals for slaughtering, production and breeding.

material from the North towards importing from neighbouring countries. The report from Togo, for example, states that "importations of genes from European countries are increasingly rare, while those originating within the region are increasing." It mentions as an example the fact that the government is seeking to import 4 000 Djallonké (sheep) rams and 1 000 Djallonké (goat) bucks, within the framework of its National Investment Programme for Agriculture and Food Security, to support the development of the country's small-ruminant sector. The country report from Bhutan notes that, whereas in the past dairy cattle genetic resources were imported in the form of semen from developed countries, they have recently been imported in the form of live animals from neighbouring countries.

More countries report that they import from their neighbours than that they export to them. This probably reflects a degree of concentration of subregional-level export trade. The species most frequently involved in the reported

Box 1C4
Gene flows into and out of South Africa

The largest livestock gene flows into South Africa occur in the dairy sector, via the import of semen for use in artificial insemination (AI). Holstein and Jersey are the main breeds involved. The use of imported semen predominates over the use of locally produced semen from the same breeds. The cost of imported semen is below the processing cost of the local product, and there is some concern over the effects this is having on the local AI industry. Import figures for cattle semen are shown in the following table. The last three rows show data for cattle breeds that have recently been introduced into South Africa. The quantities of semen involved may appear small, but they have contributed to the establishment of viable populations of the three breeds.

The amount of pig semen imported into South Africa is relatively low. In the commercial sector – in line with international trends – there has been a move towards the use of hybrid semen. However, imports are irregular and needs driven. The only regular inflow of pure-bred genes consists of Large White semen used to broaden the local gene pool of this breed, which is still in demand as a mother line for terminal crossing and for the development of hybrid sires for the local industry.

South Africa's cattle semen imports 2009 to 2013

Breed	2009	2010	2011	2012	2013
	Number of doses				
Holstein	1 022 045	953 555	1 432 844	963 118	1 519 367
Jersey	412 692	388 691	620 194	445 927	513 184
Ayrshire	22 524	48 230	52 912	72 250	53 400
Angus	10 421	13 335	31 365	21 450	50 195
Simmentaler	4 870	5 037	15 220	9 225	9 850
Ankole	0	150	0	0	0
Senepol	0	295	0	0	50
Wagyu	208	565	400	700	6 370

(Cont.)

Box 1C4 *(Cont.)*
Gene flows into and out of South Africa

South Africa's pig semen imports 2009 to 2013

Breed	2009	2010	2011	2012	2013
	Number of doses				
Large White	0	124	56	320	0
Chester White × Duroc × Yorkshire	0	21	0	0	0
Large White × Landrace	0	32	0	0	0
Yorkshire × Duroc × Hampshire	0	82	0	0	0

South Africa has established itself as a significant exporter of animal genetic resources within Africa and to some extent beyond. In 2012, the value of the country's exports of live cattle for breeding and bovine semen reached US$3 million and US$472 000 respectively. According to UN-Comtrade data, 91 percent of South Africa's exports of bovine live animals and semen between 2006 and 2012 went to other African countries, but 5 percent went to Latin America and the Caribbean, and 4 percent to the Southwest Pacific. These exports include both breeds that originated in South Africa and those originally imported from other parts of the world. Net importers of bovine genetic resources from South Africa during the 2006 to 2012 period included (in addition to a number of African countries) Brazil and Paraguay (see Figure 1C5). Examples of imports from South Africa mentioned in the country reports include those of Merino sheep and Angora goats to Lesotho; Boer goats, Black Australorp chickens and Holstein-Friesian cattle to Malawi; dairy cattle, goats and chickens to Mauritius; Boer and Kalahari Red goats to Sudan; Dorper sheep, Boer goats and Koekoek chickens to Ethiopia; and "high-yielding breeding stock" of cattle, poultry, pigs, sheep and goats to Botswana. See Boxes 1C1 and 1C5 for examples from Kenya and Uganda.

Embryo transfer plays a significant role in the export of animal genetic resources from South Africa. In 2012, the country exported 981 *in vivo* derived bovine embryos, 505 sheep embryos and 621 goat embryos. The figures for sheep and goats put South Africa among the world's major exporters of small-ruminant embryos, despite disruptions caused by an outbreak of foot-and-mouth disease in 2011.

Sources: Country reports of Botswana, Ethiopia, Lesotho, Malawi, South Africa and Sudan; UN-Comtrade 2015. Semen import data are official import statistics as quoted in the country report. Embryo transfer figures are from the International Embryo Transfer Society (Perry, 2013).

exchanges between neighbouring countries are ruminants. This probably reflects the relative dominance of pig and poultry gene flows by large commercial companies from developed regions. While in most cases the reported subregional-level exchanges involve locally adapted breeds from the respective subregion, some countries mention that they import or export exotic breeds (i.e. whose origins lie outside the subregion) to or from their neighbours.

The gene flows described in Boxes 1C1, 1C2, 1C3, 1C4, 1C5 and 1C6 include examples of gene flows at subregional level in East, West and Southern Africa, South America and Southeast Asia. Examples from other parts of the world include buffalo and goat genetic resources flowing from India to Nepal; imports of Black and White cattle into Tajikistan from the Islamic Republic of Iran (newly commenced in 2013); imports of Fayoumi chickens from Egypt into Ethiopia; exports of Jamaica Hope and Jamaica Red Poll cattle from Jamaica to Central American and Caribbean countries and Jamaica Black to Panama; and imports of Barbados Blackbelly

Box 1C5
Gene flows between Uganda and other developing countries

Uganda imports genetic resources from the North, but is also involved in exchanges with other developing counties. The main Ugandan genetic resources involved have been Ankole cattle. Exports have gone mainly to neighbouring countries (Kenya, Rwanda, South Sudan and the United Republic of Tanzania), but interest has been expressed from as far away as the United States of America. Cross-bred animals (mainly Ankole × Friesian) have been exported to Burundi, the Democratic Republic of the Congo and Rwanda. Among the 180 000 dairy cattle imported into Rwanda during the last eight years for the "One Cow per Poor Family" programme, 30 percent were procured from Uganda.

Breeds imported into Uganda from other developing countries have included the Kuroiler scavenging backyard chicken breed from India. Importation of this breed in the form of day-old chicks and hatching eggs began in 2010. By early 2014, about 270 000 day-old chicks had been distributed to farmers. The breed has proved to be popular because of its suitability for scavenging production and its relatively fast growth and high egg production.

Cattle breeds have been imported from Kenya (Friesian, Ayrshire, Guernsey, Jersey, Sahiwal, Brahman, Boran and Charolais) and South Africa (Friesian, Ayrshire, Guernsey, Jersey, Brown Swiss, Brahman and Romagnola). Goat breeds (Boer and Savanah) have been imported from South Africa. From 2006 onwards, Camborough pigs have been imported, both for pure-breeding and for cross-breeding with the Ugandan pig.

Source: Adapted from Uganda's country report.

sheep from Barbados to Jamaica (information from the country reports of Ethiopia, Nepal, Tajikistan and Jamaica).

A smaller number of country reports from developing countries mention significant longer distance South–South gene flows, i.e. imports from developing countries in different subregions or regions. Some examples are noted in Boxes 1C1, 1C4, 1C5 and 1C6. However, the number of developing countries that have become substantial exporters of genetic material beyond their own subregions is small. Exceptions include South Africa (Box 1C4) and Brazil (Box 1C6). There are also some notable inter-regional South–South gene flows originating in India. As described above (Subsection 1.1), breeds from South Asia have long played a major role in cattle production in Latin America. Gene flows between the two regions were for many years blocked by zoosanitary concerns. However, following agreements reached between Brazil and India, recent years have seen exchanges recommence (Mariante and Raymond, 2010). Another breed from India that has gained popularity in some developing countries in recent years is the dual-purpose Kuroiler chicken (see Box 1C5).

2.3 South–North gene flows

As described above (Subsection 2.1), exports from the South account for a very small proportion of recorded international gene flows. Exports from the South to the North are even more limited in scale. Exports from non-OECD to OECD countries account for less than 1 percent of global trade in pig and bovine genetic resources (see Figure 1C3). Even within this, the majority of flows come from non-OECD European countries, such as Bulgaria, Latvia, Lithuania and Romania, rather than from the developing regions of the world. As shown in Figures 1C5 and 1C6, even countries such as Brazil and South Africa that have established a presence in international markets for AnGR remain net importers of cattle genetic resources from all their major trade partners in developed regions. Four percent of South Africa's exports of

Box 1C6

Brazil's role as an exporter of genetic resources

While Brazil is heavily dependent on imported commercial lines of pigs and poultry and is a major net importer of bovine genetic resources from several countries (see Figure 1C6), it has acquired a significant role as an exporter of genetic resources, both to neighbouring countries and further afield.

According to figures from UN-Comtrade, in 2012, the value of Brazil's exports of live cattle for breeding was US$16 million. Exports of bovine semen were worth US$1.5 million. Exports of live horses for breeding were worth US$1.6 million.

While 59 percent of the country's exports of bovine live animals and semen between 2006 and 2012 went to other countries in Latin America and the Caribbean, 38 percent went to Africa and 5 percent to Asia (percentages refer to the total value of the two categories combined). In the latter two regions, significant net importers of Brazilian cattle genetic resources during this period included Angola, the Democratic Republic of the Congo and the Philippines (all figures from UN-Comtrade). A number of country reports from these regions mention imports from Brazil, including Senegal (cattle – see Box 1C3), the Philippines (buffaloes) and Sudan (Gir, Girolando and Nelore cattle, Santa Ines sheep). The Santa Ines sheep is reported (Brazil's country report) to be attracting interest from a number of countries in Africa and Latin American and the Caribbean because of its heat tolerance.

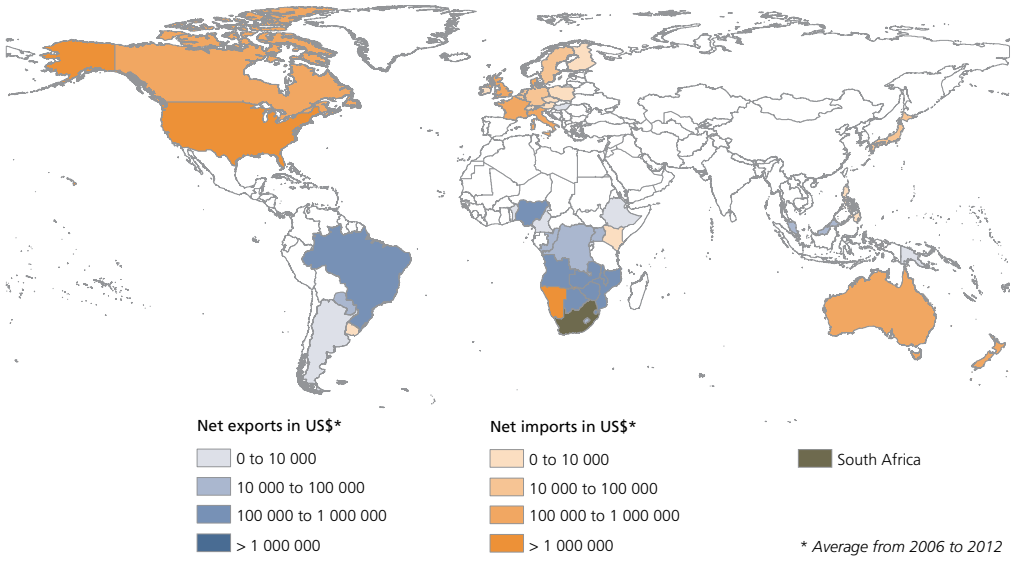
As illustrated by the above figures for the value of bovine genetic resources exports, much of the gene flow from Brazil occurs in the form of live animal exports. However, the country has also built up its production of bovine semen and embryos. The quantities and destinations of bovine semen exports reported by the Brazilian Artificial Insemination Organization for 2013 are shown in the table.

Sources: Country reports of Brazil, the Philippines, Senegal and Sudan; ASBIA, 2013; UN-Comtrade, 2015.

Bovine semen exports from Brazil

Breed	Angola	Argentina	Cabo Verde	Canada	Colombia	United Arab Emirates	Ecuador	Panama	Paraguay	Sri Lanka	Uruguay	Total
	Number of doses											
Bonsmara	2 726			20			40					2 786
Brahman	4 249			3 670	1 030		850	100	2 000			11 899
Brangus		3 000		1 000								4 000
Nelore				6 066	2 301		100		28 068			36 535
Red Angus		8 615			500				2 000			11 115
Red Brangus									4 390			4 390
Senepol		2 706		1 943	298		1 350		4 000			10 297
Others	1 260			1 705	1 420		420	100	2 700		1 400	9 005
Total meat sector	**8 235**	**14 321**		**14 404**	**5 549**		**2 760**	**200**	**41 958**		**1 400**	**90 027**
Gir				12 147	45 469		6 300	200				64 116
Girolando			500	1 465	18 866	300	2 000	400		1 000		24 581
Guzera dairy				900	1 179							2 079
Jersey			250						400			650
Total dairy sector			**750**	**14 512**	**65 514**	**300**	**8 300**	**600**	**400**	**1 000**		**91 426**

FIGURE 1C5
South Africa's trade in live pure-bred cattle and bovine semen



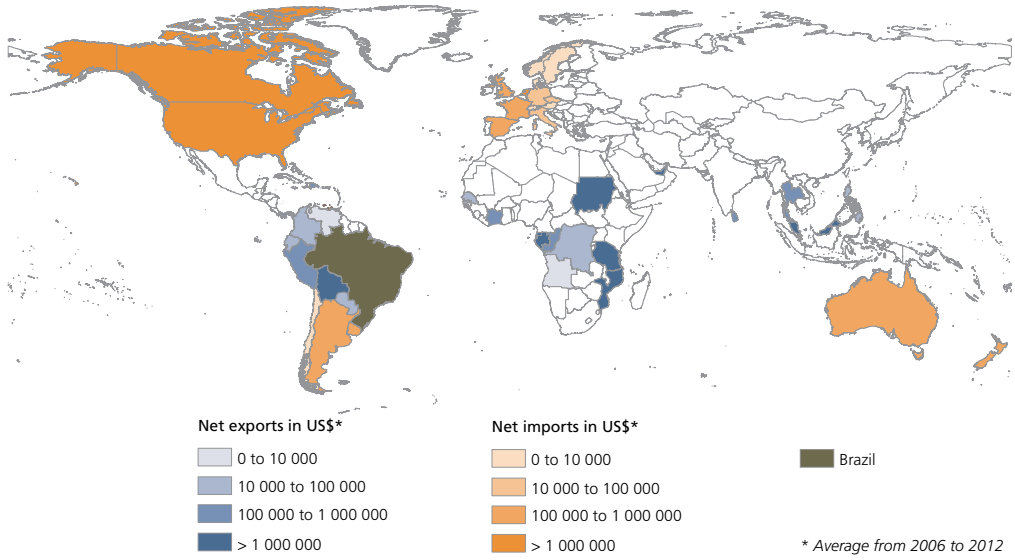
Note: Figures are based on UN-Comtrade classification HS92. They are based on import and export figures reported by Sauth Africa and may not correspond to the figures reported by the respective trade partner. Data from countries' dependent territories are treated separately in UN-Comtrade.
Source: UN-Comtrade, 2015

bovine genetic resources in recent years went to the Southwest Pacific, but a large majority went to other African countries (Box 1C4). Developing regions have accounted for almost all Brazil's exports of bovine genetic resources in recent years (Box 1C6), although figures from the Brazilian Artificial Insemination Association show that Canada imported 28 916 doses bovine semen from Brazil in 2013, accounting for 16 percent of the total number of doses exported from Brazil (see table in Box 1C6).

Few South–North gene flows are mentioned in the country reports, particularly among the main food-producing livestock species. Where South–North flows are mentioned, they consist largely of relatively specialized resources such as camelids and certain horse breeds. While, as noted above, certain breeds originating from the South have established a presence in extensive grazing systems in the North (e.g. Boran, Africander and Tuli cattle, Boer goats and Dorper sheep), the country reports provide little indication of any major recent South–North gene flows involving breeds in this category. The country report from Switzerland notes that imports of Boer goat genetics from South Africa have almost completely ceased because the gene pool in Switzerland is now sufficient for the reproduction of the breed. Australia's country report (2012),[10] however, mentions recent importations of Boer and Kalahari Red goat genetics, undertaken with the aim of improving the carcass composition, shape and overall quality of existing populations.

[10] This report was prepared in 2012 at the initiative of the Australian Government. The format does not correspond to the questionnaire-based country reports prepared at FAO's request in 2013/2014.

FIGURE 1C6
Brazil's trade in live pure-bred cattle and bovine semen



Note: Figures are based on UN-Comtrade classification HS92. They are based on import and export figures reported by Brazil and may not correspond to the figures reported by the respective trade partner. Data from countries' dependent territories are treated separately in UN-Comtrade.
Source: UN-Comtrade, 2015.

3 Drivers of gene flow in the twenty-first century

As has been the case for several decades, the growth of North–South gene flows continues to be driven by large differentials in production potential between many Northern and Southern AnGR, and the ongoing spread of production systems that enable the effective use of high-output animals. Similar factors also drive some South–South and North–North exchanges. Individual gene flows are driven by particular requirements associated with the state of demand for livestock products and services, the characteristics of production environments and the exigencies of individual breeding programmes. Patterns of exchange are also influenced by broader economic and political factors such as trade agreements and fluctuations in currency exchange rates. Flows between some countries continue to be inhibited by zoosanitary concerns or by lack of infrastructure and technical capacity in the use of reproductive biotechnologies. In some species, technical problems related to the use of frozen genetic material continue to hamper exchanges.

Where commercial operations with the wherewithal to access international markets have emerged, a large proportion of gene flows generally occur via private transactions between suppliers and purchasers (Gollin *et al.*, 2008). Nonetheless, the country reports indicate that in a number of countries, government policies directly or indirectly promote inward gene flows. Reported examples of direct government interventions to support the import of genetic materials include a project implemented by Bangladesh's

Box 1C7

Influence of policies on gene flows into Cameroon

Two policy developments have significantly affected gene flows into Cameroon in recent years. First, as a result of the avian influenza scare that occurred in 2006 and subsequent years, the government decided to revamp the national poultry sector. Imports of frozen chicken were banned and the local poultry industry, heavily if not entirely dependent on imported breeding stocks, was subsidized. This caused a significant rise in poultry gene flow into the country from the United States of America and Europe. Second, the implementation of Cameroon's Growth and Employment Strategy, and particularly its Livestock Sector Strategy, which prioritizes the promotion of short-cycle livestock-keeping activities, saw a significant rise in the importation of high-yielding small ruminants, poultry and pigs from Europe and the United States of America, as well as non-conventional livestock (e.g. cane rats) from some African countries (e.g. Benin and Togo).

Source: Adapted from Cameroon's country report.

Department of Livestock Services in 2009 that involved the importation of Brahman cattle semen from the United States of America for use in producing cross-bred animals (mentioned in Bangladesh's country report). The Brahman was chosen because of its ability to thrive in harsh environments and its resistance to parasites. The influence of government policies on gene flows into Cameroon is described in Box 1C7. A developed-country example is provided in the country report from the Russian Federation, which notes that between 2006 and 2008 the implementation of the country's National Priority Project for Development of Agro-Industrial Complex led to the government-supported importation of substantial numbers of high-quality pedigree cattle, sheep and pigs, with the aim of using the genetic potential of these animals to speed up the development of the Russian breeding sector via both pure-breeding and cross-breeding schemes.

Some countries have put policies or legal measures in place that may restrict inward flows of genetic resources. For instance, importation of new exotic breeds into South Africa is only permitted after an impact assessment study has been undertaken. These studies involve assembling information on the candidate breeds' characteristics (phenotype, usual production environments, management systems, etc.), as well as on their potential impacts on South Africa's production environments and indigenous breeds; on-site evaluation may be required (Government of South Africa, 2003; Pilling, 2007). Several breeds were reported to be undergoing impact assessments at the time of the preparation of South Africa's country report: among beef cattle, the Afrigus (a locally developed breed – Afrikaner × Angus), the Afrisim (Afrikaner × Simmental), the Ankole and the Pinzyl (Pinzgauer × Nguni); among dairy cattle, the Swedish Red; among horses, the Standardbred and the French Trotter; and among sheep, the South African Milking Sheep (a local composite breed). Few countries have made breed-level assessments of potential imports compulsory. However, many countries have put legal measures in place to regulate the quality of imported germplasm (see Part 3 Section F).

Imports and exports of AnGR are potentially affected by laws related to access and benefit-sharing. A growing number of countries are enacting legislation in this field (see Part 3 Section F), but practical impacts on the exchange of most types of AnGR appear to have been limited to date. The country report from Peru, however, notes that the export of alpacas and llamas is subject to government quotas, implemented with the aim of avoiding the loss of high-quality breeding animals. The problem of illegal exports of camelids is mentioned in the country reports of both Peru and the Plurinational State of Bolivia.

Zoosanitary restrictions create major problems for the international exchange of AnGR. They

are particularly problematic where there is a significant disparity between the disease statuses of the importing and exporting countries. This tends to disfavour developing-country exporters. However, exports from developed countries are also affected. For instance, the outbreak of Schmallenberg virus in Europe in 2012 led to additional restrictions on bovine germplasm imports from the European Union into the United States of America (APHIS USDA, 2014). A disease outbreak can devastate export trade and affected countries may have problems regaining lost markets. On the importing side, breeders may have difficulty acquiring the genetic material they need. As described above, transfers of cattle genetic resources from South Asia to Latin America have long been problematic. The country reports from Australia and New Zealand note that their strict zoosanitary controls on imports place some restrictions on access to AnGR, particularly in the case of breeding material whose commercial value is low relative to quarantine expenses.

Climate change is sometimes noted as a potential driver of increased gene flows, possibly including increased flows from the South as a result of growing demand for animals that are well-adapted to climatic extremes or climate-related disease challenges (Hiemstra *et al.*, 2006; FAO, 2009). Shifts in species and breed distributions as a result of climate change are already reported to have taken place, on a relatively local scale, in parts of Africa (FAO, 2011). There is, however, little evidence in the country reports that the search for climate-adapted genetic resources has influenced international gene flows to any significant extent or that countries expect this to change in the near future. Many country reports recognize climate change as a driver of change in livestock production systems and in AnGR management (see Part 2). However, where countries note changes, or potential changes, in demand for AnGR, they generally mention growing demand for their own locally adapted breeds rather than demand for climate-adapted imports. The country report from the United States of America states that climate change has not caused any shifts in demand for specific genetic resources and that it is anticipated that within-breed selection will be sufficient to respond to climate change-related challenges. Given growing recognition of the importance of climate-related adaptations, it is possible that concerns about climate change may to some extent dampen demand for the importation of non-adapted breeds into tropical and subtropical countries.

Loss of large numbers of animals as a result of disease outbreaks or other disastrous events can precipitate increased gene flows. The country report from Burundi, for example, notes that in recent years many cattle, particularly Friesian crosses, have been imported from other countries in the subregion as part of restocking efforts. An example of the effects of a disease outbreak is presented in Box 1C8.

Box 1C8

Effect of a disease outbreak on inward gene flow – an example from the Republic of Korea

The foot-and-mouth disease epidemic in the Republic of Korea in 2010/2011 led to a sharp temporary increase in the importation of pig breeding stocks. Pig populations that had been subject to long periods of genetic improvement disappeared, leading to increased dependence on imported breeding pigs. The large scale of the required imports also led to concerns about the quality of the imported animals. A shortage of breeding pigs led to problems such as difficulties in managing the rate of inbreeding. These problems could have been resolved by exchanging genes between farms, but this was made more difficult by differences in hygiene levels between farms. It appears that these events have led to a lasting increase in the local pig sector's dependence on imported genetics.

Source: Country report of the Republic of Korea.

4 Effects of gene flows

This subsection reviews the effects of gene flows both on the diversity of genetic resources and on livestock productivity.

4.1 Impacts on diversity

As noted in the introduction to this section, gene flow can have a number of different effects on the between- and within-breed diversity of livestock populations. The country reports mention a range of different impacts. The most commonly reported effect of gene flows is that they contribute to the erosion of AnGR, often via indiscriminate cross-breeding between imported and locally adapted breeds.[11] Concern about the effect of gene flows on diversity appears to be particularly widespread in Latin America and the Caribbean and in Africa, and to a lesser extent in Europe and the Caucasus and in Asia. The country reports provide little information about how serious this effect is (several mention that the use of imported AnGR is inadequately monitored). However, its significance seems to be underlined by the fact that indiscriminate cross-breeding (not necessarily linked to international gene flows) and replacement by exotic breeds are the two factors most commonly mentioned in the country reports as causes of genetic erosion (see Part 1 Section F).

While large-scale importation of exotic breeds may create challenges for the sustainable management of locally adapted genetic resources, significant negative effects on diversity are not inevitable. Where indiscriminate cross-breeding is concerned, the problem is not with gene flow *per se*, but with badly managed gene flow. For example, well-planned cross-breeding with exotic animals can be a means of keeping pure-bred locally adapted populations in use. Moreover, even if locally adapted breeds are increasingly being replaced by imported alternatives, various strategies can be adopted to promote their sustainable use, development and conservation (see Part 3 Section D and Part 4 Section D). The country report from Cameroon, for example, notes that while "various cattle, pigs and poultry breeds have been imported, and due to persistent unregulated and uncontrolled cross-breeding targeting high yields there has been a marked increase in genetic dilution and erosion of local indigenous AnGR," the situation has been slightly improved by compulsory organization of the recipients of imported genetic material into "common initiative groups" and the establishment of specialized cooperatives for the conservation of threatened breeds.

Unfortunately, as discussed in Part 3, capacity to manage AnGR is weak in many countries. In these circumstances, there is a danger that a kind of vicious circle will develop: lack of management capacity leads to a lack of progress in developing locally adapted AnGR; this in turn leads countries to favour the apparently easy solution of importing high-output exotic breeds; the same lack of capacity driving the process then makes it difficult to manage the inward gene flow effectively.

Several country reports note that inward gene flows have contributed to increasing the diversity of national AnGR. In some cases, this has simply been a matter of expanding the range of established breeds available to the country's livestock keepers and breeders. In others, new breeds have been developed by combining imported genetics with those of locally adapted breeds. Examples mentioned in the country reports include the Méré breed of cattle (Guinea) and the Dapaong pig (Togo). The former, a breed valued for its abilities as a draught animal, was developed by crossing N'Dama cattle with zebu cattle originating from Mali. The latter is a composite developed by crossing Large White and local-breed pigs.

A few country reports from developed countries mention the role of international gene flows in the sustainable management of transboundary breed populations or the introduction of "fresh blood" from related breeds. For example, the report from Austria states that

"gene flow within the region broadens the genetic basis of commercial breeds and

[11] Responses to an open-ended question about the effects of gene flows on AnGR and their management.

increases breeding progress. In traditional breeds with transboundary populations, gene flow occurs between Austria and neighbouring countries, to stabilize and conserve the populations."

In some circumstances, gene flows out of a country can contribute indirectly to the maintenance of diversity by providing economic incentives to continue raising locally adapted breeds. The country report from Kenya, for example, notes that

"demand for Kenyan animal genetic resources in the African region has led to increased stud registration and to farmers joining breed societies. Exports have encouraged breeding, multiplication and conservation of Kenyan breeds such as Kenyan Boran and Sahiwal cattle."

The report from Spain mentions that the breeders of locally adapted breeds have recently been targeting the development of export markets. These efforts have involved, *inter alia*, an agreement between the Ministries of Agriculture of Spain and Brazil regarding a study on the suitability of Spanish Retinta cattle for use in Brazilian production environments, both in pure-bred form and crossed with Brazilian breeds. Related points are made in the reports from Norway and the United Kingdom. The former notes that the export of breeding material is an important source of funding for breeding organizations and helps to cover the costs of running breeding programmes in Norway. The latter mentions that exports help to fund research and development activities that contribute both to the sustainable management of "mainstream" breeds and to the conservation of breeds at risk.

4.2 Impacts on livestock productivity

A number of country reports, both from developed and developing regions, note that inward gene flows have contributed to increasing levels of production or productivity in their livestock populations. The circumstances in which these improvements have occurred are not always clear. Some country reports mention that the use of exotic animals has been limited to large-scale systems or that additional management inputs have been required. The report from Mauritius, for example, mentions that only large-scale producers have been able to introduce the improved feeding, health care and housing needed in order to successfully raise exotic cattle. The report from the Plurinational State of Bolivia notes that increased milk output associated with the introduction of exotic and cross-bred cattle has only been achieved by adopting improved management measures and modifying the production environment so as to allow these animals to express their genetic potential. The report from the Philippines states that production based on exotic poultry and pig genetics now involves highly controlled production environments (e.g. the use of tunnel ventilation). It also mentions that the introduction of animals from non-traditional sources (e.g. buffaloes from Brazil and Italy) has been made possible by improvements to the country's animal health status.

Several country reports mention the challenges involved in introducing exotic breeds, particularly into small-scale or remote production systems. The report from Mali, for example, notes that cross-bred animals with exotic blood have higher demands in terms of feed, health care and housing, and that their management requires new skills and additional resources. Such animals are reported to be restricted to peri-urban zones. Similarly, the report from Eritrea mentions that the management of imported buffaloes has been a problem because of their high susceptibility to tick-borne diseases, particularly heartwater. The report from Botswana notes that farmers who have acquired imported dairy cattle have had to resort to buying supplementary feed, mainly imported from neighbouring countries, in order to supplement the animals' diets. For further discussion of the role of cross-breeding in low-input systems, see Part 4 Section C.

5 Conclusions

International flows have continued to expand over recent years. The rate of growth appears to have increased since the time the first SoW-AnGR was prepared. The main drivers of gene flow continue to be demand for higher-output animals and ongoing developments in livestock management and reproductive biotechnologies. Exchanges are still dominated by North–North and North–South exchanges, with importers taking advantage of the genetic improvements achieved in the world's most advanced breeding programmes. The share of global imports accounted for by imports into Southern countries has increased in some subsectors. This represents a large increase in gene flows of high-output international transboundary breeds from the North to the South. For many countries, South–South gene flows are also significant. These exchanges often occur between neighbouring countries, but a small number of Southern countries have become suppliers of genetic resources on a wider scale. The country reports provide little indication that interest in importing genetic resources from the South is increasing in Northern countries.

The country reports indicate that many countries are concerned about the effects of international gene flows on the diversity of their livestock populations. Moreover, while international gene flows have contributed to increasing the output of livestock products, the establishment of exotic breeds in new countries and production systems can be problematic in terms of the additional resources and management skills required and the vulnerability of the animals to diseases, feed shortages and so on. Effective management of gene flow and effective use of imported genetics involve all the main elements of AnGR management: characterization of breeds and production environments to ensure that they are well matched; well-planned breeding strategies; monitoring of outcomes in terms of productivity and genetic diversity; and measures to promote the sustainable use and conservation of breeds that may be threatened by the effects of gene flows.

References

APHIS USDA. 2014. *Schmallenberg virus information*. Website of the United States Department of Agriculture – Animal and Plant Health Inspection Service (http://tinyurl.com/n56euwc) (accessed September 2014).

ASBIA. 2013. Website of the Associação Brasileira de Inseminação Artificial (Brazilian Assocation for Artificial Insemination) (http://tinyurl.com/oygpd56) (accessed June 2014).

Country reports. 2014. Available at http://www.fao.org/3/a-i4787e/i4787e01.htm.

FAO. 2007. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at www.fao.org/3/a-a1250e.pdf).

FAO. 2009. *The use and exchange of animal genetic resources for food and agriculture*. Commission on Genetic Resources for Food and Agriculture Background Study Paper No. 43. Rome (available at ftp://ftp.fao.org/docrep/fao/meeting/017/ak222e.pdf)

FAO. 2011. *Climate change and animal genetic resources for food and agriculture: state of knowledge, risks and opportunities*. Commission on Genetic Resources for Food and Agriculture Background Study Paper No. 53. Rome (available at http://tinyurl.com/khdcegu).

Gollin, D., Van Dusen, E. & Blackburn, H. 2008. Animal genetic resource trade flows: Economic assessment. *Livestock Science*, 120: 248–255.

Government of South Africa. 2003. *Guidelines for a biological impact study. Possible introduction of a new breed of farm animal*. Department of Agriculture, Pretoria.

Hiemstra, S.J., Drucker, A.G., Tvedt, M.W., Louwaars, N., Oldenbroek, J.K., Awgichew, K., Abegaz Kebede, S., Bhat, P.N. & da Silva Mariante, A. 2006. *Exchange use and conservation of animal genetic resources. Policy and regulatory options*. Wageningnen, the Netherlands, Centre for Genetic Resources, the Netherlands (CGN), Wageningen University and Research Centre (available at http://tinyurl.com/nkltlwf).

Hoffmann, I. 2010. *International flows of animal genetic resources – historical perspective, current status*

and future expectations. Paper presented at the International Technical Expert Workshop: Exploring the Need for Specific Measures for ABS of AnGR, Wageningen, the Netherlands, 7–10 December 2010 (available at http://tinyurl.com/mkra2re).

Mariante, A. da S. & Raymond, A.K. 2010. *An overview and analysis of issues and current practices in the international exchange of animal genetic resources*. Paper presented at the International Technical Expert Workshop: Exploring the Need for Specific Measures for ABS of AnGR, Wageningen, the Netherlands, 7–10 December 2010 (available at http://tinyurl.com/kn6v2tb).

Perry, G. 2013. *2012 statistics of embryo collection and transfer in domestic farm animal*. International Embryo Transfer Society Statistics and Data Retrieval Committee Report. Champaign, IL, USA, International Embryo Transfer Society (available at http://tinyurl.com/oht7u78).

Pilling, D. 2007. Genetic impact assessments – summary of a debate. *Animal Genetic Resources Information*, 41: 101–107 (available at ftp://ftp.fao.org/docrep/fao/010/a1206t/a1206t06.pdf).

UN-Comtrade. 2015. *United Nations Comtrade Database* (available at http://comtrade.un.org) (accessed May 2015).

USAID. 2013. *Agricultural Growth Program – Livestock Market Development. End market analysis for meat/live animals, leather and leather products, dairy products value chains. Expanding livestock markets for the small-holder producers*. Washington D.C., United States Agency for International Development (available at http://tinyurl.com/lwm7xmz).

Section D

Roles, uses and values of animal genetic resources

1 Introduction

"In recognition of the essential roles and values of animal genetic resources for food and agriculture, in particular, their contribution to food security for present and future generations; aware of the threats to food security and to the sustainable livelihoods of rural communities posed by the loss and erosion of these resources ..."

As these opening words of the Interlaken Declaration on Animal Genetic Resources (FAO, 2007a) suggest, one of the main justifications for international concern about the state of animal genetic resources (AnGR) and their management is the need to ensure that livestock can continue fulfilling the roles that make them so important to the lives and livelihoods of so many people around the world, and that the value embodied in livestock biodiversity is not lost. Understanding these roles and values is fundamental to efforts to sustainably use, develop and conserve AnGR.

The phrases "roles and values" and "uses and values" are commonly used as catch-all terms for the various qualities or factors that make AnGR important. The former features in the Interlaken Declaration and in the Global Plan of Action for Animal Genetic Resources, while the latter was the title of a section of the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007b).[1] It is interesting to note that, although the phrases are used more or less interchangeably, they emphasize slightly different aspects of AnGR management, both of which are important. The word "use" draws attention to one of the most important general characteristics of AnGR, the fact that they were developed for use by humans and are subject to ongoing active management by humans in pursuit of specific objectives.[2] The fate of an individual breed is closely linked to its use. If it is no longer used, it will become extinct unless a conservation programme is established to maintain it (either as a live population or in cryoconserved form). The word "roles" has slightly broader connotations than "use" in that it implies that the benefits derived from AnGR can include not only those deliberately sought by the immediate users (i.e. the owners or managers of the animals), but also inadvertent benefits. These benefits may accrue to the owners or managers themselves, to a wider public, or to both. Because of their inadvertent nature, ensuring that benefits of this kind are supplied in an optimal manner can be challenging.

The "values" of AnGR are generally considered to extend beyond those associated with their current use (FAO, 2007b).[3] Particularly significant – and one of the main reasons why the conservation of AnGR is regarded as important – are so-called option values. This term refers to the value that arises because the continued existence of a resource increases capacity to respond to unpredictable future events. In other words, it is a kind of insurance value. In the case of AnGR, option value arises, for example, because maintaining a wide range of genetic diversity

[1] FAO, 2007b Part 1, Section D (pages 77–100).

[2] Feral populations and wild relatives of domestic species are exceptions, but are potentially of use in agriculture and food production.

[3] See, in particular, Box 93 (page 430) and Subsection 2 of Part 4 Section F (pages 442–448) of the first SoW-AnGR.

increases the likelihood that the livestock sector will be able to respond effectively to challenges such as the emergence of new diseases or climatic changes. Quantifying the values of AnGR is a complex task that involves the use of a range of economic tools. Recent developments in this field are described in Part 4 Section E. The discussion of values presented here in this section is largely descriptive.

The subsections below describe a range of different roles performed by livestock and the significance of genetic diversity in the fulfilment of each of them. The first addresses direct contributions to food production, livelihoods and economic output. Livestock's capacity to produce food and other goods and services that can be sold or used at home is generally the main reason why people choose to raise animals and why governments implement policies to support livestock-sector development. The second subsection addresses sociocultural functions. In many societies, livestock play important roles in social and cultural life: religious festivals, agricultural shows, sporting activities and so on. Some events and activities of this kind may provide income-generating opportunities for livestock keepers, but cultural activities are often pursued as ends in themselves. In many cases, benefits accrue not just to the livestock owners, but also to the general public in the local area. The third subsection addresses the ecological functions of AnGR: their roles in the provision of so-called "regulating" and "habitat" ecosystem services.[4] Livestock provide services of this kind via the effects that they have on other elements of the ecosystem as they graze, spread their dung, trample the ground and so on. The services may arise because livestock are deliberately managed so as to produce them or as a by-product of livestock management for other purposes. Benefits often accrue to the public at large rather than just to the owners of the animals that provide the services. A further subsection considers the roles of AnGR in poverty alleviation and livelihood development and their further potential to contribute in these fields.

The importance of AnGR diversity lies not only in underpinning the provision of a wide range of products and services, but also in enabling these services to be provided in a wide range of circumstances. Many harsh production environments, such as those characterized by extreme temperatures, lack of good-quality feed, high elevations, rough terrain or severe disease pressures, can only be utilized effectively by breeds that have particular characteristics that enable them to cope with these challenges. Characteristics of this type are discussed in greater detail in Part 1 Section E.

2 Contributions to food production, livelihoods and economic output

The first SoW-AnGR presented an overview of the roles of livestock in the production of goods and services for sale or for home consumption and the role of AnGR diversity in the provision of these outputs. Tables and figures provided quantitative data on the contributions of livestock to national economies (proportion of gross domestic product [GDP] supplied by the livestock sector), to food production and to international trade. These data – drawn from FAO's FAOSTAT database and from World Bank sources – were available only at species level (or in the case of GDP, for the livestock sector as a whole). In other words, the basic data shed little light on the relative contributions of different breeds (or breed categories)[5] within species to the various outputs. The data did, however, serve to illustrate the major economic significance of the livestock sector.

2.1 Food production and food security

Since 2004 (the year for which data were presented in the first SoW-AnGR), global output of food of animal origin has increased substantially (Table 1D1). Production figures are not disaggregated below species level (i.e. by breed or by breed category). However, the contribution

[4] "Provisioning" and "cultural" ecosystem services are discussed in the various other subsections.

[5] For example "locally adapted" or "exotic" breeds.

of different categories of breed and the significance of breed diversity in underpinning current production can to some extent be inferred from the way in which production is dispersed across production systems and agroclimatic zones. Figures presented in the first SoW-AnGR indicated that industrial production systems accounted for 67 percent of poultry meat production, 50 percent of egg production, 42 percent of pig meat production, 7 percent of beef production and 1 percent of sheep and goat meat production.[6] The remainder of reported production was attributed to grazing and mixed (crop–livestock) production systems. All milk production was attributed to grazing and mixed farming systems. See Part 2 Section B for further information on production-system classifications (Table 2B1) and the contributions of different systems to the output of livestock products at regional level (Figure 2B2).

Because industrial systems provide highly controlled production environments and generally supply markets that demand relatively uniform products, they make use of a narrow range of breeds. These breeds tend to belong to the international transboundary category and in many cases are considered exotic rather than locally adapted to the country in which they are kept (see Part 1 Section B for further information on breed categories). In grazing and mixed systems, production environments – and in some cases

[6] FAO, 2007b, pages 156–157. The figures, calculated in 2004 based on averages for the 2001 to 2003 period, were taken from an unpublished report (FAO, 2004). Updated figures are not available.

TABLE 1D1
Global output of animal-source foods (2004 and 2012)

Product	2004	2012	Change
	tonnes		%
Cattle meat	58 093 900	63 288 600	9
Chicken meat	68 003 800	92 812 100	36
Pig meat	92 610 000	109 122 000	18
Sheep meat	7 836 070	8 470 310	8
Goat meat	4 382 020	5 300 340	21
Turkey meat	5 199 850	5 609 530	8
Duck meat	3 093 810	4 340 810	40
Buffalo meat	2 924 490	3 597 340	23
Goose and guinea fowl meat	1 945 640	2 803 720	44
Rabbit meat	1 419 250	1 833 840	29
Horse meat	765 229	750 747	-2
Camel meat	380 947	524 390	38
Donkey meat	189 752	211 750	12
Cattle milk	529 669 000	625 754 000	18
Buffalo milk	76 872 600	97 417 100	27
Goat milk	14 368 000	17 846 100	24
Sheep milk	8 817 950	10 122 500	15
Camel milk	1 997 000	2 785 380	39
Hen eggs	55 494 700	66 373 200	20
Eggs of other birds	4 428 600	5 546 360	25

Source: FAOSTAT.

production objectives – are more diverse than in industrial systems. The output of these production systems comes from a wider range of breeds, some of which, as noted above, have to be able to survive and produce in very harsh conditions. However, where the climate is temperate and feed and veterinary inputs are available, it is often possible, even in grazing and mixed systems, to make use of high-output breeds that have no particularly specialized adaptive characteristics. Thus, global production figures for mixed and grazing systems cannot be attributed unambiguously to one or other category of breeds. They come in part from a highly diverse range of locally adapted breeds (often largely restricted to their areas of origin) and partly from a more limited range of widely distributed high-output breeds.

Increased production of animal-source foods at global or national levels does not necessarily translate into increased consumption for everyone or into health-maximizing levels of consumption for the majority. On the one hand, there are certain health risks associated with consuming excessive quantities of animal products (WHO/FAO, 2003). On the other, people may remain too poor to increase their consumption levels. Many people continue to suffer from nutritional deficiencies that might be overcome by increasing their intakes of meat, milk or eggs (Randolph *et al.*, 2007; FAO, 2014a).

Understanding the link between livestock production and food security at household or individual level requires an understanding of the role of livestock in the livelihoods of poor people. Two facts point to the significance of this role: the very large proportion of poor people that keep livestock (exact figures are not available, but a figure of 70 percent is often quoted [e.g. FAO, 2009]) and the multiple benefits that many of these people derive from their animals. The most immediate ways in which livestock contribute to the availability of food at household level are via the supply of milk, eggs, meat, etc. for direct consumption and via the supply of products and services that can be sold for cash that can then be used to buy food. For many households in mixed crop–livestock production systems another major contribution to food security comes via the supply of inputs for crop production (draught power and manure – see Subsections 2.3 and 2.4 for further discussion).

Food security depends not only on the amount and quality of food produced, but also on its being available on a continuous basis. For a household, this means the ability to produce, buy or otherwise access food through all the seasons of the year and in the face of whatever problems they may have to contend with (droughts, floods, outbreaks of crop and animal diseases, unemployment, accidents, human sickness and so on). As discussed in more detail below (Subsection 2.5), for many poor households, a flock or herd of animals serves as a form of "insurance" that can be drawn upon when problems of this kind arise. In some communities, livestock-related cultural activities, as well as gifts and loans of livestock, help to build and maintain social ties that people can draw upon in times of trouble.

The most important contribution of AnGR diversity to current[7] food production and food security – both at household and national level – probably lies in its role in enabling livestock to be raised in a wide range of production environments and in enabling production systems to better withstand shocks such as droughts and disease outbreaks. However, it also contributes to the production of more nutritionally diverse food products. This diversity is mainly at species level. However, breed-level differences do exist and have begun to attract some research attention in recent years. The FAO/INFOODS Food Composition Database for Biodiversity (FAO/INFOODS, 2012), for example, includes some data on the nutritional composition of products from different cattle breeds. Breed-level nutritional differences are discussed in greater detail in Part 1 Section G.

[7] As far as future food security is concerned, it provides the raw material for genetic improvement to increase productivity or otherwise develop the characteristics of livestock populations to meet whatever demands and challenges may arise.

2.2 Fibres, hides and skins

In terms of the value of sales and international trade, the most important non-food livestock products are fibres, hides and skins. The first SoW-AnGR included information on production levels for a range of skin and fibre products.[8] It also highlighted some examples, drawn from the country reports, of specific breeds whose distinct characteristics make them especially significant for fibre, hide or skin production. Since 2004 (the year for which data were presented in the first SoW-AnGR), total global wool production has continued its decline from a peak reached in the early 1990s. Global wool production in 2012 was almost 5 percent lower than in 2004 (FAOSTAT). However, some major wool-producing countries, such as China, Morocco, the Russian Federation and the United Kingdom, have increased their production levels over this period. In other countries, overall declines in wool production have been accompanied by increases in the production of fine, ultrafine and superfine wool (Montossi *et al.*, 2013). Demand for finer wool leads to shifts in the use of sheep genetic resources, i.e. changes in breed choice or in breeding goals (ibid.). Recent developments in genetic improvement programmes in the sheep sector are discussed in Part 4 Section C. Over the 2004 to 2012 period, world production of hides and skins from buffaloes, cattle and goats increased, but production of sheep skins fell (FAOSTAT). The figures roughly reflect population trends in these species.

2.3 Transport and agricultural draught power

In many parts of the world, animals play important roles in transport and as providers of draught power in agriculture. The first SoW-AnGR provided an overview of the significance of draught animal power in agriculture and transport, based largely on the material provided in the country reports. It was clear that animal power from a wide range of species (cattle, buffaloes, horses, donkeys, dromedaries, Bactrian camels, alpacas, llamas, yaks, reindeer and dogs – even to some extent sheep and goats) remained important in many countries, and that a range of specialized and multipurpose breeds were involved in the provision of these services. Figures quoted from an earlier FAO report (FAO, 2003) indicated a projected decline in the proportion of land cultivated using animals in most regions of the world during the period between 1999 and 2030, but an increase in sub-Saharan Africa.[9]

A more recent study prepared for FAO (Starkey, 2010) provides a systematic region-by-region analysis of the role of animal power and a discussion of factors affecting trends in its use. Overall, the study shows that the use of animal power is declining as mechanized power becomes more widely available and more affordable. However, the increasing use of draught animals in sub-Saharan Africa is again noted. In other developing regions, the use of animals for agricultural power and transport remains persistent wherever it continues to be profitable and socially acceptable and alternatives remain inaccessible or unaffordable (ibid.). This often continues to be the case for poorer sections of the population and in geographically remote areas even in countries where industrial development is relatively advanced. Trends vary markedly from country to country, with upward trends in the use of some species in some countries (e.g. the use of donkeys in parts of Central Asia) and rapid declines elsewhere (e.g. the use of donkeys in Turkey and some countries of the Near East).[10]

One interesting development in the relatively recent past was the decision taken by Cuba to promote the use of animal power in agriculture in response to the fuel shortages faced by the country following the breakup of the "soviet bloc" in the early 1990s (ibid.). This has involved the use of animal and mechanized power in a complementary manner, with oxen being used particularly for weeding – and valued for their capacity to work in wetter conditions (Henriksson

[8] FAO, 2007b, Table 28 (page 87) (annual totals per region based on FAOSTAT figures for 2004).

[9] FAO, 2007b, Table 29 (page 88).

[10] Starkey cites donkey population figures from FAOSTAT, noting that donkeys are seldom maintained if they are not used.

and Lindholm, 2000). These developments, along with the country's more general need to shift towards an agriculture that was less dependent on the use of external inputs, required changes in the use of AnGR, with an increase in the use of animals that were well adapted to local conditions (Government of Cuba, 2003).

Reliability in the face of uncertain access to (or affordability of) fuel and mechanical spare parts is one of the major advantages of animal power. However, animals are vulnerable to threats such as theft, diseases and feed shortages. Locally adapted breeds are often preferred because of their greater capacity to survive in local conditions (Starkey, 2010). These factors also affect the choice of species. One trend reported to have been occurring in parts of the world in relatively recent years is an increase in the use of draught donkeys – reasons include their comparatively low cost, ease of management, resistance to drought and the fact that they are less prone to being stolen (New Agriculturist, 2003). An increase in the use of cows or female buffaloes rather than castrated males has also been noted (ibid.).

Replacement of animal power by mechanized power is widely recognized as a potential threat to AnGR diversity. Many country reports,[11] from all regions except North America, note that the use of animal power is in decline as a result of replacement by mechanized power.[12] The strength of the trend varies from country to country. For example, the report from Lesotho notes that stock theft is leading to draught animal power being rapidly replaced by machinery. Conversely, the report from Bhutan notes that although farm mechanization is underway, the country's steep terrains mean that AnGR and their management have been affected only minimally and that future effects are also expected to be minor. The report from the Philippines states that "because of the increasing cost of oil, many farmers still rely on large animals for draught." The precise extent of the threat is difficult to estimate. Stakeholders responding to a global survey on threats to AnGR (FAO, 2009) provided information on 87 equine breeds and 212 cattle breeds. Among these, "replacement of breed functions" was ranked as the top threat in 32 equine breeds and 10 cattle breeds.[13] Relatively few country reports (7 out of 93 that include responses to the relevant question) specifically list mechanization as a major cause of genetic erosion,[14] although the figure is higher in the case of Asian countries (4 out of 17) (see Table 1F2 in Part 1 Section F).

Evidence from highly developed regions such as western Europe suggests that when breeds lose their roles as providers of transport or agricultural power, their populations often plummets towards zero. National donkey populations provide an indicator of this effect, as donkeys are rarely kept in large numbers for other purposes. To take one example, the donkey population of Italy fell by more than 50 percent between 1938 and 1968, and by 2008 had declined by 97 percent relative to the population at the time of the Second World War (Starkey, 2010). This decline is reflected in the risk status of Italy's donkey breeds, all of which, according to the figures available in the Domestic Animal Diversity Information System (DAD-IS)[15] at the time of writing, are classified as being at risk of extinction (13 breeds) or already extinct (3 breeds).

One factor that often speeds the decline of animal power (or slows its growth) is the perception that it is an old-fashioned technology whose time has passed. This perception is common both among potential users (farmers, etc.) and among development workers and policy-makers. At times, this leads to unprofitable decisions to invest in mechanized power and to the absence of support services for draught animals (Starkey, 2010). As well as leading to missed opportunities in the short

[11] For more information on the reporting process, see "About this publication" in the preliminary pages of this report.

[12] In response to a general question about changing breed functions.

[13] Answers were chosen from a list of options. In both equines and cattle, the most frequently mentioned category of threat was "economic and market-driven threats".

[14] This was an open-ended question. Countries were not specifically asked whether mechanization is a threat.

[15] http://fao.org/dad-is

term, these attitudes are not helpful to the long-term conservation and development of AnGR in breeds and species used as sources of power.

Working animals are often ignored in national agricultural and rural-transport strategies and policies, and this means that they are often not targeted by animal health interventions, research programmes, extension activities and so on (FAO, 2014b). Their significance to people's livelihoods often remains unrecognized. Donkeys, for example – a species that tends to be particularly overlooked – provide vital services to many poor households, and to women in particular, by reducing the drudgery of domestic tasks such as transporting water and firewood and by providing a source of income (Valette, 2014). Gaps in knowledge on the livelihood roles of working animals and the extent of their economic contributions need to be addressed in order to enable the design of appropriate support measures and to help raise awareness at policy level (FAO, 2014b; Valette, 2014).

2.4 Manure and fuel

Apart from draught power, the other main animal-derived agricultural input discussed in the first SoW-AnGR was manure. Several examples from the country reports illustrated the continued (and in some situations increasing) importance of livestock as a source of manure for use in agriculture. For small-scale farmers in mixed crop–livestock production systems, securing a supply of manure can be among the most important reasons for keeping animals. For example, a study conducted by Ejlertsen *et al.* (2013) in the Gambia, indicated that among mixed farmers with fewer than ten cattle, manure supply ranked as the second most important reason for keeping cows and third for keeping bulls. Among farmers with larger herds, manure supply was reported to be the most important livestock function (ibid.).

The capacity of livestock to serve as providers of manure is normally considered at the species level rather than in terms of within-species diversity. However, breeds that struggle to survive in the local production environment or – in the case of free-grazing animals – to range over the ground where the manure needs to be spread, are unlikely to be the best providers of this service. One study that did compare the level of manure provision from two different breeds (strictly speaking, one breed and one interspecies cross) compared the amount of organic matter introduced into fish ponds by Pekin ducks and mule ducks – and found that the former provided significantly more (Nikolova, 2012). The difference arose because of the faster growing rate of the Pekin ducks and because they spent more time in the water (ibid.).

The other main use made of livestock dung is as a source of fuel, either in the form of dried dung cakes or via the production of biogas. This role, along with minor uses such as burning dung to ward off insects and the use of dung as a building material, was noted in the first SoW-AnGR. These functions were mentioned in a small number of country reports, but there was no indication that they had any significant effect on the management of AnGR aside from adding some degree of extra incentive to keep livestock and hence to keep the respective breeds in use.

The use of dung for fuel has downsides in some circumstances. It can use up dung that would otherwise help to keep soils fertile, and burning dried dung in poorly ventilated homes can cause serious human health problems (IEA, 2006). On the positive side, in production systems where manure management is a challenge in itself (this is particularly the case in so-called landless systems) the use of manure as a source of energy is increasingly being regarded as an attractive option.

2.5 Savings and insurance

Another function highlighted in the first SoW-AnGR was livestock's role in the provision of savings and insurance services, a function particularly important in areas where livestock keepers do not have access to conventional financial services. Where savings are concerned, a herd or flock of animals can serve as a kind of "bank" in which spare resources (cash or physical inputs such as feed) can be invested. Animals can then be sold from time

to time to meet household expenses. Alternatively, the herd or flock may be built up with the aim of meeting some larger expense. As noted above, livestock can also serve as a form of "insurance", in the sense that if some kind of costly misfortune (sickness, a period of unemployment, crop failure, etc.) strikes the livestock owner, animals can be sold to mobilize resources to deal with the problem. For small-scale livestock keepers in developing countries these functions can be among the most important reasons for keeping livestock. For example, the above-mentioned study in the Gambia found that among poorer livestock keepers (those having fewer than ten cattle), savings and insurance was ranked as the most important reason for keeping cattle, goats and sheep (Ejlertson *et al.*, 2013).

In principle, any kind of animal can provide savings and insurance services. When the time comes to sell, an animal that commands a higher price will obviously be preferable. However, from the perspective of risk management, keeping animals that have a good chance of surviving in the local production environment will be important. Likewise, from the perspective of accumulation, keeping animals that can reproduce well in the local production environment and can make use of low-quality (and low-cost) local feed resources will have advantages.

A few country reports (e.g. Guinea-Bissau and Mali), in response to a general question about changes in livestock functions, note that livestock's savings and insurance functions are in decline. Other reports, however, specifically note that these functions remain important (e.g. Swaziland, Tajikistan, Uganda and Zimbabwe).

3 Sociocultural roles

The country reports prepared for the first SoW-AnGR clearly indicated that livestock – and often specific breeds – play important roles in many cultural activities at both household and community levels and that in many countries native breeds and species are regarded as important elements of national heritage.

The country report questionnaire for the second SoW-AnGR did not directly ask countries to provide information on the significance of the cultural roles of their AnGR. However, as part of the assessment of the effects of livestock sector trends, countries were asked to provide comments on the effects that changes in the cultural roles of livestock are having on AnGR and their management and to provide scores for the significance of these effects over the preceding ten years and for the forthcoming ten years (see Part 2). The textual answers can be roughly grouped into four categories: no clear indication of trends (61 percent); indication that cultural significance is remaining at approximately the same level (20 percent); indication of increasing cultural significance (8 percent); and indication that cultural significance is decreasing (11 percent). These figures are clearly only very approximate indicators of trends. However, it is interesting to note that all the countries mentioning downward trends are developing countries, while eight out of the ten countries reporting upward trends are developed countries.

Where downward trends are described, the reason in most cases is reported to be a decline in traditional cultural roles. For example, Togo's country report mentions that a decline in traditional beliefs has led to a loss of interest in maintaining culturally significant livestock breeds, particularly breeds of chicken. Similarly, the report from Bhutan notes that the rearing of animals for use as sacrifices or offerings is dying away. In the case of Guinea-Bissau, economic reasons are reported to have led to a decline in the practice of slaughtering large numbers of animals at funeral ceremonies. The report from Ethiopia notes that

> *"there is a change in the role of livestock in the pastoral area. Livestock used to serve as compensation in ... [the] cultural settlement of disputes, but there is an increasing tendency to use the legal system. ... [C]ash payments are replacing other cultural roles of livestock."*

The report from Uganda notes a link between changing cultural practices and the spread of exotic cattle:

"in ... [some] parts of the country, cultural aspects of livestock have not changed at all, while in other parts the changes are marked, especially in areas where exotic [breeds] are kept. For example, in Central Uganda, cattle are no longer being used as bride-price, whereas in the western and the north eastern parts of the country, this practice goes on."

Despite these various indications of decline, it should be noted that among country reports from developing countries comments of this type are outnumbered by clear statements that significant cultural roles are being maintained. It should also be noted that the decline of a cultural role does not necessarily lead to a negative effect on AnGR diversity and that an increasing role does not necessarily have a positive effect. The country report from Ethiopia, for example, states that the reported changes have had "no significant effect on the livestock genetic resources and … [are] unlikely to have sizeable effect in the foreseeable future". The country report from Samoa notes that an increase in the use of cattle to meet cultural and social obligations has led to a decline in the number of animals available for breeding purposes.

The reported increases in cultural roles in developed countries appear to relate mostly to a growing interest in the history and traditions of rural areas. The country report from Slovenia, for example, notes that "traditional events from the past (livestock exhibitions, festivals …) are becoming more attractive to the wider public." There is also some indication of increasing interest in the use of animals for therapeutic and educational purposes (mentioned in the country reports of Italy and Japan).

4 Ecological roles – the provision of regulating and habitat ecosystem services

The first SoW-AnGR noted the many ways in which livestock contribute to the functioning of the ecosystems within which they are kept. Information on these roles was, however, limited – particularly with respect to possible breed-level differences in capacity to provide services. The report, however, noted that the provision of ecosystem services in harsh production environments, such as mountains and arid rangelands, requires animals that can thrive in local conditions, and that therefore the role of locally adapted breeds was likely to be important. It also noted the possible significance of between-breed differences in grazing and browsing habits.

Interest in the links between AnGR management and the provision of ecosystem services has increased in recent years. For example, in 2013, the Commission on Genetic Resources for Food and Agriculture requested FAO to work on the identification of ecosystem services provided by different livestock species and breeds (FAO, 2013). This led, *inter alia*, to the organization of two questionnaire surveys (one targeting Europe and the other global) on the roles of livestock in the provision of ecosystem services in grassland ecosystems. The findings of these surveys, along with an extensive literature review, are presented in a background study paper (FAO, 2014c) prepared as part of the second SoW-AnGR reporting process.

Ecosystem services can be grouped into the following categories: provisioning; regulating; habitat; and cultural (see Box 1D1). Provisioning and cultural services are discussed above and were addressed at greater length in the first SoW-AnGR. Where provisioning services are concerned, the above-mentioned background study paper emphasises livestock's capacity to convert feed sources that are not edible to humans into meat, milk and eggs. This occurs, for example, when livestock graze areas that cannot be used for crop production, when they eat crop residues such as straw, when they eat the by-products of food processing and when they eat waste food products that are no longer edible to humans. These examples can be contrasted with cases in which animals are fed on feeds such as grains that could otherwise be used directly by humans.

While the most obvious consequence of the use of human-inedible material by animals may (other things being equal) be an increase in the

Box 1D1
Categories of ecosystem services

The Millennium Ecosystem Assessment (MEA, 2005) distinguished four categories of ecosystem services:

- **provisioning services** – "the products obtained from ecosystems" (e.g. food, fibre, fuel and fresh water);
- **regulating services** – "the benefits obtained from the regulation of ecosystem processes" (e.g. air-quality regulation, climate regulation, pollination and natural-hazard regulation);
- **supporting services** – "those that are necessary for the production of all other ecosystem services" (e.g. soil formation, photosynthesis and nutrient cycling); and
- **cultural services** – "non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences".

Some services (particularly supporting and regulating services) are inputs to the production of others (particularly provisioning services).

The Economics of Ecosystems and Biodiversity initiative (TEEB, 2010) subsumed supporting services within the regulating-service category. It also introduced an additional category – **habitat services** – the intention being to highlight the importance of ecosystems in the provision of habitats that, for example, allow migratory species to complete their life cycles and enable the maintenance of genetic diversity.

Source: Adapted from FAO, 2014d.

food supply, in some circumstances, the removal of unwanted plant material can constitute a service in itself. In grazing systems, the benefits concerned may relate to the removal of plant material that creates a fire hazard or to the control of invasive species (see further discussion below). In mixed systems, livestock may be used to control weeds (e.g. on fallow land) or in the management of crop residues (e.g. Hatfield *et al.*, 2011). The country report from Malaysia, for example, notes that beef cattle are raised on oil-palm estates and that their grazing and dunging reduces the need for the use of herbicides and fertilizers.

In addition to removing unwanted plant material, livestock can sometimes also play a role in the control of agricultural pests and disease vectors. Poultry, for example, can contribute to the control of ticks (Dreyer *et al.*, 1997; Duffy *et al.*, 1992). Hatfield *et al.* (2011) show the potential for using grazing sheep to control wheat stem sawfly infestations in cereal production systems in the United States of America. In China, rice–duck farming (a traditional local system) has been reintroduced in recent years, particularly in organic production, because of the benefits the ducks provide in terms of pest control (Teo, 2001; Zhang *et al.*, 2009).

The significance of livestock manure in crop production is noted above (Subsection 2.4). However, dunging also affects the health of grassland soils, which in turn is fundamental not only to the productivity of grazing systems, but also to their roles in carbon sequestration and water cycling. Outcomes depend on the particular characteristics of the ecosystem and on the type of grazing management practised. The effects of dunging have to be considered alongside the effects of grazing and trampling. Many rangelands have suffered soil compaction and erosion as a result of badly managed livestock grazing. However, appropriately managed grazing can in some circumstances contribute to improving soil health (Peco *et al.*, 2006; Aboud *et al.*, 2012).

In many countries, grazing livestock play a significant role in the creation and maintenance of fire breaks and hence in reducing the spread of wildfires (Huntsinger, 2012; Garcia *et al.*, 2013). They can also contribute to reducing the risk of avalanches (Fabre *et al.*, 2010). In addition to disaster-risk reduction, there are a number of different circumstances in which preventing the spread of particular types of vegetation may be desirable, for example in preventing the loss of wildlife habitats or particular landscape features valued for their aesthetic characteristics or for recreational use.

The use of livestock specifically for the purpose of creating or maintaining wildlife habitats has become widespread in a number of European

countries (FAO, 2014c). There are also a number of examples in North America (Schohr, 2009). The main mechanisms involved are selective grazing, nutrient redistribution, treading and seed distribution (Wrage *et al.*, 2011). While the use of livestock specifically to provide wildlife habitats is rare in the developing regions of the world, the significance of livestock has sometimes been illustrated by the unexpected and undesirable consequences of their removal from particular ecosystems. For example, in Keoladeo National Park, India, a ban on grazing by buffaloes led to uncontrolled growth of a water weed, which in turn prevented Siberian cranes, a critically endangered species, from accessing plants tubers, their main food source. This led to a dramatic decrease in the numbers of cranes in the park (Pirot *et al.*, 2000).

Studies of the provision of regulating and habitat ecosystem services by livestock have mostly focused on species-level effects, i.e. have not sought to determine whether there are any breed-level differences in capacity to provide these services (FAO, 2014c). Given that many ecosystem services are provided in production environments that are, in one way or another, harsh (mountains, arid grasslands, etc.), it can be assumed that in some cases, only locally adapted breeds can deliver the services effectively. However, there may be a number of different breeds that are able to do so, including those from outside the local area or even from other countries. This is demonstrated, for example, by the widespread use of Polish Konik horses and Scottish Highland cattle for conservation grazing outside their countries of origin. One documented case in which a breed's specific adaptive characteristics enable it to provide ecosystem services where other breeds would fail to do so is that of the Chilika buffalo, whose grazing and dunging play a vital role in maintaining the ecosystem of Chilika Lake in eastern India as a wildlife habitat and a fishing ground (Patro *et al.*, 2003; Dash *et al.*, 2010). Evidence that breed-level differences in feeding habits affect the provision of ecosystem services is limited. However, there are some cases where specific breeds are reported to be more effective than others at removing specific weeds or invasive plants (see Box 1D3 for example). There may also be other circumstances in which the use of particular breeds is important – for instance, where only lightweight breeds can be used because heavier animals would damage fragile soils (see Box 1D4 for example).

Box 1D2

The use of livestock in the provision of ecosystem services – examples from the United States of America

Livestock provide ecosystem services in a number of ways across diverse ecosystems. In the southern plains, goats and to a lesser extent sheep are used to mitigate brush encroachment. Sheep and goats are also used to manage vegetation growth (e.g. trees and shrubs) along the paths of electrical power lines in mountainous areas and thereby reduce the use of herbicides. On mountainous public lands, sheep and cattle grazing contributes to vegetation health and plant diversity. Particularly in the Great Plains, livestock grazing can stimulate plant vegetative processes that result in increased carbon sequestration. In the western half of the country, sheep are used in the biocontrol of noxious weeds. All of these roles operate at species level. They are not based on the use of specific breeds.

Source: Adapted from the country report of the United States of America.

5 Roles in poverty alleviation and livelihood development

The first SoW-AnGR recognized the widespread importance of livestock in the livelihoods of poor people, noting in particular the role of genetic diversity in underpinning the multiple services provided by livestock to many poor households and the adaptations that enable animals to thrive in harsh environments and low external input production systems. These observations appear still to be valid (see Subsection 2).

FAO's 2009 report on *The State of Food and Agriculture*, which focused on the livestock sector, noted opportunities for poverty reduction presented by the rapid growth of the livestock sector had been missed because of various institutional and policy failures. The report classified poor or small-scale livestock keepers into three groups:

1. those that have the potential to compete as commercial producers;
2. those for whom livestock continue to play an important role as a livelihood "safety net"; and
3. those who are in the process of moving out of the livestock sector.

It advocated policies and interventions to support all three groups.

Livelihood strategies with different objectives and that involve keeping animals in different production environments are likely to require different types of AnGR and any interventions aiming to support small-scale livestock keepers or pastoralists need to take this into account. While the tendency to assume that the appropriate objective in all circumstances is to introduce "improved" exotic AnGR remains prevalent, awareness of the significance of adaptedness to local conditions is probably increasing, perhaps driven in part by growing concerns about climate

Box 1D3

A special sheep breed helps to preserve centuries-old grassland in the Alps

Photo credit: Tobias Zehnder.

Reduction in land use and complete land abandonment are widespread in the mountainous regions of Europe. Shrubs and trees are expanding into montane and subalpine grassland in the Alps. In particular, the nitrogen-fixing shrub *Alnus viridis* (green alder) is currently spreading very rapidly. The shrub's ability to symbiotically fix nitrogen from the atmosphere leads to massive nitrogen enrichment, reduces biodiversity and suppresses species succession towards coniferous forests. It is nearly impossible to fight the expansion of *A. viridis* shrubs into centuries-old pastures and hay meadows that are hotspots of biodiversity and part of the region's cultural heritage. Clear-cutting is not a realistic management option given the enormous labour costs involved and the green alder's rapid "hydra-like" resprouting from its root stock. In former decades, goats browsed buds and young shoots and thus prevented the spread of the green alder. In some regions, people also used the shrubs for fuel wood. Today, goats are a marginal livestock species in the Alps and sheep are the main grazers. However, the most abundant sheep breeds feed on grass and ignore woody plants.

Once the green alder bushes are fully established – 2 to 3 metres tall and formed into dense, impenetrable thickets – specialist browsers that peel the bark are needed. An old, traditional, sheep breed known as the Engadine sheep, which was almost extinct in the 1980s (mainly because of its low slaughtering weight), does exactly this. Although it also feeds on grass, the breed appears to be addicted to young tree stems, green alder in particular. It excessively removes the bark from branches and stems, which inhibits the allocation of sugars from shoots to roots, creates open and deep wounds that are rapidly infested by diseases and ultimately causes the death of the shrubs, with almost no resprouting.

(Cont.)

Box 1D3 *(Cont.)*

A special sheep breed helps to preserve centuries-old grassland in the Alps

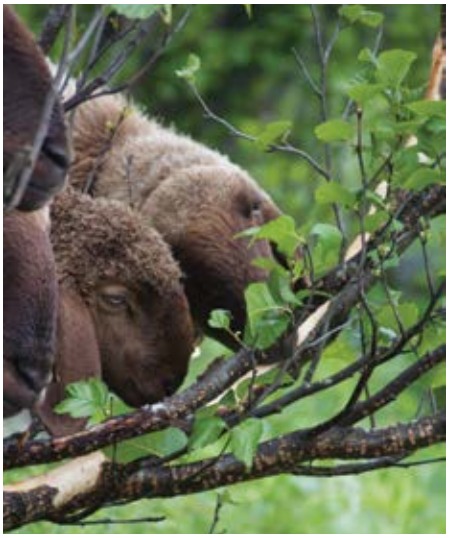


Photo credit: Tobias Zehnder.

In a controlled browsing/grazing experiment, the Engadine proved to be a very efficient land-cover engineer: a flock of ewes and lambs grazed several partially encroached pastures, with shrub coverage ranging from 25 to 55 percent (within defined paddocks), for the duration of one summer. In the following year, mortality of *A. viridis* branches (not individual shrubs) was on average 46 percent, with a maximum of 76 percent in lightly encroached pastures. A second browsing treatment increased the damage – in other words the success of the browsing treatment – even in very dense shrubland.

With a total of more than 420 000 sheep in Switzerland, even a minor replacement of common breeds by the Engadine would have great potential for fighting shrub and tree expansion into high mountain grassland, while at the same time helping to conserve a traditional livestock breed. As an additional advantage, the Engadine is very healthy and fertile, even under harsh grazing conditions. Its meat is not fatty, but the accumulated fat is rich in unsaturated fatty acids.

Provided by Tobias Zehnder, Erika Hiltbrunner, Tobias Bühlmann and Christian Körner.

Box 1D4

The use of livestock in the provision of ecosystem services – examples from Poland

There are some cases in which the provision of specific environmental services requires the use of specific species or even breeds. One example is the utilization of Polish Konik horses in vegetation control in the Biebrza National Park. It is impossible to use other species such as sheep to perform this service because of the presence of wolves. Only horses adapted to free-range grazing manage to do well in these circumstances. Another example is the Swiniarka sheep, a breed that is used to graze xerothermic grasslands in the south of Poland. These very fragile grasslands can be only grazed by animals that have a light body weight and require very little care.

Photo credit: Jacek Łojek.

Source: Adapted from the country report of Poland.

change (FAO, 2011; HPLE, 2012). Breeding strategies and programmes, including those targeting low-input production systems, are discussed in greater detail in Part 3 Section C and Part 4 Section C.

Another feature of AnGR diversity that has attracted increasing attention in recent years is its potential as a basis for the development of niche-market products. The role of niche marketing in the conservation and sustainable use of at-risk breeds is discussed in Part 4 Section D. However, it clearly also has potential implications for livestock keepers' livelihoods. Niche markets normally emerge in more affluent countries, and targeting them effectively normally requires a relatively high level of organization among producers, a reliable marketing chain, well-organized marketing campaigns and, for some types of product, an effective legal framework. Their significance in developing countries has therefore been limited. Marketing many livestock products involves particular problems because of their perishable nature and in many cases because of zoosanitary restrictions on their export to developed countries. Despite these constraints, a few examples of successful niche-market development involving small-scale livestock keepers and pastoralists keeping locally adapted breeds have been documented. Several are reported in the publication *Adding value to livestock diversity – marketing to promote local breeds and improve livelihoods* (LPP *et al.*, 2010). In addition to initiatives of this kind that target markets more or less external to the local area, it is quite common for local consumers to have long-standing preferences for food products supplied by the traditional breeds of the local area and to be willing to pay a premium price for these products. Where this is the case, the breeds in question provide their keepers with relatively high-value products to sell (in addition to contributing to the local culinary culture).

The country reports prepared for the first SoW-AnGR included several references to the role of particular species and breeds of livestock in the livelihoods of women livestock keepers. The role of women as guardians of AnGR and the role of locally adapted breeds in women's livelihoods was addressed in more detail in the FAO publication *Invisible guardians – women manage livestock diversity* (FAO, 2012). From the livelihoods perspective, two main characteristics of locally adapted breeds are highlighted as being particularly relevant to women livestock keepers. First, locally adapted breeds tend to be easier to care for than exotic breeds. Keeping these breeds can therefore more easily be combined with household and child-rearing tasks. Second, locally adapted breeds are normally better able than exotic breeds to access and utilize common property resources (because of their ability to negotiate the local terrain and make use of local feeds). This capacity tends to be particularly important for women because of the major gender inequalities that exist in terms of land ownership and hence women's greater reliance on common grazing land.

6 Conclusions and research priorities

The first SoW-AnGR concluded that while various livestock functions are gradually being replaced by alternative sources of provision, the use of livestock remained very diverse. It also noted that knowledge of these roles is often inadequate and that this hampers the development of appropriate management strategies. These conclusions remain relevant. Trends in the use of livestock products and services were not investigated in detail as part of the country-reporting process for the second SoW-AnGR. However, many country reports indicate that changes are taking place. The most frequently mentioned change of this type is a decline in the use of animal power in agriculture and transport. This implies the need to monitor trends in the population sizes of breeds used for these purposes.

As far as knowledge gaps are concerned, an important priority is to improve our understanding

of the roles of particular livestock species and breeds in the livelihoods of poor people, taking into account not only the various tangible products and services that they provide, but also their roles in risk management and the level of inputs – including the time and labour of household members – needed to raise them. Knowledge of breeds' relative capacities to produce in specified production environments needs to be strengthened. Better recording of breeds' home production environments (see Part 4 Section A) would contribute to this, as would better monitoring of the performance of exotic breeds in typical production environments in importing countries. Improving knowledge of livestock's impacts, both positive and negative, on the functioning of the ecosystems in which they are kept – carbon sequestration, regulation of water cycling, maintenance of soil fertility, provision of wildlife habitats, etc. – is another priority.

References

Aboud, A.A., Kisoyan, P.K., Said, M.Y., Notenbaert, A., de Leeuw, J., Gitau, J.W., Manzano, P., Davies, J.M., Roba, G.M., Omondi, S.O. & Odhiambo, M.O. 2012. *Natural resource management and biodiversity conservation in the drylands of Eastern and Central Africa*. Entebbe, Uganda, ASARECA.

Dash, S.K., Sethi, B.P., Rao, P.K. & Prakash, B. 2010. Characterization and prospective of Chilika buffalo – a unique germplasm of eastern India. *Journal of Livestock Biodiversity*, 2 71–76.

Dreyer, K., Fourie, L.J. & Kok, D.J. 1997. Predation of livestock ticks by chickens as a tick-control method in a resource-poor urban environment. *Onderstepoort Journal of Veterinary Research*, 64: 273–276.

Duffy, D.C., Downer, R. & Brinkley, C. 1992. The effectiveness of Helmeted Guineafowl in the control of the deer tick, the vector of Lyme disease. *Wilson Bulletin,* 104(2): 342–345.

Ejlertsen, M., Poole, J. & Marshall, K. 2013. Traditional breeding objectives and practices of goat, sheep and cattle smallholders in the Gambia and implications in relation to the design of breeding interventions. *Tropical Animal Health and Production*, 45: 219–229.

Fabre, P., Guérin, G. & Bouquet P.M. 2010. *The management of natural areas by pastoralism. A French mediterranean example: the Merinos d'Arles in transhumance*. Paper presented at the Eighth World Merino Conference, May 3–5, 2010, Rambouillet, France (available at http://tinyurl.com/ol8nzlb).

FAO. 2003. *World agriculture towards 2015/2030. An FAO perspective*, edited by J. Bruinsma. London, FAO & Earthscan (available at http://tinyurl.com/kw59gau).

FAO. 2004. *Classification and characterization of world livestock production systems. Update of the 1994 livestock production systems dataset with recent data*, by J. Groenewold. Unpublished Report. Rome.

FAO. 2007a. *The Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration*. Rome (available at http://www.fao.org/docrep/010/a1404e/a1404e00.htm).

FAO. 2007b. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2009. *The State of Food and Agriculture 2009. Livestock in the balance*. Rome (available at http://www.fao.org/docrep/012/i0680e/i0680e00.htm).

FAO. 2011. *Climate change and animal genetic resources for food and agriculture: state of knowledge, risks and opportunities*. Commission on Genetic Resources for Food and Agriculture. Background Study Paper No. 53. Rome (available at http://www.fao.org/docrep/meeting/022/mb386e.pdf).

FAO. 2012. *Livestock sector development for poverty reduction: an economic and policy perspective – Livestock's many virtues*, by J. Otte, A. Costales, J. Dijkman, U. Pica-Ciamarra, T. Robinson, V. Ahuja, C. Ly & D. Roland-Holst. Rome (available at http://tinyurl.com/lqshnv8).

FAO. 2013. *Report of the Fourteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture, Rome, Italy, 15 – 19 April 2013*. CGRFA-14/13/Report. Rome (available at http://www.fao.org/docrep/meeting/028/mg538e.pdf).

FAO. 2014a. *The State of Food Security in the World 2014. Strengthening the enabling environment for food security and nutrition*. Rome (available at http://www.fao.org/publications/sofi/2014/en/).

FAO. 2014b. *The role, impact and welfare of working (traction and transport) animals*. Animal Production and Health Report. No. 5. Rome (available at http://www.fao.org/3/a-i3381e.pdf).

FAO. 2014c. *Ecosystem services provided by livestock species and breeds, with special consideration to the contributions of small-scale livestock keepers and pastoralists*. Commission on Genetic Resources for Food and Agriculture. Background Study Paper No. 66. Rome (available at http://www.fao.org/3/a-at598e.pdf/).

FAO. 2014d. *The nature of ecosystem services provided by livestock species and breeds*. Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture, Eighth Session, 26–28 November, 2014, Rome. CGRFA/WG-AnGR-8/14/5. Rome (available at http://www.fao.org/3/a-ml779e.pdf).

FAO/INFOODS. 2012. *Food and Agriculture Organization of the United Nations / International Network of Food Data Systems - Food Composition Database for Biodiversity Version 2.0 – BioFoodCom2.0*. Rome (available at http://tinyurl.com/pep7kx6).

FAOSTAT. FAO Statistical database (available at http://faostat3.fao.org/home/E) (accessed October 2014).

Government of Cuba. 2003. *Republica de Cuba. Informe de pais sobre la situación nacional de los recursos zoogenéticos en animales de granja***.** Havana (available at http://tinyurl.com/njb92tt).

Hatfield, P., Goosey, H, Lenssen, A. & Blodgett, S. 2011. *Sheep grazing to manage crop residues, insects and weeds in northern plains grain and alfalfa systems*. SARE Agricultural Innovations Factsheet (available at http://tinyurl.com/nwlhlye).

Henriksson, M. & Lindholm, E. 2000. *The use and role of animal draught power in Cuban agriculture: a field study in Havana Province***.** Minor Field Studies 100. Uppsala, Sweden, Swedish University of Agricultural Sciences (available at http://tinyurl.com/mcrg229).

HLPE. 2012. *Climate change and food security***.** A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome (available at http://www.fao.org/cfs/cfs-hlpe/reports/en/).

Huntsinger, L., Sayre, F. & Wulfhorst, J.D. 2012. Birds, beasts and bovines: three cases of pastoralism and wildlife in the USA. *Pastoralism: Research, Policy and Practice*, 2: 1–12 (available at http://www.pastoralismjournal.com/content/2/1/12).

IEA. 2006. *World Energy Outlook 2006*. Paris, International Energy Agency (available at http://www.worldenergyoutlook.org/media/weowebsite/2008-1994/WEO2006.pdf).

LPP, LIFE Network, IUCN–WISP & FAO. 2010. *Adding value to livestock diversity. Marketing to promote local breeds and improve livelihoods***.** FAO Animal Production and Health Paper. No. 168. Rome (available at http://www.fao.org/docrep/012/i1283e/i1283e.pdf).

MEA. 2005. *Ecosystems and human well-being: synthesis*. Washington D.C., Island Press (available at http://millenniumassessment.org/en/index.aspx).

Montossi, F., De Barbieri, I., Ciappesoni, G., Ganzábal, A., Banchero, G., Luzardo, S. & San Julián, R. 2013. Intensification, diversification, and specialization to improve the competitiveness of sheep production systems under pastoral conditions: Uruguay's case. *Animal Frontiers*, 3(3): 28–35.

New Agriculturist. 2003. *Trends in traction*. New Agriculturist online (available at http://tinyurl.com/nlrnvef).

Nikolova. L. 2012. Effect of duck genotype on loading of integrated fishponds with organic matter. *Journal of Environmental Protection and Ecology*, 13(2A): 931–935.

Patro, B.N., Mishra, P.K. & Rao, P.K. 2003. Chilika buffaloes in Orissa: a unique germplasm. *Animal Genetic Resources Information*, 33: 73–79 (available at ftp://ftp.fao.org/docrep/fao/006/y4924t/y4924t00.pdf).

Peco, B., Sánchez, A.M. & Ázcarate, F.M. 2006. Abandonment in grazing systems: consequences for vegetation and soil. *Agriculture, Ecosystems and Environment*, 113: 284–294.

Pirot, J-Y., Myenell, P-J. & Elder, D. (eds.). 2009. *Ecosystem management: lessons from around the world. A guide for development and conservation practitioners*. Gland Switzerland and Cambridge UK, International Union for Conservation of Nature and Natural Resources (available at http://tinyurl.com/q5nx26w).

Randolph, T.F., Schelling, E., Grace D., Nicholson, C.F., Leroy, J.L., Cole, D.C., Demment, M.W., Omore, A., Zinsstag, J. & Ruel, M. 2007. Invited review: role of livestock in human nutrition and health for poverty reduction in developing countries. Journal of Animal Science, 85(11): 2788–2800.

Rosa García, R., Fraser, M., Celaya, R., Mendes Ferreira, L.M., García, U. & Osoro, K. 2013. Grazing land management and biodiversity in the Atlantic European heathlands: a review. *Agroforestry Systems*, 87: 19–43.

Schohr, T. 2009. *Grazing for change. Stories of ranchers preserving and enhancing California's grasslands*. Second edition. California Rangeland Conservation Coalition, California Cattlemens' Association (available at http://www.carangeland.org/images/Grazing_for_Change_-_Website.pdf).

Starkey, P. 2010. *Livestock for traction: world trends, key issues and policy implications*. Background paper prepared for FAO. Reading, UK (available at http://tinyurl.com/ncqotw8).

TEEB. 2010. *The economics of ecosystems and biodiversity. Ecological and economic foundations*, edited by P Kumar. London and Washington, Earthscan.

Teo, S.S. 2001. Evaluation of different duck varieties for the control of the golden apple snail (*Pomacea canaliculata*) in transplanted and direct seeded rice. *Crop Protection*, 20: 599–604.

Valette, D. 2014. *Invisible helpers. Women's views on the contributions of working donkeys, horses and mules to their lives. Key findings from research in Ethiopia, Kenya, India and Pakistan*. Voices for Women International Report. London, The Brooke (available at http://tinyurl.com/nvwp348).

WHO/FAO. 2003. *Diet, nutrition and the prevention of chronic diseases. Report of a joint WHO/FAO expert consultation*. WHO Technical Report Series. No. 916. Geneva (available at http://whqlibdoc.who.int/trs/who_trs_916.pdf).

Wrage, N., Strodthoff, J., Cuchillo, M.H., Isselstein, J. & Kayser, M. 2011. Phytodiversity of temperate permanent grasslands: ecosystem services for agriculture and livestock management for diversity conservation. *Biodiversity Conservation*, 20: 3317–3339.

Zhang, J., Zhao, B., Chen, X. & Luo, S. 2009. Insect damage reduction while maintaining rice yield in duck-rice farming compared with mono rice farming. *Sustainable Agriculture,* 33(8): 801–809.

Section E

Animal genetic resources and adaptation

1 Introduction

The first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first Sow-AnGR) (FAO, 2007) included a discussion of genetic resistance to, and tolerance of, diseases and parasites and the potential role of genetic diversity in disease control strategies.[1] This section updates the discussion presented in the first report, but also considers a broader range of adaptations important to the survival and productivity of animals in various production environments. The section is structured as follows: Subsection 2 summarizes the information on breed-specific (non-disease related) adaptations, recorded in the Domestic Animal Diversity Information System (DAD-IS);[2] Subsection 3 provides a discussion of non-disease related adaptations, based on the scientific literature; Subsection 4 provides an updated discussion of disease resistance and tolerance; and Subsection 5 presents some conclusions and research priorities.

2 Global information on adaptations

As described in Part 1 Section B, in the early 1990s FAO began to build up the Global Databank for Animal Genetic Resources, which now forms the backbone of DAD-IS. Along with data on population sizes, morphology, etc., DAD-IS allows countries to enter textual descriptions of their breeds' particular adaptations. To date, information of this kind has been provided only for a small number of the recorded breeds. This subsection provides an overview of the information on adaptations recorded in DAD-IS as of June 2014.

2.1 Adaptations at species and breed level

Bovines

A total of 139 breeds of buffalo are recorded in DAD-IS. Descriptions of their adaptations generally focus on their hardiness and adaptedness to high temperatures. The Anadolu Mandası of Turkey is known for its strong herd and maternal instincts and for protecting all the calves in the herd. The Chilika buffalo of India is known for its adaptedness to saline conditions.

Yaks have only a limited area of distribution – extending from the southern slopes of the Himalayas in the south to the Altai in the north and from the Pamir in the west to the Minshan Mountains in the east. They are found in cold, subhumid alpine and subalpine zones at elevations between 2 000 and 5 000 metres. In addition to its adaptedness to high elevations and cold climate, the species is recognized for its docility and hardiness. However, the records in DAD-IS provide little information about the specific adaptive characteristics of individual yak breeds.

Cattle have spread throughout the world and are found in almost all climatic zones, but not at high elevations. The most commonly reported breed-specific adaptations in this species are hardiness and

[1] FAO, 2007, Part 1 Section E (pages 101–112).
[2] http://fao.org/DAD-IS

adaptedness to heat and mountainous terrain (see Table 1E1).

Small ruminants

From a total of 681 reported goat breeds, 62 are reported to display adaptations to mountainous terrain. In general, this includes jumping ability, flexible hooves and tolerance of poor nutrition. In addition, 30 goat breeds were reported to be heat tolerant, 7 tolerant of humidity, 14 cold tolerant, 11 adapted to extreme diets, 20 adapted to water scarcity and 20 adapted to dry environments.

Like goats, sheep are frequently well adapted to harsh environments (see Table 1E2). However, the only two sheep breeds recorded in DAD-IS as being well adapted to humid environments

TABLE 1E1

Adaptations in cattle breeds as recorded in DAD-IS

Region	Number of breeds*	Heat	Cold	Humidity	Extreme diet	Water scarcity	Mountainous terrain	Dry environment	General hardiness
Africa	212	32	0	7	1	8	2	20	51
Asia	261	40	12	2	12	4	22	6	24
Southwest Pacific	399	8	0	0	0	2	0	0	1
Europe and the Caucasus	147	28	17	2	13	2	79	9	94
Latin America and the Caribbean	44	12	3	0	3	2	9	8	11
North America	19	2	0	0	0	1	0	1	2
Near and Middle East	33	3	0	1	0	5	1	3	2
World	**1 115**	**125**	**32**	**12**	**29**	**24**	**113**	**47**	**185**

Note: *Excluding extinct and international transboundary breeds.
Source: DAD-IS accessed in March 2014.

TABLE 1E2

Adaptations in sheep breeds as recorded in DAD-IS

Region	Number of breeds*	Heat	Cold	Humidity	Extreme diet	Water scarcity	Mountainous terrain	Dry environment	Docility
Africa	141	9	5	1	0	10	3	17	3
Asia	276	36	25	1	4	4	35	13	7
Southwest Pacific	687	0	3	0	0	0	1	0	0
Europe and the Caucasus	54	23	22	0	15	3	108	16	34
Latin America and the Caribbean	57	2	1	0	1	0	3	2	1
North America	27	2	1	0	0	0	0	0	2
Near and Middle East	41	11	0	0	1	4	1	7	7
World	**1 283**	**83**	**57**	**2**	**21**	**21**	**151**	**55**	**54**

Note: *Excluding extinct and international transboundary breeds.
Source: DAD-IS accessed in March 2014.

are the Djallonké of Guinea and the Xinjiang Finewool of China.

Camelids

The alpaca and the llama inhabit Andean rangelands at elevations of up to 5 000 metres above sea level. They thrive in a wide range of climates and on very poor pastures. Worldwide, eight breeds of alpaca and six breeds of llama are recorded in DAD-IS (see Part 1, Section B Figure 1B6). No particular differences in adaptedness between these breeds are reported. Bactrian camels are described as hardy, tolerant to heat, dry environments and water scarcity. All 14 reported breeds are described as being well adapted to desert conditions, extreme temperature ranges and shortages of water and food. They have the ability to rapidly gain and store large amounts of fat. Dromedaries are reported from a wide geographical area, ranging from the Atlas Mountains of northwestern Africa to the Australian outback. The majority of reported adaptations relate to tolerance of water scarcity or dry environments or to general hardiness. It is reported that the Rendille camel breed of Kenya can be kept for up to 14 days without water. The Chameau du Kanem and Gorane breeds of Chad are reported to be adapted to consumption of salt water.

Equines

Equines are found in all climatic zones. Special adaptations are documented only for a relatively small number of the 174 reported ass breeds and the 905 reported horse breeds (see Table 1E3). Horses are mostly described as being hardy and well adapted to mountainous terrain. A very few breeds (e.g. the Sunico Pony of the Plurinational State of Bolivia and the Tibetan horse) are reported to be adapted to high elevations.

Pigs

Of the 709 pig breeds reported worldwide, 63 breeds are described as being especially hardy. Special adaptedness to heat is reported for 27 breeds, to extreme diets for 11 breeds, to cold for 6 breeds and to dry environments for 7 breeds. China reports four pigs breeds adapted to a cold climate, the Bamei, Harbin White, Sanjiang White and Min. By developing layers of fat and growing thick hair during the winter, they are able to thrive in cold environments. However, this slows their growth rate in comparison to other breeds.

Chickens

Chicken breeds are kept in all geographic regions. The most commonly reported adaptations are hardiness and heat tolerance. Switzerland reports that the Appenzeller Barthuhn, with its characteristic beard and small rose comb, is resistant to cold. A wide spectrum of behavioural traits are reported. Some breeds are known for their docility and others for their fighting ability.

3 Adaptation to non-disease stressors

3.1 Introduction

One of the key features of animal genetic diversity is that it enables livestock to be kept in a wide

TABLE 1E3

Adaptations in equine breeds as recorded in DAD-IS

Species	Number of breeds*	Heat	Cold	Extreme diet	Water scarcity	Mountainous terrain	Dry environment	General hardiness
Ass	174	2	3	1	5	-	7	14
Horse	905	9	6	7	2	30	4	77

Note: *Excluding extinct and international transboundary breeds.
Source: DAD-IS accessed in March 2014.

range of production environments. As a result of natural selection, livestock populations tend, over time, to acquire characteristics that facilitate their survival and reproduction in their respective production environments. In other words, they become adapted to local conditions. Because livestock are domesticated animals that are managed by humans, the process of adaptation is complicated by, *inter alia*, the effects of artificial selection, management interventions that alter production environments and the movement of animals or germplasm from one production environment to another. Capacity to isolate animals from the stressors present in the local environment – extremes of temperature, feed shortages, diseases, etc. – has increased over the years, but the conditions in which animals are raised continue to be very diverse. Particularly in smallholder and pastoralist systems, animals often face harsh production conditions and have to rely on their adaptive characteristics.

3.2 Adaptation to available feed resources

Animals that are well adapted to coping with periods of feed scarcity may have one or more of the following characteristics: low metabolic requirements; the ability to reduce their metabolism; digestive efficiency that enables them to utilize high-fibre feed; and the ability to deposit a reserve of nutrients in the form of fat.

Having low metabolic requirements helps an animal to survive if feed is in short supply or is of poor quality. One breed that has been found to show this characteristic is the Black Bedouin goat, a small desert breed native to the Near East (Silanikove, 1986a; 2000). The energy requirement of a mammal is normally considered to be a function of its body mass raised to the power of 0.75. This implies that energy requirement per kilogram of body tissue is greater in small mammals than in larger ones and that smaller animals will have to compensate for this by eating more and/or higher-quality feed. Thus, in theory, the total energy requirements of five 20 kg Black Bedouin goats total metabolic weight = 20 $kg^{0.75}$ x 5 = 47.3 kg) should be considerably higher than that of a single large European goat weighing 100 kg (metabolic weight = 100 $kg^{0.75}$ = 31.6 kg). In fact the total requirements are similar (Silanikove, 2000).

Some mammals are able to maintain steady body weights even if their energy intakes are below voluntary intake levels. This may be due to an ability to reduce metabolism. For example, Silanikove (2000) compared the abilities of non-desert Saanen goats and Bedouin goats fed on high-quality roughages to maintain steady body weights when their consumption was restricted. The Saanen goats were able to cope with a 20 to 30 percent reduction relative to their voluntary intakes. The Bedouin goats tolerated a 50 to 55 percent reduction. The Bedouin animals had a 53 percent lower fasting heat production under feed restriction. Other herbivores that are annually exposed to long periods of severe nutritional restriction in their native habitats (e.g. zebu cattle and llamas) also possess a similar capacity to adjust to low energy intake by reducing their energy metabolism (ibid.).

Ruminants are known for their ability to utilize high-fibre feed. Goats can digest high-fibre low-quality forages more efficiently than other ruminants; one of the main reasons for this is a longer mean retention time of feed in the rumen (Devendra, 1990; Tisserand *et al.*, 1991). Goat breeds indigenous to semi-arid and arid areas are able to utilize low-quality high-fibre feed more efficiently than other goats (Silanikove *et al.*, 1993). For example, the digestive efficiency of Black Bedouin goats fed on roughage diets has been shown to be superior to that of Swiss Saanen goats (Silanikove *et al.*, 1993; Silanikove 1986a; Brosh *et al.*, 1988).

Ability to store energy in adipose tissues when sufficient feed is available and subsequently to mobilize it during periods of scarcity is an important adaptation for animals that have to cope with fluctuating feed supplies (Ball *et al.*, 1996; Ørskov, 1998). Negussie *et al.* (2000) found that in the Menz and Horro fat-tailed sheep breeds of Ethiopia, tail and rump fat depots were the most readily utilizable in the event of feed shortages.

Ermias *et al.* (2002) reported an encouraging heritability estimate (0.72±0.19) for the combined weight of tail and rump fat in Menz sheep, indicating opportunities for selective breeding.

In addition to adaptations related to feed shortages and the use of high-fibre forages, some breeds of livestock have developed unique physiological abilities that enable them to survive on unusual feed resources. For example, the North Ronaldsay, a breed of sheep native to an island off the coast of Scotland, in the United Kingdom, survives on a diet consisting mainly of the seaweed *Limnaria* (NCR, 1993). It can cope with a diet that is very low in copper and in which some elements (e.g. sodium) are present in excess. Other breeds found in Scotland, which normally feed on grass or hay, would die from lack of copper if fed on *Limnaria*.

3.3 Adaptation to extreme temperatures

When animals are exposed to heat stress, their feed intakes decrease and they suffer metabolic disturbances (Marai *et al.*, 2007). This, in turn, impairs their productive and reproductive performance. The effects are aggravated when heat stress is accompanied by high humidity. Differences in thermal tolerance exist between livestock species (ruminants are more tolerant than monogastrics), between breeds and within breeds (Berman, 2011; Caldwell, *et al.*, 2011; Coleman, *et al.*, 2012; Renaudeau *et al.*, 2012; Menéndez-Buxadera *et al.*, 2012). For example, McManus *et al.* (2009a) compared physiological traits (sweating, respiratory and heart rates, rectal and skin temperatures) and blood parameters (packed cell volume, total plasma proteins, red blood cell count, and haemoglobin concentration) in different sheep populations in Brazil: the Santa Inês (a hair sheep with three different coat colours – brown, black and white), the Bergamasca (a wool sheep) and Santa Inês × Bergamasca crosses. The study found that there were significant differences between animals due to breed and skin type, and concluded that the white-coloured Santa Inês animals were the best adapted to high temperatures and that the Bergamasca were the least well adapted. The genetic correlation between milk production and heat tolerance in sheep is reported to be negative (Finocchiaro *et al.,* 2005), indicating that selection for increased milk production will reduce heat tolerance.

The adaptedness of zebu cattle to hot climates is related to the characteristics of their coats, hides and skins, as well as to their haematological characteristics and to their form, growth and physiology (Turner, 1980). Zebu cattle are smooth coated, have better-developed sweat and sebaceous glands than taurine cattle (ibid.). McManus *et al.* (2009b) compared parameters related to heat tolerance in seven cattle breeds (including zebu and taurine breeds and breeds considered exotic and locally adapted to Brazilian conditions) and found the zebu Nelore to be the best adapted to heat stress and the taurine Holstein to be the least well adapted.

Adaptation to cold (see Box 1E1) involves a number of different mechanisms. For example, a long thick hair coat contributes to thermal insulation. Sheep originating from and living in cold areas deposit more of their body fat under the skin than those adapted to warmer areas (Kempster, 1980; Farid, 1991; Bhat, 1999; Negussie *et al.*, 2000; Ermias *et al.*, 2002). In many sheep adapted to arid conditions, almost all fat is deposited on the rump and/or in the tail (Bhat, 1999). This helps the animals avoid thermal stress, as these deposits do not greatly impede heat loss from the body. Studies of the Horro and Menz sheep breeds of Ethiopia (Negussie *et al.,* 2000; Ermias *et al.,* 2002) have shown that, in the former, a large proportion of total body fat is deposited in the rump and tail, while subcutaneous and intramuscular deposits predominate in the latter. The production environment of the Menz is cooler than that of the Horro, which lives at a slightly lower elevation.

3.4 Adaptation to water scarcity

Breeds of ruminants native to arid lands are able to withstand prolonged periods of water deprivation and can graze rangelands where watering sites are 50 km or more far apart (Silanikove, 1994; Bayer and Feldmann, 2003). Livestock that

Box 1E1

Yakutian cattle – a breed well adapted to subarctic climatic conditions

The Yakutian cattle of the Sakha Republic in the Russian Federation, a unique population of Turano-Mongolian type *Bos taurus*, are believed to be the last remaining indigenous Siberian cattle. They are dual-purpose animals (milk and meat) and have small but strong bodies, small firm udders and short firm legs. Their bodies and teats are covered with thick hair. They are well adapted to the extreme environment and climate of the subarctic region, characterized by long, dark and cold winters, during which the temperature can fall to -60 °C. They are capable of thriving on the poor feed provided by the plants of the northern environment and require less body maintenance energy during winter than other cattle. They grow and fatten rapidly during the short summer. They are reported to be resistant to tuberculosis, leucosis and brucellosis. They have a long productive life, some cows living for more than 20 years and calving more than ten times.

Sources: Ovaska and Soini, 2011; Li *et al.*, 2012.

Photo credit: Anu Osva (previously published in Granberg et al., *2009, reproduced with permission).*

need little water and do not have to go back to a watering point every day can access larger areas of pasture and thus obtain more feed during periods of drought. For example, dromedaries can survive up to 17 days of water deprivation when consuming dry food in hot conditions or can go without drinking water for 30 to 60 days when grazing on green vegetation (Schmidt-Nielsen, 1955; Schmidt-Nielsen *et al.*, 1956). There are also donkey, goat, sheep and cattle breeds that can go without drinking for several days (Bayer and Feldmann, 2003). Such animals drink large amounts of water quickly, but their overall water intake is lower than that of animals that are watered daily. Reduced water intake reduces feed intake and metabolic rate, and animals can therefore survive for longer when feed is scarce. Desert goats are reported to be the ruminants that have the greatest ability to withstand dehydration (Silanikove, 1994). For example, the Black Bedouin goat of the Near East and the Barmer goat of India often drink only once in every four days (Khan *et al.*, 1979a,b,c; Silanikove, 2000). Bedouin goats are also able to maintain a good level of milk production under water deprivation. The basis of these breeds' ability to cope with severe water shortages is their ability to withstand dehydration and to minimize water losses via urine and faeces. By the fourth day of dehydration, the water losses of Barmer and Bedouin goats may exceed 40 percent of their body weights (Khan *et al.*, 1979a,b; Silanikove, 2000).

3.5 Adaptation to interaction with humans

The process of domestication (see Part 1 Section A) involved adaptation to human management. Domesticated animals are more docile than their wild ancestors and less fearful of humans. Nonetheless, routine management procedures (e.g. shearing, castration, tail docking, dehorning, vaccination, herding and transportation) can still trigger fear and thereby negatively affect animal welfare (Boissy *et al.*, 2005). Excessive fear can also reduce productivity. For instance, fear-related reactions affect sexual and maternal behaviours in cattle and sheep. Estimates of the heritability of fear range between 0.09 and 0.53 in dairy cattle and between 0.28 and 0.48 in sheep; a moderate heritability of 0.22 has been estimated for reactions to handling in beef cattle (ibid.). Thus, selection based on reduced fearfulness could have a significant influence on the welfare of ruminant livestock.

3.6 Adaptation to predators

Domesticated animals express less vigorous anti-predator behaviour than their wild counterparts, probably because human protection has reduced selection pressure for anti-predator traits. There is some evidence of between-breed differences in antipredator behaviour. Hansen *et al.* (2001) compared the responses of light, medium-weight and heavy sheep breeds to the presence of predator-related stimuli (leashed dogs or stuffed wild predators on trolleys) and found that the light breeds displayed stronger antipredator reactions (longest flight distance, tightest flocking behaviour and longest recovery time). A more recent study suggested that this response to predator-like stimuli could explain, at least partially, the improved survivability of free-ranging lambs in light breeds (Steinheim *et al*., 2012).

4 Disease resistance and tolerance

4.1 Introduction

Diseases are one of the major constraints to livestock productivity and profitability worldwide. A range of disease-control options exist, including chemical or biological treatments, vaccination and preventive management. Each of these approaches has its strengths, weaknesses and limitations. Another option is to utilize genetic approaches, which can serve either to substitute or to complement other disease-control strategies.

Evidence of genetic influence on disease susceptibility has been reported for many animal diseases (e.g. Bishop and Morris, 2007; Gauly *et al*., 2010). Advantages of genetic approaches to disease control include the long duration of the effect, the possibility of broad spectrum effects (resistance to more than one disease) and the possibility of using genetics in concert with other approaches (FAO, 1999). In addition, genetic changes should, theoretically, be less subject to pathogen resistance, as they will often be the result of relatively small effects at many genes, none of which alone will be sufficient to drive a genetic response in the pathogen (Berry *et al*., 2011). Two concepts need to be distinguished in this context: "resistance" refers to the ability of the host to control infection by a given pathogen, whereas "tolerance" refers to the ability of the host to mitigate the adverse effects of the pathogen once infection occurs.

Genetic management of disease can involve a number of different strategies, including breed substitution, cross-breeding and within-breed selection. The appropriate choice of strategy will depend on the disease, the production environment and the resources available. Within-breed selection can be facilitated if molecular genetic markers associated with the desired traits have been identified (CABI, 2010).

Whatever strategy is chosen, genetic diversity in the targeted livestock populations is a necessary precondition. If genetic resources are eroded, potentially important means of combating disease may be lost. Maintaining multiple breeds increases the options available for matching breeds to production environments, including the disease challenges present in these production environments. Maintaining within-breed diversity allows for individual selection. Even where genetic strategies are not immediately required in order to combat current animal health problems, maintaining diversity in the genes underlying resistance means maintaining an important resource for combating the effects of possible future pathogen evolution. Furthermore, at individual animal level, increased genetic diversity may allow for a more robust immune response to a wider range of pathogen strains and species. A recent study of African cattle reported an association between genetic diversity (as measured by molecular heterozygosity) and lower incidence, and higher survival, of infectious diseases (Murray *et al*., 2013).

This subsection serves as an update of the discussion of the genetics of disease resistance and tolerance presented in the first SoW-AnGR.[3] In addition to presenting the latest data available

[3] FAO, 2007, Part 1 Section E (pages 101–112).

in DAD-IS on breeds' resistance and tolerance to specific diseases, it briefly discusses recent scientific developments in this field and their potential significance for disease-control strategies, focusing particularly on research findings published since the first SoW-AnGR was prepared. The discussion generally emphasizes diseases for which breed-level resistance or tolerance has been reported to DAD-IS, although research results for other diseases are also cited.

4.2 Disease resistant or tolerant breeds

In theory, breeds that have been present an extended period of time in an area where a given disease is endemic may develop genetic resistance or tolerance to that disease. This is because natural selection should favour the accumulation of alleles associated with greater survival. In the case of many common livestock diseases, evidence is available in the scientific literature that some breeds are more resistant or tolerant than others. A number of examples, drawn from recent (i.e. after 2006) studies are presented in Table 1E4. The information entered by countries into DAD-IS includes many anecdotal reports of such adaptations. Table 1E5 presents an overview of the entries in DAD-IS that report disease resistance or tolerance in mammalian breeds. Tables 1E6 to 1E12 list breeds reported to be resistant or tolerant to specific diseases or disease types. In most of these cases, the claims made for specific breeds have not been subject to scientific investigation.

Few new reports of breeds with resistance or tolerance to specific diseases have been entered into DAD-IS since 2007. New examples have generally been from countries that have undertaken comprehensive characterization studies for the first time. However, many more cases of general disease resistance have been reported. In addition, a great deal of research has been undertaken to substantiate anecdotal evidence and uncover the biological mechanisms associated with differences among breeds in terms of their susceptibility to common livestock diseases. Recent scientific developments with respect to the main diseases featured in the DAD-IS data – including several that did not feature in the discussion presented in the first SoW-AnGR – are briefly discussed in the following subsections. Short discussions are also presented for some diseases for which no information on breed resistance has been entered into DAD-IS, but for which information is available in the scientific literature.

Trypanosomosis

Tsetse-transmitted trypanosomosis remains a serious and costly disease throughout West, Central and, to a lesser extent, East Africa, despite multifaceted attempts to control it. Although trypanocidal drugs can be useful, parasite resistance to these drugs increases yearly. Fortunately, locally adapted breeds of ruminants in areas of high tsetse fly challenge show consistent tolerance to this disease. Table 1E6 contains a full list of breeds recorded in DAD-IS as being trypanotolerant or resistant. As was the case at the time the first SoW-AnGR was prepared, the most commonly reported trypanotolerant breeds are N'Dama cattle and Djallonké sheep and goats (also known as West African Dwarf or under other names, depending on the country). Since the time of the first SoW-AnGR, information on trypanotolerant cattle, sheep and goats breeds has been recorded in DAD-IS by Sudan and information on trypanotolerant pigs and equines by several West and Central African countries.

Various studies have been undertaken in recent years to elucidate the biological basis for trypanotolerance (e.g. O'Gorman *et al.*, 2009; Stijlemans *et al.,* 2010; Noyes *et al.*, 2011). Two physiological mechanisms seem to be involved: 1) increased control of parasitaemia; and 2) greater ability to limit anaemia (Naessens *et al.*, 2006). One group of scientists is currently attempting to use genetic modification to create a trypanosome-resistant strain of cattle, based on a genetic mechanism present in baboons and some human populations (Willyard, 2011).

TABLE 1E4

Examples of studies indicating breed differences in resistance, tolerance or immune response to specific diseases

Disease/parasite	Breed(s) or genotype(s) showing the favourable phenotype	Compared to which breed(s) or genotype(s)	Experimental conditions	Results	Reference
Theileria annulata	Sahiwal cattle	Holstein	Artificial infection of isolated monocytes	Less severe clinical signs in the Sahiwal, gene expression profile of monocytes differs between the two breeds	Glass and Jensen, 2007
Trypanosomosis	N'Dama × Kenya-Boran cattle	Kenya-Boran	Field challenge	N'dama cross-breed more trypanotolerant, especially females	Orenge *et al.*, 2012
Tuberculosis	Zebu cattle	Holstein	Natural and artificial infection	Zebu have fewer clinical signs and decreased morbidity	Ameni *et al.*, 2007; Vordermeier *et al.*, 2012
Fasciola gigantica	Buffalo	Ongole cattle	Artificial infection	Buffalo have 1/5 the number of flukes Ongole cattle have	Wiedosari *et al.*, 2006
Rhipicephalus microplus	Nguni cattle	Bonsmara	Natural infection	Leukocyte profile differs between infected Nguni and Bonsmara	Marufu *et al.*, 2011
Rhipicephalus microplus	Braford, Brangus, Nelore cattle	Charolais	Natural infection	Fewer ticks carried by the Braford, Brangus and Nelore	Molento *et al.*, 2013
Haemonchus contortus	Caribbean hair sheep	Wool sheep	Artificial infection	Caribbean Hair sheep have higher PCV, lower FEC, higher IgA than the wool sheep	MacKinnon *et al.*, 2010
Haemonchus contortus	Gulf Coast Native sheep	Suffolk	Pasture-based infection	Native lambs have more robust immune response to infection	Shakya *et al.*, 2009
Fasciola gigantica	Indonesian Thin Tail sheep	Merino	Artificial infection	Type1 immune response makes Indonesian Thin Tail more resistant	Pleasance *et al.*, 2011
Porcine reproductive and respiratory syndrome (PRRS)	Miniature pigs	Pietrain pigs	Artificial infection	Virus replication in the miniature pigs only 3.3% of that in the Pietrain	Reiner *et al.*, 2010
PRRS	Meishan pigs	Duroc, Hampshire	Artificial infection	Meishan have less PRRS antigen in their lungs	Xing *et al.*, 2014
Marek's disease	Erlang Mountain chickens	Commercial broiler	Artificial infection	Erlang show reduced clinical signs and faster clearance of virus	Feng *et al.*, 2013
Infectious bursal disease virus	Aseel chickens	Commercial	Artificial infection	TH1 immunity, upregulation in the Aseel	Raj *et al.*, 2011
Avian influenza	Fayoumi chickens	Leghorn	Artificial infection	Resistance to infection in the Fayoumi	Wang *et al.*, 2014
Newcastle disease	Naked-neck chickens	Frizzle- and smooth-feathered chickens	Artificial infection	Naked-neck shows lower mortality	Bobbo *et al.*, 2013

Note: FEC = faecal egg count; PCV = packed cell volume; IgA = immunoglobulin A; TH1 = type 1 T helper cell.

TABLE 1E5

Number of mammalian breed populations recorded in DAD-IS as having resistance or tolerance to specific diseases or parasites

Disease/parasite	Number of reported resistant or tolerant breed populations* per species							
	Buffalo	Cattle	Goats	Sheep	Pigs	Horses	Deer	Camelids
Unspecified	8	74	22	32	27	36		1
Trypanosomosis		48	22	18	2	3		
Tick infestation/burden	1	24		5			1	
Tick-borne diseases (unspecified)	1	26	1	5			1	
Anaplasmosis		2						
Piroplasmosis/babesiosis						1		
Heartwater/cowdriosis		2		2				
Theileria		2						
Internal parasites	3	1	2	16	1	3	1	
Fascioliasis		1						
Bovine leukosis		11		1				
Foot rot		1		13				
African swine fever					6			
Tuberculosis		13	3	1				
Brucellosis	1	7	3	2				
Foot-and-mouth disease	2	1						
Total	**16**	**236**	**54**	**94**	**36**	**43**	**3**	**1**

Note: *"Breed population" = a given breed within a given country.
Source: DAD-IS accessed in March 2014.

Ticks and tick-borne diseases

Ticks continue to cause disease and production loss throughout the world, most notably in tropical and subtropical areas. Tick infestation causes blood loss and decreased milk or meat production. Ticks also transmit a number of diseases, including babesiosis, anaplasmosis and cowdriosis. Some breeds of cattle are reported to be resistant to tick infestation and tick-borne disease. There are several potential explanations for the greater resistance of some breeds to tick infestation, including their coat characteristics, skin sensitivity, grooming behaviour and degree of inflammatory response (Mattioli *et al.*, 1995; Marufu *et al.*, 2011; Mapholi *et al.*, 2014). Tables 1E7 and 1E8 show the breeds recorded in DAD-IS as being resistant to, or tolerant of, tick infestation and/or tick-borne diseases.

Recent findings suggest that susceptibility and resistance to tick infestation may be related to differences in the types of immune responses that occur in susceptible and resistant animals. Marufu *et al.* (2014) report that an increased immune response involving basophils, monocytes and mast cells was noted in resistant Nguni cattle, whereas in susceptible animals, neutrophils and eosinophils were the primary cellular responders to tick bite. Increased neutrophil concentrations were hypothesized to facilitate the distribution of tick-borne pathogens within infected hosts, as enzymes that they release compromise the extracellular matrix. Mast cells and basophils,

TABLE 1E6
Breeds recorded in DAD-IS as showing resistance or tolerance to trypanosomosis

Species	Region/subregion	Number of breeds	Most common name of breed
Cattle	North and West Africa	15	N'Dama (20), Lagune (Lagoon) (6), Baoulé (4), Borgou/Ketuku (3), Somba (2), Muturu (2), Dahomey (Daomé), Ghana Shorthorn, Kapsiki, Kuri, Namchi, Toupouri
	East Africa	2	Jiddu, Shekko
	Southern Africa	2	N'Dama, Dahomey (Daomé)
	Near and Middle East	1	Nuba Mountain
Sheep	North and West Africa	2	Djallonké (West African Dwarf) (13), Vogan (2)
	Near and Middle East	3	Mongalla, Nilotic, Nuba Mountain Dwarf
Goats	North and West Africa	1	Djallonké (West African Dwarf) (20)
	Near and Middle East	2	Nilotic, Yei
Pigs	West Africa	2	Local Pig of Benin, Nigerian Native
Horses	North and West Africa	2	Bandiagara (2), Poney du Logone

Note: Figures in brackets indicate the number of countries (if more than one) reporting that the breed is resistant or tolerant.
Source: DAD-IS accessed in March 2014.

on the other hand, increased immune response in the area of the bite, in addition to promoting grooming behaviours that promote tick removal. Although further research is needed, greater understanding of the immunological basis for between-breed differences in resistance may facilitate the development of more effective control strategies.

Internal parasites

Helminthosis continues to cause major production losses throughout the world, particularly as parasite resistance to anthelminthic drugs increases. This latter development places additional pressure on livestock keepers and governments to rely more heavily on genetically resistant or tolerant breeds for production in parasite-infested areas. Breeds noted in DAD-IS as having some resistance to internal parasites are listed in Table 1E9. Many breeds of small ruminants have been characterized as parasite resistant (González *et al.*, 2012).

As described in the first SoW-AnGR, the Red Maasai sheep of Kenya is noted for its resistance to the parasite *Haemonchus contortus.* Direct breed comparison studies have shown lower faecal egg counts in Red Maasai than in Dorper lambs (Baker *et al.,* 2004). A more recent study of specific quantitative trait loci in cross-bred animals found that all favourable alleles were associated with the Red Maasai (Marshall *et al.*, 2013). Recent studies have also indicated that the Thalli sheep of Pakistan shows significant resistance to *Haemonchus contortus* infection and lower levels of anaemia during infection than other Pakistani breeds (Babar *et al.*, 2013). Similarly, Santa Ines ewes (a Brazilian breed) have been found to be more resistant than Ile de France ewes when challenged with this parasite (Rocha *et al.*, 2011). Since the first SoW-AnGR was prepared, a number of within- and across-breed genomic studies have been undertaken (e.g. Riggio *et al.*, 2013).

The first SoW-AnGR noted that resistance to *Fasciola gigantica* had been reported in Indonesian Thin Tail sheep. Since that time, researchers have confirmed that this resistance is quite pathogen specific and does not extend to other liver flukes such as *F. hepatica* (Pleasance *et al.*, 2010). There are indications that the resistance is based on an early type 1 innate immune

TABLE 1E7

Breeds recorded in DAD-IS as showing resistance or tolerance to tick burden

Species	Region/subregion	Number of breeds	Most common name of breed
Cattle	Southern Africa	10	Nguni (2), Bonsmara, Kashibi, Nandi, Pedi, Shangaan, Sul do Save, Tswana, Tuli, Venda
	Southeast Asia	6	Australian Milking Zebu, Droughtmaster, Java, Local Indian Dairy Cow, Pesisir, Thai
	Europe and the Caucasus	1	Zebu of Azerbaijan
	South America	1	Romosinuano
	Southwest Pacific	5	Australian Charbray, Australian Friesian Sahiwal, Australian Milking Zebu, Australian Sahiwal, Javanese Zebu
Sheep	Southern Africa	3	Nguni (3), Landim, Pedi
Buffalo	Southeast Asia	1	Krabue
Deer	Southeast Asia	1	Sambar

Note: Figures in brackets indicate the number of countries (if more than one) reporting that the breed is resistant or tolerant.
Source: DAD-IS accessed in March 2014.

TABLE 1E8

Breeds recorded in DAD-IS as showing resistance or tolerance to tick-borne diseases

Species	Region/subregion	Diseases	Number of breeds	Most common name of breed
Cattle	North and West Africa	Tick-borne (unspecified)	3	Baoulé (3), Ghana Shorthorn, Sahiwal,
		Piroplasmosis	1	Noire Pie de Meknès
	East Africa	Tick-borne (unspecified)	2	Sahiwal (2), Nandi
	Southern Africa	Piroplasmosis	3	N'Dama, Nguni, Sahiwal
		Theileria	1	Angoni
	Europe and the Caucasus	Piroplasmosis	3	Cinisara, Modicana, Southern Beef
		Anaplasmosis	2	Cinisara, Modicana
		Heartwater (cowdriosis)*	1	Creolé (2)
	East Asia	Theileria	1	Jeju Black cattle
	South Asia	Tick-borne (unspecified)	2	Sahiwal (5), Local Indian Dairy Cow
	Southeast Asia	Tick-borne (unspecified)	1	Sahiwal (4)
	Caribbean	Tick-borne (unspecified)	1	Sahiwal (2)
	South America	Tick-borne (unspecified)	1	Creole (2), Sahiwal
	Southwest Pacific	Tick-borne (unspecified)	1	Sahiwal
Sheep	Southern Africa	Heartwater (cowdriosis)	1	Damara (2)
Horses	Europe and the Caucasus	Piroplasmosis	1	Pottok

Note: *These reports are from the French overseas territories of Guadeloupe and Martinique, i.e. not geographically from the Europe and the Caucasus region. Figures in brackets indicate the number of countries (if more than one) reporting that the breed is resistant or tolerant.
Source: DAD-IS accessed in March 2014.

TABLE 1E9
Breeds recorded in DAD-IS as showing resistance or tolerance to internal parasites

Species	Region/subregion	Number of breeds	Most common name of breed
Cattle	Southern Africa	1	Madagascar Zebu
Goats	Southeast Asia	1	Kacang
	East Asia	1	Tokara
Sheep	Southern Africa	1	Kumumawa
	Northern Africa	1	Rahmani
	Southeast Asia	2	Garut, Malin
	Europe and the Caucasus	1	Solognot
	Latin America and the Caribbean	3	Criollo (9), Morado Nova, Priangen
Horse	Southeast Asia	2	Bajau, Kuda Padi
	South America	1	Peruano de Paso
Deer	Southeast Asia	1	Sambar

Note: Figures in brackets indicate the number of countries (if more than one) reporting that the breed is resistant or tolerant.
Source: DAD-IS accessed in March 2014.

response.[4] A response of this kind is hypothesized to be effective only against *F. gigantica,* which develops more rapidly than *F. hepatica* (Pleasance *et al.*, 2011). In molecular and biochemical terms, infections with *F. gigantica* and *F. hepatica* elicited different responses in the Indonesian Thin Tail sheep. Immunological responses to *F. gigantica* also differed between Indonesian Thin Tail sheep and Merino sheep (a non-resistant breed).

Foot-and-mouth disease

Foot-and-mouth disease is a highly contagious viral disease of cloven-hooved animals. A vaccine exists, but the disease is also controlled by tight restrictions on the movement of animals from affected to non-affected countries and in some countries by culling programmes in the event of an outbreak. Two buffalo and one cattle breed have been declared in DAD-IS to show some level of resistance to this disease. These reports have yet to be substantiated in the scientific literature.

Bovine leukosis

Bovine leukosis occurs in a proportion of cattle infected with the bovine leukosis virus (BLV). Although not all animals infected with the virus become clinically affected, the condition causes significant losses in production and increased mortality. Evidence of breed-based resistance to clinical leukosis is scant and primarily anecdotal. Reports of resistance are limited to breeds from Central Asia and the Russian Federation (see Table 1E10). However, research on some common international transboundary dairy breeds has indicated a genetic basis for susceptibility to the disease (Abdalla *et al.*, 2013). Research regarding the molecular explanation of resistance suggests that imbalances in certain receptors (tumor necrosis factor alpha in particular) can contribute to increased susceptibility (Konnai *et al.*, 2005).

[4] Immune responses to infectious diseases comprise types 1 and 2. The two types differ according to the cells involved (T helper 1 vs. T helper 2 cells) and the secretions produced by these cells. Type 1 immune response is characterized by high phagocytic activity, whereas type 2 involves high levels of antibody production. Type 1 immunity is generally protective, whereas type 2 usually involves resolution of cell-mediated immunity. For more information, see Spellberg and Edwards (2001).

TABLE 1E10
Cattle breeds recorded in DAD-IS as showing resistance or tolerance to leukosis

Region/subregion	Number of breeds	Most common name of breed
Central Asia	1	Bestuzhevskaya
Europe and the Caucasus	9	Istobenskaya, Krasnaya gorbatovskaya, Southern beef, Suksunskaya skot, Sura de stepa, Yakutskii Skot, Yaroslavskaya, Yurinskaya, Volinian beef

Source: DAD-IS accessed in March 2014.

Bovine tuberculosis

Bovine tuberculosis is a respiratory disease that can be transmitted through milk and has significant negative consequences – both as a disease of livestock and as a zoonosis – particularly in developing countries. Several breeds (13 cattle breeds, 3 goat breeds and 1 sheep breed) are recorded in DAD-IS as being resistant to this disease. These breeds are primarily reported by countries from the Europe and the Caucasus region. Although it has not been recorded in DAD-IS, a recent scientific study (Vordermeier *et al.,* 2012) comparing native Zebu cattle to Holstein cattle in Ethiopia found that the Zebu was more resistant to tuberculosis. Within-breed quantitative genetic studies have found evidence of heritable control of susceptibility to this disease (e.g. Bermingham *et al.*, 2009; Brotherstone *et al.*, 2010; Tsairidou *et al.,* 2014) and genome-wide association studies have identified genomic regions with putative associations with disease incidence (e.g. Bermingham *et al.*, 2014).

Brucellosis

Brucellosis is a zoonosis that particularly affects cattle and goats. Transmission to humans is usually through consumption of contaminated milk or dairy products. Reproductive failure is the main negative consequence in livestock. Anecdotal claims of brucellosis resistance have been made in DAD-IS for one buffalo breed, seven cattle breeds, three goat breeds and two sheep breeds. Genetic studies have primarily concentrated on pathogen strains rather than livestock breeds, but a recent study of polymorphism in genes associated with immune function reported some associations with disease prevalence in cattle (Prakash *et al.*, 2014). In addition, Martínez *et al.* (2010) studied brucellosis resistance in two Colombian cattle breeds (Blanco Orejinegro and Zebu) and their crosses and observed statistically significant genetic effects according to both quantitative and molecular genetic models.

Scrapie

Scrapie is a fatal neurodegenerative disease of sheep and goats that is endemic in many countries in Europe and North America. Although no information on scrapie has been entered into DAD-IS, the disease can be considered a textbook case with regard to within- and between-breed genetic variability in disease resistance. It has been shown that variability of the so-called PrP locus accounts for a large proportion of the variation in resistance to the disease (Bishop and Morris, 2007). Selection for scrapie resistance based on PrP genotype has been implemented in various sheep breeds (Palhière *et al.,* 2008), including some at-risk breeds (Windig *et al.,* 2007; Sartore *et al.,* 2013). This has led to significant decreases in the frequency of one susceptible haplotype (VRQ), if not its elimination, and to increases in the frequency of a resistance haplotype (ARR). In many cases, it has been possible to implement efficient selection programmes to reduce the susceptible haplotype without having much effect on neutral diversity (Windig *et al.,* 2007; Palhière *et al.,* 2008). However, Sartore *et al.* (2013) reported an increase in inbreeding in the Italian Sambucana breed after selection started.

These contrasting empirical results underline the importance of considering genetic variability when designing selection programmes (Dawson *et al.,* 2008).

Foot rot

Foot rot caused by *Dichelobacter nodosus* or *Fusobacterium* is a highly contagious disease of sheep, in particular, and can cause production losses and animal welfare concerns. Table 1E11 shows breeds recorded in DAD-IS as being resistant to foot-rot infection. Current knowledge with regard to resistant breeds is similar to that available at the time the first SoW-AnGR was prepared. Disease control may in fact be better achieved through within-breed foot-rot lesion scoring (Conington *et al.*, 2008) than through breed selection. A recent epidemiological modelling study suggests that foot rot may be eradicated from a given flock by employing a combination of genetic selection, pasture rotation and timely antibiotic administration (Russell *et al.*, 2013; McRae *et al.*, 2014).

African swine fever

African swine fever is a highly contagious disease that causes the rapid death of infected animals. Although recent advances have been made in vaccine development, no commercial product is available and control still relies on strict protocols for disease identification, restriction of animal movements and culling of infected animals. The first SoW-AnGR highlighted the resistance of wild pigs to African swine fever.[5] DAD-IS now lists six breeds that are anecdotally reported to have some degree of resistance or tolerance to this disease, including breeds from Southern Africa, Spain and Jamaica. However, no scientifically confirmed reports of genetic resistance are available. Researchers in the United Kingdom have recently used gene-editing procedures to create domestic pigs with the putative genetic mechanism for resistance found in wild pigs (Lillico *et al.*, 2013).

Porcine reproductive and respiratory syndrome

Porcine reproductive and respiratory syndrome, more commonly known by the acronym PRRS, is a viral disease caused by the *Arteriviridae* family. The clinical signs of infection are manifold and can include widespread reproductive failure, including stillbirths, mummified foetuses, premature births and weak piglets. The disease also causes a characteristic thumping respiratory pattern in post-weaning piglets, which can lead to decreased growth and increased mortality. Containment and eradication of the disease is difficult due to the ease with which it is spread. No breeds are recorded in DAD-IS as being resistant to this disease, but differences between breeds and populations have been reported in the scientific literature (Lewis *et al.,*

[5] FAO, 2007, Box 14 (page 109).

TABLE 1E11

Breeds recorded in DAD-IS as showing resistance or tolerance to foot rot

Species	Region/subregion	Number of breeds	Most common name of breed
Cattle	Europe and the Caucasus	1	Sayaguesa
Sheep	North and West Africa	1	Beni Ahsen
	East Asia	1	Small Tailed Han
	Europe and the Caucasus	10	Bündner Oberländerschaf, Churra Lebrijana, Engadiner Schaf, Latxa, Leine, Montafoner Steinschaf, Owca kamieniecka, Polska owca długowełnista, Soay, Waldschaf,
	Southwest Pacific	1	Broomfield Corriedale

Source: DAD-IS accessed in March 2014.

2007). Reiner *et al.* (2010) report evidence of resistance to the virus in a population of "Wiesenauer Miniature" pigs developed in Germany; compared to animals belonging to the commercial Pietrain breed, the miniature pigs showed a 96.7 percent lower viral load. Research into the molecular explanation of resistance would allow for better understanding of the mechanisms of resistance to this viral pathogen. Such research is ongoing in a number of laboratories across the world (e.g. Lewis *et al.,* 2009; Boddicker *et al.,* 2012; 2014a,b; Serão *et al.,* 2014).

Diseases of poultry

Table 1E12 lists the avian breeds that are recorded in DAD-IS as being resistant to specific diseases Some level of general or unspecified resistance is reported for 75 other avian breeds (56 chicken, 11 duck, 2 goose, 3 guinea fowl, 1 pigeon, 1 quail and 3 turkey breeds).

Newcastle disease is a highly destructive viral infection affecting poultry and other avian species. The virus is endemic in certain areas of the world and can cause high levels of morbidity and mortality, particularly in intensive poultry management systems. A study comparing the relative resistance of three phenotypes of indigenous chickens in Nigeria found that Naked Neck chickens were more resistant to infection than others and more able to tolerate infection once it occurred (Bobbo *et al.*, 2013). The Yoruba chicken of Nigeria has been noted to have increased immune response to the virus and to be better able to resist and eliminate infection (Adeyemo *et al.*, 2012).

Over the last decade or so, avian influenza virus has become a global threat due to its devastating effects on poultry populations and the risks it poses to human health. No breeds are recorded in DAD-IS as being resistant to avian influenza. However, research indicates that the Mx gene in the Indonesian native chicken may confer increased resistance to infection (Sartika *et al.*, 2011). Moreover, resistance to the virus has been noted in the Fayoumi chicken breed, originally from Egypt but now present worldwide. Molecular analysis suggests that, in the event of infection, genes related to haemoglobin are highly expressed in the Fayoumi. Wang *et al.* (2014) postulate that this may aid the delivery of oxygen to various tissues, thus reducing the severity and duration of infection. Certain breeds of pigeons are known for their resistance to highly pathogenic avian influenza virus H5N1 (Liu *et al.*, 2009). Transmission of avian influenza in chickens relies in large part on specific receptors in the respiratory tract that allow the virus to attach. Analysis of these receptors in pigeons suggests that they are more similar to those of humans than those of chickens. Given that humans are also less susceptible than chickens to avian influenza H5N1, this could explain the pigeons' relatively high levels of resistance.

Genetic resistance to avian leucosis is recorded in DAD-IS for two Egyptian chicken breeds. Development of genetically resistant lines and the use of specific animal husbandry methods have enabled successful eradication of this disease from most commercial breeding populations.

4.3 Opportunities to breed for disease resistance

Breed-to-breed differences in disease susceptibility provide opportunities to decrease disease incidence through cross-breeding or breed substitution. However, these approaches are not applicable if the objective is to continue raising a given breed in pure-bred form or if relevant breed substitutions or cross-breeding strategies are not feasible. Therefore, for a number of diseases, selection to take advantage of within-breed variation in disease resistance is an important control strategy.

Numerous examples of within-breed selection for disease resistance exist and various selection strategies have been applied. Within-breed selection has been performed using both major genes and genetic markers (e.g. against scrapie in sheep) and quantitative genetic approaches (e.g. against Marek's disease in chickens, internal parasites in sheep and mastitis in dairy cows and sheep).

Within-breed selection programmes have always given emphasis to yield traits. However, consideration of heath traits has been increasing. This

TABLE 1E12
Avian breeds recorded in DAD-IS as showing resistance to diseases

Species	Region/subregion	Disease	Number of breeds	Most common name of breed
Chickens	North and West Africa	Newcastle	1	Poule De Benna
	Southeast Asia	Newcastle	1	Red Jungle Fowl
	Central America	Newcastle	2	Gallina criolla o de rancho, Gallina de cuello desnudo
	Europe and the Caucasus	Marek's	5	Scots Dumpy, Hrvatica, Borky 117, Poltavian Clay, Rhode Island Red
	Southeast Asia	Marek's, IBD (infectious bursal disease), coccidiosis	1	Ayam Kampong
	Southern Africa	Internal parasites	1	Basotho chicken
	Southeast Asia	Internal parasites	1	Papua New Guinea Native
		Respiratory diseases	3	Camarines, Paraoakan, Banaba (also fowl pox)
	North and West Africa	Mycoplasmosis avian pseudo plaque and pasteurellosis	1	Naked Neck
	Near and Middle East	Leukosis and spiroketosis	2	Egypt Baladi Beheri, Fayoumi
		Fowl pox and chronic respiratory disease (CRD)	1	Oman Baladi
	Europe and the Caucasus	*Eimeria necatrix*	1	Penedesenca Negra
		Oncorna virus	1	Single Comb White Leghorn-Line 12
Ducks	North and West Africa	Newcastle	3	Local Duck of Gredaya and Massakory, Local Duck of Moulkou and Bongor, Local Muscovy Duck of Karal and Massakory
	Southeast Asia	Duck viral enteritis and leg paralysis	1	Philippine Mallard Duck (Domestic)
	East Asia	Duck and goose viral hepatitis	1	Black Muscovy l303
Geese	Southeast Asia	Viral hepatitis	1	Itik Kampong
		"Skin venom"	1	Philippine Domestic Goose
Guinea fowl	North and West Africa	Newcastle	2	Djaoule, *Numida meleagris galeata* Pallas
Pigeons	Southeast Asia	"Skin venom"	1	Philippine Domestic Pigeon
Turkeys	North and West Africa	Newcastle	1	Moroccan Beldi
	Southeast Asia	Histomoniasis and sinusitis	1	Philippine Native

Source: DAD-IS accessed in March 2014.

has probably occurred for three main reasons: 1) greater awareness of the costs of disease; 2) decreasing fitness due to antagonistic relationships with selection and management for increased yield; and 3) increasing capacity to measure and evaluate health-related traits. In some cases, problems with other approaches, including the effects of increased resistance of pathogens to chemical and antibiotic treatments, have led breeders and livestock keepers to seek alternatives.

The most common approach to within-breed selection for health is not based on direct measures of resistance to a given pathogen, but rather aims to improve various phenotypes associated with disease complexes. For example, breeding for decreased mastitis may involve giving consideration to observed mastitis incidence, concentration of somatic cells (leukocytes) in milk and udder conformation. Selection against foot rot may be based on animal-mobility scores. Longevity is

often included in selection indices as a measure of general health and disease resistance.

Some researchers have speculated that "–omics" technologies will greatly increase the capacity of breeders to incorporate genetic selection into disease-reduction programmes (e.g. Berry *et al.,* 2011; Parker-Gaddis *et al.,* 2014). The term "–omics" refers to a group of fields of advanced study of biological systems. Examples of potential relevance for the genetics of adaptation and disease resistance include "genomics", the study of genes and chromosomes; "transcriptomics", the study of transcribed gene products; "proteomics", the study of proteins; and "metabolomics", the study of metabolism. Genomics, particularly "genome-enabled" or "genomic" selection (see Part 4 Section C), may be particularly applicable to diseases for which measurement is difficult or expensive.

In the case of internal parasites, selection for resistance is successfully implemented in Australia and New Zealand by using faecal egg count as the selection criterion. However, measuring faecal egg count requires specific skills and equipment, which may not be available everywhere. One simpler alternative is to make use of the FAMACHA scoring system (a method of identifying anaemic animals by evaluating the redness of mucous membranes around the eyes) (van Wyk and Bath, 2002) to determine which animals within a small-ruminant flock are more resistant to parasites and should therefore be selected for breeding (Burke and Miller, 2008). A recent study reported low to moderate heritabilities of FAMACHA scores, indicating the possibility of using them as a selection criterion (Riley and Van Vyk, 2009). FAMACHA scoring is, however, only applicable in situations where *Haemonchus contortus* is the predominant parasite. The parasites more commonly found in temperate environments generally do not provoke anaemia and hence do not affect the colour of eye mucous membranes.

Research into genetic markers of within-breed resistance to internal parasites in Uruguay and other countries suggests that there are various molecular markers associated with resistance that could be used in selection programmes (e.g. Ciappesoni *et al.*, 2011). However, few of the associations observed for individual genes show consistency across breeds, presumably due to the biological complexity of parasite infection and the immune system (resulting in a polygenic nature for parasite resistance), as well as effects of recombination that cause differences among breeds in the linkage between genes affecting resistance and the genetic markers used in the research studies (Kemper *et al.,* 2011). In theory, genomic selection may be an effective means of controlling parasite infection (see Riggio *et al.,* 2014). However, the cost and expertise required mean that this approach is beyond the means of most sheep-breeding systems, particularly those in developing countries.

5 Conclusions and research priorities

The information recorded in DAD-IS, while incomplete, provides some indication of the state of knowledge of adaptive characteristics in breeds of livestock. In many cases, the information reported is anecdotal and has not been evaluated by scientific studies. More information is recorded for cattle and small ruminants than for other species. For some species that undoubtedly have specific adaptations (e.g. the yak), no information on breed-level adaptedness is recorded in DAD-IS. There is need for further research, particularly on species and breeds adapted to low-input production systems in developing countries or to other production systems where environmental conditions are harsh. Anecdotal information such as that provided in DAD-IS may, however, assist researchers in the identification of AnGR that merit further investigation of their adaptive characteristics.

Evidence indicates that, where the production environment is harsh, breeds whose evolutionary roots lie in the local area tend to be better adapted than breeds introduced from elsewhere. Thus, plans to introduce breeds into a new area must give due attention to ensuring that they

are sufficiently well-matched to local conditions (taking into account temporal variations and the potential for extreme events such as droughts) and that any adaptations to livestock management practices that may be needed are feasible and sustainable. There is a need to set selection goals that are appropriate to the production system rather than ambitious performance objectives that cannot be reached under prevailing conditions. The integration of fitness traits into breeding programmes is constrained by a number of factors, including low heritability, measurement problems and underlying antagonistic relationships with productive performance traits. Research priorities include improving understanding of the functional genetics and genomics of adaptation traits and the identification and measurement of indicator traits of adaptation, with a view to their possible incorporation into breeding goals. Better mapping of breeds' geographical distributions and better description of their production environments (see Part 4 Section A) would facilitate the identification of breeds that are likely to be adapted to particular combinations of stressors.

Although the optimal approach will vary from case to case, the inclusion of genetic elements in disease-control strategies is often a prudent and effective approach. Documented successes have been achieved, but the use of genetics in disease control is still far from having reached its full potential, and continued research into the genetics of resistance and tolerance is needed. If breeds become extinct or within-breed diversity is lost before critical knowledge is gained and utilization strategies are developed, opportunities that could greatly contribute to improving animal health and productivity may be lost forever. Where the design and implementation of breeding programmes are concerned, consideration should be given to incorporating productivity and disease resistance as primary traits weighted according to their respective economic values.

Lack of information is the major constraint with respect to fully understanding the genetic mechanisms of disease resistance and tolerance in livestock. As noted throughout this section, many reports of breed-specific disease resistance are anecdotal, especially in developing countries, and are based on observations in a single production environment. Addressing the following research priorities would help to bridge these knowledge gaps and enhance the utilization of genetics in the control of animal diseases:

- continued phenotypic characterization to confirm anecdotal observations recorded in DAD-IS and elsewhere;
- genetic characterization to help understand the biological mechanisms underlying observed disease-resistance traits; and
- development of simple, accurate and cost-effective approaches for routine collection of phenotypic information on disease incidence, to support both characterization and genetic improvement.

References

Abdalla, E.A., Rosa, G.J., Weigel, K.A. & Byrem, T. 2013. Genetic analysis of leukosis incidence in United States Holstein and Jersey populations. *Journal of Dairy Science*, 96: 6022–6029.

Adeyemo, S.A., Salako, A.E., Emikpe, B.O., Ogie, A.J. & Oladele, P.O. 2012. Comparative disease resistance to Newcastle disease in Nigerian local ecotype chickens: probable genetic influence. *Bulletin Animal Health and Production in Africa*, 60: 359–368.

Ameni, G., Aseffa, A., Engers, H., Young, D., Gordon, S., Hewinson, G. & Vordermeier, M. 2007. High pevalence and increased severity of pathology of bovine tuberculosis in Holsteins compared to zebu breeds under field cattle husbandry in Central Ethiopia. *Clinical Vaccine Immunology,* 14: 1356–1361.

Babar, M.E., Hussain, T., Abdullah, M., Ali, A., Nadeem, A., Kamran, Z. & Ali, M.M. 2013. Evaluation of genetic resistance to *Haemonchus contortus* infection in Pakistani sheep breeds. *Journal of Animal and Plant Science* 23: 1219–1222.

Ball, A.J., Thompson, J.M. & Pleasants, A.B. 1996. Seasonal changes in body composition of growing Merino sheep. *Livestock Production Science,* 46: 173–180.

Baker, R.L., Mugambi, J.M., Audho, J.O., Carles, A.B. & Thorpe, W. 2004. Genotype by environment interactions for productivity and resistance to gastro-intestinal nematode parasites in Red Maasai and Dorper sheep. *Animal Science,* 79: 343–353.

Bayer, W. & Feldmann, A. 2003. Diversity of animals adapted to smallholder system. In *Conservation and sustainable use of agricultural biodiversity. A sourcebook,* pp. 207–215. Los Banos, Laguna, Philippines International Potato Center-Users Perspectives With Agricultural Research and Development (CIP-UPWARD) (available at http://tinyurl.com/ogosjxf).

Berman, A. 2011. Are adaptations present to support dairy cattle productivity in warm climates, invited review. *Journal of Dairy Science,* 94: 2147–2158.

Bermingham, M.L., Bishop, S.C., Woolliams. J.A., Pong-Wong, R., Allen, A.R., McBride, S.H., Ryder, J.J., Wright, D.M., Skuce, R.A., McDowell, S.W. & Glass, E.J. 2014. Genome-wide association study identifies novel loci associated with resistance to bovine tuberculosis. *Heredity,* 112: 543–551.

Bermingham, M., More, S., Good, M., Cromie, A., Higgins, I., Brotherstone, S. & Berry, D.P. 2009. Genetics of tuberculosis in Irish Holstein–Friesian dairy herds. *Journal of Dairy Science*, 92: 3447–3456.

Berry, D.P., Bermingham, M.L., Good, M. & More, S.J. 2011. Genetics of animal health and disease in cattle. *Irish Veterinary Journal,* 64: 5.

Bhat, P.N. 1999. Sheep. *In* W.J.A Payne & T. Wilson, eds. *An introduction to animal husbandry in the tropics*. Fifth editon, pp. 405–446. Oxford, UK, Blackwell Science Ltd.

Bishop, S.C. & Morris, C.A. 2007. Genetics of disease resistance in sheep and goats. *Small Ruminant Research,* 70: 48–59.

Bobbo, A.G., Baba, S.S., Yahaya, M.S. & El-Yuguda, A.D. 2013. Susceptibility of three phenotypes of village chickens to Newcastle disease in Adamawa State. *Alexandria Journal Veterinary Science* 39: 133–140.

Boddicker, N.J., Waide, E.H. , Rowland, R.R.R., Lunney, J.K., Garrick, D.J., Reecy, J.M. & Dekkers, J.C.M. 2012. Evidence for a major QTL associated with host response to porcine reproductive and respiratory syndrome virus challenge. *Journal of Animal Science,* 90: 1733–1746.

Boddicker, N.J., Garrick, D.J., Rowland, R.R.R., Lunney, J.K., Reecy, J.M. & Dekkers, J.C.M. 2014a. Validation and further characterization of a major quantitative trait locus associated with host response to experimental infection with porcine reproductive and respiratory syndrome virus. *Animal Genetics*, 45: 48–58.

Boddicker, N.J., Bjorquist, A., Rowland, R.R.R., Lunney, J.K., Reecy, J.M. & Dekkers, J.C.M. 2014b. Genome-wide association and genomic prediction for host response to Porcine Reproductive and Respiratory Syndrome infection. *Genetics Selection Evolution,* 46: 18.

Boissy, A., Fisher, A.D., Bouix, J., Hinch, G.N. & Neindre, P.L. 2005. Genetics of fear in ruminant livestock. *Livestock Production Science*, 93: 23–32.

Brosh, A., Aharoni, Y., Degen, A.A., Wright, D. & Young, B. 1988. Estimation of energy expenditure from heart rate measurements in cattle maintained under different conditions. *Journal of Animal Science*, 76: 3054–3064.

Brotherstone, S., White, I., Coffey, M., Downs, S., Mitchell, A., Clifton-Hadley, R., More, S.J., Good, M. & Woolliams, J.A. 2010. Evidence of genetic resistance of cattle to infection with *Mycobacterium bovis*. *Journal of Dairy Science*, 93:1234–1242.

Burke, J. M. & Miller, J.E. 2008. Use of FAMACHA system to evaluate gastrointestinal nematode resistance/resilience in offspring of stud rams. *Veterinary Parasitology,* 153: 85–92.

CABI. 2010. *Breeding for disease resistance in farm animals. Third edition,* edited by S.C. Bishop, R.F.E. Axford, F.W. Nicholas & J.B. Owen. Wallingford UK, C.A.B. International.

Caldwell, L.C., Chase, C.C., Riley, D.G., Coleman, S.W., Phillips, W.A., Spicer, L.J., Welsh, T.H. & Randel, R.D. 2011. The influence of tropical adaptation on plasma concentrations of insulin-like growth factor-I in purebred and crossbred beef cattle. *Journal of Animal Science*, 89: 4017-4022.

Ciappesoni, C.G., Nicolini, P., Kelly, L., Grasso, N., Peraza, P., Cabrera, A. & Goldberg, V. 2012. Molecular characterization of parasite resistant/susceptible Uruguayan Merino lambs. *Archivos Latinoamericanos de Producción Animal*, 20: 34–41.

Coleman, S.W., Chase, C.C., Phillips, W.A., Riley, D.G. & Olson, T.A. 2012. Evaluation of tropically adapted straightbred cattle: postweaning BW gain and feed efficiency when finished in a temperate climate. *Journal of Animal Science*, 90: 1955–1965.

Conington, J., Hosien, B., Nieuwhof, G.J., Bishop, S.C. & Bunger, L. 2008. Breeding for resistance to footrot – the use of hoof lesion scoring to quantify footrot in sheep. *Veterinary Research Communications*, 2: 583–589.

Dawson, M., Moore, R.C. & Bishop, S.C. 2008. Progress and limits of PrP gene selection policy. *Veterinary Research,* 39: 25.

Devendra, C. 1990. Comparative aspects of digestive physiology and nutrition in goats and sheep. *In* C. Devendra & E. Imazumi, eds. *Ruminant nutrition and physiology in Asia*, pp. 45–60. Singapore, IDRC.

Ermias, E., Yami, A. & Rege, J.E.O. 2002. Fat deposition in tropical sheep as adaptive attribute to periodic feed fluctuation. *Journal of Animal Breeding and Genetics*, 119: 235–246.

FAO. 1999. *Opportunities for incorporating genetic elements into the management of farm animal diseases: policy issues*, by S. Bishop, M. de Jong & D. Gray. Background Study Paper No. 18. Commission on Genetic Resources for Food and Agriculture. Rome (available at ftp://ftp.fao.org/docrep/fao/meeting/015/aj629e.pdf).

FAO. 2007. *The state of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

Farid, A. 1991. Slaughter and carcass characteristics of three fat-tailed sheep breeds and their crosses with Corriedale and Targhee rams. *Small Ruminant Research*, 5(3): 255–271.

Feng, Z.Q., Lian, T., Huang, Y., Zhu, Q. & Liu, Y.P. 2013. Expression pattern of genes of RLR-mediated antiviral pathway in different-breed chicken response to Marek's disease virus infection. *BioMed Research International*, 2013: Article ID 419256.

Finocchiaro, R., van Kaam, J.B.C.H.M., Portolano, B. & Misztal, I. 2005. Effect of heat stress on production of Mediterranean dairy sheep. *Journal of Dairy Science*, 88(5): 1855–1864.

Gauly, M., Besbes, B., Pinard-van der Laan, M.H., Hoffmann, I., Greeff, J., Thevenon, S., Baker, L., Tibbo, M., Bishop, S.C., Mugambi, J., Dempfle, L., Sidibe, I., Mandonnet, N., Amarande, A.F.T. & Miller, J.E. 2010. *Ruminant genetic resources and their resistance/tolerance to parasitic diseases*. Paper presented at the Ninth World Congress on Genetics Applied to Livestock Production, 1–6 August 2010, Leipzig, Germany (Paper 10: 455).

Glass, E.J. & Jensen, K. 2007. Resistance and susceptibility to a protozoan parasite of cattle—Gene expression differences in macrophages from different breeds of cattle. *Veterinary Immunology and Immunopathology*, 120: 20–30.

González, J.F., Hernández, J.N. & Piedrafita, D. (eds.). 2012. *Final report of the International Workshop on Genetic Resistance to Parasites in Small Ruminants, 22-23 September 2012, Gran Canaria, Spain*.

Granberg, L., Kantahen, J. & Soini, K. 2009. *Sakha Ynaga. Cattle of the Yakuts*. Helsinki, Finnish Academy of Science and Letters.

Hansen, I., Christiansen, F., Hansen, H.S., Braastad, B. & Bakken, M. 2001. Variation in behavioural responses of ewes towards predator-related stimuli. *Applied Animal Behaviour Science*, 70: 227–237.

Kemper, K.E., Emery, D.L., Bishop, S.C., Oddy, H., Hayes, B.J., Dominik, S, Henshall, J.M. & Goddard, M.E. 2011. The distribution of SNP marker effects for faecal worm egg count in sheep, and the feasibility of using these markers to predict genetic merit for resistance to worm infections. *Genetics Research,* 93: 203–219.

Kempster, A.J. 1980. Fat partition and distribution in the carcasses of cattle, sheep and pigs. A review. *Meat Science*, 24: 83–98.

Khan, M.S., Sasidharan, T.U. & Ghosh, P.K. 1979a. Water economy of the Barmer goat of the Rajasthan desert. *Journal of Arid Environments*, 1: 351–355.

Khan, M.S., Sasidharan, T.U. & Ghosh, P.K. 1979b. Water regulation in the Barmer goat of the Rajasthan desert. *Experientia*, 3: 1185.

Khan, M.S., Sasidharan, T.U. & Ghosh, P.K. 1979c. Glomerular filtration rate and blood and urinary urea concentrations in Barmers goats of the Rajasthan desert. *Journal of Agricultural Science (Cambridge)*, 93: 247–248.

Konnai, S., Usui, T., Ikeda, M., Kohara, J., Hirata, T., Okada, K., Ohashi, K. & Onuma, M. 2005. Imbalance of tumor necrosis factor receptors during progression in bovine leukemia virus infection. *Virology*, 339: 239–248.

Lewis, C.R.G., Ait-Ali, T., Clapperton, M., Archibald, A.L. & Bishop, S.C. 2007. Genetic perspectives on host responses to Porcine Reproductive and Respiratory Syndrome (PRRS). *Viral Immunology,* 20: 343–357.

Lewis, C.R.G., Torremorell, M., Galina-Pantoja, L. & Bishop, S.C. 2009. Genetic parameters for performance traits in commercial sows estimated before and after an outbreak of Porcine Reproductive and Respiratory Syndrome (PRRS). *Journal of Animal Science,* 87: 876–884.

Li, M.-H., Osva, A. & Kantanen, J. 2012. Supporting conservation of livestock biodiversity through multidisciplinary studies: a case study of the Yakutian cattle in Siberia, the far east of Russia. *Animal Genetic Resources*, 50: 97–104 (available at http://www.fao.org/docrep/015/i2673t/i2673t00.pdf).

Lillico, S.G., Proudfoot, C., Carlson, D.F., Stervakova, D., Neil, C., Blain, C., King, T.J., Ritchie, W.A., Mileham, A., McLaren, D., Fahrenkrug, S.C. & Whitelaw, C.B.A. 2013. Live pigs produced from genome edited zygotes. *Scientific Reports,* 3: 1–4.

Liu, Y., Han, C., Wang, X., Lin, J., Ma, M., Shu, Y., Zhou, J., Yang, H., Liang, Q., Guo, C., Zhu, J., Wei, H., Zhao, J., Ma, Z. & Pan, J. 2009. Influenza A virus receptors in the respiratory and intestinal tracts of pigeons. *Avian Pathology*, 38: 263–266.

MacKinnon, K.M., Zajac, A.M., Kooyman, F.N. & Notter, D.R. 2010. Differences in immune parameters are associated with resistance to *Haemonchus contortus* in Caribbean hair sheep. *Parasite Immunology*, 32: 484–493.

Marai, I.F.M., El-Darawany, A.A., Fadiel, A. & Abdel-Hafez M.A.M. 2007. Physiological traits as affected by heat stress in sheep: a review. *Small Ruminant Research*, 71: 1–12.

Marshall, K., Mugambi, J.M., Nagda, S., Sonstegard, T.S., Van Tassell, C.P., Baker, R.L. & Gibson, J.P. 2013. Quantitative trait loci for resistance to *Haemonchus contortus* artificial challenge in Red Maasai and Dorper sheep of East Africa. *Animal Genetics*, 44: 285–295.

Mapholi, M.O., Marufu, M.C., Maiwashe, A., Banga, C.B., Muchenje, V., MacNeil, M.D., Chimonyo, M. & Dzama, K. 2014. Towards a genomics approach to tick (Acari: Ixodidae) control in cattle: a review. *Ticks and Tick-borne Diseases,* 5: 475–483.

Martínez, R., Dunner, S., Toro, R., Tobón, J., Gallego, J. & Cañón, J. 2010. Effect of polymorphisms in the Slc11a1 coding region on resistance to brucellosis by macrophages *in vitro* and after challenge in two *Bos* breeds (Blanco Orejinegro and Zebu). *Genetics and Molecular Biology,* 33: 463–470.

Marufu, M.C., Dzama, K. & Chimonyo, M. 2014. Cellular responses to *Rhipicephalus microplus* infestations in pre-sensitised cattle with differing phenotypes of infestation. *Experimental and Applied Acarology*, 62: 241–252.

Marufu, M.C., Qokweni, L., Chimonyo, M. & Dzama, K. 2011. Relationships between tick counts and coat characteristics in Nguni and Bonsmara cattle reared on semiarid rangelands in South Africa. *Ticks and Tick-borne Diseases,* 2: 172–177.

Mattioli, R.C., Bah, M., Kora, S., Cassama, M. & Clifford, D.J. 1995. Susceptibility to different tick genera in Gambian N'Dama and Gobra zebu cattle exposed to naturally occurring tick infection. *Tropical Animal Health and Production*, 27: 995–1005.

McManus, C., Paludo, G.R., Louvandini, H., Gugel, R., Sasaki, L.C.B. & Paiva, S.R. 2009a. Heat tolerance in Brazilian sheep: physiological and blood parameters. *Tropical Animal Health and Production*, 41: 95–101.

McManus, C., Prescott, E., Paludo, G.R., Bianchini, E., Louvandini, H. & Mariante, A.S. 2009b. Heat tolerance in naturalized Brazilian cattle breeds. *Livestock Science.,* 120: 256–264.

McRae, K.M., McEwan, J.C., Dodds, K.G. & Gemmell, N.J. 2014. Signatures of selection in sheep bred for resistance or susceptibility to gastrointestinal nematodes. *BioMed Central Genomics*, 15: 637.

Menéndez-Buxadera, A., Molina, A., Arrebola, F., Clemente, I. & Serradilla, J.M. 2012. Genetic variation of adaptation to heat stress in two Spanish dairy goat breeds. *Journal of Animal Breeding and Genetics*, 129: 306–315.

Molento, M.B., Fortes, F.S., Buzatti, A., Kloster, F.S., Sprenger, L.K., Coimbra, E. & Soares, L.D. 2013. Partial selective treatment of *Rhipicephalus microplus* and breed resistance variation in beef cows in Rio Grande do Sul, Brazil. *Veterinary Parasitology,* 192: 234–239.

Murray, G.G., Woolhouse, M.E., Tapio, M., Mbole-Kariuki, M.N., Sonstegard, T.S., Thumbi, S.M., Jennings, A.E., van Wyk, I.C., Chase-Topping, M., Kiara, H., Toye, P., Coetzer, K., deC Bronsvoort, B.M., & Hanotte, O. 2013. Genetic susceptibility to infectious disease in East African Shorthorn Zebu: a genome-wide analysis of the effect of heterozygosity and exotic introgression. *BioMed Central Evolutionary Biology,* 13: 246.

Naessens, J. 2006. Bovine trypanotolerance: a natural ability to prevent severe anaemia and haemophagocytic syndrome? *International Journal of Parasitololgy*, 36: 521–528.

National Research Council (NRC) 1993. *Managing global genetic resources: livestock*. Washington, D.C., National Academy Press.

Negussie, E., Rottmann O.J., Pirchner F. & Rege J.E.O. 2000. Allometric growth coefficients and partitioning of fat deposits in indigenous Ethiopian Menz and Horro sheep breeds. *In* R.C. Merkel, G. Abebe & A.L. Goetsch, eds. *The opportunities and challenges of enhancing goat production in East Africa. Proceedings of a conference held at Debub University, Awassa*.

Noyes, H., Brass, A., Obara, I., Anderson, S., Archibald, A.L., Bradley, D.G., Fisher, P., Freeman, A., Gibson, J., Gicheru, M., Hall, L., Hanotte, O., Hulme, H., McKeever, D., Murray, C., Oh, S.J., Tate, C., Smith, K., Tapio, M., Wambugu, J., Williams, D.J., Agaba, M. & Kemp, S.J. 2011. Genetic and expression analysis of cattle identifies candidate genes in pathways responding to *Trypanosoma congolense* infection. *Proceedings of the National Academy of Sciencesof the United States of America,* 108: 9304–9309.

O'Gorman, G.M., Park, S.D., Hill, E.W., Meade, K.G., Coussens, P.M., Agaba, M., Naessens, J., Kemp, S.J. & MacHugh D.E. 2009. Transcriptional profiling of cattle infected with *Trypanosoma congolense* highlights gene expression signatures underlying trypanotolerance and trypanosusceptibility. *BioMed Central Genomics*, 10: 207.

Orenge, C.O., Munga, L., Kimwele, C.N., Kemp, S., Korol, A., Gibson, J.P., Hanotte, O. & Soller, M. 2012. Trypanotolerance in N'Dama x Boran crosses under natural trypanosome challenge: effect of test-year environment, gender, and breed composition. *BioMed Central Genetics*, 13: 87.

Ørskov, E.R. 1998. Feed evaluation with emphasis on fibrous roughages and fluctuating supply of nutrients. A review. *Small Ruminant Research*, 28: 1–8.

Ovaska, U. & Soini, K. 2011. The conservation values of Yakutian cattle. *Animal Genetic Resources*, 49: 97–106 (available at http://www.fao.org/docrep/014/ba0128t/ba0128t00.pdf).

Palhière, I., Brochard, M., Moazami-Goudarzi, K., Laloë, D., Amigues, Y., Bed'hom, B., Neuts, E., Leymarie, C., Pantano , T., Cribiu, E.P., Bibé, B. & Verrier, E. 2008. Impact of strong selection for the PrP major gene on genetic variability of four French sheep breeds. *Genetics Selection Evolution*, 40: 663–680.

Parker-Gaddis, K.L, Cole, J.B., Clay, J.S. & Maltecca, C. 2014. Genomic selection for producer-recorded health event data in US dairy cattle. *Journal of Dairy Science*, 97: 3190–3199.

Pleasance, J., Raadsma, H.W., Estuningsih, S.E., Widjajanti, S., Meeusen, E. & Piedrafita, D. 2010. Innate and adaptive resistance of Indonesian Thin Tail sheep to liver fluke: a comparative analysis of *Fasciola gigantica* and *F. hepatica* infection. *Veterinary Parasitology,* 178: 264–272.

Pleasance, J., Wiedosari, E., Raadsma, H.W., Meeusen, E. & Piedrafita, D. 2011. Resistance to liver fluke infection in the natural sheep host is correlated with a type-1 cytokine response. *Parasite Immunology*, 33: 495–505.

Prakash, O., Kumar, A., Sonwane, A., Rathore, R., Singh, R.V., Chauhan, A., Kumar, P., Renjith, R., Yadav, R., Bhaladhare, A., Baqir, M. & Sharma, D. 2014. Polymorphism of cytokine and innate immunity genes associated with bovine brucellosis in cattle. *Molecular Biology Reports,* 41: 2815–2825.

Raj, G.D., Rajanathan, T.M., Kumanan, K. & Elankumaran, S. 2011. Changes in the cytokine and toll-like receptor gene expression following infection of indigenous and commercial chickens with infectious bursal disease virus. *Indian Journal of Virology*, 22: 146–151.

Reiner, G, Willems, H., Pesch, S. & Ohlinger, V.F. 2010. Variation in resistance to the porcine reproductive and respiratory syndrome virus (PRRSV) in Pietrain and Miniature pigs. *Journal of Animal Breeding and Genetics*, 127: 100–106.

Renaudeau, D., Collin, A., Yahav, S., de Basillio, V., Gourdine, J.L. & Collier, R.J. 2012. Adaptation to hot climate and strategies to alleviate heat stress in livestock production. *Animal*, 6(5): 707–728.

Riggio, V., Abdel-Aziz, M., Matika, O., Moreno, C.R., Carta, A. & Bishop, S.C. 2014. Accuracy of genomic prediction within and across populations for nematode resistance and body weight traits in sheep. *Animal,* 8: 520–528.

Riggio, V., Matika, O., Pong-Wong, R., Stear, M.J. & Bishop, S.C. 2013. Genome-wide association and regional heritability mapping to identify loci underlying variation in nematode resistance and body weight in Scottish Blackface lambs. *Heredity,* 110: 420-429.

Riley, D.G. & Van Wyk, J.A. 2009. Genetic parameters for FAMACHA score and related traits for host resistance/resilience and production at differing severities of worm challenge in a Merino flock in South Africa. *Veterinary Parasitology,* 164: 44–52.

Rocha, R.A., Bricarello, P.A., Silva, M.B., Houdijk, J.G., Almeida, F.A., Cardia, D.F. & Amarante, A.F. 2011. Influence of protein supplementation during late pregnancy and lactation on the resistance of Santa Ines and Ile de France ewes to *Haemonchus contortus*. *Veterinary Parasitology*, 181: 229–238.

Russell, V.N.L., Green, L.E., Bishop, S.C. & Medley, G.F. 2013. The interaction of host genetics and disease processes in chronic livestock disease: A simulation model of ovine footrot. *Preventive Veterinary Medicine*, 108: 294–303.

Sartika, T., Sulandari, S. & Zein, M.S. 2011.Selection of Mx gene genotype as genetic marker for avian influenza resistance in Indonesian native chicken. *BioMed Central Proceedings*, 5 Suppl. 4: S37.

Sartore, S., Rasero, R., Colussi, S., Acutis, P.L., Peletto, S., Soglia, D., Maione, S., Spalenza, V. & Sacchi, P. 2013. Effect of selection for scrapie resistance on genetic diversity in a rare and locally adapted sheep breed: The case of Sambucana. *Livestock Science*, 157: 75–80.

Schmidt-Nielsen, K. 1955. *Investigations on the physiology of the camel: preliminary report*. Paris, UNESCO (available at http://unesdoc.unesco.org/images/0014/001486/148616eb.pdf).

Schmidt-Nielsen, B., Schmidt-Nielsen, K., Houpt, T.R. & Jarnum, S.A. 1956. Water balance of the camel. *American Journal of Physiology*, 185: 185–194.

Serão, N.V.L., Matika, O., Kemp, R.A., Harding, J.C.S., Bishop, S.C., Plastow, G.S. & Dekkers, J.C.M. 2014. Genetic analysis of reproductive traits and antibody response in a PRRS outbreak herd. *Journal of Animal Science,* 92: 2905–2921.

Shakya, K.P., Miller, J.E. & Horohov, D.W. 2009. A Th2 type of immune response is associated with increased resistance to *Haemonchus contortus* in naturally infected Gulf Coast Native lambs. *Veterinary Parasitology*, 163: 57–66.

Silanikove, N. 1986. Interrelationships between feed quality, digestibility, feed consumption, and energy requirements in desert (Bedouin), and energy requirements in desert (Bedouin) and non-desert (Saanen) goats. *Journal of Dairy Science*, 69: 2157–2162.

Silanikove, N. 1994. The struggle to maintain hydration and osmoregulation in animals experiencing severe dehydration and rapid rehydration: the story of ruminants. *Experimental. Physiology*, 79: 281–300.

Silanikove, N. 2000. The physiological basis of adaptation in goats to harsh environments: a review. *Small Ruminant Research*, 35: 181–193.

Silanikove, N., Tagari, H. & Shkolnik, A. 1993. Comparison of rate passage, fermentation rate and efficiency of digestion of high fiber diet in desert black Bedouin goats as compared to Swiss Saanen goats. *Small Ruminant Research*, 12: 45–60.

Steinheim, G., Eikje L.S., Klemetsdal G., Adnoy, T. & Odegard, J. 2012. The effect of breed and breed-by-flock interaction on summer mortality of free-ranging lambs in Norwegian sheep. *Small Ruminant Research*, 105(1-3): 79–82.

Spellberg, B. & Edwards, Jr., J.E. 2001. Type 1/Type 2 immunity in infectious diseases. *Clinical Infectious Diseases,* 32: 76–102.

Stijlemans, B., Vankrunkelsven, A., Brys, L., Raes, G., Magez, S. & De Baetselier, P. 2010. Scrutinizing the mechanisms underlying the induction of anemia of inflammation through GPI-mediated modulation of macrophage activation in a model of African trypanosomiasis. *Microbes and Infection,* 12: 389–399.

Tisserand, J.L., Hadjipanayiotou, M. & Gihad, E.A. 1991. Digestion in goats. *In* P. Morand-Fehr, ed. *Goat nutrition*, pp. 46–60. Wageningen, the Netherlands, Pudoc.

Tsairidou, T., Woolliams, J.A., Allen, A.R., Skuce, R.A., McBride, A.H., Wright, D.M., Bermingham, M.L., Pong-Wong, R., Matika, O., McDowell, S.W.J., Glass, E.J. & Bishop, S.C. 2014. Genomic prediction for tuberculosis resistance in dairy cattle. *Public Library of Science One,* 9: e96728.

Turner, J.W., 1980. Genetic and biological aspects of Zebu adaptability. *Journal of Animal Science*, 50(6): 1201–1205.

van Wyk, J.A. & Bath, G.F. 2002. The FAMACHA system for managing haemonchosis in sheep and goats by clinically identifying individual animals for treatment. *Veterinary Research*, 33: 509–529.

Vordermeier, M., Ameni, G., Berg, S., Bishop, R., Robertson, B.D., Aseffa, A., Hewinson, R.G. & Young, D.B. 2012. The influence of cattle breed on susceptibility to bovine tuberculosis in Ethiopia. *Comparative Immunology, Microbiology and Infectious Diseases.* 35: 227–232.

Wang, Y., Lupiani, B., Reddy, S.M., Lamont, S.J. & Zhou, H. 2014. RNA-seq analysis revealed novel genes and signaling pathway associated with disease resistance to avian influenza virus infection in chickens. *Poultry Science*, 93: 485–493.

Wiedosari, E, Hayakawa, H. & Copeman, B. 2006. Host differences in response to trickle infection with *Fasciola gigantica* in buffalo, Ongole and Bali calves. *Tropical Animal Health and Production*, 38: 43–53.

Willyard, C. 2011. Putting sleeping sickness to bed. *Nature Medicine*, 17: 14–17.

Windig, J.J., Meuleman, H. & Kaal, L. 2007. Selection for scrapie resistance and simultaneous restriction of inbreeding in the rare sheep breed "Mergellander". *Preventive Veterinary Medicine*, 78: 161–171.

Xing, J., Xing, F., Zhang, C., Zhang, Y., Wang, N., Li, Y., Yang, L., Jiang, C., Zhang, C., Wen, C. & Jiang, Y. 2014. Genome-wide gene expression profiles in lung tissues of pig breeds differing in resistance to porcine reproductive and respiratory syndrome virus. *Public Library of Science One*, 9: e86101.

Section F

Threats to livestock genetic diversity

1 Introduction

Threats to animal genetic resources (AnGR) include a wide variety of factors, ranging from inappropriate approaches to AnGR management on a local scale to major national or global economic, social and environmental trends (Gibson *et al.*, 2005; FAO, 2007a; FAO, 2009a; Alemayehu, 2013). They operate on a range of different time and geographical scales. Some AnGR populations are more vulnerable than others to particular threats. Addressing threats to genetic diversity is one of the most important challenges in AnGR management. It requires not only an understanding of the nature and scale of the threats, but also an understanding of where opportunities to address them may lie.

This section aims to update the discussion of threats to AnGR presented in the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007a). The first SoW-AnGR distinguished threats arising because of relatively gradual changes in livestock production systems from those associated with acute events such as animal disease epidemics and other kinds of disasters and emergencies. A similar approach is taken in this update.

Detailed information on livestock-sector trends is presented elsewhere in the report (Part 2). Of particular relevance to the analysis of threats is Part 2 Section C, which discusses the effects of livestock-sector trends on AnGR and their management. Also relevant to the analysis of threats is the information on gene flows presented in Part 1 Section C and the information on management capacities presented in Part 3.

Subsection 2 below discusses how the various livestock-sector trends described in Part 2 can translate into threats to AnGR. Subsection 2.1 provides a general overview of the pressures that trends of this kind can exert on livestock diversity. Subsection 2.2 presents some concrete examples of how specific breeds have been affected by various threats, both recently and in the more distant past. Subsection 2.3 presents a review of the information on current threats provided in the country reports.[1] Options for addressing these threats are not discussed in detail in this section. Effectively addressing threats associated with livestock-sector trends depends on all the various elements of AnGR management, from the characterization of breeds and their production environments, to the establishment of conservation programmes for at-risk breeds and the establishment of appropriate policy and institutional frameworks. The state of capacity in AnGR management is discussed in Part 3 of the report and the state of the art in management methods in Part 4.

Subsections 3 and 4 below update, respectively, the discussions of disasters and emergencies and of disease epidemics presented in the first SoW-AnGR.

[1] For information on the country-reporting process, see "About this publication" in the preliminary pages of this report.

PART **1**

2 Livestock sector trends

2.1 Overview of trends and their effects on diversity

As discussed in Part 1 Section A, prior to, approximately, the mid-twentieth century, the world's livestock were raised under very diverse conditions. Animals had to be well adapted to their particular production environments if they were to survive, reproduce and meet the requirements of their owners. Moving AnGR around the world was more difficult than it is today, both in terms of transportation and in terms of establishing livestock populations in new locations. Under these conditions, global AnGR diversity flourished.

Today's livestock sector presents a different picture. A number of trends have combined to undermine the bulwarks of livestock diversity that had remained largely in place since the days when livestock keeping first spread around the world from the various centres of domestication where it originated. First, a range of technological developments have increasingly enabled production environments to be controlled. Second – again because of technological developments – it has become easier to transport genetic material over long distances. Third, in many production systems, livestock keeping is less multipurpose than it was in the past. Fourth, the livestock sector (particularly the breeding industry), along with the food-processing and retail sectors, has become increasingly dominated by a limited number of large-scale commercial companies. Fifth (again because of technological developments) the number of offspring that can be obtained from individual high-quality or popular animals (particularly male animals) has greatly increased.

While these trends largely emerged in industrialized regions, such as Europe and North America, recent decades have seen them become increasingly significant in parts of the developing world, driven by rapidly rising demand for animal products. The result has often been to create both the opportunity and the motivation to replace diverse locally adapted AnGR with those drawn from a narrow range of high-output breeds. The latter group of breeds, while their populations may be large, are not immune to the threat of genetic erosion. The fifth trend noted above has enabled the very widespread use of a limited number of popular sires. The tendency is reinforced by other trends – homogenization of production environments and breeding goals, greater capacity to transport genetic material and the consolidation of the breeding industry. The outcome has been to greatly reduced the effective population size of a number of widely used breeds (see examples in Table 1F1). Low effective population size implies a high rate of inbreeding and a loss of genetic diversity. It potentially leads to inbreeding depression and higher occurrence of genetic defects. For further information on the effects of inbreeding, see Box 4C1 in Part4 Section C.

The outcome of these trends can be seen in breed risk-status data from the developed regions of the world (see Part 1 Section B). Many breeds became extinct during the twentieth century and many others declined to the brink of extinction. These developments eventually gave rise to concerns about the loss of diversity and to the establishment of breed conservation programmes that have, with varying degrees of success, attempted to revive the fortunes of at-risk breeds (see Part 3 Section D and Part 4 Section D).

Given the experience of developed countries, the spread of industrialized livestock production into the developing world has raised concerns about the fate of the locally adapted breeds of developing regions, particularly those such as East and Southeast Asia that have been greatly affected by the so-called livestock revolution (Delgado *et al.*, 1999) – rapid expansion of large-scale "industrial" livestock production in response to surging demand. The first SoW-AnGR, for example, argued that future "hotspots" of diversity loss were likely to be found in the global "South".[2] Describing developments in Thailand, Charoensook *et al.* (2013) note that

> *"since 1981 pig breeding has steadily been industrialised ... Thus, indigenous native*

[2] FAO, 2007a, page 72. The "South" in this context refers to the developing regions of the world.

TABLE 1F1
Estimates of effective population size in transboundary breeds based on genealogical or molecular data

Species	Breed	Range of N_e estimates	References
Cattle	Holstein	49–110	De Roos *et al.*, 2008; Leroy *et al.*, 2013; Lu *et al.*, 2012; Rodriguew-Ramilo *et al.*, 2015; Thomasen *et al.*, 2013
	Jersey	110–135	
	Charolais	198–958	
Sheep	Meat Lacaune	73–835	Kijas *et al.*, 2012; Leroy *et al.*, 2013
Goat	Alpine	143–149	Brito *et al.*, 2015; Larroque *et al.*, 2014
	Saanen	113–120	
Pig	Landrace	74–91	Uimari and Tapio, 2012; Welsh *et al.*, 2010
	Yorkshire	55–113	
Horse	Thoroughbred	77–250	Corbin *et al.*, 2012; Lee *et al.*, 2014

Note: N_e = effective population size. Estimates based on various methods and datasets across the world.

pigs have been increasingly mated with imported breeds ...[they] have gradually become crossbreeds and are finally replaced by European commercial breeds as the meat-delivering end product in the pork industry."

In this context, it is important to note that countries affected by the livestock revolution are not simply retracing the trajectories followed by their more-developed counterparts. For example, as described in the first SoW-AnGR, the development of poultry production is often "discontinuous", i.e. rather than "organic" growth through which small poultry farmers gradually expand and intensify their production, "as soon as urban markets, transport infrastructure and services develop, investors ... step in and establish large-scale industrial-type units, integrated with modern processing and marketing methods."[3] Likewise, where genetic improvement is concerned, there is a tendency to make use of the genetic progress that has already been achieved in high-output international transboundary breeds[4] rather than to establish breeding programmes for locally adapted breeds (Tisdell, 2003). This means that locally adapted breeds remain far behind the newly introduced breeds in terms of their production potential in high-input systems.

Despite the significance of the changes associated with the livestock revolution, it should also be recalled that the livestock production systems of the developing world remain diverse and that not all countries have followed the same pattern of development (see Part 2). Many livestock continue to be kept by poor rural people in more or less traditional production systems. They supply a range of products and services (see Part 1 Section D) for use within the household or for sale through informal channels. Even where large-scale production has taken off, it can coexist with more traditional production in rural areas, as well as with small-scale production of various types in urban and peri-urban zones (commercially oriented small-scale dairy producers keeping a small number of cattle or buffaloes, slum dwellers keeping a few poultry, goats or pigs to supplement their livelihoods, and so on).

Many countries face the challenge of managing the use of AnGR across a range of very different production systems, sometimes co-existing in close proximity to each other. In these circumstances, one potential threat to diversity (and to effective use of currently available resources) may be a "one size fits all" approach to the use of AnGR, i.e. the increasing use of a narrow range of breeds across

[3] FAO, 2007a, page 156.

[4] Transboundary breeds are breeds that are present in more than one country. See Part 1 Section B for further discussion.

still diverse production environments. This may be exacerbated by a lack of knowledge of relative merits of different types of AnGR under different conditions. As discussed in Part 3 Section B, many breeds remain inadequately characterized. Heavy promotion of exotic germplasm by breeding companies or development agencies may also be a factor (Rege and Gibson, 2003).

The speed of change associated with the livestock revolution may also exacerbate threats to diversity. Where livestock production is in a state of rapid flux, with new production systems emerging, traditional systems being transformed and non-traditional types of AnGR becoming more accessible, breeds may fall out of use so rapidly that it is difficult for stakeholders to react and introduce measures to promote their sustainable use and conservation. Unfortunately, monitoring programmes for trends in the size and structure of breed populations and other trends that may affect their risk status (FAO, 2011b), remain inadequate in many countries (see Part 1 Section B and Part 3 Section B).

Where environmental conditions are harsh, external inputs are in short supply and animals have to serve multiple purposes, replacing locally adapted breeds with exotic alternatives continues to be relatively difficult, so some locally adapted breeds may, by default, be protected to some degree from the threat of being replaced by exotic alternatives. However, production systems of this type are not free of threats to AnGR. Rural livestock-keeping livelihoods can be disrupted by a range of factors, including degradation of natural resources, land-use changes or regulations that restrict access to grazing land and other resources, loss of livestock-keeping labour caused by outmigration in search of work, emerging animal health problems that reduce income from livestock keeping and the imposition of marketing restrictions associated with disease-control efforts. In some circumstances, pressures on natural resources may, rather than promoting the maintenance of well-adapted breeds that are relatively well able to deal with the problems associated with these pressures, increase the demand for alternative, apparently higher producing, breeds.

Production system changes feature prominently among the threats to AnGR noted in the report submitted by the African Union Interafrican Bureau of Animal Resources as part of the second SoW-AnGR reporting process (see Box 1F1).

Among environmental trends generating threats to livestock diversity, the first SoW-AnGR recognized that global climate change was likely to present a major challenge. The report noted that threats associated with climate change

Box 1F1

Production system changes as threats to animal genetic resources – a view from Africa

Changes in production systems are a major factor leading to the elimination of indigenous animal genetic resources. The switch to certain cash crops eliminates crop residues that used to be an important source of fodder. Irrigation makes two or three crops a year possible, eliminating the possibility of grazing on stubble or browsing on trees in the fields. Replacement of draught power by tractors for agricultural work or transportation is a prime cause of the gradual extinction of many draught livestock breeds. The establishment of wildlife sanctuaries, national parks and other types of protected areas almost always deprives livestock keepers of pasturelands.

Making a living from keeping livestock is hard work that ties people down day in and day out and many young people succumb to the attractions of city life. Animal-handling skills are disappearing very quickly, within one generation. Village-based breeding institutions, such as keeping a community bull, also deteriorate rapidly once economic returns are not sufficient or social networks break down. Once such institutions have disappeared, they are very difficult to resurrect.

Source: Adapted from the African Union Interafrican Bureau of Animal Resources' submission to the second SoW-AnGR reporting process. The report is available at http://www.fao.org/3/a-i4787e/i4787e03.htm.

could be associated with gradual changes in livestock-production systems (i.e. changes of the type described in this subsection) or in sudden catastrophic events (climatic disasters and disease outbreaks – see the following subsections). The significance of climate change is, likewise, noted at several points in the Global Plan of Action for Animal Genetic Resources (FAO, 2007b). However, emphasis is placed largely on the potential role of AnGR in climate change adaptation, rather than on the role of climate change as a potential threat to AnGR diversity.

Since 2007, concerns about climate change have continued to increase. In the field of genetic resources management, this was reflected in the adoption, in 2013, of the Commission on Genetic Resources for Food and Agriculture (CGRFA)'s Programme of Work on Climate Change and Genetic Resources for Food and Agriculture (FAO, 2013a) and in the publication of a set of CGRFA background study papers on the links between genetic resources management and climate change, including one on the AnGR subsector (FAO, 2011a).

Climate change affects livestock production systems in many ways. If temperatures increase, heat stress in the animals themselves may become an increasing problem (ibid.). The availability of feed and the prevalence of diseases and parasites can be affected by changes in the local ecosystem. If changes are rapid, the adaptive link between a breed and the production environment in which it has traditionally been raised may be broken. Production systems may also be affected in more indirect ways: via the effect of climate change on input prices and via the effect of climate change mitigation strategies (ibid.). The effects of climatic disasters (floods, hurricanes, etc.) are discussed in more detail below (Subsection 3).

It remains difficult to predict the impact that climate change will have on AnGR diversity. This is partly because the effects of climate change are generally difficult to predict, particularly effects on complex aspects of ecosystem function, such as the epidemiology of diseases. However, it is also true that the vulnerability of particular breeds or populations to the effects of climate change is generally not well understood, whether in terms of their distribution in relation to geographical areas likely to be affected by climate change, the capacity of particular AnGR to thrive in changed agroclimatic conditions or the capacity of relevant groups of livestock keepers to adapt their management practices. Box 1F2 illustrates the potential impact of climate change on the geographical distribution of the production environment of a Kenyan cattle breed.

Livestock-sector trends that threaten AnGR diversity are not necessarily simply a matter of the sector responding to economic, social, environmental and technological drivers of the type described above (and in more detail in Part 2). They can also be influenced by public policy. Actions taken by national or local governments can make it easier or more difficult to make a living from particular types of production system (or from livestock keeping in general). If production systems that harbour diverse livestock populations are adversely affected, whether directly or because of competition from other production systems that benefit disproportionally, public policies can constitute a threat to AnGR. The first SoW-AnGR noted, for example, that policies that promote the introduction of high external input production systems or the use of exotic animals can pose a threat to locally adapted breeds.[5] Clearly, policies of this type cannot be dismissed simply on the grounds that they might put breeds at risk. All the various pros and cons from economic, social and environmental perspectives need to be weighed up. From the AnGR management perspective, the objective should be to ensure that whatever developments are planned, the breeds used are well matched to their production environments and that potential impacts on genetic diversity are assessed so that conservation measures can be taken if necessary.

It is also possible for livestock-sector policies to have a positive effect on AnGR diversity. This may be an inadvertent consequence of polices that

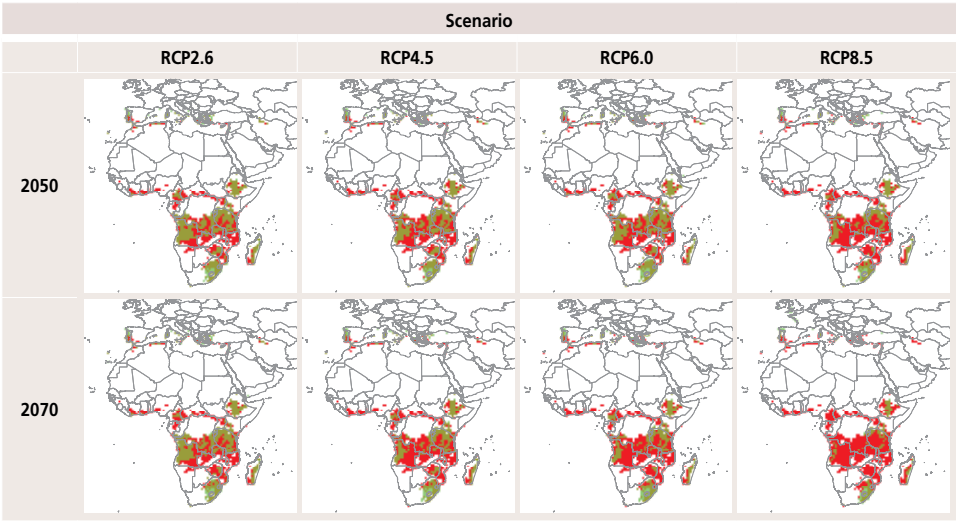
[5] FAO, 2007a, pages 117–120.

Box 1F2

The potential impact of climate change on breed distribution – an example from Kenya

The current geographic distribution of Kenyan Kamba cattle, as recorded in DAD-IS, was used to model the breed's potential distribution, taking several temperature and humidity characteristics of its production environment into account. This information served to define potential current and future habitats for this breed. Future habitats were modelled using the "Hadley Global Environment Model 2 – Earth System" and four scenarios (representative concentration pathways: IPPC, 2013a) were selected. Differences between potential current and future habitats were mapped using a simple colour scale, where areas of habitat loss appear in red, areas of no expected change in dark green and areas of habitat gain in light green. Analyses of this kind can potentially contribute to more informed decision-making on breed management in a changing climate and hence strengthen the capacity of national governments, livestock keepers and farmers to protect and enhance food security and manage their animal genetic resources sustainably.

Source: Maps based on DAD-IS (http://fao.org/dad-is) data (as of June 2014) and the Hadley Global Environment Model 2 – Earth System and four scenarios or representative concentration pathways (RCP).



(e.g. for livelihood-related reasons) promote the continued existence of diverse forms of livestock production. Alternatively, it may be the effect of conscious mainstreaming of AnGR-related concerns into other aspects of livestock development. It may also be the effect of the establishment of national strategies, plans or policies specifically intended to promote the sustainable management of AnGR. In the eyes of some stakeholders, the absence or weakness of such policies constitutes, in itself, a threat to AnGR diversity (FAO, 2009a). The argument has sometimes been taken a step further, with a lack of political will to support AnGR management programmes or to support rural communities being identified as a threat (ibid.). The links between national policies and AnGR management are discussed in more detail in Part 3 Section F.

Broad economic, social, environmental and policy drivers of change translate into a loss of AnGR diversity when they mean that livestock keepers who maintain the various breeds and populations that contribute to this diversity are no longer able or willing to do so (and if no one else is willing and able to take on the role). Even if breeds do not fall out of use, loss of diversity can occur if they are subject to genetic erosion caused by inbreeding or so-called indiscriminate cross-breeding (see below for further discussion). As discussed above, inbreeding can be an issue

Box 1F3

Animal genetic resources and access to grazing land – an example from India

In India, as elsewhere, the survival of many locally adapted breeds is linked to continued access to the communally owned grazing land in which they evolved and of which they are a part. The Raika are a community of herders in Rajasthan that have bred a number of livestock breeds, including various strains of camel, the Marwari and Boti sheep breeds, and the Nari cattle. For centuries they freely grazed their animals in the forest and on village commons, harvested fields and marginal lands. Because of their economic importance, they and other communities were accorded grazing privileges by local rulers. However, after India's independence in 1947, the forest came to be managed by a specialized department. The herders' grazing rights were curbed, the village commons were encroached upon and, due to irrigation, fallow land became more scarce.

The Kumbhalgarh Protected Area in southern Rajasthan has been at the centre of protracted efforts by the Raika to regain their customary rights. When their grazing permits were denied in the mid 1990s, the Raika, with support of a local NGO, took their case to the Supreme Court of India, making reference to Article 8j of the UN Convention on Biological Diversity (CBD), to which India is a party, to support their demand. The article commits countries to

"… subject to national legislation, respect, preserve and maintain knowledge innovations and practices of indigenous and local communities embodying traditional lifestyles relevant for the conservation and sustainable use of biological diversity."

Photo credit: Ilse Köhler-Rollefson.

While the case was never concluded, India passed another piece of legislation, the "Forest Rights Act" of 2006, which provides rights not only to forest dwellers, but also to seasonal forest users, if they can prove that they have used the forest for three generations. The Raika and several other communities have claimed these rights, but the claims have not been processed.

In order to stake their claim under the CBD, the Raikas – and a handful of other communities, such as the Maldhari in Kutch (Gujarat) and a group of Lingayats living in the Bargur forest in Tamil Nadu – have developed a "Biocultural Protocol", in which they establish themselves as a local community whose lifestyle protects biological diversity. In the protocol, they document how they do this: by preventing forest fires, guarding wildlife and by keeping locally evolved livestock breeds.

The latest twist to the story is a plan to convert the Kumbhalgarh Wildlife Sanctuary into a National Park. Unless provisions for the inclusion of the Raika and other communities in the co-management of the park are made, several locally adapted breeds may become extinct.

Provided by Ilse Köhler-Rollefson.
For further information see LPPS, 2013.

even in breeds that remain popular and have large population sizes.

The immediate factors leading to breeds being abandoned (i.e. no longer being used) are diverse and often act in conjunction. Examples include:

- changes in demand that mean that products and services from certain types of livestock are no longer sought-after;
- competition (from other breeds, species, production systems or from outside the livestock sector);
- degradation of natural resources required to maintain particular types of livestock (or livestock in general) or livestock keepers' lack of access to these resources (see Box 1F3 for an example);
- availability of alternative livelihood options (e.g. jobs in manufacturing, services, etc.);
- additional costs associated with livestock keeping (or particular types of livestock keeping);
- sociocultural factors that make livestock keeping (or particular types of livestock keeping) unattractive as a livelihood activity; and
- other changes (e.g. to climate, disease epidemiology or husbandry practices) that mean that particular breeds are no longer well matched to their production environments.

Indiscriminate cross-breeding is widely recognized as a threat to AnGR diversity. The Global Plan of Action for Animal Genetic Resources (FAO, 2007b) notes, for example, that

> *"indiscriminate cross-breeding with exotic breeds is also rapidly compromising the genetic integrity of local populations."*[6]

It is important to note in this context cross-breeding is not necessarily a threat. Well-planned cross-breeding activities can help to keep potentially threatened breeds in use (FAO, 2010; 2013b). The word "indiscriminate" refers to a lack of attention to the choice of which animals should be mated to which. This can occur simply because animals are free roaming and mating is uncontrolled or because of unstructured attempts by individual livestock keepers to improve their herds or flocks. The problem may be exacerbated by policies that encourage artificial insemination with exotic genetics but do not ensure that this is done in a well-planned way. As well as being a threat to diversity, indiscriminate cross-breeding can also lead to problems in terms

Box 1F4

Indiscriminate cross-breeding as a threat to animal genetic resources in Egypt

Although many of the breeds present in Egypt can be placed in the "not at risk" category, it has been argued that local cattle and poultry may nonetheless be undergoing alarming genetic erosion. Census figures show that the percentage of the cattle population accounted for by cross-bred animals has been increasing, with the share of pure-bred locally adapted breeds decreasing and that of pure-bred exotics remaining more or less constant. The introgression of exotic genes into local cattle breeds is mostly indiscriminate. Surplus males from exotic breeds, as well as F1 and later generations of cross-bred males and females from planned cross-breeding projects, are sent to market and are then used for breeding. During the last ten years, local buffalo genotypes have been subjected to progressive cross-breeding using Italian buffalo semen. Given the production systems prevailing in the poultry, and rabbit industries, the situation for locally adapted breeds in these species could also be alarming, but there are no figures to substantiate this. In contrast, national efforts to conserve locally adapted chicken breeds, such as the Fayoumi, through utilization illustrate what can be done to support the maintenance of livestock biodiversity. The use of exotic sheep and goat breeds has not taken root to a degree that is likely to pose a threat to locally adapted breeds.

Source: Adapted from the country report of Egypt.

[6] Paragraph 32.

of the productivity of the affected population or its resilience to shocks (droughts, disease outbreaks, etc.). The case of the Red Maasai sheep of East Africa was highlighted in the first SoW-AnGR as an example of a breed severely affected by indiscriminate cross-breeding (in this case with the Dorper breed, introduced from South Africa).[7] The potential risks associated with these developments are illustrated in the following quotation from Ojango *et al.*, 2014:

> *"The changing climatic conditions, notably the severe droughts, have been disastrous to the pastoral animal populations in general, and especially for pure and higher grades of Dorper crosses. The indigenous sheep breeds have however withstood such challenges much better."*

It is, of course, possible that "upgrading" a population via continuous cross-breeding may be chosen as an organized (as opposed to "indiscriminate") strategy. If this strategy is widely implemented it may pose a threat to the existence of the targeted breed and require the implementation of some kind of conservation programme if the breed's extinction is to be avoided.

2.2 Threats to individual breeds – examples from literature

The discussion presented above provides an overview of how livestock-sector trends are likely to exert pressures on livestock diversity. However, the global livestock sector is very diverse and each individual breed faces a particular combination of threats and opportunities and has a particular set of characteristics (strengths and weaknesses) that influence the likelihood that it will continue to be used under changing circumstances. It is therefore difficult to predict the future of an individual breed based merely on a general analysis of how the livestock sector is evolving. As discussed in Part 4 Section D, conserving and promoting the sustainable use and development of an at-risk or vulnerable breed requires a careful assessment of the concrete circumstances facing the breed and those who keep (or potentially keep) it. While there is no substitute for a thorough analysis of the characteristics of the targeted breed, its production system and the trends affecting them, it is possible that lessons can be learned from studying how, in other circumstances, factors have combined to drive specific breeds towards extinction. Unfortunately, in many cases, the factors leading to the decline of individual breeds have not been recorded in detail. This subsection present some examples drawn from scientific and historical literature (examples from the country reports can be found in Subsection 2.3 below and in Part 2 Section C).

Zander (2011) reports that sedentarization among the Borana pastoralists of Ethiopia and Kenya has led to the uptake of new livelihood activities such as crop farming, as well as providing the opportunity to purchase cattle from breeds other than the Borana. This is reported to have led to a dwindling of the breed's population, as well as to its dilution through cross-breeding. Interestingly, the same paper reports that in Kenya the main threat has been associated with exotic breeds, while in Ethiopia the main threat has been replacement and dilution by other locally adapted breeds.

Rahman *et al.* (2013), in a paper on the causes of genetic erosion among "indigenous cattle" in Mymensingh district Bangladesh, also report that indiscriminate cross-breeding is a major problem. They also note that "using various equipment and machineries in agricultural fields… seems to be a major cause of the loss of indigenous draught animals."

The case of the Sheko cattle breed of Ethiopia, as described by Taye *et al.* (2009), provides an example of how changes to the production environment can interact with a breed's particular characteristics to threaten its survival. Reduced availability of grazing land is reported to have led to smaller herd sizes and to greater use of tethering as opposed to free grazing. Smaller herd sizes meant that fewer farmers kept Sheko bulls, and this led to a shortage of bulls for breeding and more cross-breeding with "non-descript" local bulls. The Sheko is not well adapted to a tethering system, because of its aggressive nature and its lack of horns, which also contributed to the

[7] FAO, 2007a, Box 95 (page 444).

Box 1F5

Lessons from history? Breed extinctions and near extinctions during the nineteenth century

The following quotations taken from old books and articles on the history of livestock describe some of the factors that drove breeds towards extinction:

Cattle

"The cross [Aberdeen Angus × Shorthorn] ... became a craze throughout northeastern Scotland [sometime after 1810], with the result that the **Aberdeen-Angus** were nearly wiped out of existence. However, during this critical period, a few breeders and one in particular, kept faith in the Aberdeen-Angus breed." (Vaughan, 1931)

"During the last half of the nineteenth century the Galloway country very largely gave up beef production in favour of dairying and the feeding of crossbred sheep. Ayrshire cattle displaced the **Galloways** to a considerable extent, and the breed would have become extinct, except for the efforts of a few persevering breeders, and as it was, the breed was greatly reduced in numbers." (Vaughan, 1931)

"[Extinction] was to be fate of the **Glamorgans**; when the pastures were broken up, the cattle chosen for feeding were of those modern breeds which mature more quickly." (H.E. in 'The Field', 1893).

"The **Irish Maoiles** [Irish Moiled] – Hornless cattle of the old Irish race are found here and there chiefly in the west and the north: from the level of Roscommon to Donegal and Antrim. Their numbers are now small, and there being no systematic attempt to breed them pure unless by a very few owners of small herds, their extinction seems only a matter of not very many years." (Wilson, 1909)

Sheep

"The **Ryeland**, as you are doubtless aware, is one of the oldest of British breeds of sheep, and some fifty years ago was the leading breed in this district. A desire for new breeds springing up, it was almost allowed to become extinct, but by a few good old judges refusing to part with their stock for other blood the breed has been saved its existence." (Wrightson, 1913)

Horses

"When the railways were established the [**Hackney**] breed suffered a setback, being too light for use exclusively as a farm horse. Later a succession of bad seasons from 1875 to 1885 resulted in the sale of much good breeding stock that should have been retained. It is said that the breed might have become extinct were it not for the loyalty of a few old admirers who later reaped a rich reward for their perseverance." (Vaughan, 1931)

"With the coming of the railroad and the river boat, the **Conestoga** horses and wagons were quickly displaced and no further efforts were made to breed heavy horses in America until about 1870. The blood of the Conestoga was absorbed into the common stock of the country and the type became extinct." (Vaughan, 1931)

Pigs

"In speaking of the breeds of pigs belonging to this county, we must not omit the now extinct **Rudgwick swine**, which ... were some of the largest hogs produced in England. They fattened but slowly, and were consequently deemed unprofitable, but yielded excellent meat and in considerable quantities. They have, however, passed away before the alterations produced by the general aim of the present system of breeding." (Youatt *et al.*, 1865)

"... two breeds of pigs which had classes provided for them at the Royal and some other Shows have become extinct. These were the Small White and the Small Black breeds – the sole cause of their disappearance being the unsuitability of the pigs of the breeds to supply the present requisites of the consumer." (Sanders, 1919)

"This breed [the **Old English Hog**] is nearly extinct having been crossed successively by Chinese and other good breeds ..." (Allen, 1865)

"The old English breed of this name [the **Cheshire**] is virtually extinct, having been crossed upon by smaller and earlier maturing breeds." (Shaw, 1900)

Box 1F6

The near extinction of the Cleveland Bay horse of the United Kingdom

The Cleveland Bay horse of northern England almost became extinct twice during the nineteenth century. On the first occasion, during the early part of the century, rising grain prices led farmers to want heavier horses for use in ploughing heavy soils converted from pasture and for carting grain to market. At the same time it became fashionable to use "big upstanding" horses for carriage driving. Both factors led to the cross-breeding of the Cleveland – on the one hand with "cart horses" and on the other with Thoroughbreds – to such an extent that it almost disappeared as a pure breed. On the second occasion, in the 1860s, the growth of the iron trade created demand for heavy horses, well adapted for drawing heavy loads on the roads and in the mines. Cart horses were improved and the Clevelands increasingly neglected. At this point "foreigners came in, and bought what they could of the best, and the men who kept their mares, bred hunters from them, and crossed them out of recognition."

Source: Adapted from Blew *et al.*, 1898 (direct quotations are taken from this source).

Box 1F7

The near extinction of the Lleyn sheep of the United Kingdom

Prior to the Second World War, the Lleyn sheep was a popular breed in northwestern Wales in the United Kingdom. The war years brought a policy of compulsory ploughing of a third to a quarter of all ploughable land on every farm, which meant that there was less land for grazing, and for sheep production in particular. Wartime demand for food led to cross-breeding with breeds such as the Southdown "to produce an early maturing lamb with plenty of fat." Moreover, farmers wanted "to keep the same number of ewes that they kept prior to the introduction of the ploughing quota. The only way was to purchase the small Welsh Mountain ewe, which could be stocked at twice the density of the Lleyn and was cheaper to buy ... the Southdown was ideal for crossing with the Welsh [Mountain] ewe". The opening of a farmer-owned creamery in the area increased the attractiveness of dairy (cattle) farming and led to some farmers moving completely out of sheep production.

By the 1960s the breed was on the brink of extinction. Its subsequent recovery is described in a text box in the first SoW-AnGR.[1]

Source: Adapted from Rees-Roberts (undated) (direct quotations are taken from this source).

[1] FAO, 2007a, Box 96 (page 446).

decline in its use (ibid.). The Sheko is the only surviving taurine cattle breed in that part of Africa and has numerous characteristics that are reportedly appreciated by farmers (e.g. relatively high milk yield, disease tolerance, draught stamina, less-selective feeding behaviour, attractive appearance, ability to maintaining good body condition, short inter-calving period and long lactation period). Nonetheless, at the time the Taye *et al.* (2009) study was undertaken (2004–2005), a lack of appreciation of the breed's importance and a lack of intervention to support its sustainable management were reported to be among the threats to its survival. Ethiopia's country report indicates that the current situation is more promising in this respect, with an *in situ* conservation programme in operation based on extension activities to improve management, awareness-raising activities and the use of artificial insemination using Sheko semen to help overcome the shortage of bulls. For further information on threats to the Sheko and other Ethiopian cattle breeds, see Box 1F8.

As noted above, detailed information on the factors currently threatening individual breeds is not widely available. On the other hand, numerous snippets of information can be found in more historical literature about how breeds in developed countries (when they were relatively less "developed") were driven towards extinction. Breed replacement,

Box 1F8

Threats to animal genetic resources in Ethiopia

Overview

Exotic cattle and chicken breeds, and to a limited extent sheep and goat breeds, have been introduced into the country. Lack of a breeding policy, uncontrolled use of artificial insemination in cattle and extensive distribution of exotic chickens among farming communities have posed a serious threat to indigenous cattle and chicken genetic resources. Drought, occurring as a result of climate change, has been causing significant losses of animal genetic resources. Disaster risk management measures are in place, and post-disaster restocking activities are meant to involve the use of breeds that are well matched to local conditions. However, implementation is fraught with problems and restocking usually takes place without consideration to the type of species or breed used. In some pastoral areas, climate change has resulted in shift in species use from cattle to dromedaries and goats, and this is posing a threat to cattle genetic resources. Lifestyle changes, particularly a shift from mobile pastoralism to sedentary agriculture, has affected livestock's livelihood roles and led to a reduction in population sizes and changes in the species used. Human population growth has affected animal genetic resources indirectly as a result of declining availability of grazing land caused by the expansion of cropland to meet the demands of the increased population.

Threats to specific breeds

Fogera cattle used to be kept under a livestock-dominated crop–livestock production system in a wetland area. In a period of less than three decades, the breeding tract of the breed has been turned into a monoculture rice cultivation area. Rice became the major source of livelihood and grazing lands have been turned into rice fields, depriving the breed of its grazing area. As a result, the size of the Fogera population has declined dramatically. Fogera animals have been moved to other upland areas in search of feed and in these areas have been exposed to interbreeding with zebu breeds.

Photo credit: Ethiopian Biodiversity Institute.

Sheko cattle (the only short-horned cattle breed of Eastern Africa) used to be managed under free grazing in a forest area. With growth in the population and expansion of crop farming, tethering management has been introduced. Because of the aggressive nature of the breed (mainly the male) under tethering management, early castration or removal of the male has been common. This has caused a significant threat to the existence of this trypanotolerant breed.

Photo credit: Ethiopian Biodiversity Institute.

The area where **Boran** cattle are kept is being affected by climate change and there has been a significant change in the amount of rainfall and the frequency of drought. As a result, there has been a shift from cattle to dromedaries and the number of Borans kept by pastoralist households has declined significantly.

Source: Adapted from the country report of Ethiopia (the report cites Yosef *et al.*, 2013 as a source of information on Boran cattle).

cross-breeding to the point of disappearance, replacement of breed function, poor management of breeding, among other factors, all played a role (see Box 1F5). In several cases, it appears that breeds were only saved by the perseverance of a small number of breeders. Driving forces of change included changing market demand and changes to the production system. However, changing fashions and "crazes" also appear to have played a role. Where relatively detailed accounts are available, they generally indicate that a combination of factors was involved (see Boxes 1F6 and 1F7).

2.3 Country-report analysis

The concluding chapter of the first SoW-AnGR[8] noted that the discussion of threats to AnGR diversity had thus far tended to remain focused on changes at the level of the livestock production system. In other words (as noted above), it generally remained unclear how broadly identified threats were operating in concrete circumstances to drive specific breeds towards extinction. It could equally have been stated that there had been little detailed analysis of which among the various threats identified were actually creating the most serious challenges for stakeholders trying to promote the sustainable management of AnGR at national level. In an attempt to fill the latter knowledge gap, countries were asked, as part of the reporting process for the second SoW-AnGR, to describe how livestock-sector trends (broadly those identified as significant in the first SoW-AnGR) were affecting the management of their AnGR. Countries were also asked to describe the factors leading to the erosion of their AnGR and to specify what breeds or species were affected. Analysis of countries' responses to the questions on livestock-sector trends is presented in Part 2 Section C.

The factors most frequently mentioned in countries' responses to the question about the causes of genetic erosion are shown in Table 1F2. The question was open-ended, i.e. countries were asked to provide textual answers. Some chose to refer to high-level drivers of change, while others focused on factors operating at the level of the production system, holding or herd, or on policy or institutional weaknesses. Thus, while the answers presumably reflect priority concerns, they probably do not present a comprehensive picture of all the factors contributing to genetic erosion in the respective countries. It should also be noted that only about 35 percent of reporting countries indicated that they regularly assess the factors leading to the erosion of their AnGR, and that assessments of this kind are far more common in Europe and the Caucasus and North America than in other regions.

The most frequently mentioned cause of genetic erosion was indiscriminate cross-breeding. The prevalence of this threat (reported particularly frequently by African countries) implies that improving the management of breeding could contribute significantly to reducing genetic erosion. However, the implementation of such improvements is likely to be challenging in many countries, particularly given that the third most commonly mentioned factor contributing to genetic erosion was a lack of, or weak, AnGR-management programmes, policies or institutions (for further discussion of capacity to implement breeding programmes, see Part 3 Section C). The second and the fourth most frequently mentioned threats were replacement of locally adapted breeds by exotic breeds and the lack of competitiveness or poor performance of some breeds (usually those in the locally adapted category). These two threats are inter-related. Lack of competitiveness or profitability is often caused by the presence of more competitive (often exotic) alternatives. The decision to start using exotic breeds is normally taken because these breeds are more profitable (or at least are expected to be so). An example of the interplay between lack of management capacity, demand for high-output animals, breed replacement and uncontrolled cross-breeding as threats to diversity is described in Box 1F9.

In addition to the above-mentioned responses related to breeds' lack of profitability, a small number of country reports (7 percent or less) mention either unspecified economic and market-related factors or broad economic trends such

[8] Part 5 Needs and challenges in animal genetic resources management (FAO, 2007a, pages 483–503).

TABLE 1F2

Factors reported in the country reports as causes of genetic erosion

Threats	Africa	Asia	Europe and the Caucasus	Latin America and the Caribbean	Near and Middle East	North America	Southwest Pacific	World
	n = 32	n = 17	n= 23	n = 14	n = 3	n =1	n = 3	n = 93
	Percentage of countries mentioning the threat in response to open-ended question							
(Indiscriminate) cross-breeding*	63	41	17	29	67	100	33	42
Introduction/increased use of exotic breeds	22	29	35	64	33	0	67	34
Lack of/weak AnGR management policies, programmes or institutions	19	41	22	14	100	0	33	26
Breeds not profitable/competitive or have poor performance	3	12	48	7	0	100	0	17
Intensification of production or decline of traditional production systems or small farms	0	12	39	29	0	0	0	16
Disease/disease management	28	12	13	7	0	0	0	16
Loss/lack of grazing land or other elements of the production environment	9	24	13	21	0	0	0	14
Inbreeding or other problems in the management of breeding	3	6	26	7	0	0	0	10
Migration from countryside/uptake of alternative employment	3	18	17	0	0	0	0	9
Changes to consumer/retailer demand/ habits	0	12	17	0	0	100	0	8
Mechanization	3	24	9	14	0	0	0	8
Value of locally adapted breeds not appreciated	6	18	0	0	0	0	0	8
Unspecified economic/market factors	3	18	9	0	0	0	0	6
Climate change	16	6	0	0	0	0	0	6
Globalization, trade liberalization or imports	0	12	9	7	0	0	0	5
Lack of infrastructure or support for production, processing or marketing	3	6	4	0	0	100	0	4
Aging farmers or lack of interest among the young generation	0	0	13	0	0	0	0	3

Note: The cells are coloured according to a graded scale from red (100%) to green (0%).
Additional factors reported by a small number of countries included theft, lack of public/policy-maker awareness, high costs of inputs (including labour), urbanization, specialization of production, species replacement, drought, unspecified natural disasters, war, marketing restrictions (due to disease), livestock being regarded as environmental problem, improved disease prophylaxis, excessive slaughter during religious events, extension activities focusing on production not sustainability, inappropriate husbandry practices, unspecified cultural issues, unspecified production system issues and unspecified social constraints.
*Some countries specified that the cross-breeding causing the threat is indiscriminate.
Source: Country reports, 2014.

Box 1F9
Threats to animal genetic resources in Mozambique

In the past, selection and cross-breeding studies were conducted, with the aim of identifying the best genetic resources for use in the production sector. However, because of war and lack of expertise, funds and infrastructure, there was no follow up to these studies, and the resulting progeny were used for indiscriminate breeding and uncontrolled cross-breeding. As a result, with the exception of some commercial/private farms, the animals in the current population have various (and unknown) levels of exotic × native blood, and reductions in productivity have been reported. Because of this reduced productivity and the need to increase output in order to satisfy growing consumer demand, farmers tend to replace native breeds with exotic breeds, with all the problematic consequences of introducing temperate breeds into harsh tropical conditions. The replacement of native breeds and uncontrolled breeding is placing these breeds at risk of extinction or at least genetic erosion.

Source: Adapted from the country report of Mozambique.

Box 1F10
Shifting consumer demand as a threat to animal genetic resources – examples from around the world

Country-report responses to a question about the causes of genetic erosion included a number of references to specific changes in consumer demand:

China: "The products ... from locally adapted breeds do not meet the consumption demands of contemporary people."

Ireland: "The downturn in the economy is leading to excess production of all equines and a reduction in customer demand."

Portugal: "The current crisis leads consumer to choose cheaper foods rather than higher-quality products."

Tajikistan: "A lack of demand for Karakul skins."

United Kingdom: "Retailer-driven specifications for commodity animal products are causing rapid and substantial introgression of external genetics into some breeds – notably dairy and beef cattle breeds."

United States of America: "A strong consumer shift towards higher demand for eating quality (primarily tenderness and flavour) has resulted in a rapid decline in the population size of the Hampshire pig breed, which is associated with lean carcasses with low water-holding capacity, resulting in less palatable meat."

Sources: Country reports of China, Ireland, Portugal, Tajikistan, the United Kingdom and the United States of America.

as globalization, trade liberalization or increasing levels of imports. A few mention specific changes in consumer demand that have led to falling demand for the products or services of particular breeds or species. The examples are quite diverse and include cases from both developed countries and developing countries (see Box 1F10). They also include shifts both away from and towards demand for higher-quality products.

After lack of profitability, the next most commonly mentioned threat (16 percent of responses) was intensification of production or decline of traditional or small-scale production systems. This threat was more frequently mentioned in the country reports from Europe and the Caucasus (39 percent) than in those from other regions, although also quite frequently mentioned in the reports from Latin America and the Caribbean (29 percent). Another threat to the production systems that underpin AnGR diversity – loss of grazing land or other components of the production environment – received the same number of responses. The country report from Guinea, for example, notes that the area available for pastoral grazing is being reduced by the expansion of the agricultural frontier and the spread of mining operations. The country report from South Africa notes that mining is reducing the availability of grazing land and also affecting water quality and that wildlife ranching is also encroaching on grazing land. Further examples are provided in Boxes 1F1, 1F3 and 1F8 and in Part 2 Section C.

Box 1F11
Threats to animal genetic resources in the United States of America

Across species, consumer-demand drives the success or failure of livestock breeds. The vast majority of consumers demand low-cost animal products. Breeds capable of supplying products at the lowest cost (usually expressed on a per animal basis) have successfully captured larger shares of the market. However, as segments of society generate demand for livestock produced locally or with lower levels of production intensity, pockets of demand have been created for breeds that provide products at lower quantities per animal or with greater bio-economic efficiencies.

For beef cattle, there are a few large breed associations that generate enough revenue to maintain staff, and have breeders that can afford a full-scale programme. However, small breed associations struggle to maintain an office, databases of registered animals, germplasm preservation, etc.

The loss of the government price-support system for wool and fibre has had a detrimental impact on some sheep and goat breeds. In the goat industry, the importation of the Boer goat has resulted in extensive cross-breeding with landrace breeds, especially the Spanish goat, and this has resulted in a threat to the survival of these breeds in pure-bred form.

A shift towards demand for meat with higher eating quality has resulted in a rapid decline in the size of the Hampshire pig population (see Box 1F10). Conversely, it has led to an expansion in the population size of the Berkshire breed, which has high levels of intramuscular lipid, resulting in enhanced eating quality. A small countervailing force is the expansion of niche markets, which can be exploited by small-scale farmers delivering pork products to local consumers. At-risk breeds are frequently utilized in these niche-production programmes.

Source: Adapted from the country report of the United States of America.

Box 1F12
Threats to animal genetic resources in Peru

Alpacas and llamas: Genetic erosion is being caused by the absorption or replacement of coloured types by those that produce fine white fibre. Herds producing coloured fibre or fibre that is highly variable in its fineness have been shrinking and in some cases have lost colours or shades.

Criollo cattle: The introduction of exotic breeds into the country has led to a reduction in the size of criollo populations. The distribution of criollos has become restricted to extreme environments where availability of forage and water is restricted.

Native guinea pig: The growing market for guinea pig meat has led to priority being given to the use of breeds genetically improved for meat production. It is anticipated that this will affect the numbers and the genetic diversity of native breeds.

Other species: Threats to locally adapted breeds of sheep, pigs, goats, horses, ducks, etc. are mainly related to the increasing use of exotic breeds.

Source: Adapted from the country report of Peru.

Disease or disease-control measures were also mentioned in 16 percent of responses. Details of the mechanisms involved were not always provided. However, in some cases the country reports indicate that culling measures are a threat (see Box 1F13 for an example). The threat posed by disease epidemics is discussed in further detail below (Subsection 4).

A number of responses (10 percent) mention problems related to the inappropriate management of breeding programmes, particularly practices that lead to inbreeding. This answer was more common in country reports from Europe and the Caucasus than in those from other regions.

Another threat mentioned in a similar number of responses (9 percent), mostly in reports from Asia and Europe and the Caucasus, is migration from rural areas or uptake of alternative employment. For example, the country report from China, notes that

Box 1F13
Threats to animal genetic resources in Botswana

Factors leading to genetic erosion in Botswana include indiscriminate cross-breeding with exotic breeds. This occurs because most livestock in the country is found in communal areas where controlled breeding is hard to practice. As such, indigenous Tswana breeds of various species (cattle, sheep, goats and pigs) are at risk because most farmers want to farm with "improved" stock due to their high growth performance and economic returns.

Animal diseases outbreaks also erode the country's animal genetic resources, especially cattle, because of the stamping out (eradication of disease through mass slaughtering) that occurs in affected regions.

Source: Adapted from the country report of Peru.

Box 1F14
Effects of predation on sheep production in Norway

The sheep population is decreasing due to poor profitability and conflicts with the wolf and other predators. Most of the sheep farming in Norway is based on letting the sheep out in outlying and mountainous areas during the grazing season (approximately four months). With the return of predators such as bears, wolves, lynx and wolverine, and with hunting them being prohibited, many sheep farmers cannot or will not let their flocks graze on outlying land without herding. The areas where the sheep used to graze are enormous, so herding is difficult and expensive. This is part of the explanation for the decrease in the number of sheep and sheep farmers during the last decade (7 percent and 20 percent, respectively). The number of sheep farmers in 2013 was 14 000.

Source: Adapted from the country report of Norway.

> *"thousands of families in rural areas have quit animal rearing ... The accelerated withdrawal of backyard farmers will inevitably lead to reduction or even extinction of local genetic resources."*

A related factor mentioned in a smaller number of responses (3 percent – all from Europe and the Caucasus) is ageing of the faming population and a lack of interest in livestock keeping among the younger generation.

Mechanization of agriculture and transport leading to the decline of breeds used for draught was mentioned in 7 percent of responses overall, but considerably more frequently among those from Asian countries (24 percent). Climate change, in contrast, was mentioned most frequently in responses from African countries (16 percent, as compared to 6 percent for the world as a whole). Species replacement as a result of climate change is noted, for example, in the country report from Ethiopia (see Box 1F8). The report from Mali notes that climatic changes have led to changes in transhumance patterns, with pastoralist herds remaining for longer in the southern part of the country. This in turn has led to degradation of natural resources, conflicts over resource use and indiscriminate cross-breeding between breeds from the north of the country and those from the south. The potential for climate change to increase risks associated with meteorological disasters is further discussed below (Subsection 3).

A range of other threats were mentioned by a limited number of countries. One issue that is causing some concern in parts of Europe is the threat from predator animals, the populations of some of which are expanding in some areas because of restrictions on hunting (see Box 1F14).[9] The threat to livestock has been exacerbated by changes in management – larger flocks per shepherd – that have increased animals' vulnerability. Elsewhere in the world, the country report

[9] Predation was not mentioned in response to the question in the country-report questionnaire directly referring to the causes of genetic erosion and therefore does not feature in Table 1F2.

from South Africa notes that predation, along with theft, remains a major challenge and some farmers have moved from conventional livestock keeping to wildlife ranching as a result. It further notes that an in-depth scientific evaluation of predation is being undertaken with the aim of developing more acceptable control methods.

3 Disasters and emergencies

As noted in the introduction to this section, the first SoW-AnGR distinguished threats associated with gradual changes to productions systems from those associated with acute events such as climatic disasters. These two different types of threat present quite distinct challenges in terms of AnGR management and it is therefore useful to discuss them separately. In reality, however, there are many connections between the two. A gradual trend may make an acute disaster more likely, increase its impact or increase the vulnerability of a given livestock population to its effects. This subsection updates the discussion of disasters and emergencies presented in the first SoW-AnGR. Threats of this type and efforts to manage them are not discussed in any detail elsewhere in the report. This subsection therefore presents a relatively detailed analysis of developments in this field.

It is well recognized that a catastrophic event that kills large numbers of animals can pose a threat to AnGR diversity, particularly to breeds or populations that are concentrated within a limited geographical area. This kind of threat was discussed in some detail in the first SoW-AnGR. The report noted that impacts on AnGR can occur both because of the direct effects of an "inciting event", such as a hurricane or earthquake, and because of longer-term disruptions associated with a "state of emergency" brought about by an event of this kind. It also recognized that actions taken to deal with an emergency situation, particularly the restocking of livestock populations, can have a significant effect on AnGR diversity. A distinction was drawn between "acute" and "chronic" emergencies. The former correspond to the above-described pattern: a major inciting event that occurs in a short, discrete, period of time is followed by a longer, but finite, period of disruption. A chronic emergency, in contrast, involves an ongoing state of disruption caused by continuing, or periodically recurring, problems (e.g. intermittent droughts, intermittent military conflicts or the effects of human-health problems such as HIV/AIDS). Chronic emergencies, while they may not involve such devastating impacts in terms of livestock mortality, can have a significant effect on AnGR diversity, both because of disruptions to livestock-keeping livelihoods and because of associated livestock-related development interventions, such as projects that introduce exotic animals.

In addition to the direct effects that they can have in terms of livestock deaths and disruptions to livelihoods, disasters can also disrupt the delivery of livestock-related services and the operation of management programmes, including those related to the sustainable use and development of AnGR. The following quotation is taken from Liberia's National Biodiversity Strategy and Action Plan:

> *"Skills essential for environment and biodiversity management were lost through death, incapacities and migration. Records and publications (biodiversity information) important for the conservation and sustainable use of biological resources were destroyed. The only research institution, CARI, was vandalized and destroyed during the war, resulting in loss of crop and livestock genetic materials. Domestic animals were decimated, including pets like cats and dogs."(Government of Liberia, 2004).*

Another potential threat is that a large-scale disaster, such as a war, may create such urgent demand for food that animals are slaughtered indiscriminately without sufficient attention being paid to the need to retain high-quality breeding animals. This effect is reported to have threatened the survival of several British pig breeds during the First World War (Wiseman, 2000).

Disasters and emergencies did not feature prominently among responses to the country-report question on causes of genetic erosion (Table 1F2). A few countries mentioned military conflicts, and this threat was also noted in the reports submitted by both AU-IBAR and the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) as part of the second SoW-AnGR reporting process.[10] As noted above, several countries mentioned climate change as a threat, but generally these responses did not refer explicitly to disaster risk. Several countries (e.g. Ethiopia, the Islamic Republic of Iran and Kenya), noted drought as a significant threat.

In terms what can be done to protect AnGR from the effects of disasters and emergencies, the first SoW-AnGR recognized that at the height of major acute emergency, interventions to protect animals would rarely be a priority. The importance of taking precautions in advance was therefore emphasized. If possible, breeds or populations that are vulnerable to the effects of disasters should be included in *ex situ* conservation programmes under which cryoconserved material and/or live animals are kept at a location (or preferably more than one location) outside the disaster-prone area. In the case of emergencies that have a slower onset or are less severe in terms of their effects on the human population, the first SoW-AnGR noted that there might be more scope for taking action to protect at-risk breed populations from destruction. However, it also recognized that this would generally require a degree of advanced planning and good knowledge of where threatened populations are located. The need to improve knowledge of breeds' geographical distribution was one of the main recommendations of the first SoW-AnGR with respect to the threats posed by disasters and emergencies.

In addition to establishing *ex situ* conservation schemes, disaster preparedness can also include practical steps to mitigate the effects of disasters. Examples include the creation of fodder banks in areas that are prone to climatic disasters such as droughts or severe winter weather, and contingency plans for the provision of feed, water and veterinary services in the event of a disaster. Disaster early-warning systems may help to give people the time needed to implement measures to protect their animals. Further information on livestock-related emergency preparedness measures can be found in the *Livestock and emergency guidelines* (LEGS, 2009) published by the Livestock and Emergency Guidelines and Standards Project.

In some cases, preparedness measures may include the establishment of facilities that can be used to physically protect animals from the immediate effects of a disaster. For example, in Bangladesh, where more than 1 million cattle were killed by Cyclone Sidr in 2007, the Swiss Agency for Development and Cooperation has constructed a number of multipurpose cyclone shelters that can house both people and animals (IRIN, 2012). Another measure taken in some parts of Bangladesh is to construct elevated earth structures, known as *killas*, upon which livestock can be kept during cyclones (Choudhury, 1993; Floreani and Gattolin, 2011). Where naturally safer ground is accessible, specialized constructions may be unnecessary. For example, in the wake of Hurricane Isodore, which struck Mexico in 2002, local municipalities in Yucatan purchased areas of land a few kilometres away from the coast and promoted the relocation of animals from vulnerable coastal areas (UNISDR, 2013). In Indonesia, when the Mount Merapi volcano erupted in 2010, local authorities provided livestock feed and shelter in safe areas so that animals did not have to be left in villages threatened by the eruptions (Husein *et al.*, 2010).

Measures taken to protect animals from the physical effects of a disaster need to be well adapted to local circumstances and feasible in terms of the resources available. Taking Bangladesh again as an example, the current number of cyclone shelters is insufficient to protect the whole human population in cyclone-affected zones, and therefore construction of relatively elaborate combined human–animal shelters may not always be regarded as a priority (IRIN, 2012). *Killas*, on the other hand, are

[10] Reports from international organizations are available at http://www.fao.org/3/a-i4787e/i4787e03.htm.

simple constructions, but tend to fall into disrepair when not in use. People may also be unwilling to take their animals to *killas* if they are located far away from human shelters. It has been argued that some kind of combination of a shelter for the people and a *killa* for the animals is the preferable option in these circumstances (Choudhury, 1994; Floreani and Gattolin, 2011).

Preparedness measures, if taken at all, will generally focus on protecting livestock in general rather than on protecting AnGR diversity *per se*. However, increasing the proportion of the livestock population protected will, by default, tend to increase the probability that particularly significant subpopulations (e.g. breeds that are rare or have unique features) will be protected. If such populations have been identified and their locations are known, it may be possible to take steps to ensure that they are covered by whatever preparedness measures are in place in the local area, or even to prioritize them.

In the case of post-disaster restocking, choosing appropriate breeds or species is an important part of the planning process. It may be tempting to use the restocking exercise as an opportunity to "improve" the local livestock population. However, given the difficult conditions that are likely to prevail in a post-disaster situation, introducing animals that require higher levels of care and inputs may be a risky strategy. Even at the best of times, introducing a new breed requires careful planning to ensure that the animals and the production system are well matched (FAO, 2010). Using locally adapted rather than exotic breeds for restocking is likely to reduce the potential for negative consequences for AnGR diversity. However, even in these circumstances, it is possible that restocking may have negative effects on specific breeds. The ability to identify any such potential threats is, again, likely to depend on the availability of good knowledge of the characteristics, distribution and demographics of local livestock populations.

Where interventions that aim to address more chronic emergencies or longer-term post-disaster development are concerned (i.e. actions taken once the disruptions of the immediate aftermath have subsided), the "standard" AnGR-related advice applies (see for example FAO, 2010): any breeds or crosses that are introduced must be appropriate for the local production environment and the needs of the local livestock keepers; potential impacts on the AnGR of the local area should be assessed and, if necessary, conservation measures (FAO, 2013b) should be implemented.

While, given the destructive power of many disasters and the geographical concentration of some breed populations, the existence of a potential threat to AnGR diversity appears to be quite clear – and is widely recognized among those involved in AnGR management – the first SoW-AnGR noted that the scale of this threat was unclear. In fact, it was difficult to find any documented examples in which the risk status of specific breed populations had been significantly worsened by a disaster or emergency. The main exception to this was a case study on the effects that the 1992 to 1995 war in Bosnia and Herzegovina (and subsequent efforts to rehabilitate the country's livestock sector) had had on AnGR, particularly the Busha breed of cattle, whose population reportedly declined from over 80 000 in 1991 to below 100 in 2003.[11] This kind of "before versus after" analysis is, clearly, reliant on the existence of reasonably precise and up-to-date figures for the size of the respective breed population in the run up to the emergency and on there being sufficient capacity to assess the post-emergency situation (i.e. to carry out some type of population survey). Breed-specific data on the number of animals killed by acute disasters are, not surprisingly, rarely available – and no such examples were presented in the first SoW-AnGR.

[11] In 2011, "BushaLive", a regional project (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Montenegro, Serbia and The Former Yugoslav Republic of Macedonia) aiming to promote the conservation of the Busha, was chosen to receive funding under the Funding Strategy for the Implementation of the Global Plan of Action for Animal Genetic Resources (for more details, see http://www.fao.org/ag/againfo/programmes/en/genetics/first_call.html).

The first SoW-AnGR cited sources (IFRC, 2004; EM-DAT database)[12] indicating that the frequency of many types of disaster had been increasing over the preceding years and decades.[13] Recent data indicate that, while at global scale there may be a downward trend in human mortality rates associated with hydrometeoroligical disasters, overall economic and livelihood losses associated with disasters are increasing rapidly (UNISDR, 2013; Lavall and Maskrey, 2013). In very broad terms, it seems that improved early warning systems, along with better developed infrastructure, health care systems, etc. have often allowed more human lives to be saved,[14] while little progress has been made in terms of the land use planning and environmental-management measures that might reduce exposure to certain types of disaster (UNISDR, 2013). Disaster trends also vary greatly from one region to another. For example, in contrast to the general trend, flood mortality rates in sub-Saharan Africa have been increasing consistently in recent decades. Increases in the hazard exposure of "produced capital" have been particularly marked in areas where economic growth has been rapid (e.g. in parts of Asia) (ibid.).

Disaster risk is also probably being affected by climate change. The Intergovernmental Panel on Climate Change, in its special report on managing extreme events and disasters (IPCC, 2013b), concluded that, at global scale, climate change can be expected to increase the frequency and/or severity of several types of extreme weather events and other potentially disastrous phenomena (e.g. slope instabilities and lake outburst floods caused by glacial retreat or permafrost degradation) in the coming decades (see Box 1F15). Certain other types of extreme event are, however, predicted to become less frequent. There are also expected to be shifts in the geographical distribution of certain types of event.

[12] http://www.emdat.be

[13] FAO, 2007a, Figure 36 (pages 120–121).

[14] Mortality rates in the event of an earthquake are closely correlated to building collapse. In contrast to mortality rates associated with hydrometeorological disasters, human earthquake mortality rates have been increasing globally in recent years.

The advice on disasters and emergencies presented in the first SoW-AnGR was, in broad terms, taken up in the Global Plan of Action for Animal Genetic Resources (FAO, 2007b), which calls for the establishment of "integrated support arrangements to protect breeds and populations at risk from emergency or other disaster scenarios, and to enable restocking after emergencies, in line with the national policy."[15] It also calls for the establishment of backup *ex situ* conservation systems for "protection against the risk of emergency or disaster scenarios."[16] According to the country reports, 30 percent of countries have put arrangements in place to protect breeds and populations that are at risk from natural or human-induced disasters (FAO, 2014). However, the scope of these measures is in some cases limited to measures such as the provision of compensation to livestock keepers affected by natural disasters or the implementation of broad disaster-management strategies.

Another field in which there have been significant developments since the publication of the first SoW-AnGR is the assessment of geographical distribution as a factor affecting breeds' risk statuses. The significance of geographical concentration was, for example, highlighted in a paper by Carson *et al.* (2009), which showed that out of 12 British sheep breeds assessed, 10 had 95 percent of their population numbers concentrated within a radius of 65 km or less (in some cases less than 30 km). Geographical concentration was subsequently incorporated into the United Kingdom's breed risk classification system (Alderson, 2009). In another study, Bahmani *et al.* (2011) analysed the distribution of the Markhoz goat in the Islamic Republic of Iran and discovered that 77 percent of its population was concentrated within a circle with a radius of 7 km. In this case, natural disasters such as droughts are reported to have already contributed to the decline of the breed's population (ibid.).

[15] FAO, 2007b, Strategic Priority 10, Action 2.

[16] FAO, 2007b, Strategic Priority 23, Action 3.

Box 1F15

Projections for the risk of climatic disasters

The Intergovernmental Panel on Climate Change's special report *Managing the risks of extreme events and disasters to advance climate change adaptation,* published in 2013, includes a number of projections of future trends in the occurrence and severity of extreme climatic events. The main predictions are summarized in the following quotations.

"Models project substantial warming in temperature extremes by the end of the 21st century. It is *virtually certain* that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21st century at the global scale. It is *very likely* that the length, frequency, and/or intensity of warm spells or heat waves will increase over most land areas ..."

"It is *likely* that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe. This is particularly the case in the high latitudes and tropical regions, and in winter in the northern mid-latitudes. Heavy rainfalls associated with tropical cyclones are *likely* to increase with continued warming. There is *medium confidence* that, in some regions, increases in heavy precipitation will occur despite projected decreases in total precipitation in those regions ..."

"Average tropical cyclone maximum wind speed is likely to increase, although increases may not occur in all ocean basins. It is *likely* that the global frequency of tropical cyclones will either decrease or remain essentially unchanged."

"There is *medium confidence* that there will be a reduction in the number of extratropical cyclones averaged over each hemisphere. While there is *low confidence* in the detailed geographical projections of extratropical cyclone activity, there is medium confidence in a projected poleward shift of extratropical storm tracks ..."

"There is *medium confidence* that droughts will intensify in the 21st century in some seasons and areas, due to reduced precipitation and/or increased evapotranspiration. This applies to regions including southern Europe and the Mediterranean region, central Europe, central North America, Central America and Mexico, northeast Brazil, and southern Africa. Elsewhere there is overall *low confidence* because of inconsistent projections of drought changes (dependent both on model and dryness index) ..."

"Projected precipitation and temperature changes imply possible changes in floods, although overall there is *low confidence* in projections of changes in fluvial floods. Confidence is low due to *limited evidence* and because the causes of regional changes are complex, although there are exceptions to this statement. There is *medium confidence* (based on physical reasoning) that projected increases in heavy rainfall would contribute to increases in local flooding in some catchments or regions."

"It is *very likely* that mean sea level rise will contribute to upward trends in extreme coastal high water levels in the future. For example, the *very likely* contribution of mean sea level rise to increased extreme coastal high water levels, coupled with the likely increase in tropical cyclone maximum wind speed, is a specific issue for tropical small island states."

"There is *high confidence* that changes in heat waves, glacial retreat, and/or permafrost degradation will affect high mountain phenomena such as slope instabilities, movements of mass, and glacial lake outburst floods. There is also *high confidence* that changes in heavy precipitation will affect landslides in some regions."

"There is *low confidence* in projections of changes in large-scale patterns of natural climate variability. For example, confidence is low in projections of changes in monsoons (rainfall, circulation) because there is little consensus in climate models regarding the sign of future change in the monsoons ..."

Source: IPCC, 2013b.

More generally, access to data on breed distribution will be improved by the development of the production environment descriptors (PEDS) module of the Domestic Animal Diversity Information System (DAD-IS),[17] which will allow National Coordinators for the Management of Animal Genetic Resources to record the distribution of their countries' breeds on electronic maps. The importance of collecting data on the distribution of breed populations is emphasized in FAO's guideline publications on surveying and monitoring of AnGR and on phenotypic characterization (FAO, 2011b; FAO, 2012a).

Once breed distribution data are available, a potential next step is to relate these data to the geographical distribution of disaster risk.[18] This might, for example, help provide an indication of the scale of the potential threat and draw attention to areas where risk-reduction activities for AnGR are particularly needed. It should, however, be borne in mind that sophisticated risk-mapping exercises are not necessarily a prerequisite for action. As some of the examples presented above suggest, basic knowledge of how risk is geographically distributed on a local scale can provide a basis for preparedness measures to protect livestock (and potentially to protect specific breed populations).

To what extent has awareness of AnGR management issues spread beyond the "AnGR community" and into the consciousness of a wider layer of stakeholders involved in the management of disasters and emergencies? The first SoW-AnGR noted that disaster-preparedness and risk-management activities had, in general, tended to include few specific recommendations for the livestock sector, although some efforts were being made by some international agencies to address these deficiencies. The report also noted that while post-disaster rehabilitation activities often involve livestock-related interventions, the literature on the subject included little mention of AnGR issues.

As noted above, since the publication of the first SoW-AnGR, the literature on general livestock-related interventions to assist people affected by humanitarian crises has been augmented by the work of the Livestock Emergency Guidelines and Standards (LEGS) Project. The LEGS Handbook (LEGS, 2009) recommends that animals used for restocking should be from locally adapted breeds, both because of their good capacity to thrive in local conditions and because local people will know how to manage them. However, it offers no guidance on how to address threats to specific AnGR that may arise because of a disaster or emergency or because of response measures. This pattern – recognition of the importance of using appropriate locally adapted animals for restocking, but no more specific AnGR-related advice – reflects much of the earlier literature on the topic (e.g. Heath *et al.*, 1999; Simpkin, 2005; Nyariki *et al.*, 2005). It is unclear whether awareness of AnGR-related issues among practitioners involved in restocking projects or in implementing other disaster-related interventions has increased in recent years. Practical implementation seems to remain a problem, at least in some countries (see Box 1F8 for example).

At national level, many countries have plans or strategies[19] – and in some cases also legislation[20] – related to the management of disasters and emergencies. As part of a survey on legal and policy frameworks affecting AnGR management conducted by FAO in 2013 (see Part 3 Section F for more details), countries were asked whether they had any legal or policy instruments related to

[17] http://fao.org/dad-is

[18] The global electronic disaster-risk maps produced by the Global Risk Data Platform (http://preview.grid.unep.ch/) might be useful in this respect. Data on disaster-related livestock deaths recorded in DesInventar (http://www.desinventar.org/) databases can also be displayed on maps at the level of within-country administrative areas. About 30 countries, mostly in Latin America and the Caribbean, are covered.

[19] Many national strategy documents can be accessed via the PreventionWeb website (http://www.preventionweb.net/english/professional/policies/) operated by the United Nations Office for Disaster Risk Reduction (UNISDR).

[20] Many laws and regulations on disaster management can be accessed via the Disaster Law Database operated by the International Federation of Red Cross and Red Crescent Societies (http://www.ifrc.org/en/publications-and-reports/idrl-database/).

disasters and emergencies and whether these had any impact on AnGR management. The results indicate that 76 percent of the 48 responding countries have legislation on disaster prevention measures either in place or under development and almost as many (74 percent) have policies in place or under development. A number of countries reported that these instruments include provisions related to the protection of livestock and in several cases also specifically to the protection of AnGR. In some cases, however, it appears that these measures relate only to the control of animal disease epidemics and in others that the only measures taken are precautionary gene banking.

One of the few reported laws that specifically addresses the protection of AnGR from a range of natural and human-induced disasters is Slovenia's Livestock Breeding Act (2002),[21] which states that

> *"if due to the state of emergency or state of war, or due to natural or other disasters the preservation of the breeding materials necessary to ensure, to a minimum extent, the reproduction of domestic animals is endangered, or if the biological diversity of domestic animals in the Republic of Slovenia is endangered to a larger extent, the Minister may assign to breeding organizations and breeders, as well as to other recognized and approved organizations hereunder special technical and other tasks in order to prevent such endangering."*

Another example is Viet Nam's Ordinance on Livestock Breeds (2004),[22] which refers to "the restoration of livestock breeds in cases where natural disasters or enemy sabotages cause serious consequences."

Several of the survey responses mention that national disaster prevention policies include provisions related to the protection of livestock or that this task falls within the mandate of disaster-protection agencies. However, few details are provided. Several responses note the need to introduce AnGR-specific measures into disaster-related policies. The protection of livestock in general is mentioned, for example, in Bulgaria's Disaster Protection Act (2006),[23] which refers to "temporary evacuation of persons, domestic animals or livestock" and "providing food and temporary shelter to victims of disaster, domestic animals and livestock" and Viet Nam's Law on Natural Disaster Prevention and Control (2013),[24] under which basic provisions for dealing with droughts and seawater intrusions include "adjusting the structures of plants, animals and crops based on forecasts, warnings and developments of drought and seawater intrusion" and for disasters associated with cold weather include "ensuring sufficient feed for livestock."

Looking beyond the survey results, most national policies on disasters and emergencies make no specific references to the protection of animals from the effects of disasters. Exceptions include Uganda's National Policy for Disaster Preparedness and Management, which includes measures related to the provision of emergency feed supplies during droughts, as well as to the control of cattle rustling and disease epidemics.[25] Nepal's National Strategy for Disaster Risk Management includes among its priorities for action the establishment of a monitoring system for crops and livestock in high-risk areas and improvements to

[21] Zakon o Živinoreji (ZŽiv) (available in Slovenian at http://tinyurl.com/o6o4pbw and in English at http://tinyurl.com/n2thv8c).

[22] PHÁPLỆNH GIỐNG VẬT NUÔI (Số: 16/2004/PL-UBTVQH11) (available in Vietnamese at http://www.moj.gov.vn/vbpq/Lists/Vn%20bn%20php%20lut/View_Detail.aspx?ItemID=19426 and in English at http://tinyurl.com/k6t74qu).

[23] Закон за защита при бедствия (available in Bulgarian at http://www.mi.government.bg/library/index/download/lang/bg/fileId/304 and in English at http://www.ifrc.org/docs/idrl/867EN.pdf).

[24] LUẬT PHÒNG, CHỐNG THIÊN TAI (Luật số: 33/2013/QH13) (available in Vietnamese at http://tinyurl.com/oyl48me and in English at http://tinyurl.com/kapdwca).

[25] A number of national policies treat animal disease epidemics as a class of disaster in their own right. Plans for dealing with epidemics are, of necessity, oriented towards the livestock sector. However, this does not necessarily mean that the sector receives any particular attention in the respective country's plans for dealing with other kinds of disaster.

animal feed storage systems and animal shelters (Government of Nepal, 2009). India's Standard Operating Procedure for Responding to Natural Disasters refers to the need to "devise appropriate measures to protect animals and find means to shelter and feed them during disasters and their aftermath" (Government of India, 2010). India has taken a number of initiatives in this field in recent years. In 2013, the country's National Disaster Management Authority co-organized an event entitled "National Conference on Animal Disaster Management – Animals Matter in Disasters" with the World Society for the Protection of Animals (NDMA, 2013). A model district disaster management plan developed for the Madhubani district of Bihar, and published in 2013, includes detailed plans for action by the Animal and Fisheries Department and by local livestock management committees, covering emergency actions such as rescue and evacuation of animals and the provision of veterinary care, fodder and water, as well as livestock-related risk-reduction activities (DDMA, 2013).

4 Animal disease epidemics

This subsection updates the discussion on animal disease epidemics as threats to AnGR diversity presented in the first SoW-AnGR. Epidemics share some of the features of other kinds of disaster and emergency (see Subsection 3). They have the potential to kill large numbers of animals in a short period of time. They are a particular threat to breed populations that are concentrated within a limited geographical area. They often trigger a burst of activity on the part of national authorities and these responses can in themselves sometimes be a threat to AnGR. However, unlike many other kinds of disaster and emergency, in the case of an epidemic, livestock are not marginal to response efforts. They are the main focus of attention. Concretely, the acute threat associated with disease epidemics is that large numbers of animals, potentially a large proportion of a given breed population, will die, either directly because of the effects of the disease or because of a culling programme implemented to control the disease.

Other things being equal, large epidemics (affecting a large number of animals and a wide geographical area) pose a greater threat to AnGR than smaller epidemics. Likewise, epidemics that produce a high mortality rate in the affected areas pose a greater threat. Culling campaigns can be particularly problematic in this respect because, if carried out thoroughly, they kill 100 percent of the animals of the relevant species in the area designated for the cull. However, certain diseases, African swine fever, for example, produce very high mortality rates even if there is no culling.

While the effects of large-scale epidemics are likely to be the most serious, the potential threat from epidemics that are relatively limited in terms of the size of the area they affect and the mortality rates they produce should not be overlooked. For an at-risk breed or a breed that is close to falling into an at-risk category, the death of a few thousand, a few hundred or even a few tens of animals can be devastating.

During the decade preceding the publication of the first SoW-AnGR there were a number of extremely serious epidemics in various parts of the world, several of which resulted in the deaths of millions or hundreds of thousands of animals.[26] In many cases, the number of culled animals was far larger than the number of deaths caused by the disease itself. During the period since 2007, while there have been no incidents on quite the same scale in terms of livestock deaths as the United Kingdom foot-and-mouth disease epidemic of 2001 or the avian influenza outbreaks that struck parts of Southeast Asia in 2003/2004, disease epidemics have continued to inflict enormous losses on the livestock sector. In terms of shifts in the distribution of major epidemic diseases with the potential to devastate livestock populations, one of the most worrying recent developments has been the spread of African swine fever into the Caucasus and the Russian Federation (FAO, 2012b).

[26] FAO, 2007a, Table 40 (page 128).

The effect of climate change on the distribution of animal diseases is an area of study that is receiving increasing attention. Vector-borne and waterborne diseases are the most likely to be affected (World Bank, 2014). Given the high mortality rates associated with some of these diseases, it is possible that shifts in disease distribution driven by climate change could pose a threat to AnGR. However, because of the potential for complex interactions between the climate and pathogens, vectors, host animals and other ecosystem components, in addition to the effects of a range of human activities that may increase or decrease the likelihood that a disease will spread to a new area, it is generally difficult to predict how severe such effects are likely to be (FAO, 2011a; 2013c). Nonetheless, some attempts have been made to predict outlooks for specific diseases in the context of climate change (World Bank, 2014). It is argued that conducting studies of this kind is "important when building long-term disease mitigation plans as it provides a framework for governments to invest in research in order to reduce uncertainties and to develop disease mitigation efforts" (ibid.). Early warning systems for individual outbreaks of climate-sensitive diseases are likely to become increasingly necessary and a number of such systems are reported to be under development (ibid.). One disease that is causing some concern as a potential threat to AnGR in Europe is bluetongue, which appeared in northern Europe for the first time in 2006 (European Commission, 2013).

As discussed above, diseases and disease management featured prominently among the factors reported by countries as causes of genetic erosion, particularly in the case of African countries (see Table 1F2). In many cases, it is not clear whether these reports refer to the acute effects of epidemics or to the more general effects of disease problems as constraints to livestock-keeping livelihoods. Few countries provide examples of specific breed populations that have been severely affected by disease outbreaks. However, the report from Latvia notes that an outbreak of swine brucellosis led to the death of more than half the sows belonging to the Latvian White breed. The report from Botswana includes the following comment on the effects of post-epidemic restocking:

> *"Disease outbreaks in certain zones have led to mass slaughter of animals … This reduces population size and also affects … diversity since restocking has to be done using animals from other zones. Furthermore, … the restocking exercise brings in improved animals not indigenous ones which are adaptable to the local production environment. This … was … evident in North East District where 25 000 sheep and goats (mostly indigenous) were replaced by crossbreds and exotic breeds."*

More general effects on AnGR management are noted in the country report from Mauritius: an African swine fever epidemic in 2007 is reported to have wiped out 70 percent of the country's pig population. A relaunch programme based on the importation of exotic breeds reportedly led to indiscriminate cross-breeding and the production of poor-quality piglets. Further action on the part of the government was then required in order to rectify the problem.

The first SoW-AnGR noted that there had been some recognition of the potential need to protect rare or valuable breed populations from the effects of compulsory culling measures, for example in some European Union legislation. However, it also noted that the success of any attempts to "rescue" breed populations in affected areas once an epidemic had begun were likely to depend heavily on a high level of advanced planning. While there have been some initiatives in this field over recent years (see for example Box 1F16), the evidence provided in the country reports, the responses to the survey on legal and policy measures conducted by FAO in 2013 (see Part 3 Section F) and the reports received from international organizations[27] suggest that, overall, progress has been limited. As in the case of other types of disaster, the establishment of back-up *ex situ* conservation measures is

[27] For details, see "About this publication" in the preliminary pages.

Box 1F16
The European Livestock Breeds Ark and Rescue Net

The European Livestock Breeds Ark and Rescue Net (ELBARN) was envisioned as a network of stakeholders and farms that would perform two main functions:

- rescuing animals belonging to rare breeds if they are threatened by a crisis; and
- creating an online guide to places where indigenous livestock breeds can be seen by the public.

A third objective was to develop and promote a concept for protecting indigenous livestock breeds from culling during disease epidemics.

ELBARN began in 2007 with a three-year project funded by the European Commission. The most sustainable part of the project has been the online guide (www.arca-net.info), which now (June 2014) has 623 entries from 46 European countries. Every year, members are invited to update their information, so that Arca-Net is kept up to date.

The "rescue" aspects are more difficult to implement without adequate financial support. The principles of rescue were discussed at an international workshop in 2008. It was concluded that rescue is a temporary act: animals must be moved back into farming systems as soon as possible. Rescue must be done professionally, and a network of experts needs to be put in place to accomplish the task. Emergency funds need to be available so that action can be taken quickly. Veterinarians should be educated about threatened breeds, so that they are able to identify important breeds and set a rescue action in motion if the breeds are threatened by an epidemic.

It is clear that rescue can only be successful with prior planning. Both animals and holdings need to be recorded and registered, and contingency plans need to be prepared. Any person serving in a decision-making capacity during an animal disease epidemic should have received training about threatened breeds. Countries developing new regulations concerning disease control should consider including provisions related to the protection rare breeds. It would also be a positive development if such provisions were included in the Terrestrial Animal Health Code of the World Organisation for Animal Health (OIE).

The lessons learnt from ELBARN are that, without adequate funding, ideas cannot be implemented, even if they are supported by all stakeholders. The long-term goal is still to anchor the protection of indigenous breeds in national and international regulations. However, the austerity measures put in place following the global economic crisis of 2008 have led to a focus on self-sustaining measures such as Arca-Net.

Provided by Elli Broxham, SAVE Foundation.

an important means of reducing the risk of total extinction as a result of a disease outbreak.

5 Conclusions

Information on threats to AnGR diversity remains far from complete. As discussed in Part 1 Section B, the risk status of the majority of breeds is classified as "unknown" and even where population trends are monitored detailed assessments of threats to specific breeds are not common. It is therefore difficult to draw firm conclusions regarding the relative significance of different threats, particularly given that in most cases a range of interacting factors are likely to be involved. It is also difficult to determine whether particular threats have become more or less prominent during the period since the first SoW-AnGR was prepared. Country-reporting exercises during the intervening years (the second SoW-AnGR reporting process and the 2012 assessment of progress in implementing the Global Plan of Action) have highlighted the role of indiscriminate cross-breeding as a major problem, particularly in developing countries. Many

countries consider that the weakness of their AnGR management programmes, policies and institutions constitutes a threat in its own right. As described in Part 3 of this report, there is ample scope for improvements in these fields, and in many countries strengthening institutions and improving breeding policies and strategies are likely to be prerequisites for tackling the problem of indiscriminate cross-breeding.

Economic and market-related factors are also frequently highlighted by stakeholders as threats to AnGR. The most direct threat to the survival of many breeds is that they can no longer be raised profitably because of some shift in market demand or increase in the level of competition from other breeds, species or non-livestock sources. Shifts of this kind are an inevitable part of social and economic change and thus there are always likely to be some breeds that are at risk of declining towards extinction if no action is taken. In some cases, it may be necessary either to intervene directly to maintain the breed through *in situ* or *ex situ* conservation measures or to accept that it may become extinct. However, there may also be measures that can be taken to reduce economic threats either by "valorizing" individual at-risk breeds via marketing initiatives, genetic improvement or the identification of new roles, or by more general policy interventions such as eliminating support measures that create economic incentives for breed replacement.

Given the major roles of small-scale livestock keepers and pastoralists in maintaining AnGR diversity, factors that undermine the sustainability of smallholder and pastoralist production systems constitute significant threats to AnGR. These threats include both market-related factors and problems related the degradation of (or lack of access to) natural resources. Given the importance of livestock keeping to the livelihoods of many of the world's poorest people and the major significance of livestock keeping areas (e.g. grasslands) in the provision of ecosystem services (carbon sequestration, water cycling, provision of wildlife habitats, etc.), the sustainable development of these production systems is clearly a challenge that extends beyond the immediate field of AnGR management. Balancing different objectives is unlikely to be easy. However, there may be scope for synergies in efforts to promote AnGR-management, livelihood and environmental objectives.

Concerns about climate change have increased yet further since the time the first SoW-AnGR was prepared. Some countries report that they have already experienced climate-driven changes in AnGR management, including species substitutions. However, it remains difficult to predict how climate change will affect the future of livestock production and what the consequences will be for AnGR diversity. The uncertainty of climatic projections is a major constraint, but on the AnGR side there is also frequently a lack of adequate data on breeds' characteristics, their distributions and their production environments.

Similarly, while it is expected that climate change will increase the frequency of extreme weather events, the extent that this poses an additional threat to AnGR is difficult to estimate. In general, information about the level of threat posed to AnGR by disasters and emergencies remains limited. Lack of information on breed distributions is again a constraint. In some countries, there appears to be increasing interest in disaster-management strategies for the livestock sector. As noted in the first SoW-AnGR, if anything is to be done to protect specific breed populations (e.g. at-risk breeds), it will require advanced planning and good knowledge of where the relevant herds and flocks are located. Given that in many disaster situations organizing rescue efforts for animals will be impractical, efforts should be made to establish appropriate *ex situ* conservation measures for any breeds that are identified as being under serious threat from disastrous events.

The extent of the threat posed to AnGR by animal disease epidemics is, likewise, difficult to estimate accurately. Disease and disease-management measures, however, featured relatively prominently among causes of genetic erosion reported in the country reports, particularly among reports from African countries. These

cases do not necessarily all refer to the threat posed by major epidemics that devastate breed populations in a short period of time. However, given the concentration of some breeds in limited geographical areas and the high mortality rates associated with some diseases, the acute threat from disease epidemics should not be ignored. The potential threat posed by compulsory culling campaigns was noted in the first SoW-AnGR. While there is some indication that awareness of this threat has increased, there is little evidence that governments have taken many practical steps towards the establishment of rescue procedures for at-risk breeds threatened in this way.

Threats to specific breeds often arise because of a combination of factors associated with the changing nature of livestock production systems and the particular vulnerabilities of the respective breeds. Improved understanding of breeds characteristics, their production environments and how they are used thus needs to be combined with better understanding of livestock-sector trends and the demands and constraints that these place on the use of particular types of AnGR. Strategic Priority 5 of the Global Plan of Action for Animal Genetic Resources calls, *inter alia*, for "assess [ment] of environmental and socio-economic trends that may require a medium and long-term policy revision in animal genetic resources management."[28] Assessments of this kind should help countries identify existing and upcoming threats to their AnGR and potentially also identify strategies for countering some of these threats.

References

Alderson, L. 2009. Breeds at risk: definition and measurement of the factors which determine endangerment. *Livestock Science*, 123: 23–27.

Alemayehu, K. 2103.Threats, attempts and opportunities of conserving indigenous animal genetic resources in Ethiopia. *African Journal of Agricultural Research*, 8(23): 2806–2813.

Allen, R.L. 1865. *Domestic animals: history and description of the horse, mule, cattle, sheep, swine, poultry and farm dogs; with directions for their management, breeding, crossing, rearing, feeding, and preparation for a profitable market; also, their diseases and remedies together with full directions for the management of the dairy.* New York, USA, O. Judd Company (available at http://chla.library.cornell.edu/cgi/t/text/text-idx?c=chla;idno=3058099).

Bahmani, H.R., Tahmoorespur, M., Aslaminejad, A.A., Abbasi, M.A. & Ebnabbasi, R. 2011. Assessment of demographic, geographical and genetic risks in Markhoz goat population. *Journal of Animal and Veterinary Advances*, 10(2): 162–168.

Blew, W.C.A., Dixon, W.S., Fleming, G. & Shaw, V. 1898. *Light horses. Breeds and management*. Third edition. Livestock Handbooks No. II. London, Vinton & Company Ltd. (available at https://archive.org/details/lighthorsesbreed00blewrich).

Brito, L.F., Jafarikia, M., Grossi, D.A., Kijas, J.W., Porto-Neto, L.R., Ventura, R.V., Salgorzaei, M. & Schenkel, F.S. 2015. Characterization of linkage disequilibrium, consistency of gametic phase and admixture in Australian and Canadian goats. *BMC Genetics*, 16: 67.

Carrington, W.T., Gilbert, G., Morton, J.C., Murray, G., Spencer, S. & Wortley-Axe, J. 1919. *Livestock*. Eighth edition. London, Vinton & Co. (available at http://chla.library.cornell.edu/cgi/t/text/text-idx?c=chla;idno=3080643).

Carson, A., Elliott, M., Groom, J., Winter, A. & Bowles, D. 2009. Geographical isolation of native sheep breeds in the UK – evidence of endemism as a risk factor to genetic resources. *Livestock Science*, 123(2-3): 288–299.

Charoensook, R., Knorr, C., Brenig, B. & Gatphayak, K. 2013. Thai pigs and cattle production, genetic diversity of livestock and strategies for preserving animal genetic resources. *Maejo International Journal of Science and Technology,* 7(01): 113–132.

Choudhury, J.R. 1994. *Cyclone shelter and its multipurpose use*. Nagoya, Japan, UN Centre for Regional Development (available at http://tinyurl.com/qj6ssul).

Corbin, L.J., Liu, A.Y., Bishop, S.C. & Woolliams, J.A. 2012. Estimation of historical effective population size using linkage disequilibria with marker data. *Journal of Animal Breeding and Genetics*, 129**:** 257–270.

[28] FAO, 2007b, Strategic Priority 5, Action 1.

Country reports. 2014. Available at http://www.fao.org/3/a-i4787e/i4787e01.htm.

DDMA. 2013. *District disaster management plan – Madhubani. Volume 4. Specific action plans for line departments, gram panchayat committees and other non-govt. stakeholders*. Madhubani, Bihar, India, District Disaster Management Authority (available at http://tinyurl.com/paqz3tb).

De Roos, A.P.W., Hayes, B.J., Spelman, R.J. & Goddard, M.E. 2008. Linkage disequilibrium and persistence of phase in Holstein–Friesian, Jersey and Angus cattle. *Genetics*, 179: 1503–1512.

European Commission. 2013. *Preserving genetic resources in agriculture. Achievements of the 17 projects of the Community Programme 2006-2011*. Brussels (available at http://tinyurl.com/npb2y4s).

FAO. 2007a. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at www.fao.org/3/a-a1250e.pdf).

FAO. 2007b. *The Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration*. Rome (available at http://www.fao.org/docrep/010/a1404e/a1404e00.htm).

FAO. 2009a. *Threats to animal genetic resources – their relevance, importance and opportunities to decrease their impact.* Commission on Genetic Resources for Food and Agriculture Background Study Paper No. 50. Rome (available at ftp://ftp.fao.org/docrep/fao/meeting/017/ak572e.pdf).

FAO. 2009b. *Development of country-based early warning and response systems for animal resources.* Working Document, Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture, Fifth Session, Rome, 29–30 January 2009 (CGRFA/WG-AnGR-5/09/4). Rome (available at http://www.fao.org/docrep/meeting/021/K3812e.pdf).

FAO. 2010. *Breeding strategies for sustainable management of animal genetic resources.* FAO Animal Production and Health Guidelines. No. 3. Rome (available at http://www.fao.org/docrep/012/i1103e/i1103e00.htm).

FAO. 2011a. *Climate change and animal genetic resource for food and agriculture: state of knowledge, risks and opportunities*. Commission on Genetic Resources for Food and Agriculture Background Study Paper No. 53. Rome (available at http://www.fao.org/docrep/meeting/022/mb386e.pdf).

FAO. 2011b. *Surveying and monitoring of animal genetic resources*. FAO Animal Production and Health Guidelines. No. 7. Rome (available at http://www.fao.org/docrep/014/ba0055e/ba0055e00.htm).

FAO. 2012a. *Phenotypic characterization of animal genetic resources.* FAO Animal Production and Health Guidelines No. 11. Rome (available at http://www.fao.org/docrep/015/i2686e/i2686e00.htm).

FAO. 2012b. *African swine fever (ASF) recent developments and timely updates. Worrisome dynamics: steady spread towards unaffected areas could have disastrous impact*. EMPRES Emergency Prevention System. Focus on (electronic bulletin). No. 6. September 2012. Rome (available at http://www.fao.org/docrep/016/ap372e/ap372e.pdf).

FAO. 2013a. *Report of the Fourteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture, Rome, Italy, 15 – 19 April 2013.* CGRFA-14/13/Report. Rome (available at http://www.fao.org/docrep/meeting/028/mg538e.pdf).

FAO. 2013b. In vivo *conservation of animal genetic resources*. FAO Animal Production and Health Guidelines. No. 14. Rome (http://www.fao.org/docrep/018/i3327e/i3327e.pdf).

FAO. 2013c. *World Livestock 2013. Changing disease landscapes*. Rome (available at http://www.fao.org/docrep/019/i3440e/i3440e.pdf).

FAO. 2014. *Synthesis progress report on the implementation of the global plan of action for animal genetic resources – 2014*. Information Document, Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture, Eighth Session, Rome 26–28 November 2014 (CGRFA/WG-AnGR-8/14/Inf.5). Rome (available at http://www.fao.org/3/a-at136e.pdf).

Floreani, S. & Gattolin, G. 2011. *Mud and bamboo: cyclone shelter as sustainable adaptation strategy to climate change*. Venice, Italy, Università IUAV di Venezia (available at http://tinyurl.com/qdzhjyx).

Gibson, J., Gamage, S., Hanotte, O., Iñigueze, L., Maillard, J.C., Rischkowsky, B., Semambo, D. & Toll, J. 2005. *Options and strategies for the conservation of farm animal genetic resources*.

Report of an international workshop, Agropolis, Montpellier, France, 7–10 November 2005. Rome, CGIAR System-wide Genetic Resources Programme/ Bioversity International.

Government of India. 2010. *Standard operating procedure for responding to natural disasters.* New Delhi, Ministry of Home Affairs, Disaster Management Division (available at http://ndmindia.nic.in/SOP-NDM-2010.pdf).

Government of Liberia. 2004. *Liberia's National Strategy and Action Plan*. Monrovia (available at http://tinyurl.com/phedtq2 and http://tinyurl.com/p7kqmqw).

Government of Nepal. 2009. *National strategy for disaster risk management, 2009*. Kathmandu, Ministry of Home Affairs (unofficial English translation available at http://tinyurl.com/oct4yh7).

H.E. in 'The Field'. 1893. The farmer. The hardier breeds of cattle. *Bruce Herald*, Volume XXIV, Issue 2467, 14 April 1893, p. 4 (Newspaper article: available at http://tinyurl.com/nyaj2md).

Heath, S.E., Kenyon, S.J. & Zepeda Sein, C.A. 1999. Emergency management of disasters involving livestock in developing countries. *Revue scientifique et technique de l'Office international des Epizooties*, 18(1): 256–271.

Husein, A., Nashir, M. & Arriani, A. 2010. *Indonesia: Red Cross responds to double disaster*. Article on the website of the International Federation of Red Cross and Red Crescent Societies (http://tinyurl.com/onzpfkt) (accessed 15 October 2013).

IFRCS. 2004. *World Disasters Report 2004. Focus on community resilience.* Geneva, Switzerland, International Federation of Red Cross and Red Crescent Societies (available at http://tinyurl.com/nkrdewt).

IPCC. 2013a. Annex III: Glossary, edited by S. Planton, *In* T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P.M. Midgley, eds. *Climate change 2013: the physical science basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press (available at http://tinyurl.com/p7d6xwb).

IPCC. 2013b. *Managing the risks of extreme events and disasters to advance climate change adaptation.* Special report of the Intergovernmental Panel on Climate Change, edited by C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor & P.M. Midgley. Cambridge, UK and New York, NY, USA, Cambridge University Press (available at http://tinyurl.com/o7fvl8k).

IRIN. 2012. *Bangladesh: cyclone shelters for livestock too*. Website of IRIN humanitarian news and analysis, a service of the UN Office for the Coordination of Humanitarian Affairs (available at http://tinyurl.com/pnkzdl6) (accessed 18 November 2013).

Kijas, J.W., Lenstra, J.A., Hayes, B., Boitard, S., Porto Neto, L.R., San Cristobal, M., Servin, B., McCulloch, R., Whan, V., Gietzen, K., Paiva, S., Barendse, W., Ciani, E., Raadsma, H., McEwan, J., Dalrymple, B. & International Sheep Genomics Consortium Members. 2012. Genome-wide analysis of the world's sheep breeds reveals high levels of historic mixture and strong recent selection. *PLoS Biology*, 10: e1001258.

Larroque, H., Barillet, F., Baloche, G., Astruc, J., Buisson, D., Shumbusho, F., Clement, V, Lagriffoul, G., Palhiere, I., Rupp, R., Carillier, C., Robert-Granie, C. & Legarra, A. 2014. Toward genomic breeding programs in French dairy sheep and goats. In *Proceedings of the 10th World Congress of Genetics Applied to Livestock Production, 17–22 August 2014, Vancouver, Canada.*

Lavell, A. & Maskrey, A. 2013. The future of disaster risk management. An ongoing discussion. In *Draft synthesis document, meeting notes, background papers and additional materials from a scoping meeting for GAR 2014, San José, Costa Rica 18th to 19th April 2013,* pp 3–23. San José, United Nations Office for Disaster Risk Reduction (UNISDR) Facultad Latinoamericana de Ciencias Sociales (FLACSO) (available at http://tinyurl.com/qx67xnx).

Lee, Y.S., Lee, J.W. & Kim, H.B. 2014. Estimating effective population size of thoroughbred horses using linkage disequilibrium and theta (4Nμ) value. *Livestock Science*, 168: 32–37.

LEGS. 2009. *Livestock emergency guidelines and standards*. Rugby, UK, Livestock Emergency Guidelines and Standards Project, Practical Action Publishing (available at http://tinyurl.com/nlmy8wj).

Leroy, G., Mary-Huard, T., Verrier, E., Danvy, S., Charvolin, E. & Danchin-Burge, C. 2013. Methods to estimate effective population size using pedigree data: examples in dog, sheep, cattle and horse. *Genetics Selection and Evolution*, 45: 1.

LPPS. 2013. *The camels of Kumbhalgarh. A biodiversity treasure*. Sadri, India, Lokhit Pashu-Palak Sansthan (available at http://tinyurl.com/pax5kyy).

Lu, D., Sargolzaei, M., Kelly, M., Li, C., Vander Voort, G., Wang, Z., Plastow, G., Moore, S. & Miller, S.P. 2012. Linkage disequilibrium in Angus, Charolais, and crossbred beef cattle. *Frontiers in Genetics*, 3: 1–10.

NDMA. 2013. *Community resilience is not possible unless we address the animal disaster management issues*. Press release 17 April 2013. New Delhi, National Disaster Management Authority.

Nyariki, D.M., Makau, B.F., Ekaya, W.N. & Gathuma, J.M. 2005. *Guidelines for emergency livestock offtake. Handbook*. Arid Lands Resource Management Project, Office of the President. Nairobi, Agricultural Research Foundation.

Ojango, J., Oyieng, E., Audho, J. & Okeyo, A.M. 2014. *Indigenous sheep to help improve market access and livelihood security among pastoralists in Kenya: results of a baseline survey.* Nairobi, International Livestock Research Institute (available at http://tinyurl.com/puk3khb).

Rahman, M.M., Hoque, M.A., Saha, N.G. & Faruque, M.O. 2013.Studies on management system and identification of the causes of genetic erosion of indigenous cattle in Mymensingh district. *Bangladesh Journal of Animal Science*, 42(1): 23–28.

Rees-Roberts, T. undated. *History of the Lleyn*. Article on the website of the Lleyn Sheep Society (available at http://www.lleynsheep.com/society/history/) (accessed 28 July 2014).

Rege, J.E.O. & Gibson, J.P. 2003. Animal genetic resources and economic development: issues in relation to economic valuation. *Ecological Economics*, 45(3): 319–330 (available at http://tinyurl.com/nzl9k3w).

Rodríguez-Ramilo, S.T., Fernández, J., Toro, M.A., Hernández, D. & Villanueva, B. 2015. Genome-wide estimates of coancestry, inbreeding and effective population size in the Spanish Holstein population. *PLoS ONE*, 10(4): e0124157.

Sanders, S. 1919. *The pig. Breeding, rearing and marketing*. London, C. Arthur Pearson Ltd. (available at http://tinyurl.com/p2rhwqt).

Shaw, T. 1900. *The study of breeds in America: cattle, sheep and swine*. New York, USA, Orange Judd (available at http://tinyurl.com/pel2kyb).

Simpkin, S.P. 2005. *Regional livestock study in the Greater Horn of Africa*. Nairobi, International Committee of the Red Cross (available at http://tinyurl.com/ngcqbgm).

Taye, T., Ayalew, W. & Hegde, B.P. 2009. Status of Ethiopian indigenous Sheko cattle breed and the need for participatory breed management plan. *Ethiopian Journal of Animal Production*, 9(1): 1–12. (available at http://tinyurl.com/os3va5p).

Thomasen, J.R., Sørensen, A.C., Su, G., Madsen, P., Lund, M.S. & Guldbrandtsen, B. 2013. The admixed population structure in Danish Jersey challenges accurate genomic predictions. *Journal of Animal Science*, 91: 3105–3112.

Tisdell, C. 2003. Socioeconomic causes of loss of animal genetic diversity: analysis and assessment. *Ecological Economics*, 45(3): 365–376 (available at http://tinyurl.com/otvvjss).

Uimari, P. & Tapio, M. 2011. Extent of linkage disequilibrium and effective population size in Finnish Landrace and Finnish Yorkshire pig breeds. *Journal of Animal Science*, 89(3): 609-614–28.

UNISDR. 2013. *From shared risk to shared value – the business case for disaster risk reduction. Global assessment report on disaster risk reduction.* Geneva, Switzerland, United Nations Office for Disaster Risk Reduction (available at http://tinyurl.com/oh8s4tg).

Vaughan, H.W. 1931. *Breeds of live stock in America*. Columbus, Ohio, USA, R.G. Adams and Company (available at http://tinyurl.com/omwhybj).

Welsh, C.S., Stewart, T.S., Schwab, C. & Blackburn, H.D. 2010. Pedigree analysis of 5 swine breeds in the United States and the implications for genetic conservation. *Journal of Animal Science*, 88(5): 1610–1618.

Wilson, J. 1909. *The evolution of British cattle and the fashioning of breeds*. London, Vinton & Company (available at http://tinyurl.com/pqc7wwo).

Wiseman, J. 2000. *The pig. A British history*. Second Edition. London, Gerald Duckworth & Co. Ltd.

World Bank. 2014. *Reducing climate sensitive disease risks*. Agriculture and Environmental Services Discussion Paper 07. World Bank Report Number 84956-GLB. Washington DC (available at http://tinyurl.com/knmj6ww).

Wrightson, J. 1913. *Sheep breeds and management*. London, Vinton & Company Ltd. (available at http://tinyurl.com/pb7mavk).

Youatt, W., Martin, W.C.L. & Stevens, A. 1855. *The hog: a treatise on the breeds, management, feeding, and medical treatment of swine: with directions for salting pork and curing bacon and hams.* New York, USA, Orange Judd (available at http://tinyurl.com/nt6vjlx).

Yosef, T., Mengistu, U., Solomon, A., Mohammed, Y.K. & Kefelegn, K. 2013. Camel and cattle population dynamics and livelihood diversification as a response to climate change in pastoral areas of Ethiopia. *Livestock Research for Rural Development,* 25: Article 166 (available at http://www.lrrd.org/lrrd25/9/yose25166.htm).

Zander, K.K. 2011. Attitudes of livestock keepers to breeding strategies – threats and opportunities for on-farm conservation of the Borana cattle breed. *Journal of Agricultural Science*, 3(2): 3–12.

Section G

Livestock diversity and human nutrition

1 Introduction

Genetics has a major influence on the composition of animal-source foods (primary foods, such as meat, offal, milk and eggs, and products such as cheese and sausages). Foods obtained from different animal species differ, to varying degrees, in both their macronutrient and their micronutrient compositions. Nutrient composition is also affected by processing methods and, in the case of meat, is affected by the particular cut or part of the animal from which it comes. Meat from one species can contain more than twice as much fat as the equivalent cut from another species. For example, pork loin (taking the lean part of the cut into consideration) contains 2.2 g of fat/100 g edible portion on a fresh weight basis (EP), while the equivalent figure for beef loin is 5.1 g/100 g EP. The iron content of pork liver is 23.3 mg/100 g EP, while that of beef liver is less than 5 mg/100 g. Further examples are shown in Table 1G1.

This section focuses on the influence of genetics on the nutritional contents of raw primary animal-source foods. The first subsection below discusses the increasing interest in food biodiversity witnessed in recent years and the degree to which this trend has extended into the livestock sector.[1] This is followed by a look at efforts that have been made to assemble and disseminate information on the topic and then by an overview of the state of knowledge regarding the potential significance for human nutrition of genetic influence on the composition of animal-source foods. The final subsection identifies some research priorities in this field.

[1] The inclusion of this section devoted to livestock diversity and human nutrition, for which there was no equivalent in the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007a), is an indication of this growing interest.

2 Growing interest in food biodiversity

While nutritional differences between foods obtained from the most widely used livestock species (cattle, pigs, chickens, sheep and goats) have been relatively well documented, less attention has been paid to foods obtained from other species and to differences between products obtained from different breeds within species. Recent years have, however, seen growing interest in food biodiversity. For example, in 2006, the Convention on Biological Diversity adopted a framework for a cross-cutting initiative on biodiversity for food and nutrition (CBD, 2006). In 2007, the Commission on Genetic Resources for Food and Agriculture decided to integrate work on biodiversity and nutrition into its Multi-Year Programme of Work (FAO, 2007b). Food biodiversity in this context is defined as "food identified at the taxonomic level below the species level, and underutilized or wild species" (FAO, 2013a).

While work on food biodiversity is less advanced in animals than it is in plants, some studies have looked at nutritional differences between cattle milk and milk from "underutilized" species. For example, horse milk has been shown to be lower in fat than cattle milk. Moreover, the fatty-acid profile of milk from these two species is different, with horse milk being higher in total n-3 fatty acids.

TABLE 1G1

Nutrient composition of selected animal-source foods

Animals-source foods	Energy*	Moisture	Protein	Fat	Available carbo-hydrates**	Ash	SFA	MUFA	PUFA	Calcium	Iron	Zinc	Vitamin A, RAE	Vitamin B12
	kJ (kcal)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(mg)	(mg)	(mg)	(µg)	(µg)
Beef, tenderloin steak, lean, raw[a]	566 (135)	73.0	22.2	5.1	0	1.1	1.71	1.80	0.38	14	2.48	3.37	2	3.7
Pork, tenderloin, lean, raw[a]	436 (103)	76.0	21.0	2.2	0	1.0	0.70	0.79	0.37	5	0.98	1.89	0	0.5
Beef, liver, raw[a]	546 (130)	70.8	20.4	3.6	3.9	1.3	1.23	0.48	0.47	5	4.90	4.00	4968	59.3
Pork, liver, raw[a]	542 (129)	71.1	21.4	3.7	2.4	1.4	1.17	0.52	0.87	9	23.30	5.76	6502	26.0
Mutton, shoulder, raw[d]	947 (228)	62.7	18.7	17.0	0	1.6	8.30	6.40	0.80	8	1.8	3.50	45	5
Mutton, round, raw[d]	564 (134)	71.9	20.1	6.0	0	2.0	2.90	2.30	0.30	8	2.4	3.70	45	3.0
Goat, meat, raw[c]	690 (165)	68.0	17.5	10.6	0	1.1	-	-	-	11	2.4	3.45	0	1.1
Chicken, breast, raw[a]	479 (114)	73.9	22.5	2.6	0	1.1	0.56	0.69	0.42	5	0.37	0.68	7	0.2
Turkey, breast, raw[a]	457 (108)	74.9	23.7	1.5	0	1.0	0.29	0.26	0.26	11	0.73	1.28	6	0.6
Egg, chicken, whole, raw[a]	577 (139)	76.2	12.6	9.5	0.7	1.1	3.13	3.66	1.91	56	1.75	1.29	160	0.9
Egg, ostrich, whole, raw[b]	640 (154)	75.1	12.2	11.7	0	1.4	-	-	-	65	2.5	1.34	6***	-
Milk, goat[c]	318 (76)													
Milk, cattle, whole, 3.25% milkfat[a]	256 (61)	88.1	3.2	3.3	4.8	0.7	1.87	0.81	0.20	113	0.03	0.37	46	0.5

Note: All nutrient values are expressed per 100 g edible portion on fresh weight basis (EP); SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; RAE = retinol activity equivalents. Slaughter weight and degree of maturity at slaughter weight will influence the compositions.

* Calculated using the following factors: 1 g fat = 37 kJ (9 kcal); 1 g carbohydrates = 17 kJ (4 kcal); 1 g protein = 17 kJ (4 kcal).

** Calculated as 100 - (moisture + protein + fat + dietary fibre + ash), or assumed zero for flesh meat.

*** In this case, vitamin A contents were expressed in retinol equivalents (RE).

[a] USDA–ARS, 2013 (food item ID 23374, 10060, 13325, 10110, 05062, 05219, 01123, 01211); [b] Sayed *et al.*, 1999 (food item ID 7_4317); [c] Stadlmayr *et al.*, 2012 (food item ID 07_046); [d] Saxholt *et al.*, 2008 (food item ID 0053, 0054).

For human populations that have no access to essential n-3 fatty acids from fish (e.g. those in landlocked areas such as Mongolia), horse milk can potentially make an important contribution to meeting nutritional requirements. Horse milk has also been found to be more similar than cattle milk to human milk in terms of protein and lactose content, fatty-acid and protein profiles, and mineral content (which is fairly low); it can potentially therefore be regarded as a better food for human infants than cattle milk (Iacono *et al.*, 1992; Malacarne *et al.*, 2002, cited in Wijesinha-Bettoni and Burlingame, 2013).

Because of the confounding effects of factors such as management practices, it is more difficult to assess the influence of breed on the nutritional composition of animal-source foods than it is in the case of plant-source foods. The feed given to animals strongly influences meat, milk and egg composition, especially their fatty-acid composition (Woods and Fearon, 2009). Production system and the animal's sex and its age and weight at slaughter also affect meat composition. Milk composition is affected both by the feed eaten by the animal and by its stage of lactation. It is also affected by the number of times the animal has given birth (parity), seasonal variation and the animal's age and health. This shows that comparing findings from different studies is not straightforward, and this may be part of the reason why far fewer studies on breed-level effects on the nutrient composition of animal-source foods are available in the scientific literature than studies on effects at the cultivar and variety level in plants.

Most research on breed-level differences addresses economically significant production outcomes such as milk or meat yield, carcass composition and product quality, rather than differences in nutritional composition. However, some of the attributes investigated in such studies may be closely linked to compositional characteristics that are relevant to human nutrition. For example, intramuscular fat in meat cuts is positively associated with sensory properties such as juiciness, flavour and tenderness as perceived by consumers (Hocquette *et al.*, 2010). The fat content of muscles and the fatty-acid composition of this fat also have nutritional implications (Sevane *et al.*, 2014; Scollan *et al.*, 2014; Scollan *et al.*, 2006). Studies in various species, in both developed and developing countries, have shown the effect of breed on meat quality, both in terms of instrumental measurements (colour, water-holding capacity, collagen content, shear values, etc.) and in terms of sensorial attributes (tenderness, flavour, juiciness, etc.) (Chambaz *et al.,* 2003; Dyubele *et al.,* 2010; Jelenikova *et al.,* 2008; Li *et al.,* 2013; Muchenje *et al.,* 2008; Sanudo *et al.,*1997).

Studies of potential breed-level differences in nutrient composition have often targeted the most widespread transboundary breeds. However, a few comparative studies have evaluated locally adapted breeds (Jayansan *et al.*, 2013; Pavloski *et al*, 2013; Xie *et al.*, 2012). Breed-level data on mineral and vitamin content are scarce. Hardly any review papers or meta-analyses that provide breed-level compositional data or analyse possible differences in nutrient values have been published.

3 Filling the knowledge gap

FAO has contributed to filling the knowledge gap on biodiversity and nutrition by developing the FAO/INFOODS Food Composition Database for Biodiversity (BioFoodComp) (FAO, 2013b). The database includes data on several animal-source foods: milk from buffalo breeds and minor dairy species (273 food records, representing a total of 92 breeds) (Medhammar *et al.*, 2012); and beef (213 food records, 49 breeds) (Barnes *et al.*, 2012). Data on pork (253 food records, 110 breeds/genotypes) (Kerns *et al.,* 2015; FAO, 2015) will be added to the next version of the database. BioFoodComp has become the most comprehensive global repository of nutrient values of foods described at breed level and foods from underutilized species.

As discussed above, multiple factors influence the composition of animal-source foods and it is therefore difficult to compare compositional

data from the various studies used to populate the BioFoodComp database. The protein content in milk is very stable with respect to changes in animal nutrition and feeding practices; however, the fat content and fatty-acid composition of milk are strongly affected (Walker *et al.*, 2004; Jenkins and McGuire, 2006; Laben, 1963), which complicates the interpretation of data related to these nutrients. Stage of lactation greatly influences both fat and protein content. An inverse trend to the lactation curve can generally be observed in most species, i.e. fat and protein contents are higher in early and late lactation and lower in mid lactation. Where beef is concerned, factors such as nutrition and genetics have less influence on protein content and amino acid profile, but it is recognized that micronutrient content, fat content and fatty-acid composition may be altered (Scollan *et al.*, 2006; 2014). Genetic factors generally produce smaller differences in the fatty-acid composition of meat than dietary factors (De Smet *et al.*, 2004; Shingfield, Bonnet and Scollan, 2013).

While potential confounding effects need to be borne in mind, it is interesting to note the breed-level differences in nutritional content recorded in BioFoodComp. Medhammar *et al.* (2012) report differences in milk composition for different buffalo, yak, horse and dromedary breeds. Fat and protein contents vary significantly between breeds, with differences of approximately 4 g fat and 2 g protein per 100 g milk between the highest and lowest values. Protein values for buffalo milk range from 2.7 g to 4.6 g/100 g, meaning a difference of more than 41 percent between the breeds with the highest and the lowest values. Large variations are also reported for mineral and vitamin contents. For example, calcium content is reported to differ by 73 mg/100 g between the breed with the lowest value, the Kuttanad Dwarf buffalo, and the breed with the highest value, the Egyptian buffalo. Differences between breeds, albeit smaller, are also recorded for horse milk (48 mg/100 g) and dromedary milk (15 mg/100 g). Table 1G2 presents a selection of milk-nutrient composition ranges for buffaloes, horses and dromedaries.

Data on beef and pork show between-breed differences in nutrient values for the same raw meat cut. Barnes *et al.* (2012) studied compositional data on beef from more than 30 different breeds published in BioFoodComp. Recorded fat values for the longissimus muscle range from 0.6 g to 16.0 g/100 g EP, with the lowest values reported for a Hereford–Friesian cross and highest for the Hanwoo. Value ranges for a selection of other nutrients are presented in Table 1G3. In pork, recorded fat content ranges from 0.7 g to 18.2 g fat per 100 g EP, the lowest value being from the Landrace and the highest from the Mangalitsa (Kerns *et al.,* 2015; FAO, 2015). These variations affect the saturated and mono- and polyunsaturated fatty acid contents of the meat, as well as its cholesterol content. Hardly any data on mineral and vitamin composition are available for beef or pork.

4 Potential significance for human nutrition

Animal-source foods are energy dense and are a rich source of protein, minerals, vitamins and essential fatty acids. The protein in these foods is considered to be of the highest quality because of its favourable amino-acid composition. Iron, zinc and vitamin A are the main micronutrients available in meat; calcium, vitamin B12 and riboflavin are provided in abundance by milk, which is however very low in iron. Compared to foods derived from plants, the bioavailability of these nutrients in animal-source foods is high, because of the presence of haeme-protein and the absence of phytates and fibre (Neumann *et al.*, 2002).

The roles of animal-source foods in human nutrition have been widely discussed, including their roles in alleviating undernutrition and deficiencies that lead to poor growth, impaired mental development and ill health (e.g. Dror and Allen, 2011; Neumann *et al.*, 2002; Neumann *et al.*, 2010) and their beneficial and potential negative roles with respect to diet-related non-communicable diseases (e.g. Weaver *et al.*, 2013; Givens, 2010; McAfee *et al.*, 2010).

TABLE 1G2

Selected nutrient composition ranges for milk from buffalo, horse and dromedary breeds

	Average ± SD	Range	Breed with lowest value	Breed with highest value
Buffalo-milk composition (values per 100 g milk)				
Protein (g)	4.0 ± 0.5 n = 42	2.7–4.6	Non-descript hill buffalo (Kumaon region, India)	Mediterranean
Fat (g)	7.4 ± 0.9 n = 75	5.3–9.0	Bulgarian x Murrah breed (Bulgaria)	Bhadawari
Lactose (g)	4.4 ± 0.6 n = 23	3.2–4.9	Kuttanad Dwarf (Kerala, India)	Bulgarian Murrah
Calcium (mg)	191 ± 38 n = 9	147–220	Kuttanad Dwarf (Kerala, India)	Egyptian
Magnesium (g)	12 ± 5 n = 6	2–16	Kuttanad Dwarf (Kerala, India)	Murrah (Bombay, India; France)
Horse-milk composition (values per 100 g milk)				
Protein (g)	2.0 ± 0.4 n = 33	1.4–3.2	Sana, "mtsyri"	Palomino
Fat (g)	1.6 ± 0.7 n = 45	0.5–4.2	Lusitano	Saddle pony
Lactose (g)	6.6 ± 0.4 n = 31	5.6–7.2	Buryat	Trotters
Calcium (mg)	95 ± 19 n = 26	76–124	Thoroughbred	Palomino
Magnesium (mg)	7 ± 2 n = 18	4-12	Lusitano	Palomino
Zinc (mg)	0.2 ± 0.1 n = 8	0.2-0.3	Shetland	Italian saddle horse
Vitamin C (mg)	4.3 ± 3.3 n = 6	1.7–8.1	Saddle pony	Palomino
Dromedary-milk composition (values per 100 g milk)				
Protein (g)	3.1 ± 0.5 n = 12	2.4–4.2	Kachchhi	Wadah
Fat (g)	3.2 ± 1.1 n = 23	2.0–6.0	Kachchhi	Arvana
Lactose (g)	4.3 ± 0.4 n = 15	3.5-4.9	Arvana	Hamra
Calcium (mg)	114 ± 6 n = 5	105–120	Arvana	Majaheem
Magnesium (mg)	13 ± 1 n = 4	12-14	Hamra	Najdi
Zinc (mg)	0.6 ± 0.1 n = 4	0.4-0.6	Najdi	Majaheem
Vitamin C (mg)	6.7 ± 7 n = 5	2.5–18.4	Majaheem	Arvana

Note: Locations, where listed, indicate the places of origin of the animals from which milk samples were taken for analysis.
n = number of total data points (where data for the same dairy breed were available from more than one study, the mean value for the breed was calculated and used; n represents the number of data points before averaging for breed). Composition is affected by management factors as well as by genetics (see main text for further discussion).
Source: Adapted from Medhammar *et al.*, 2012.

TABLE 1G3
Selected nutrient composition ranges for beef (longissimus muscle) from different cattle breeds

Nutrients	Average ± SD	Range	Breed with lowest value	Breed with highest value
Protein (g)	21.8 ± 1.1 n = 64	18.6–25.7	Brown Swiss (Spain)	Criollo Argentino (Argentina)
Fat (g)	3.2 ± 2.7 n = 123	0.6–16	Hereford–Friesian cross (New Zealand)	Hanwoo (Republic of Korea)
Cholesterol (mg)	48 ± 9 n = 22	36–68	Bonsmara (South Africa)	Aberdeen Angus (Czech Republic)
SFA (g)	1.54 ± 1.69 n = 63	0.14–8.39	Austriana Valles (Spain)	Hanwoo (Republic of Korea)
MUFA (g)	1.36 ± 1.27 n = 62	0.10–5.92	Austriana Valles (Spain)	Hanwoo (Republic of Korea)
PUFA (g)	0.26 ± 0.23 n = 58	0.08–1.46	Criollo Argentino (Argentina)	Charolais × Angus (Argentina)
FA C14:0 (g)	0.08 ± 0.01 n = 86	0.01–0.60	Austriana Valles (Spain)	Hanwoo (Republic of Korea)
FA C18:2 n-6 (LA) (g)	0.13 ± 0.10 n = 47	0.02–0.43	Bonsmara (South Africa)	Aberdeen Angus (Czech Republic)
FA C20:5 n-3 (EPA) (g)	0.01 ± 0.01 n = 46	<0.01–0.04	Tudanca (Spain)	Barrosa (Portugal)

Note: Values per 100 g edible portion on fresh weight basis; n = number of total data points (nutrient values of same breeds have not been averaged); FA = fatty acid; SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; LA = linoleic acid; EPA = eicosapentaenoic acid. Locations indicate the places of origin of the animals from which meat samples were taken for analysis. Composition is affected by management factors as well as by genetics (see main text for further discussion).
Sources: Barnes *et al.*, 2012; FAO, 2013b.

Dietary fat receives a lot of attention with regard to its roles in the epidemiology of non-communicable diseases such as cardiovascular pathologies, cancer and type-2 diabetes (e.g. WHO/FAO, 2003; FAO, 2010). These diseases are becoming more common in both developed and developing countries (WHO/FAO, 2003). Emphasis has been placed on reducing the intake of total fat, saturated fatty acids (SFA – considered to be associated with increased LDL-cholesterol) and increasing the intake of n-3 polyunsaturated fatty acids (PUFA – recognized to be protective against cardiovascular diseases and to play a beneficial role in terms of promoting general health). Dietary recommendations have been published for fatty-acid classes as well as for specific fatty acids (FAO, 2010).

Meat plays an important role in the diet of many populations, and although the general contribution of meat to fat supply in the human diet is low (less than 20 percent) (Culioli *et al.*, 2003), identifying breeds whose products have beneficial fatty-acid profiles has the potential to contribute to healthier diets (e.g. Sevane *et al.*, 2014). A comparison of beef from three breeds (Cuvelier *et al.*, 2006) showed large between-breed differences in SFA content: Belgian Blue, Limousin and Aberdeen Angus, respectively, provided 2.2 percent, 6.2 percent and 9.2 percent of the recommended SFA intake. Large differences in n-3 PUFA content between these breeds were also reported.

In low-input systems, cross-breeding with exotic breeds can potentially lead to lower nutrient densities in milk, with potential consequences for human nutrition. Mapekula *et al.* (2011) report an instance of this effect in dairy cattle grazed on rangeland in South Africa and note that it may be related to the cross-bred animals having a lower capacity to convert poor-quality feed into milk protein.

Micronutrient malnutrition (i.e. vitamin and mineral nutritional deficiency) is very prevalent in developing countries. Milk is considered to be an important source of zinc for children at risk of micronutrient deficiencies (Neumann *et al.*, 2002). Two cups (500 ml) of milk per day provide 24 to 72 percent of the recommended nutrient intake (RNI) of zinc for children in the one-year to three-year age group, depending on the species of the dairy animal (Table 1G4). Between-breed differences can be almost as large as those between species. For example, according to the figures presented in Table 1G2, two cups of milk from the Najdi breed of dromedary provide less than 50 percent of the zinc RNI per day for children in this age group, while the equivalent amount from the Majaheem breed provides more than 70 percent.

Findings on the vitamin C content of horse and dromedary milk are also interesting: while two cups of milk from the breeds whose milk has the lowest reported vitamin C content supply less than 50 percent of the RNI for children aged one to three years, the equivalent amount of milk from the breeds whose milk has the highest vitamin C content exceeds the RNI, with milk from the Palomino horse supplying 132 percent of the RNI and milk from the Arvana dromedary supplying 301 percent. The large amount of vitamin C in dromedary milk is recognized as being important in desert areas, where vegetables and fruits are scarce (Barłowska *et al.*, 2011). Cattle milk, in contrast, is reported to be low in vitamin C.

5 Research priorities

The composition of animal-source foods is influenced by a number of different factors. Some comparative studies that assess the effect of breed *per se* and identify nutritional differences by controlling for other factors have been undertaken. However, high-quality studies are lacking, i.e. studies that include all the necessary information on confounding factors and analytical methods used and, preferably, have a control group for comparison. Meta-analyses that enable sound conclusions to be drawn from results obtained in different studies are needed. There is also a need to expand the range of species and breeds targeted by nutritional composition studies. Studies often focus on a narrow range of nutrients that influence product quality. Research needs to target a wider range of nutrients of public-health concern, including studies on amino-acid composition and protein digestibility. Data on vitamin and mineral contents are particularly needed.

TABLE 1G4

Mineral content of milk from various species in relation to recommended nutrient intake

Minerals	RNI for children aged 1–3 years Breed with lowest value	Buffalo		Horse		Dromedary		Cattle
		Breed with lowest value	Breed with highest value	Breed with lowest value	Breed with highest value	Breed with lowest value	Breed with highest value	Average value
Calcium (mg)	500	✓✓	✓✓	✓	✓✓	✓✓	✓✓	✓✓
Magnesium (mg)	60		✓✓		✓	✓	✓✓	✓
Zinc (mg)	4.1	n/a	n/a				✓	
Vitamin C (mg)	30	n/a	n/a		✓✓		✓✓	

Note: RNI = recommended nutrient intake values for children aged 1-3 years (FAO, 2002).
✓✓ = 100% of RNI supplied by 2 cups (500 ml) of milk; ✓ = 70–99% of RNI supplied by 2 cups (500 ml) of milk; empty cells = less than 70% of RNI supplied by 2 cups (500 ml) of milk; n/a = data unavailable.
Sources: RNI supply for buffalo, horse and dromedary milk is calculated using the nutrient values presented in Table 1G2. Cattle data are from USDA–ARS, 2013.

Given that there is evidence that breed influences the composition of animal-source foods, there is a need to:

- obtain data on different breeds and their production environments, so as to be able to disentangle genetic and environmental factors;
- generate, compile and disseminate more compositional data on animal-source foods from different breeds, especially locally adapted breeds;
- further investigate evidence for the significance of species- and breed-level differences to human health by developing meta-analysis approaches and strategies for avoiding confounding effects (such as differences in nutritional habits other than consumption of meat and dairy products); and
- take information on the composition of animal-source foods into account in nutrition and agricultural policies and programmes.

References

Barłowska, J., Szwajkowska, M., Litwińczuk, Z. & Król, J. 2011. Nutritional value and technological suitability of milk from various animal species used for dairy production. *Comprehensive Reviews in Food Science and Food Safety*, 10: 291–302.

Barnes, K., Collins, T., Dion, S., Reynolds, H., Riess, S., Stanzyk, A., Wolfe, A., Lonergan, S., Boettcher P., Charrondiere, U.R. & Stadlmayr, B. 2012. Importance of cattle biodiversity and its influence on the nutrient composition of beef. *Animal Frontiers*, 2: 54–60.

CBD. 2006. *Decision adopted by the Conference of the Parties to the Convention on Biological Diversity at its Eighth Meeting VIII/23. Agricultural biodiversity*. Conference of the Parties to the Convention on Biological Diversity, Eighth meeting Curitiba, Brazil, 20–31 March 2006. Montreal, Canada (available at http://www.cbd.int/doc/decisions/cop-08/cop-08-dec-23-en.pdf).

Chambaz, A., Scheeder, M.R.L., Kreuzer, M. & Dufey, P.A. 2003. Meat quality of Angus, Simmental, Charolais and Limousin steers compared at the same intramuscular fat content. *Meat Science*, 63: 491–500.

Culioli, J., Berri, C. & Mourot, J. 2003. Muscles foods: consumption and composition. *Sciences des Aliments*, 23: 13–34.

Cuvelier, C., Clinquart, A., Hocquette, J.F., Cabaraux, J.F., Dufrasne, I., Istasse, L. & Hornick, J.L. 2006. Comparison of composition and quality traits of meat from young finishing bulls from Belgian Blue, Limousin and Aberdeen Angus breeds. *Meat Science*, 74: 522–531.

De Smet, S., Raes, K. & Demeyer, D. 2004. Meat fatty acid composition as affected by fatness and genetic factors: a review. *Animal Research*, 53: 81–98.

Dror, D.K. & Allen, L.H. 2011. The importance of milk and other animal-source foods for children in low-income countries. *Food and Nutrition Bulletin*, 32(3): 227–243.

Dyubele, N.L., Muchenje V, Nkukwana T.T., & Chimonyo M. 2010. Consumer sensory characteristics of broiler and indigenous chicken meat: a South African example. *Food Quality and Preference*, 21: 815–819.

FAO. 2002. *Human vitamin and mineral requirements. Report of a joint FAO/WHO expert consultation.* FAO/WHO non-series publication. Rome (available at http://www.fao.org/docrep/004/y2809e/y2809e00.htm).

FAO. 2007a. *The state of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2007b. *Report of the Eleventh Regular Session of the Commission on Genetic Resources for Food and Agriculture. Rome, 11–15 June 2007.* CGRFA-11/07/Report. Rome (available at ftp://ftp.fao.org/docrep/fao/meeting/014/k0385e.pdf).

FAO. 2010. *Fats and fatty acids in human nutrition. Report of an expert consultation.* FAO Food and Nutrition Paper. No. 91. Rome (available at http://www.fao.org/docrep/013/i1953e/i1953e00.pdf).

FAO. 2013a. *Review of key issues on biodiversity and nutrition*. Working Document. Fourteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture, Rome, 15–19 April 2013 (CGRFA-14/13/8). Rome (available at http://www.fao.org/docrep/meeting/027/mf917e.pdf).

FAO. 2013b. *FAO/INFOODS Food Composition Database for Biodiversity Version 2.1 –BioFoodComp2.1*. Rome

(available at http://www.fao.org/infoods/infoods/food-biodiversity/en/).

FAO. 2015. *FAO/INFOODS Food Composition Database for Biodiversity Version 3.0 - BioFoodComp3.0*. Rome (available at http://www.fao.org/infoods/infoods/food-biodiversity/en/).

Givens, D.I. 2010. Milk and meat in our diet good or bad for health? *Animal*, 4: 1941–1952.

Higenyi, J., Kabasa, J.D., & Muyanja, C. 2014. Social and quality attributes influencing consumption of native poultry in eastern Uganda. *Animal and Veterinary Sciences*, 2(2): 42–48.

Hocquette, J.F., Gondret, F., Baéza, E., Médale, F., Jurie, C. & Pethick, D.W. 2010. Intramuscular fat content in meat-producing animals: development, genetic and nutritional control, and identification of putative markers. *Animal*, 4: 303–319.

Jayasena, D.D., Jung, S., Kim, H.J., Bae, Y.S., Yong, H.I., Lee, J.H., Kim, J.G. & Jo., C. 2013. Comparison of quality traits of meat from Korean native chickens and broilers used in two different traditional Korean cuisines. *Asian Australian Journal of Animal Science*, 26: 1038–1046.

Jelenikova, J., Pipek P. & Miyahara, M. 2008. The effects of breed, sex, intramuscular fat and ultimate pH on pork tenderness. *European Food Research and Technology*, 227(4): 989–994.

Jenkins, T.C. & McGuire, A. 2006. Major advances in nutrition: impact on milk composition. *Journal of Dairy Science*, 89(4): 1302–1310.

Kerns, M., Rossman, B., Liewer, S., Powell, M., Herr, S., Taylor, S., Colletti, J., Lonergan, S.M., Boettcher, P. & Charrondiere, R. 2015. Documentation of factors that contribute to the variation of pork nutrient composition. *Journal of Animal Science*, 93 (Suppl. 2): 72.

Laben, R.C. 1963. Factors responsible for variation in milk composition. *Journal of Dairy Science*, 85(1): 190–197.

Li, Y.X, Cabling, M.M., Sang, H.S., Kim, T.S., Yeom, S.C., Sohn, Y.G., Kim, S.H., Nam, K.C. & Seo, K.S. 2013. Comparison and correlation analysis of different swine breeds meat quality. *Asian-Australasian Journal of Animal Sciences*, 26(7): 905–910.

Mapekula, M., Chimonyo, M., Mapiye, C. & Dzama, K. 2011. Fatty acids, amino acids and mineral composition of milk from Nguni and local crossbred cows in South Africa. *Journal of Food Composition and Analysis*, 24: 529–536.

McAfee, A.J., McSorley, E.M., Cuskelly, G.J., Moss, B.W., Wallace, J.M.W., Bonham, M.P. & Fearon, A.M. 2010. Red meat consumption: An overview of the risks and benefits. *Meat Science*, 84: 1–13.

Medhammar, E., Wijesinha-Bettoni, R., Stadlmayr, B., Nilsson, E., Charrondiere, U.R. & Burlingame, B. 2012. Composition of milk from minor dairy animals and buffalo breeds: a biodiversity perspective. *Journal of the Science of Food and Agriculture*, 92(3), 445–474.

Neumann, C.G., Bwibo, N.O., Gewa, C.A. & Drorbaugh, N. 2010. Animal-source foods as a food-based approach to address nutrient deficiencies and functional outcomes: A study among Kenyan schoolchildren. *In* B. Thompson & L. Amoroso, eds. *Combating micronutrient deficiencies: food-based approaches*. Rome, FAO, CAB International (available at http://www.fao.org/docrep/013/am027e/am027e.pdf).

Neumann, C.G., Harris, D.M. & Rogers, L.M. 2002. Contribution of animal source foods in improving diet quality and function in children in the developing world. *Nutrition Research*, 22: 193–220.

Pavolski, Z., Skrbic, Z., Stanisic, N., Lilic, S., Hengl, B., Lukic, M. & Petricevic, V. 2013. Differences in fatty acid composition of meat between naked neck and two commercial broiler chicken breeds. *Biotechnology in Animal Husbandry*, 29(3): 467–476.

Sanudo, C., Alfons, M., Sanchez, A., Delfa, R., & Teixeira, A. 2000. Carcass and meat quality in light lambs from different fat classes in the EU carcass classidication system. *Meat Science*, 56: 89–94.

Sayed, N., Frans, Y. & Schönfeldt, H.C. 1999. *Composition of South African foods: milk and milk products, eggs, meat and meat products: supplement to the MRC food composition of tables 1991*. Parow, South Africa, Medical Research Council.

Saxholt, E., Christensen, A.T., Møller, A., Hartkopp, H.B., Hess Yigil, K. & Hels, O.H. 2008. *Danish food composition databank, revision 7.01*. Department of Nutrition, National Food Institute, Technical University of Denmark (available at www.foodcomp.dk/).

Scollan, N.D., Dannenberger, D., Nuernberg, K., Richardson, I., MacKintosh, S., Hocquette, J.-F. & Moloney A.P. 2014. Enhancing the nutritional and health value of beef lipids and their relationship with meat quality. *Meat Science*, 97: 384–394.

Scollan, N., Hocquette, J-F., Nuernberg, K., Dannenberger, D., Richardson, I. & Moloney, A. 2006. Innovations in beef production systems that enhance the nutritional and health value of beef lipids and their relationship with meat quality. *Meat Science*, 74: 17–33.

Sevane, N., Nute, G., Sañudo, C., Cortes, O., Cañon, J., Williams, J.L., Dunner, S. & the GemQual Consortium. 2014. Muscle lipid composition in bulls from 15 European breeds. *Livestock Science*, 160: 1–11.

Shingfield, K.J., Bonnet, M. & Scollan, N.D. 2013. Recent developments in altering the fatty acid composition of ruminant-derived foods. *Animal*, 7(s1): 132–162.

Stadlmayr, B., Charrondiere, U.R., Enujiugha, V.N., Bayili, R.G., Fagbohoun, E.G., Samb, B., Addy, P., Barikmo, I., Ouattara, F., Oshaug, A., Akinyele, I., Annor, G.A., Bomfeh, K., Ene-Obong, H., Smith, I.F., Thiam, I. & Burlingame, B. 2012. *West African Food Composition Table / Table de composition des aliments d'Afrique de l'Ouest*. Rome, FAO (available at http://www.fao.org/infoods/infoods/tables-and-databases/africa/en/).

USDA–ARS. 2013. *USDA National Nutrient Database for Standard Reference, Release 26*. Nutrient Data Laboratory, Beltsville Human Nutrition Research Center, Agriculture Research Service, United States Department of Agriculture (retrieved from http://www.ars.usda.gov/ba/bhnrc/ndl).

Walker, G.P., Dunshea F.R. & Doyle, P.T. 2004. Effects of nutrition and management on the production and composition of milk fat and protein: a review. *Australian Journal of Agricultural Research*, 55: 1009–1028.

Weaver, C., Wijesinha-Bettoni, R., McMahon, D. & Spence, L. 2013. Milk and dairy products as part of the diet. *In* E. Muehlhoff, A. Bennett & D. McMahon, eds. *Milk and dairy products in human nutrition*. Rome, FAO (available at http://www.fao.org/docrep/018/i3396e/i3396e.pdf).

WHO/FAO. 2003. *Report of a joint WHO/FAO expert consultation on diet, nutrition and the prevention of chronic diseases*. WHO Technical Report Series 916. Geneva (available at http://www.fao.org/docrep/005/ac911e/ac911e00.htm#Contents).

Wijesinha-Bettoni, R. & Burlingame, B. 2013. Milk and dairy product composition. *In* E. Muehlhoff, A. Bennett & D. McMahon, eds. *Milk and dairy products in human nutrition*. Rome, FAO (available at http://www.fao.org/docrep/018/i3396e/i3396e.pdf).

Woods, V.B. & Fearon, A.M. 2009. Dietary sources of unsaturated fatty acids for animals and their transfer into meat, milk, and eggs: A review. *Livestock Science*, 126: 1–20.

Xie, X., Meng, Q., Cui, Z. & Ren, L. 2012. Effect of cattle breed on meat quality, muscle characteristics, lipid oxidation and fatty acids in China. *Asian Australian Journal of Animal Science*, 25(6): 824-831.

Part 2

LIVESTOCK SECTOR TRENDS

Introduction

Livestock production systems are the context in which animal genetic resources (AnGR) are used and developed. As production systems change, new demands are placed upon AnGR, threats may arise and new opportunities for sustainable use may emerge. This part of the report reviews production system trends and their influence on AnGR management. It serves as an update of Part 2 of the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* and focuses particularly on recent developments.

Section A discusses the major drivers of change in the global livestock sector. Section B considers how these trends are affecting different production systems. Section C, drawing mainly on the material provided in the country reports,[1] looks at how AnGR management is being affected by production system trends and how this may change during the coming years. Section D offers some conclusions based on the analysis presented in the other sections.

[1] For further information on the reporting process, see "About this publication" in the preliminary pages of this report.

Section A

Drivers of change in the livestock sector

1 Introduction

The description of livestock-sector trends presented in the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007a) focused on the period between 1980 and 2005, a time when the livestock sector was expanding, intensifying and scaling-up, as a result of drivers from both the demand and the supply sides. Demand-side drivers were particularly strong in developing countries, where consumption of animal-source food grew fastest. Consumption of meat, milk and eggs rose steadily in a number of developing countries as a result of growth in the human population and rising purchasing power. Growth rates were highest for poultry meat and pork, averaging 4.7 percent and 2.6 percent per year, respectively, between 1981 and 2007 (Alexandratos and Bruinsma, 2012), with consumption growth in China making an important contribution. Growing urban populations, together with changes in consumer preference, resulted in greater demand for assured food safety and quality, and this led to additional certification requirements and costs. These developments favoured large-scale production and processing units. On the supply side, low and stable feed costs made it possible to expand intensive livestock production, while breeding technology produced animals that had high output potential and were adapted to intensive production. The period was also characterized by a growing volume and value of international trade in livestock products and feed, and the emerging dominance of large retailers.

By 2005, it was already evident that livestock-sector growth was slowing. Consumption growth was projected to slow (FAO, 2006), while rising energy costs and increasingly limited land and water resources meant that production growth was becoming ever more dependent on higher productivity from each unit of resources used. These challenges still exist. In addition, the supply-side advantage of cheap feed has disappeared as grain prices have risen and become more volatile. A global economic recession has affected consumption patterns among both poor and middle-class consumers. Concerns about livestock's contribution to climate change through greenhouse gas emissions (Steinfeld *et al.*, 2006) are having an ever-increasing influence on livestock-sector policies and industry strategies. Epidemics of major livestock diseases have been a feature of the sector for decades and cause periodic disruption to the international trade on which the sector increasingly depends. All of these issues are explored in this section as it reviews the way that the drivers of change in the livestock sector have evolved in the eight or so years since the first SoW-AnGR was written.

2 Changes in demand

Demand for animal-source products continues to grow, driven by growth in the human population and dietary changes associated with urbanization. Purchasing power was affected by the food-price crisis of 2007-2008, but is recovering. Projections indicate that the consumption of poultry meat and dairy products in particular will continue to

increase. Each of these drivers is discussed in more detail in the following subsections.

2.1 Consumption trends

Projections published in 2012 (Alexandratos and Bruinsma, 2012) suggest that global meat and milk consumption will continue increasing until 2030 and beyond, although growth rates are expected to be slower than those in the past (Tables 2A1 and 2A2). Global growth of meat and milk consumption is projected to be 1.6 and 1.3 percent per year, respectively, in the 2007–2030 period, down from 2.5 and 1.6 percent in 1991–2007. There will be regional differences in these trends, with growth coming mainly from developing countries. Industrialized countries, which already have high levels of consumption of animal-source foods and where population growth is slow, are likely to see much slower growth in demand than developing countries, although their per capita consumption is expected to remain higher (Tables 2A1 to 2A3).

Meat consumption boomed between 1981 and 2007, but in most parts of the world growth in demand is slowing. In Latin America and East and Southeast Asia, annual growth in meat consumption is projected to decrease over time, reflecting economic trends, although still to remain higher than in industrial and transitional economies. In South Asia, meat consumption is predicted to grow faster than before, predominantly through increased consumption of chicken meat in India. Sub-Saharan Africa, which has previously experienced slower growth than other parts of the world, may become a new centre of consumption growth, with annual increases in meat consumption predicted to remain steady until 2050. However, given their dependence on trends in the gross national incomes of the region's countries, consumption trends for Africa are difficult to predict precisely. Estimates by Acosta (2014) suggest that there is likely to be particularly high demand in Africa for milk, poultry meat and beef, although with some potential for cross-elasticity between poultry meat and beef, meaning that a strong demand for poultry may suppress growth in demand for beef.

The poultry sector has been the most buoyant part of the livestock sector in the past few decades and this is likely to continue. Poultry are efficient feed converters (of grains) and

TABLE 2A1

Previous and projected trends in meat consumption

Region	2005/2007 1 000 tonnes *per annum*	1981–2007 % change *per annum*	1991–2007 % change *per annum*	2005/2007–2030 % change *per annum*	2005/2007–2050 % change *per annum*
Sub-Saharan Africa	7 334	2.7	3.4	3.2	3.0
Near East / North Africa	10 292	3.1	3.7	2.7	2.3
Latin America and the Caribbean	34 557	3.9	3.6	1.7	1.3
- excluding Brazil	19 995	3.1	3.4	2.0	1.6
South Asia	6 685	2.1	1.2	4.5	4.2
East Asia	86 806	6.4	4.7	1.9	1.4
- excluding China	18 967	4.6	3.7	2.4	2.0
Developing countries	146 797	4.9	4.1	2.2	1.8
Developed countries	109 382	0.7	0.7	0.6	0.4
World	256 179	2.6	2.5	1.6	1.3

Source: Alexandratos and Bruinsma, 2012.

TABLE 2A2
Previous and projected trends in milk consumption

Region	2005/2007 million tonnes	1981–2007 % change *per annum*	1991–2007 % change *per annum*	2005/2007–2030 % change *per annum*	2005/2007–2050 % change *per annum*
Sub-Saharan Africa	24	2.3	3.5	2.5	2.3
Near East / North Africa	41	2.0	2.8	1.9	1.6
Latin America and the Caribbean	72	2.6	2.6	1.5	1.1
South Asia	135	4.3	4.1	2.3	2.0
East Asia	50	6.7	7.9	2.2	1.5
- excluding China	14	4.0	3.0	2.3	1.8
Developing countries	324	3.6	3.9	2.1	1.7
Developed countries	333	-0.4	-0.1	0.5	0.3
World	657	1.1	1.6	1.3	1.1

Source: Alexandratos and Bruinsma, 2012.

hence poultry meat tends to be cheaper than other meats, whether bought or home-produced. Chicken meat and other poultry products are also very widely consumed across regions and religious and social groups. Growth in global pork consumption, which has been leading the growth of meat consumption jointly with poultry, is heavily influenced by trends in China, where growth in demand is predicted to slow (OECD/FAO, 2014). Conversely, increasing poultry consumption is a worldwide phenomenon. Per capita demand for poultry meat is projected to increase by 271 percent in South Asia, 116 percent in Eastern Europe and Central Asia, 97 percent in the Middle East and North Africa and 91 percent in East Asia and the Pacific during the 2000 to 2030 period (Table 2A3). Evolution of per capita demand for poultry in India is striking, with a predicted increase of 577 percent between 2000 and 2030. Poultry meat is also the animal-source food with the highest demand growth in high-income countries, where per capita demand for beef and mutton is expected to decrease.

Milk consumption has grown more slowly than meat consumption, except in South Asia. Over the period 1991 to 2007, global milk consumption grew by 1.6 percent per year (Table 2A2), mainly due to a surge in demand for milk in China and India. In India, per capita demand for milk is expected to increase by 57 percent between 2007 and 2030 according to one projection (Table 2A3); another estimate suggests that consumption of fresh milk will reach 170 kg per capita in 2023 (OECD/FAO, 2014). Herrero *et al.* (2014) estimate that milk consumption is likely to triple by 2050 in sub-Saharan Africa, mostly led by East Africa. The overall effect is that global consumption of milk is projected to grow slightly faster between 2007 and 2030 than it did between 1981 and 2007 (Table 2A2), with steady annual growth to 2050 in Africa and a decreasing rate of growth in the rest of the world.

2.2 Purchasing power

Purchasing power is considered the main demand-side driver for livestock products. Lower-and middle-income consumers have a strong influence on consumption trends, as the effect of increased income on diets is greatest in this group (Delgado *et al.*, 2002; Devine, 2003). Increasing incomes in developing countries were an important driver of the boom in consumption of livestock products, particularly meat.

TABLE 2A3
Growth in per capita demand for livestock products from 2000 to 2030

Region	Beef		Milk		Mutton		Pork		Poultry meat		Eggs	
	Increase (percentage and absolute value)											
	%	kg	%	kg	%	kg	%	kg	%	kg	%	kg
East Asia and Pacific	61	3.8	55	7.6	39	0.2	61	6.3	91	7.7	48	2.8
China	103	4.3	113	10.1	37	0.8	35	11.5	94	9.1	17	2.8
Eastern Europe and Central Asia	25	10.7	20	26.2	15	0.5	28	2.0	116	11.4	36	3.8
Latin America and the Caribbean	16	17.2	27	24.7	8	0.1	34	2.5	73	13.7	45	2.6
Middle East and North Africa	42	5.5	31	20.9	31	1.6	12	0.0	97	11.2	49	2.6
South Asia	24	4.2	32	20.7	45	1.0	78	0.2	271	4.1	134	1.9
India	8	0.2	57	37.6	33	0.2	86	0.5	577	6.0	173	2.6
Sub-Saharan Africa	25	5.3	17	6.1	30	0.7	47	0.6	73	2.6	66	0.9
High-income countries	-1	-21.0	3	6.1	-10	-0.7	11	2.0	36	9.3	9	0.9

Source: FAO, 2011a.

Poultry and dairy products have been found to have higher income elasticities of demand than other animal-source foods, meaning that consumption levels are more responsive to income; this effect is particularly strong in low-income populations (OECD/FAO, 2014; Gerosa and Skoet, 2012). At a fixed income, the prices of livestock products affect consumption levels. The lower price of poultry meat relative to beef has led to a shift from beef to poultry consumption in Latin America and the Caribbean, and generally in the world (CEPAL, FAO and IICA, 2014). The food-price crisis of 2007-2008 had a significant impact on demand for dairy products, but consumption is recovering due to increasing incomes and changing lifestyles (Gerosa and Skoet, 2012). Prices of other sources of animal protein also affect demand for livestock products. For instance, future demand for meat could be affected by more competitive fish prices (FAO, 2011b).

It is hardly surprising that consumption of poultry meat and dairy products is projected to continue growing. As well as being the most income-elastic animal-source foods, they are often cheaper than other livestock products and are also the most likely to be produced for home consumption by smallholder farmers.

2.3 Demographic changes and urbanization

The world population is predicted to reach 9.6 billion by 2050, i.e. 2.5 billion more than in 2013 (United Nations, 2014). While population growth is expected to decelerate in many regions, strong growth is expected in sub-Saharan Africa. Currently accounting for 13 percent of the total world population, this region is anticipated to account for 23 percent in 2050. As discussed above (Subsection 2.1), per capita consumption of poultry products is expected to increase in this region, reversing a decline in previous decades (FAO, 2009a).

Urbanization was noted in the first SoW-AnGR as the second main factor, after purchasing power, influencing per capita consumption of animal products. It also affects consumer preferences for particular types of animal products (see further discussion below). Since 2007, the world's urban population has surpassed the rural population. It is expected to increase from 54 percent

of the world total in 2013 to 66 percent in 2050 (United Nations, 2014). Urbanization leads to a shift from cereal-based diets to energy-dense diets that include a higher proportion of animal-source food. Diets can be expected to change substantially in Africa and Asia, where urbanization is fastest. In India, a country undergoing strong urbanization, per capita consumption of dairy products was estimated to be 20 percent higher in urban areas than in rural areas in 2009-2010 (Ahuja, 2013). Urban dwellers who can afford it are likely to eat a wider variety of foods than people in rural areas, and to eat more processed food and fast food. These tend to be sourced from large-scale producers where possible, because it is easier for food retail companies to manage supply and quality from fewer, larger farms. Urbanization also leads to improvements in infrastructure and cold chains, meaning that perishable goods, such as fresh milk, can be transported further (Thornton, 2010).

While urban populations are on average richer than those in rural areas, there are still very large numbers of low-income urban families who are vulnerable to economic recession. During the food-price crisis of 2007-2008, when world prices of cereal staples rose by three to five times, the poor in many large cities cut back on food consumption and ate less animal-source food (FAO, 2011b). Current projections for consumption growth will be affected by any future volatility in the global economy.

2.4 Consumer taste and preference

Consumption preferences are affected by a variety of cultural factors and life choices. Cultural factors influence decisions as to whether to eat meat or whether to eat meat from particular species; one of the reasons for the boom in poultry consumption may be that it is acceptable in almost every society that eats meat. Cultural norms can also be related to food safety. Many consumers in developing countries prefer to eat meat from animals bought live at the market and slaughtered on the day of consumption, as where there is no reliable refrigeration or obligatory labelling this is the most dependable way of ensuring the safety and quality of the meat. Preferences are not static and are affected by demographic change. Many developing-country consumers prefer the taste of meat from traditional breeds kept extensively, but tastes are changing as middle-class urban households increasingly opt for the convenience of supermarket-purchased meat from intensive production systems.

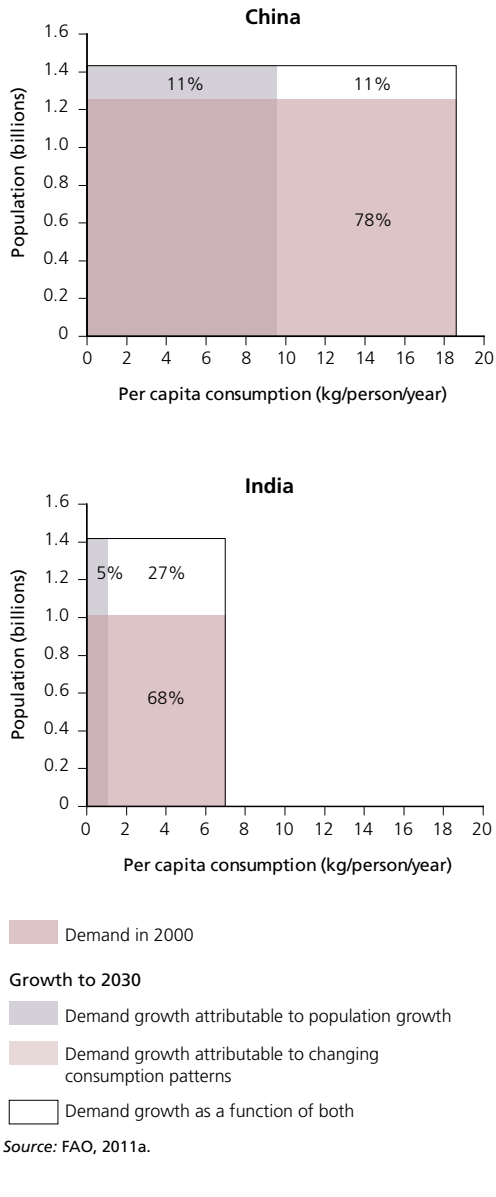
Meat and milk consumption in developed countries is increasingly affected by concerns about healthy diets, the environmental impacts of livestock production and animal-welfare issues. These concerns drive both trends and shocks in consumption and may sometimes pull in opposite directions. For example, the shift from red meat to poultry meat in high-income countries is partly explained by health concerns, as poultry is perceived to be low in fat (OECD/FAO, 2014); yet during the highly pathogenic avian influenza crisis of 2003 to 2006, demand for poultry meat experienced a short, sharp drop in Italy when consumers feared they might be infected (McLeod, 2008; Beach *et al.*, 2008). Concerns about animal welfare led to a European Union (EU)-wide ban on conventional battery cages for laying hens in 2012, which resulted in an increase in the number of free-range birds in some countries.

Concerns about health issues and food quality are increasing in developing countries due to higher purchasing power and changing lifestyles (Jabbar *et al.*, 2010) and this is already changing the livestock industry, with more standards and norms applied to production and processing (Hoffmann *et al.*, 2014). Thornton (2010) notes that animal welfare is becoming a global concern because of globalization and international trade. In 2013, concerns about animal welfare led the Australian livestock industry to suspend live exports to Egypt. In 2014, exports resumed under the Exporter Supply Chain Assurance System (ESCAS), which places responsibility on exporters to guarantee animal welfare throughout the entire supply chain (Australian Government, Department of Agriculture, 2014).

Population growth alone may not significantly change the structure of the livestock sector, provided that the ratio of producers to consumers does not change. In contrast, changes in consumption patterns are likely to affect sector structure. FAO (2011a) analysed the relative impacts of population growth and changing consumption patterns on total consumption and predicted, for example, that 78 percent of demand growth for poultry meat in China and 68 percent in India would come from increased consumption per capita (Figure 2A1). It is expected that India will respond to growth in demand for poultry by increasing domestic production from large farms, and this implies restructuring of the poultry industry.

FIGURE 2A1

Demand growth for poultry meat in China and India (2000 to 2030)



Source: FAO, 2011a.

3 Changes in trade and retailing

As demand for animal-source food has increased worldwide and advances in technology have made their transport easier, international trade and the role of large retailers have increased, creating a situation in which an increasing number of livestock producers face global competition. Some developing-country producers face high production costs because they have to import feed, and this reduces their competitiveness. Likewise, some processors are unable to invest on the scale needed to be competitive. Many smallholders and pastoralists face particular problems because they cannot meet the standards and norms required in order to sell their products to large retailers and international markets, and yet they face competition from imported products on their domestic markets. Vertical integration in the market chains controlled by large companies limits the access of smallholders to growing urban and export markets.

3.1 Flows of livestock and their products

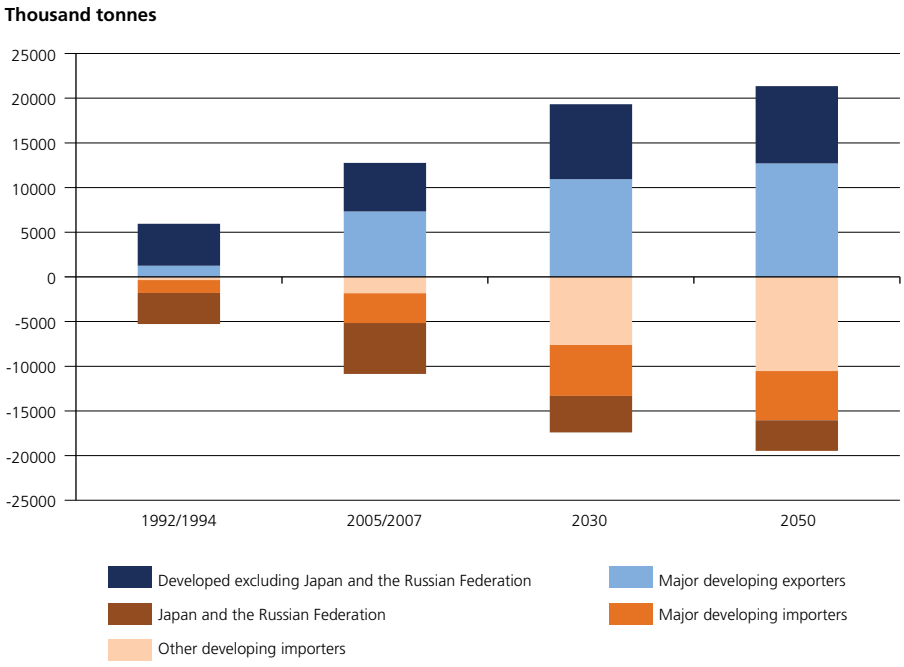
Animal products and live animals for slaughtering or breeding are traded on international and domestic markets. Domestic trade accounts for almost 90 percent of recorded trade by volume – and probably a larger percentage of total trade,

given that many local transactions in developing countries are unrecorded. However, international trade is expanding: from 4 percent of trade by volume in the early 1980s to around 10 percent in 2007 and 12 percent in 2013 (Guyomard *et al.*, 2013). Large companies dominate market chains in developed countries and are becoming increasingly important in developing countries in terms of both international trade and inward investment.

International trade in live animals and livestock products is expected to keep growing (Figure 2A2). Trade in dairy products is expected to increase, while the proportion of meat traded is anticipated to remain at around 10 percent of production (OECD/FAO, 2014). Bovine meat, which has the highest value, is the most traded meat, with about 15.8 percent of production being traded (ibid.).

Flow patterns of live animals and animal products are evolving. Live-animal exports are constrained by animal-health regulations, even more so than trade in livestock products, and by high transport costs. The most internationally traded live animals are day-old chicks, sent between large producers all over the world, and ruminants, exported from Australia and the Horn of Africa to the Middle East for halal slaughter. The latter may be restricted in the future because of animal welfare concerns. High-value breeding animals and their semen are also traded internationally (for further information see Part 1 Section C). In Africa and Southeast Asia, animals travel across national borders for slaughter in adjacent countries, not all of them officially recorded. However, this trade can be abruptly disrupted by livestock

FIGURE 2A2
Net meat trade of major importer and exporter country groups



Note: Country groups defined in source. Historical data go back only to 1992, because of the unavailability of data for the Russian Federation for years prior to 1992.
Source: Alexandratos and Bruinsma, 2012.

disease outbreaks and changes in animal-health regulations.

Dairy exports are still dominated by a few developed countries, namely Australia, European Union (EU) countries, New Zealand and the United States of America. However, Argentina, Belarus, Egypt, Saudi Arabia, Turkey and Ukraine export significant amounts of cheese to neighbouring countries, and India is expected to increase its skim milk powder exports. In Latin America and the Caribbean, dairy exports may remain limited; for example, exports from Argentina are projected to decrease by 9 percent in the next ten years (CEPAL, FAO and IICA, 2014).

Meat exports from developing countries are expected to gain market share relative to those from developed countries (Figure 2A2). A few large countries have the largest market shares. Brazil and Argentina dominate beef and veal exports jointly with Australia, New Zealand and the United States of America. Brazil and the United States of America account for around 70 percent of global exports of poultry meat (Guyomard *et al.*, 2013). India is consolidating its buffalo-meat exports, with a highly competitive sector (OECD/FAO, 2014). The EU's position as a meat exporter has weakened in recent years because of high production costs and a strong euro and may weaken further (ibid.).

A wider range of countries have become importers of livestock products, and with consumption remaining higher than production in many developing countries imports are expected to grow. Between 2005/2007 and 2050, meat imports to Africa are predicted to increase from 0.9 million tonnes to around 5 million tonnes and milk imports from 5.7 million tonnes to 10.2 million tonnes (World Bank, 2014). The proportion of consumption in Africa accounted for by imports is anticipated to reach around 15 percent for beef and 21 percent for poultry meat by 2030 (ibid.).

An important feature of international trade is that many developing countries are, or have the potential to be, both importers and exporters of livestock products – and both types of trade affect the development of their livestock sectors. Export is a costly process, with average bound tariffs[1] for meat varying from 82 to 106 percent in OECD countries and from 68 to 75 percent in non-OECD countries (Steinfeld *et al.*, 2010). Exporters therefore aim to sell their highest-quality products to premium markets in developed countries, or if that is not possible, to target regional markets with high demand, such as South Africa and China. Developed countries place strict animal-health requirements on imports and the main regional markets are also becoming increasingly demanding in this respect. Premium markets also tend to have strict requirements for quality and certification. If export is prioritized in national strategies, this tends to accelerate concentration and scaling-up and to exclude smallholders. This effect is particularly marked in the poultry-meat sector (see Box 2A2 for example). Exclusion can also occur if a disease-free zone created for export restricts the access of smallholders' animals to seasonal grazing or local markets. Where imports are concerned, a strategy of inward investment by large retailers, often in response to demand in growing cities, can also prove to be exclusionary. Supermarkets and fast-food businesses source their food products from a combination of international and domestic markets, but may impose requirements that make it hard for smallholders to supply them. Importation of livestock products can also, and separately, introduce competition when large exporting countries sell the products that are less preferred in premium markets cheaply into developing-country markets. This may not necessarily affect smallholders; it is more likely to be detrimental to small- and medium-sized commercial producers.

While exchanges of livestock products and live animals are growing, trade is becoming more challenging. One of the consequences of globalization has been a large number of protectionist policies. While in recent years there has been a general tendency towards liberalization of world

[1] "Bound" tariffs are rates of duty agreed by the World Trade Organization.

Box 2A1

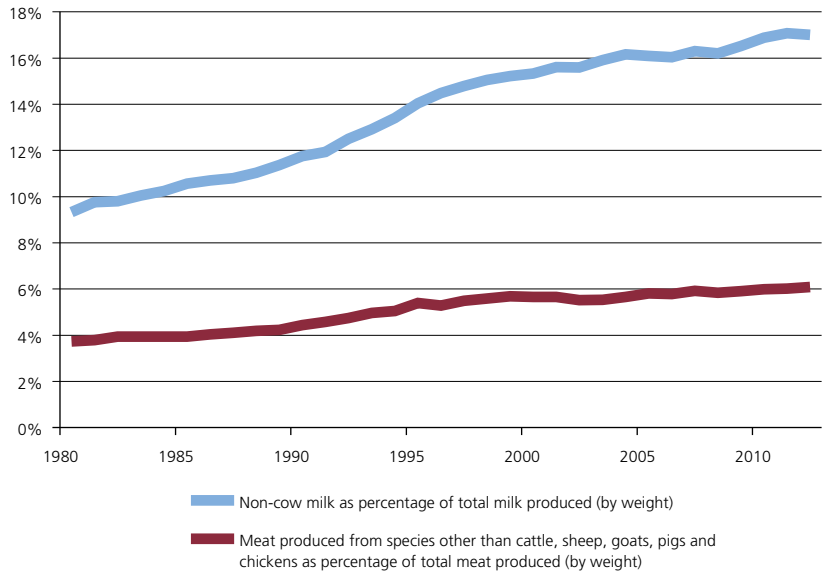
Demand for animal-source foods from minority species and breeds

The main global trends in demand for animal-source foods are assessed using data on the production and consumption of "majority" products, namely beef, pork, chicken meat and milk. These are important in providing a broad picture, but in order to assess implications for animal genetic resources and their management it is also important to look at the finer detail: to review trends for products from minority species and breeds.

The production of milk from species other than cattle and meat from species other than cattle, pigs and chickens has become more important in the past 30 years. FAOSTAT data show that milk production from buffaloes, sheep, goats, dromedaries and Bactrian camels has been increasing as a proportion of total production. Other locally important milk-producing species, such as reindeer, yaks and horses, are not included in these statistics. The proportion of meat production contributed by meat from sheep, goats, buffaloes, dromedaries and Bactrian camels and other camelids has increased by a small amount since 1980.

Equally important to genetic diversity, but harder to assess from published statistics, are breed-related changes in consumption. For the most part, these can only be surmised by observing general trends. For example, free-range egg production has recently increased in developed countries and this may result in changes to the genetic make-up of chicken populations. However, the chickens used in large-scale commercial free-range systems are not those used in scavenging backyard flocks; they have been bred to grow quickly under conditions of good care and feeding. Smallholder chicken producers – in India or Africa, for example – who wish to make a higher income than can be obtained from traditional scavenging flocks may adopt specially bred birds such as the "Kuroiler" and supplement their scavenging diets with concentrate feed.

Changes in the proportion of milk and meat production provided by minor species



(Cont.)

Box 2A1 *(Cont.)*
Demand for animal-source foods from minority species and breeds

Urbanization can result in a series of changes to consumption patterns. As cities expand, the first effect observed is that people consume more animal-source foods, which they may buy from a variety of sources, including live-animal and fresh-food markets. Rural consumers and those that are recent incomers to urban areas tend to prefer meat from traditional breeds and production systems. As supermarkets and fast-food outlets are established and live-animal markets are moved beyond city limits, purchasing patterns change and more food is bought from large retailers, much of it originating from large-scale commercial production systems. Over time, however, some consumers begin to demand specialist foods: locally-sourced; from traditional breeds; from systems perceived to be sustainable; harvested from the wild; or from "exotic" species. Although these demands are never likely to affect the main global statistics, they provide a livelihood for a limited number of small-scale entrepreneurs and opportunities to raise traditional breeds profitably.

Sources: FAOSTAT; Ahuja *et al.*, 2008; FAO, 2011b; Cawthorn and Hoffman, 2014.

trade, restrictive measures continue to be applied to animal products (WTO, 2011; 2014). As a consequence, bilateral and multilateral agreements between countries are increasingly being used. These agreements aim to preserve sanitary standards while reducing tariff barriers. For instance, in December 2013, Australia and the Republic of Korea announced a free-trade agreement including elimination of high tariffs on Australian agricultural exports such as dairy products and meat (Department of Foreign Affairs and Trade, 2013). In the same year, the EU and Canada signed an agreement aimed at promoting trade in bovine and pig meat (Government of Canada, 2013). Such arrangements have the potential to further distance smallholders from export markets.

3.2 The rise of large retailers and vertical coordination along the food chain

As discussed in the first SoW-AnGR, supermarkets have spread all over the world. In the developing world, this has mainly occurred since the early 1990s. Supermarkets and large food companies have established vertically integrated production and marketing chains involving contracts with farmers who meet their quality and sanitary standards. This enables them to reduce transaction costs. The private sector is increasingly investing in livestock production systems (Gerber *et al.*, 2010).

Meeting quality and sanitary demands is challenging, especially for smallholders in developing countries. Concerns about the exclusion of smallholders in Africa are rising, as supermarkets require frequent supplies and demand quality standards that small-scale producers may not be able to meet (Tschirley *et al.*, 2010). However, it is possible to involve smallholders in changing markets, particularly in the case of dairy products. Development projects and large retailers have invested in engaging small-scale producers in dairy-product market chains, providing advice on animal health, feeding practices, breeding and in some cases quality assurance (Gerber 2010; FAO, 2013d). In Bangladesh, a well-organized contract-farming system involves large numbers of small-scale farmers in commercial poultry production (FAO, 2013a).

4 Changing natural environment

In the context of increasing demand for food and ever greater competition for land and other resources, there are growing concerns about the sustainability of livestock production systems and their impacts on the environment.

Box 2A2

Development of the poultry sector in Thailand

The Thai poultry industry was on a fast growth trajectory until the 2004 outbreak of highly pathogenic avian influenza (HPAI). In the 1960s, the industry consisted of a network of small-scale farmers, live-bird traders and wholesalers who brought chickens from rural areas to the cities. During the 1970s and 1980s, the Charoen Pokphand company, in partnership with the American firm Arbor Acres, imported exotic chickens from the United States of America and the United Kingdom and used them to develop a nationally based breeding programme. Contract growers raising an average of 10 000 birds were important to the company and were given the security of price-guaranteed contracts. Although commercial production was expanding and scaling-up during this period, backyard production continued to be important; in 1985, 99.7 percent of chicken producers kept backyard flocks.

During the 1990s, the sector scaled-up and concentrated. By 1996, twelve companies, including the Charoen Pokphand company, controlled about 80 percent of broiler production in Thailand, with large mechanized production units providing economies of scale. Contract farming continued, but vertically integrated production was beginning to expand. The average size of farms continued to increase and new technology was used to cut production costs. The Asian financial crisis of the mid-1990s, preceded by a slump in poultry exports, further concentrated the sector. The main broiler companies came together to form the Broiler Breeding Stock Centre in order to control the supply of breeding stock. The poultry sector survived the economic crisis by shifting towards value-added, processed products. Devaluation of the local currency (the baht) was advantageous for exporters, but small and medium-sized farms, relying on a domestic market in which poultry meat consumption had declined by 20 percent, were more affected by the crisis.

From 2000 onwards, vertical integration became more common, because of the need to meet health and welfare standards demanded by export markets. By 2003, Thailand was the world's fifth-largest exporter of poultry meat by value. The trend to integration was accelerated after the HPAI outbreaks that occurred between May 2004 and August 2006. Loss of 64 million birds, mostly through culling, and loss of the export market, dealt the sector a devastating blow. In order to regain and protect the export market, new regulations were established by the Department of Livestock Development, as well as by the European Union and Japan, both major markets for Thai exports. Under these regulations, companies had more incentive to vertically integrate in order to meet the required standards at every stage of production. It is now common for medium- to large-scale companies to own feed mills and for large integrated farms to include feed-processing plants. The standards do not apply to small farmers operating within local/informal supply chains, but raising poultry and fish in integrated systems, previously common in the delta areas of the country, has been prohibited in most areas. After the HPAI outbreaks, many farmers ceased raising native chickens for sale.

The domestic market now takes approximately 65 percent of national production and export takes 35 percent. Both markets are expected to grow. Five companies supply 70–75 percent of the export market. Japan is the main export destination, but the market is diversifying as more developed countries allow Thai poultry products back into their markets. On the domestic market, chicken meat is the most consumed meat, partly because it is the cheapest. The market shares of ready-to-cook meat and fast food are growing. It is estimated that Thailand's broilers and layers consume 8 million tonnes of feed per year, including 4.8 million tonnes of maize and 2.2 million tonnes of soybeans, of which 4.6 and 0.96 million tonnes, respectively, are produced locally.

Sources: Heft-Neal *et al.*, 2010; IPSOS Business Consulting, 2013.

PART **2**

4.1 Climate change

Concerns about climate change, already prevalent at the time the first SoW-AnGR was prepared, have deepened still further over recent years (FAO, 2009b; Nardone *et al.*, 2010; IPCC, 2014). Livestock production systems are experiencing the effects of changes in precipitation, temperature and increasing frequency of extreme weather events. Changes of this kind can affect livestock production both directly and indirectly (e.g. by affecting feed production) (Table 2A4). The potential impacts of heat stress on livestock include temperature-related illness and death, as well as declines in production and reproductive ability (Nardone *et al.*, 2010). Extreme weather events threaten rangelands, as well as feed production for non-grazing systems. They can pose a direct threat to the survival of livestock populations caught in their paths (see Part 1 Section F for further discussion). They can also have significant effects on livestock markets (OECD/FAO, 2014).

4.2 Pressure on land and other natural resources

There is increasing pressure on land and other natural resources as a result of developments in agricultural production systems as well as urbanization and industrial development. These pressures are being exacerbated by climate change. The livestock sector accounts for approximately 3.9 billion hectares of land, divided into 500 million hectares used for feed-crop production, 1.4 billion hectares of relatively highly productive pastures and 2 billion hectares of relatively unproductive extensive pastures (Steinfeld *et al.*, 2010). The evolution of land use varies from region to region. Between 1961 and 2001, both arable lands and pastures expanded in Asia, North Africa, and Latin America and the Caribbean, while arable lands replaced pastures in Oceania and sub-Saharan Africa. In the Baltic states and the Commonwealth of Independent States, lands dedicated to pastures expanded, while croplands decreased; in western and eastern Europe and in North America, both pasture and arable land decreased (Steinfeld *et al.*, 2010). In some parts of the world, notably Africa, land degradation as a result of overgrazing added to pressures on the land resource. Between 2000 and 2010, the area under pasture grew at the expense of arable land in North America, whereas it decreased in the Southwest Pacific and in Asia (Table 2A5).

Water and fossil fuels are also finite and in high demand. Competition for these resources, a concern for the past decade, is anticipated to get stronger in the future. Developments of this kind lead to high prices for feed and energy and raise the costs of livestock production. A recent response to fossil-fuel scarcity has been the introduction of government incentives for the development of biofuel production. This may affect the livestock sector, as crops used for feed have

TABLE 2A4

Direct and indirect effects of climate change on livestock production systems

	Grazing systems	Non-grazing systems
Direct impacts	• Increased frequency of extreme weather events • Increased frequency and magnitude of drought and floods • Productivity losses (physiological stress) due to temperature increase • Change in water availability (may increase or decrease, depending on the region)	• Change in water availability (may increase or decrease, depending on the region) • Increased frequency of extreme weather events (impact less acute than for extensive systems)
Indirect impacts	Agro-ecological changes and ecosystem shifts leading to: • alteration of fodder quantity and quality • changes in host–pathogen interactions resulting in an increased incidence of emerging diseases • disease epidemics	• Increased resource prices (e.g. feed, water and energy) • Disease epidemics • Increased cost of animal housing (e.g. cooling systems)

Source: FAO, 2009a.

TABLE 2A5
Change in area of arable and pasture land (2000 to 2010)

Regions and subregions	Arable land	Permanent meadows and pastures
	%	
Africa	**11.5**	**1.2**
East Africa	31.2	-0.1
North and West Africa	6.0	2.5
Southern Africa	11.5	0.4
Asia	**-1.6**	**-4.0**
Central Asia	8.5	-5.8
East Asia	-9.2	-3.2
South Asia	-2.7	-2.6
Southeast Asia	8.9	2.4
Southwest Pacific	**-11.7**	**-13.1**
Europe and the Caucasus	**-5.3**	**0.0**
Latin America and the Caribbean	**16.1**	**1.3**
Caribbean	-5.9	-0.4
Central America	1.5	-0.3
South America	20.9	1.7
North America	**-9.9**	**5.1**
Near and Middle East	**4.5**	**0.6**
World	**-0.4**	**-1.7**

Source: FAOSTAT.

begun to be used for biofuel production. For instance, policies in the United States of America have led to a surge in the use of maize, one of the main livestock feeds, for bioethanol production (Miljkovic *et al.*, 2012). The availability of by-products from the bioethanol industry and shifts towards new feeds may, however, diminish the negative effects of biofuel production on the livestock sector (FAO, 2012a).

Feed availability and price volatility are becoming major issues. In Asia, the amount of feed protein required by the poultry and pig sectors is anticipated to double between 2009 and 2020 (Ahuja, 2013). This represents a major challenge, especially given that Asia already experiences chronic shortages of feed (ibid.).

4.3 Distribution of livestock diseases and parasites

The distribution of diseases and parasites and the emergence of new diseases are expected to continue evolving, influenced by high livestock densities, international trade, human travel and climate change. It has been argued that these drivers have led to a "booming era of emerging infectious disease" (Bouley *et al.,* 2014). Precise developments are difficult to predict. Climate change, for example, has the potential to affect all the components of disease systems, i.e. pathogens, hosts and vectors. However, it is difficult to clearly distinguish the effects of climate change from those of other drivers (FAO, 2013b). Problems related to emerging diseases and the

spread of diseases and parasites into new areas are potentially exacerbated by the spread of antibiotic resistance and resistance to treatments used against parasites and disease vectors.

5 Advances in technology

Advances in technology (e.g. those related to feeding, breeding, housing, transportation and marketing) have been major drivers of change in the livestock sector in recent decades. Feeding and breeding have been crucial, particularly in the poultry, pig and dairy industries. However, these developments have mainly been undertaken by the private sector and aimed at (relatively large-scale) commercial producers; they are therefore relatively less available to – and applicable for use by – smallholders than the technologies that led to the "green revolution" in the crop sector (FAO, 2009a).

5.1 Feed technology

Feed-use efficiencies have substantially improved in the pig, poultry and dairy industries. Moreover, low feed prices, resulting mainly from intensification of croplands and advances in feed production and genetics, have contributed to the rapid growth of the livestock sector. However, feed prices – including the prices of cereals, oilseeds and meat and fish meals – have increased sharply since 2008, and are expected to remain high because of increasing demand, land competition, water scarcity, high energy prices and climate change. Increases in feed prices particularly affect developing countries, as they are deficient in feed resources and their livestock sectors are generally dependent on feed imports. This, along with decreasing availability of arable land and increasing food–feed competition, has led to a reassessment of feeding practices and search for new protein- and energy-rich feed resources that do not compete with human food (FAO, 2012b). Potential options include insects (FAO, 2013c; Makkar *et al.*, 2014), co-products of the biofuel industry, including algae (FAO, 2012a), ensiled vegetable and fruit wastes (Wadhwa and Bakshi, 2013) and other unconventional feed resources such as moringa and mulberry leaves. A variety of different insect larvae may be suitable for processing into animal feed, and could potentially replace 25 to 100 percent of the soymeal or fishmeal in the diet – depending on the animal species – with some supplementation with methionine, lysine and calcium (Makkar *et al.*, 2014).

To promote more efficient use of available feed resources, greater emphasis is now being placed on resource assessments and characterizing feeding systems at national level (Makkar and Ankers, 2014). Other strategies include greater use of precision or balanced feeding, identification and use of smart feeding options (Makkar, 2013) and efforts to decrease feed wastage by using densified complete crop residue based feed blocks or pellets and total mixed rations instead of feeding individual feed components (FAO, 2012c).

5.2 Genetics and reproductive biotechnologies

Reproductive technologies, such as artificial insemination, embryo transfer and more recently sex-sorted semen, have been extensively used in the poultry, pig and dairy industries in developed countries (see Part 3 Section E). Molecular and quantitative genetics have provided new opportunities in animal breeding (see Part 4 Section C). Conversely, cloning and the use of genetically modified animals have been limited due to social and ethical concerns and problems with the efficiency of the procedures. Genetically modified livestock are used in research and in the production of proteins for medical purposes.

Use of genetics to improve productivity has been particularly prominent in the poultry industry, where high reproductive rates and short generation intervals have allowed rapid improvements in feed efficiency and growth rates using classical animal-breeding methods based on quantitative genetics (FAO, 2009a). In dairy cattle, the use of artificial insemination has allowed the wide diffusion of semen from a limited number of bulls with accurately estimated breeding values and has resulted in significant genetic progress.

While the main focus of genetic improvement programmes has been on increasing production, increasing emphasis is now being given to functional traits influencing the costs of production. In the future, selection goals are likely to take other traits, such as disease resistance and environmental impact, including greenhouse gas emissions, increasingly into account.

Newly developed biotechnologies offer many opportunities to improve selection, but have the potential to create certain risks (e.g. compromised food safety and animal welfare) and thus need to be regulated by adequate institutional frameworks. Some relevant national and international legal and policy frameworks have been established (see Part 3 Section F), but adequate provisions are not in place in all countries.

5.3 Animal-health technology

Animal-health technologies such as vaccines, antibiotics and diagnostic tools have supported the growth of the livestock sector by reducing the burden of diseases. However, livestock diseases continue to be a problem for both small-scale and large-scale producers. Effective control of existing diseases and emerging problems will require better and more accessible diagnostic tests (Thornton, 2010) and continued development of vaccines and drugs, as well as packaging and distribution networks that make technologies more accessible to farmers. Technology alone will not be sufficient to deal with future animal-health problems; continued investment in the infrastructure and human capacity of animal-health systems in developing countries is also needed. Moreover, the need to respond to crises has meant that chronic and endemic diseases have been neglected, particularly in smallholder and pastoralist livestock systems in developing countries (FAO, 2013b). The critical need for smallholders and pastoralists is not new technology, but animal and public health systems that are more embedded in communities.

In developed countries, the potential effects of antimicrobial resistance on public health are causing increasing concern (Rushton *et al.*, 2014). Improved surveillance in the livestock sector is needed; the latest World Health Organization report on this issue (WHO, 2014) notes the existence of significant gaps in data on antibiotic resistance in bacteria carried by livestock and in the food chain.

5.4 Future technologies

In vitro meat, also referred to as artificial meat, is currently under development and may be a contributor to the meat supply in the future, although its use will probably be limited to processed products. It has not yet been produced in a form suitable for commercial use and is very expensive (FAO, 2011b). Another technology that may affect the livestock sector in the future is nanotechnology (Thornton, 2010). This technology can be applied in animal health (e.g. drug delivery), feeding and waste management. However, as with many technologies, risks need to be assessed and addressed via appropriate legal and policy frameworks.

6 Policy environment

The first SoW-AnGR described public policies as "forces that add to the drivers described above and influence changes in the sector with the aim of achieving a particular set of societal objectives." Public policies aim to expose, contain and mitigate the hidden costs of an expanding livestock sector, including those associated with environmental degradation, livelihood disruption and threats to veterinary and human public health.

Veterinary and public health concerns have been strongly regulated internationally since the sanitary and phytosanitary (SPS) agreement of the World Trade Organization was established in 1995, and this high level of regulation can be expected to continue in the future. The agreement was developed, by negotiation between the main trading nations at the time, to protect national livestock and human populations from the most infectious livestock, zoonotic and foodborne diseases. It has been argued that SPS standards act as a barrier to export from developing countries.

They have certainly been influential in shaping the livestock sector and its trade flows; for example, in 2009, almost 70 percent of world trade in animals and meat from species susceptible to foot-and-mouth disease came from a small number of countries that were officially recognized as free of the disease by the World Organisation for Animal Health (OIE) or historically recognized to be disease free (OECD/FAO, 2009).

Regulations are evolving in ways that may be beneficial for developing countries. Historically, it was only possible to export to premium markets from countries or geographical zones that were free of disease. All producers living within disease-free countries or zones had to adhere to the same regulations, even if they did not intend to export. Within the past ten years, two new concepts have been introduced into the OIE's Terrestrial Animal Health Code (OIE, undated). "Compartmentalization" in essence permits export from a certified value chain. "Commodity-based trade", more recently introduced into international guidelines, permits products assessed as being of minimum risk to be exported, even if they come from countries where disease is present. Both concepts introduce the potential for export trade to be developed in parallel with the provision of support to smallholder farming and pastoralism, although no impact assessments based on practical experience have yet been published.

International policies and regulations on the environment are a more recent phenomenon for the livestock sector and less clear-cut than the SPS agreement. An international agreement on conservation and management of marine fish stocks has been in place since 1995, but moves towards the development of international agreements on sustainable livestock production began only relatively recently. The Global Plan of Action for Animal Genetic Resources was adopted in 2007 (FAO, 2007b) and concerns about the links between livestock and climate change are stimulating further interest in international environmental agreements addressing the livestock sector. An increasing number of public and private discussion fora are now playing an important role in shaping international norms and agreements, including the Global Agenda for Sustainable Livestock,[2] spearheaded by FAO. Issues being explored include the management of grazing livestock to provide environmental services, including the improvement of carbon markets so that individual livestock keepers can more easily benefit from them. Additional areas of interest are the management of animal manure for full recovery of nutrients and improving the efficiency of production in developing-country livestock systems, both of which will require a combination of technological, policy and voluntary action. There is also a growing body of research publications on "sustainable intensification" (Garnett and Godfray, 2012; The Montpellier Panel, 2013; Van Buren *et al.*, 2014).

Nationally, land ownership has been an important driver in shaping production systems. Assured access to land and water is important for livestock production, whether through legal ownership or customary land rights, and this will become increasingly urgent as grazing land is lost to crop production and climate change affects marginal areas where many indigenous animals are kept. A report by IFAD (2009) concluded that increased control by indigenous people over access to grazing land, water rights and land-tenure laws were all important means of preventing land degradation and ensuring sustainable land use.

Emerging policy issues in the livestock sector include animal welfare and the regulation of biotechnology (see Part 3 Section F for further discussion). There are also a number of policy areas that affect the sector indirectly. For instance, as noted above, incentives for biofuel production have already affected feed prices and created competition for land and water. A notable trend in the past ten years has been the growth of coalitions, such as the Global Agenda for Sustainable Livestock (see above) and the Global Roundtable

[2] http://www.livestockdialogue.org

TABLE 2A6

A policy framework for inclusive growth of the livestock sector

	Policy goal	Examples of policy instruments	Rationale
Context for livestock policies	Creating a conducive macroenvironment	Macroeconomic policies and institutional reforms	Sound macroeconomic fundamentals and high-quality institutions are positively associated with economic and social indicators of well-being.
Managing the basics for livestock production	Securing access to land, feed and water	State-driven land and agrarian reform Market-driven land reform Regulation of land rental markets Land titling Recognition of customary tenure Land co-management	Livestock producers need adequate and secure access to land (and associated feed and water resources).
	Providing insurance and risk-coping mechanisms	Livestock insurance Early-warning systems Contingency plans Emergency feeding Grazing reserves Destocking Restocking	Variable returns prevent livestock keepers from making efficient use of their resources and lead to adoption of conservative investment decisions.
Enhancing livestock productivity and competitiveness	Securing access to livestock/animal-health services	Decentralization Cost recovery Joint human–animal health systems Subcontracting "Smart" subsidies for private service providers Community animal-health workers Membership-based organizations "Smart" subsidies for livestock keepers	Livestock keepers are often poor, poorly educated, dispersed, and unable to demand public and private livestock services effectively.
	Securing access to credit and other inputs	Portfolio diversification Livestock as collateral for loans Warehouse receipt systems Mobile banking Branchless banking Member-based financial institutions Credit bureaus and scoring	Imperfect and asymmetric information and high transaction costs limit access to credit and other production inputs, as private agents are rarely willing to serve poor and dispersed livestock producers.
Sustaining livestock productivity and competitiveness	Promoting access to national/international markets	Livestock-keepers'/traders' associations Livestock brokers Periodic markets Contract farming Market information systems Commodity exchanges Sanitary and phytosanitary standards Disease-free export zones Commodity-based trade Trade-enhancing infrastructure Quarantine zones	Markets' capacities to indicate how livestock producers should allocate their productive resources are constrained, *inter alia*, by poor communication and transport infrastructure, lack of or limited information, and unequal bargaining power among contracting parties.
	Promoting the provision of public goods: research	Decentralization Matching research grants Levy-funded research Competitive research funds Strengthened intellectual property rights Participatory livestock research	Private research centres are willing to invest in profitable breeds/technologies, but poor livestock keepers rarely constitute an attractive market for the private sector.
	Promoting the provision of public goods: food safety, and environmental protection	Controlled grazing Co-management of common pastures Livestock zoning Discharge quotas Payments for environmental services Marketing of environmental goods Environmental taxes Education from school to university level	Livestock production systems may be associated with negative externalities, which need to be dealt with through collective actions.

Sources: FAO, 2010; FAO, 2012b.

for Sustainable Beef,[3] that aim to accommodate environmental and social concerns into sector strategy. Social concerns such as public health, animal welfare and environmental impacts are increasingly factored into private-sector voluntary agreements.

Policies aimed at supporting the livestock sector have often neglected smallholders and pastoralists, who account for a large proportion of the producers in developing countries. Smallholders are also neglected by the private sector, other than through contract-farming arrangements and limited investment initiatives. It is, however, likely that policy-makers looking to reduce poverty will, in future, increasingly aim to take the needs of smallholders into account. FAO (2010 and 2012b) has proposed an inclusive policy framework aimed at including smallholders (Table 2A6).

References

Acosta, A. 2014. *Market perspectives for the livestock sector in Africa: a vector autoregressive approach*. FAO internal paper. Rome.

Ahuja, V. (ed). 2013. *Asian livestock: challenges, opportunities and the response*. Proceedings of an International Policy Forum held in Bangkok, Thailand, 16–17 August 2012. Animal Production and Health Commission for Asia and the Pacific, ILRI and FAO (available at http://www.fao.org/docrep/017/i3166e/i3166e00.htm).

Alexandratos, N. & Bruinsma, J. 2012. *World agriculture towards 2030/2050: the 2012 revision*. ESA Working paper No. 12-03. Rome, FAO (available at http://www.fao.org/docrep/016/ap106e/ap106e.pdf).

Australian Government, Department of Agriculture. 2014. *Exporter Supply Chain Assurance System (ESCAS) web page* (available at http://tinyurl.com/oa8yfoc) (accessed August 2014).

Beach, R.H., Kuchler, F., Leibtag, E. & Zhen, C. 2008. *The effects of avian influenza news on consumer purchasing behavior: a case study of Italian consumers' retail purchases.* Economic Research Report No. 65, August 2008. Washington, DC, United States Department of Agriculture, Economic Research Service (available at http://tinyurl.com/nlxrfog).

Bouley, T., Gilbert, M., Whung, P.Y., Le Gall, F. & Plante, C. 2014. *Reducing climate-sensitive disease risks.* Agriculture and Environmental Services Discussion Paper. No. 7. Washington, DC, World Bank Group (available at http://tinyurl.com/knmj6ww).

Casey, J.A., Curriero, F.C., Cosgrove, S.E., Nachman, K.E. & Schwartz, B.S. 2013. High-density livestock operations, crop field application of manure, and risk of community-associated methicillin-resistant staphylococcus aureus infection in Pennsylvania. *JAMA Internal Medicine*, 173(21): 1980–1990.

Cawthorn, D.-M. & Hoffman, L.C. 2014. The role of traditional and non-traditional meat animals in feeding a growing and evolving world. *Animal Frontiers*, 4(4): 6-12 (available at http://dx.doi.org/10.2527/af.2014-0027).

CEPAL, FAO & IICA. 2014. *Perspectivas de la agricultura y del desarrollo rural en las Américas: una mirada hacia América Latina y el Caribe. 2014*. San José, IICA (available at http://www.fao.org/docrep/019/i3702s/i3702s.pdf).

Delgado, C., Rosegrant, M. & Meijer, S. 2002. *Livestock to 2020: the revolution continues*. Paper presented at the World Brahman Congress, Rockhampton, Australia, April 16, 2002.

Department of Foreign Affairs and Trade, Government of Australia. 2013. *Korea–Australia free-trade agreement. Fact sheet: trade in goods.* Canberra (available at http://tinyurl.com/pu2t47t)

FAO. 2006. World Agriculture: towards 2030/2050. Interim report. Rome (available at www.fao.org/docrep/009/a0607e/a0607e00.HTM).

FAO. 2007a. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2007b. *The Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration*. Rome (available at http://www.fao.org/docrep/010/a1404e/a1404e00.htm).

FAO. 2009. *The State of the Food and Agriculture. Livestock in the balance*. Rome (available at http://www.fao.org/docrep/012/i0680e/i0680e.pdf).

[3] http://grsbeef.org

FAO. 2010. *Livestock sector policies and programmes in developing countries – a menu for practitioners*, by U. Pica-Ciamarra, J. Otte & C. Martini. Rome (available at http://www.fao.org/docrep/012/i1520e/i1520e00.pdf).

FAO. 2011a. *Mapping supply and demand for animal-source foods to 2030*, by T.P. Robinson & F. Pozzi. Animal Production and Health Working Paper. No. 2. Rome (available at http://www.fao.org/docrep/014/i2425e/i2425e00.pdf).

FAO. 2011b. *World Livestock 2011. Livestock in food security*. Rome (available at http://www.fao.org/docrep/014/i2373e/i2373e.pdf).

FAO. 2102a. *Biofuel co-products as livestock feed. Opportunities and challenges*, edited by H.P.S. Makkar. Rome (available at http://www.fao.org/docrep/016/i3009e/i3009e.pdf).

FAO. 2012b. *Livestock sector development for poverty reduction: an economic and policy perspective – livestock's many virtues*, by J. Otte, A. Costales, J. Dijkman, U. Pica-Ciamarra, T. Robinson & V. Ahuja. Rome (available at http://www.fao.org/docrep/015/i2744e/i2744e00.pdf).

FAO. 2012c. *Balanced feeding for improving livestock productivity – increase in milk production and nutrient use efficiency and decrease in methane emission*, by M.R. Garg. FAO Animal Production and Health Paper 173. Rome (available at http://www.fao.org/docrep/016/i3014e/i3014e00.pdf).

FAO. 2013a. *Contract farming for inclusive market access*. Rome (available at http://www.fao.org/3/a-i3526e.pdf).

FAO. 2013b. *World Livestock 2013. Changing disease landscapes*. Rome (available at http://www.fao.org/docrep/019/i3440e/i3440e.pdf).

FAO. 2013c. *Edible insects. Future prospects for food and feed security*. Rome (available at http://www.fao.org/docrep/018/i3253e/i3253e.pdf).

FAO. 2013d. *Milk and dairy products in human nutrition*, edited by E. Muehlhoff, A. Bennett & D. McMahon. Rome (available at http://www.fao.org/docrep/018/i3396e/i3396e.pdf).

FAOSTAT. *FAO Statistical database* (available at http://faostat3.fao.org/faostat-gateway/go/to/home/E) (accessed 30 October 2014).

Garnett, T. & Godfray, C. 2012. *Sustainable intensification in agriculture. Navigating a course through competing food system priorities*. Oxford, UK, Food Climate Research Network and the Oxford Martin Programme on the Future of Food, UK, University of Oxford (available at http://tinyurl.com/oucab73).

Gerber, P., Mooney, H., Dijkman, J., Tarawali, S. & de Haan, C. 2010. *Livestock in a changing landscape. Volume 2. Experiences and regional perspectives*. Washington, DC, Island Press.

Government of Canada. 2013. *Technical summary of final negotiated outcomes, Canada-European Union Comprehensive Economic and Trade Agreement*. Ottawa (available at http://tinyurl.com/pkap545).

Guyomard, H., Manceron, S. & Peyraud, J.L. 2013. Trade in feed grains, animals, and animal products: Current trends, future prospects, and main issues. *Animal Frontiers*, 3(1): 14–18 (available at https://www.animalsciencepublications.org/publications/af/articles/3/1/14).

Heft-Neal, S., Otte, J., Pupphavessa, W., Roland-Holst, D., Sudsawad, S. & Zilberman, D. 2010. *Supply chain auditing for poultry production in Thailand*. PPLPI Research Report. Rome, FAO (available at http://tinyurl.com/o585sl6).

Herrero, M., Havlik, P., McIntire, J., Palazzo, A. & Valin, H. 2014. *African livestock futures: realizing the potential of livestock for food security, Poverty reduction and the environment in sub-Saharan Africa*. Geneva, Switzerland, Office of the Special Representative of the UN Secretary General for Food Security and Nutrition and the United Nations System Influenza Coordination (UNSIC) (available at http://preview.tinyurl.com/ocuqphk).

Hoffmann I., Baumung, R. & Wandro, C. 2014. *Survey on (private) voluntary standards in the livestock sector. In* A. Meybeck & S. Redfern, eds. Voluntary standards for sustainable food systems: challenges and opportunities, pp. 127–142. Rome, FAO (available at http://www.fao.org/3/a-i3421e.pdf).

IFAD. 2009. *Livestock and land*. Livestock Thematic Papers: Tools for Project Design. Rome, International Fund for Agricultural Development (available at http://www.ifad.org/lrkm/factsheet/land.pdf).

IPCC. 2014: Summary for policymakers. *In* C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada,

R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea & L.L. White, eds. *Climate change 2014: impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 1–32. Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press (available at http://www.ipcc.ch/report/ar5/wg2/).

IPSOS Business Consulting. 2013. *Thailand's poultry industry*. Bangkok, IPSOS Business Consulting (available at http://tinyurl.com/o5ow5fh).

Jabbar, M.A., Baker, D. & Fadiga, M.L. (eds). 2010. *Demand for livestock products in developing countries with a focus on quality and safety attributes: Evidence from Asia and Africa*. ILRI Research Report 24. Nairobi, ILRI (available at http://tinyurl.com/q49wcmh).

Makkar, H.P.S. 2013. Precision feeding – A developing countries perspective for sustainable ruminant production. *In* D. Berckmans & J. Vandermeulen, eds. *Precison livestock farming '13. 6th European Conference on Precision Livestock Farming, 10–12 September 2013, Leuven, Belgium*, pp. 95-105.

Makkar, H.P.S. & Ankers, P. 2014. A need for generating sound quantitative data at national levels for feed-efficient animal production. *Animal Production Science*, 54(10): 1569–1574.

Makkar, H.P.S., Tran, G., Heuzé, V. & Ankers, P. 2014. State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology*, 197: 1–33.

McLeod, A. 2008. The economics of avian influenza. *In* D.E. Swayne, ed. *Avian influenza*, pp. 537–560. John Wiley and Sons.

Miljkovic, D., Shaik, S. & Braun, D. 2012. Impact of biofuel policies on livestock production in the United States. *Journal of Policy Modeling*, 34(6): 817–831.

Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M.S & Bernabucci, U. 2010. Effects of climate changes on animal production and sustainability of livestock systems. *Livestock Science*, 130(1–3): 57–69 (10th World Conference on Animal Production [WCAP]).

OECD/FAO. 2009. *OECD-FAO World Agricultural Outlook 2009-2018*. Paris, OECD Publishing (available at http://www.agri-outlook.org/43040036.pdf).

OECD/FAO. 2014. *OECD-FAO Agricultural Outlook 2014–2023*. Paris, OECD Publishing (available at http://tinyurl.com/okd6y7j).

OIE. undated. *Terrestrial Animal Health Code*. Paris, World Organisation for Animal Health (available at http://www.oie.int/international-standard-setting/terrestrial-code/).

Rushton, J., Pinto Ferreira, J. & Stärk, K.D. 2014. *Antimicrobial resistance. The use of antimicrobials in the livestock sector*. OECD Food, Agriculture and Fisheries Papers, No. 68. Paris, OECD Publishing (available at http://tinyurl.com/q6y94qm).

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. & de Haan, C. 2006. *Livestock's long shadow: environmental issues and options*. Rome, FAO (available at ftp://ftp.fao.org/docrep/fao/010/a0701e/a0701e00.pdf).

Steinfeld, H., Mooney, H.A., Schneider, F. & Neville, L.E. 2010. *Livestock in a changing landscape. Volume 1. Drivers, consequences, and responses*. Washington, DC, Island Press.

The Montpellier Panel. 2013. *Sustainable intensification: a new paradigm for African agriculture.* London, Agriculture for Impact (available at http://tinyurl.com/ktbl2of).

Thornton, P.K. 2010. Livestock production: recent trends, future prospects. Philosophical *Transactions of the Royal Society B: Biological Sciences*, 365(1554): 2853–2867.

Tschirley, D., Ayieko, M., Hichaambwa, M., Goeb, J. & Loescher, W. 2010. *Modernizing Africa's fresh produce supply chains without rapid supermarket takeover: towards a definition of research and investment priorities*. MSU International Development Working Paper No. 106, June 2010. East Lansing USA, Michigan State University (available at http://fsg.afre.msu.edu/papers/idwp106.pdf).

United Nations, Department of Economic and Social Affairs, Population Division. 2014. *World urbanization prospects: the 2014 revision, highlights (ST/ESA/SER.A/352)*. New York, USA (available at http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf).

Van Bueren, E., Lammerts van Bueren, E. & van der Zijpp, A. 2014. Understanding wicked problems

and organized irresponsibility: challenges for governing the sustainable intensification of chicken meat production current opinion. *Environmental Sustainability*, 8: 1–14 (available at http://dx.doi.org/10.1016/j.cosust.2014.06.002).

Wadhwa, M. & Bakshi, M.P.S. 2013. *Utilization of fruit and vegetable wastes as livestock feed and as substrates for generation of other value-added products*, edited by H.P.S. Makkar. Rome, FAO (available at http://www.fao.org/docrep/018/i3273e/i3273e.pdf).

WHO. 2014. *Antimicrobial resistance: global report on surveillance*. Geneva, Switzerland (available at http://apps.who.int/iris/bitstream/10665/112642/1/9789241564748_eng.pdf).

World Bank. 2014. *Business and livelihoods in African livestock: investments to overcome information gaps*. Washington, DC (available at http://www.fao.org/docrep/019/i3724e/i3724e.pdf).

WTO. 2011. *Report on G20 trade measures (Mid-October 2010 to April 2011)* Geneva, Switzerland (available at http://tinyurl.com/q744p4r).

WTO. 2014. *Report on G20 trade measures (Mid-May 2014 to mid-October 2014)* Geneva, Switzerland (available at http://tinyurl.com/nmdns7d).

Section B

The livestock sector's response

The drivers of change discussed in Section A induce various responses from the livestock sector. The first SoW-AnGR described these responses for each of the main livestock production systems defined by Seré and Steinfeld (1996) (Table 2B1). For consistency, the present report follows the same structure. The classification defines systems based on the proportion of feed dry matter that comes from crops, the proportion of non-livestock farming activities in the total value of farm production and the stocking rate. It differentiates grassland-based, mixed farming and landless systems. Mixed farming (rainfed and irrigated) and grassland-based systems are subdivided by agro-ecological zone.

A recent mapping by ILRI and FAO illustrates the spatial distribution of production systems around the world (Figure 2B1). Grassland-based systems are estimated to account for 26 percent of the ice-free land surface of the world (Steinfeld *et al.*, 2006). However, mixed farming and intensive landless systems account for the majority of production (Steinfeld *et al.*, 2006; Steinfeld *et al.*, 2010; Herrero *et al.*, 2014).

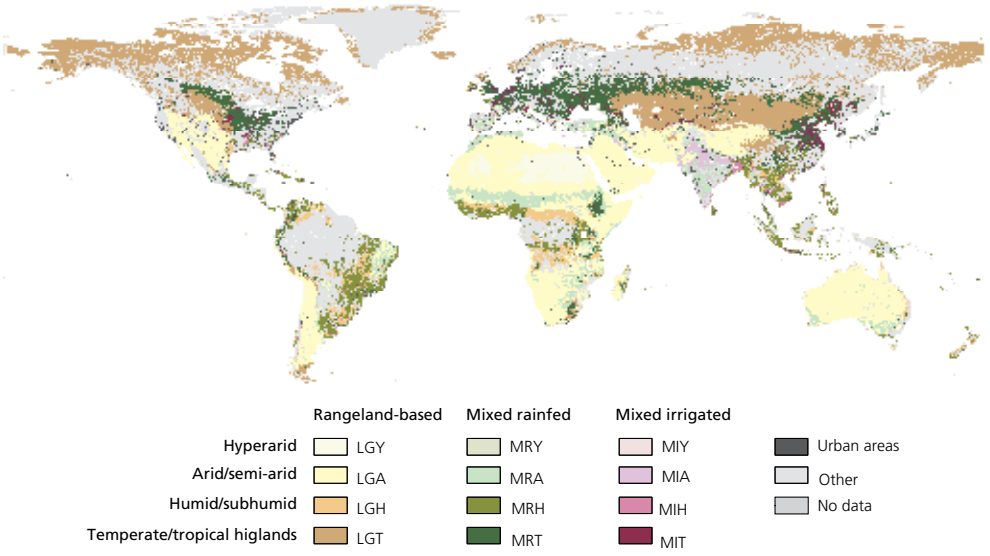
TABLE 2B1
Livestock production systems classification

First system breakdown	Second breakdown	The eleven systems
Grassland-based systems (LG): <10% of dry matter fed to animals comes from crops; and annual average stocking production rates are <10 livestock units ha^{-1} agricultural land		Temperate and tropical highlands (LGT)
		Humid/subhumid tropics and subtropics (LGH)
		Arid/semi-arid tropics and subtropics (LGA)
Mixed farming systems (M): >10% of the dry matter fed to animals comes from crop by-products and stubble or >10% of the total value of production comes from non-livestock farming activities	Mixed-rainfed systems (MR): > 90% of the value of crops comes from rainfed land use	Temperate and tropical highlands (MRT)
		Humid/subhumid tropics and subtropics (MRH)
		Arid/semi-arid tropics and subtropics (MRA)
	Mixed-irrigated (MI): > 10% of the value of crops comes from irrigated land	Temperate and tropical highlands (MIT)
		Humid/subhumid tropics and subtropics (MIH)
		Arid/semi-arid tropics and subtropics (MIA)
Landless (LL): <10% of dry matter fed to animals is produced on the farm; and average stocking production rates are >10 livestock units ha^{-1} agricultural land		Landless monogastric systems (LLM)
		Landless ruminant systems (LLR)

Source: Seré and Steinfeld, 1996.

PART **2**

FIGURE 2B1
Distribution of livestock production systems



Note: For explanation of the abbreviations, see Table 2B1. In this figure, hyper-arid systems (denoted with a "Y") are distinguished from arid and semi-arid systems.
Source: FAO/ILRI, 2011.

The geographical distribution of cattle, sheep, goats, pigs and chickens has also been mapped (Robinson *et al.*, 2014). Ruminants are widely distributed, although goats are mainly found in Africa, Asia and the Near and Middle East. High cattle densities are found predominantly in mixed-rainfed and mixed-irrigated systems, but can be also found in grassland-based systems. (FAO, 2013a). Chicken and pig densities follow human population densities (for further discussion of the geographical distribution of livestock species, see Part 1 Section B).

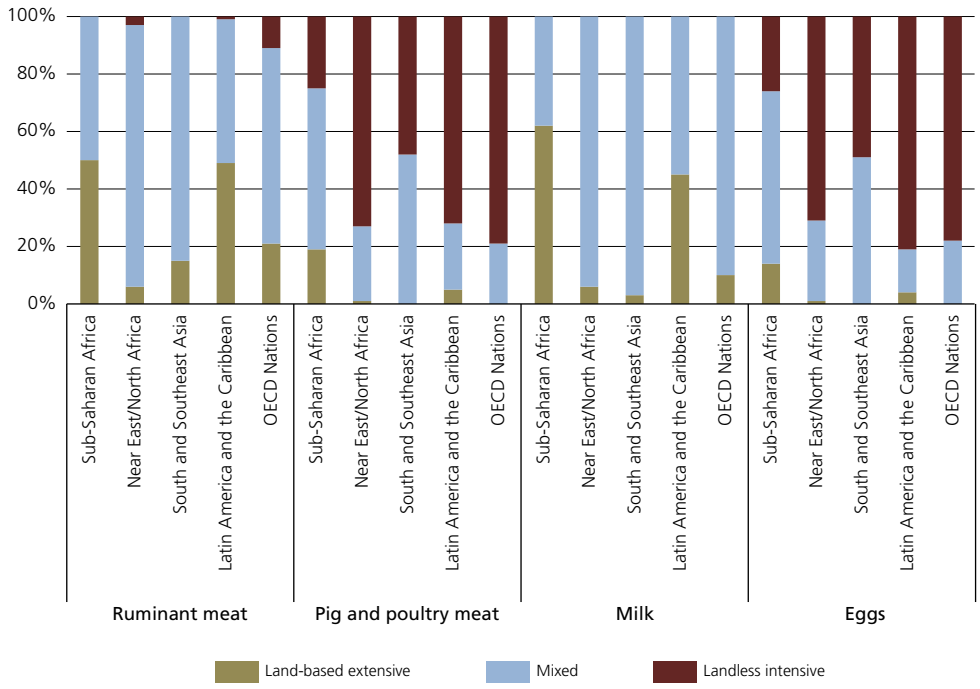
1 Landless industrialized production systems

1.1 Overview

"Industrialization" of production systems (resulting from intensification, scaling-up and geographical concentration of specialized production and processing units) has been a response to increasing demand for animal products. It began in the 1960s in developed countries and in the 1980s in developing countries. Not all landless production is industrialized, but industrialized systems are a substantial and growing part of landless systems. The trend to industrialization has accelerated since the 1990s in developing countries, but has plateaued in the rest of the world. Systems of this type are particularly dominant in the pig and poultry sectors. By the early 2000s, they already accounted for 72 percent of poultry-meat production, 55 percent of pig-meat production and 61 percent of egg production globally (de Haan *et al.*, 2010), although with great variation from region to region (Figure 2B2).

Large-scale landless production systems are economically competitive where demand is relatively high and where large retailers are well

FIGURE 2B2
Production from the main livestock production systems



Note: Land-based extensive = grassland-based.
Source: Graphic prepared using figures for 2004 published in Costales *et al.*, 2010.

established. These systems have benefited from technological advances and have advantages over small-scale production with respect to economies of scale and the ability to provide large and regular supplies to retailers. Large producers also find it easier to manage quality and sanitary standards. Food chains and large retailers have generally preferred contracting with industrial production systems and have stimulated the development of these systems. This is particularly true for poultry meat, egg and pork production.

1.2 Major trends

Expanding production to meet growing demand. Expansion has been particularly marked in monogastric systems, which since the 1980s have experienced faster growth than ruminant systems, a trend that is expected to continue until 2050, especially in the developing world. Herrero *et al.* (2014) estimated that, in 2000, 78 percent of monogastric production came from industrial systems.[1] In 2050, between 85 and 95 percent of production is likely to come from these systems. In contrast, growth in ruminant industrialized systems has been somewhat stagnant. Large-scale beef feedlots have been a feature of production systems in Australia and North America (Galyean *et al.*, 2011), but national herd sizes in these areas have declined in recent years as a result of drought. The systems are also not fully landless, as animals do

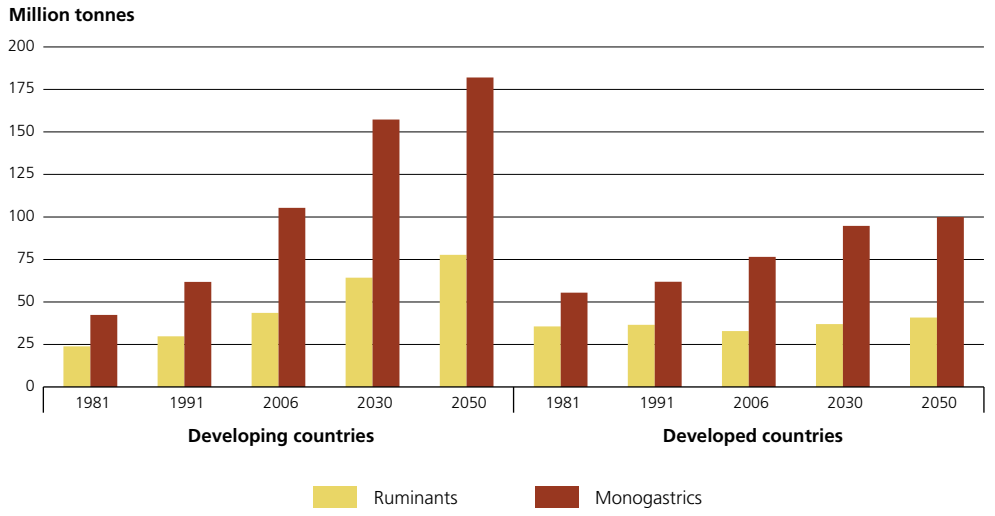
[1] For monogastric production, Herrero *et al.* (2014) differentiated industrial systems from smallholder systems. Ruminant production systems were classified as in the Seré and Steinfeld (1996) classification.

not enter the feedlot until they are one to two years old. The use of feedlots in the Brazilian beef industry has expanded in recent years, accounting for 13 percent of the country's beef production in 2012 (Millen and Arrigoni, 2013). Dairy cattle and small ruminants are much less susceptible to industrialization than monogastrics; although industrial systems exist, the majority of production still comes from mixed farms and grassland-based systems (FAO, IDF and IFCN, 2014).

Moving the production base from developed to developing countries. This trend began in the 1980s and is still evident. Monogastric production, which has historically accounted for much of the output of landless systems and lends itself to industrialization, is growing particularly sharply in developing countries (Figure 2B3). In 1980, industrial systems accounted for more than 90 percent of monogastric production in Europe and Latin America and only 33 percent in Africa and the Middle East. By 2050, industrial production systems may account for 80 percent of the production in developing countries. In Africa, the establishment of intensive poultry farms near cities is becoming more widespread (FAO, 2011a). Industrialization of the dairy sector in developing countries is very slow (Gerosa and Skoet, 2012). Two factors contribute to this effect. In some locations, including the periphery of many large cities and more generally in South and Southeast Asia, farm sizes and herds are small, making it hard to achieve economies of scale. Elsewhere, land holdings and herd sizes are larger, but grazing makes an important contribution to the animals' diets (FAO, IDF and IFCN, 2014). Exceptions to this pattern are North Africa and the Near East, where an arid climate limits the availability of grazing and dairy feedlots are common.

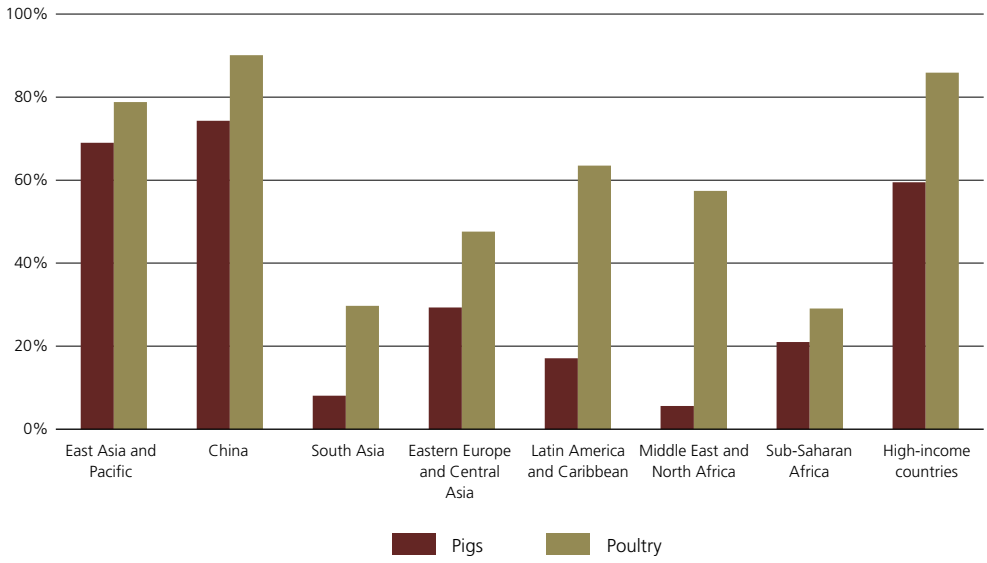
China, India and Brazil have been major contributors to industrialization. In China, for instance, 90 percent of poultry and 74 percent of pigs were raised in industrial systems in 2005, higher proportions than in high-income countries (Figure 2B4).

FIGURE 2B3
Meat production trends in developing and developed countries (1981 to 2050)



Source: Alexandratos and Bruinsma, 2012.

FIGURE 2B4
Proportion of pigs and poultry raised in intensive systems in 2005



Source: Robinson *et al.*, 2011.

Investment against future shocks. Major developing-country producers are taking advantage of developments in technology and animal-health policy to protect themselves against future shocks from disease outbreaks. Large poultry companies, such as Cobb in Brazil and Aviagen in India, are developing certified disease-free compartments, while Chile and South Africa have both introduced compartmentalization schemes for pigs. In Thailand, one of the top-ten poultry exporters before 2003, the largest poultry companies have invested heavily in processing technology, as processed meat is less susceptible to trade bans.

However, it is hard for producers to prepare for shocks caused by price volatility. Prospects for industrialized systems in developing countries will be affected by the price and price volatility of livestock feeds, as many developing countries are (or will be) feed importers (Guyomard *et al.*, 2013). Alexandratos and Bruinsma (2012) estimated a 2 percent annual growth rate in the use of cereal feed in developing countries over the 2005/2007 to 2050 period.

Changing practices in response to societal concerns. Recent years have seen animal welfare issues entering the international policy agenda and affecting livestock-industry practice to a greater degree than they have in the past. Since 2005, the World Assembly of OIE Delegates has adopted ten animal welfare standards for inclusion in the Terrestrial Animal Health Code, including standards for the transport of animals by land, sea and air, slaughter of animals, killing of animals for disease-control purposes, and animal welfare in beef cattle and broiler chicken production. While these standards apply to all livestock production systems, they are most closely scrutinized in industrialized systems. As noted above, concerns about animal welfare led to an EU-wide ban on traditional battery cages for hens in 2012, with producers switching to "enriched" cages, barn production or free-range systems.

Pig producers in Australia are voluntarily phasing out sow gestation stalls, and several large producers in North America and Europe have made small changes to improve welfare in their value chains.

Industrialized systems have also begun to respond to concerns about environmental issues. These systems require large quantities of land, fossil fuels and water to produce feed. They have also been associated with spillages of manure, which can contaminate soil and water (FAO, 2009). Contamination of pastures and croplands with heavy metals (added as supplements to livestock diets and excreted in manure) are particularly hazardous for food-chain safety. Industrial intensive systems affect biodiversity through the destruction and pollution of habitats and their expansion can contribute to the erosion of animal genetic resources (see Section C below and Part 1 Sections B and F). Advances in technology and improvements to management may mitigate some of these impacts. While practices have not yet changed a great deal, research is being carried out on the recovery of nutrients and production of biogas from manure (Cuéllar and Webber, 2008), genetic improvements to improve feed-conversion efficiency and use of alternative feed sources (FAO 2012; 2013b). Some large companies also contribute to discussion fora such as the Global Agenda for Sustainable Livestock (see Section A above).

2 Small-scale landless systems

2.1 Overview

In the developing world, many millions of landless people (i.e. rural or urban people that do not own cropland or pastures and do not have access to large communal grazing areas) keep livestock (Birthal *et al.*, 2006). Animals kept in systems of this kind can provide their keepers with food and other products for sale or home use and play a role in waste management (FAO, 2011). Various feed resources are used, including limited communal grazing, scavenged feed (from streets, yards, etc.), wastes (from kitchens, markets, etc.) and purchased feeds. Small-scale landless production does not fall neatly into widely used production system classifications, and its contribution to global output is difficult to estimate, as is the number of people practising this kind of production.

Small-scale landless producers often use locally adapted breeds, as they tend to be well adapted to scavenging, produce efficiently in backyard conditions and are able to cope relatively well with some diseases and parasites. The main exception to this is in small-scale dairying, where cross-bred cows are often preferred because – provided they receive sufficient feed and appropriate management – they give higher milk yields. Other exotic animals are sometimes raised if they can be accessed easily and production conditions are not too extreme.

Small-scale landless livestock keepers are mostly found in urban and peri-urban areas, close to demand centres. However, they can also be found in rural areas dominated by mixed farming systems where the population density is high and/or land ownership is unequally distributed. Many small-scale landless producers face significant constraints in terms of their ability to access or afford feed and animal-health services. As a consequence, their level of production is low. In rural areas, small-scale landless production is quite peripheral to livestock-sector policies and mostly ignored by government services. The exception is control of major disease outbreaks by culling, which can temporarily decimate livestock populations. In urban areas, small-scale landless production may be targeted by public health and environmental policies. Livestock in cities are a public health concern, as they may transmit zoonotic diseases and parasites. They also cause environmental problems if waste management systems cannot cope with the disposal of manure.

2.1 Major trends

Although the contribution of small-scale landless systems to global production is small, the number of producers is expected to rise in the future. In some countries, access to rural land is becoming increasingly difficult and landless livestock ownership may increase. As authorities often try to exclude livestock keeping from urban areas because of public

health and environmental concerns FAO, 2011), urbanization might be expected to reduce the numbers of landless livestock keepers. However, when rural people migrate to cities to seek new work opportunities they often bring small livestock with them. Urban poverty is still very high and livestock owning provides poor people with a source of income and food. Peri-urban dairy cattle and poultry keeping is also important in the provision of food supplies to growing cities. The first SoW-AnGR suggested that the presence of small-scale intensive systems might prove to be a transitional phase that would be superseded once large-scale production took off. At present, however, "new and old" poultry systems are coexisting in China and small-scale dairy systems remain important in India. It seems likely that this will continue to be the case, at least in the near future.

3 Grassland-based systems

3.1 Overview

Grassland-based systems are found all over the world, predominantly in areas that are unsuitable or geographically inconvenient for crop production. As these systems are highly dependent on the natural environment, livestock breeds are generally well adapted to local water availability, forage and climate. Pastoralist and ranching systems are an important source of protein, converting human-inedible forage into meat and milk (FAO, 2011). Pastoralists, estimated at around 120 million people (FAO, 2011), have developed breeds and management strategies that are well adapted to specific production environments (Watershed Organisation Trust, 2013; FAO, 2013a). In temperate areas, grazing systems are frequently rather intensive and use advanced technologies and specialized breeds (i.e. high-output breeds specializing in the production of single products). In terms of global output of animal products, grassland-based systems are of greatest importance in the cattle and small-ruminant sectors (Figure 2B2).

Grassland-based livestock systems face various pressures. They have to deal with the extreme weather events and new disease threats brought about by climate change with very limited technological options. Pastoralist systems are particularly vulnerable to livestock disease outbreaks, as they often have limited access to animal-health services. They also often have to cope with the effects of civil unrest and various kinds of social and political disruption. In addition to continuing competition from the expansion of croplands and land-use changes associated with the expansion of cities, grassland-based livestock systems face competition from other potential land uses. For example, grasslands can be managed to provide ecosystem services such as regulating water flow in rivers, recharging underground water sources, conservation of wild biodiversity and carbon sequestration, or as sites for wind turbines. In some instances these can be complementary activities to livestock raising, provided that appropriate livestock management is practised. Notwithstanding these challenges, the current consensus is that grazing systems will maintain their current land area until at least 2030 (see next subsection for further discussion).

3.2 Major trends

Maintaining land area. Letourneau *et al.* (2012) estimated that between 2000 and 2030 2.8 million km^2 of pastoral areas will be replaced with rainfed cropland systems. However, the total land area under grazing systems is expected to remain approximately constant to 2030 because of an expansion of 2.7 million km^2 into forested areas. It is likely that replacement of forest by pasture is almost over in Latin America and the Caribbean and declining in South, Southeast and East Asia (FAO, 2013b). Conversely, pastoral systems in sub-Saharan Africa are expected to continue replacing forest areas during the coming decade (ibid).

Increasing importance of arid and semi-arid grassland-based systems. Some of the world's most fragile and sensitive grassland ecosystems, such as the Brazilian and Argentinean cerrados and the savanna areas of certain parts of East

Africa, are under pressure as a result of climate change and the expansion of croplands (IPCC 2014, citing Lambin and Meyfroidt, 2011). Despite these challenges, projections suggest that arid and semi-arid grassland-based livestock systems in sub-Saharan Africa will increase their output of small-ruminant meat and milk and, to a lesser extent, beef and cattle milk (Herrero *et al.*, 2014).

Diversification within pastoralist systems. The various pressures affecting pastoralist systems are leading to changes in the lifestyles and livelihoods of livestock keepers, including a trend towards sedenterization (FAO, 2011). Economic circumstances have created a growing gap between richer and poorer pastoralists in the Horn of Africa, with some becoming contract herders, while others become more substantial livestock owners and traders (Aklilu and Catley, 2010; FAO, 2011). As the human population in Mongolia grows, it appears that herders with smaller numbers of animals are being gradually forced out of herding, while among those who remain as herding households, many are acutely vulnerable to poor climatic conditions and are likely to face periodic food insecurity (FAO, 2011). Historically, policies have generally not been helpful to pastoralists, but some changes aimed at providing appropriate rights and services to pastoralist populations are occurring, for instance in China and Senegal (Steinfeld *et al.*, 2010).

Changes in ranch systems. Ranch systems in Latin America and the Caribbean have faced changes as a result of pressure from expanding croplands and mixed systems. This has recently led to changes in Brazilian beef production systems, with increasing use of feedlots (Millen and Arrigoni, 2013).

Limited progress in mitigating rangeland degradation and deforestation. Rangeland degradation is a major issue in grazing systems and may be exacerbated by climate change, land competition and increasing grazing intensities. Over the 2000 to 2050 period, grazing intensities are expected to increase by 70 percent in Latin America and the Caribbean (Robinson *et al.*, 2011). It has been estimated that in Burkina Faso, Mali, Niger, Nigeria and Senegal, around 70 percent of rangelands are degraded (Gerber *et al.*, 2010). Preventing pasture degradation where institutions for resource management are lacking is difficult (FAO, 2011). However, policies are increasingly targeting pasture restoration and the mitigation of rangeland degradation. In China, for example, the Loess Plateau and the grasslands of Inner Mongolia are especially vulnerable to land degradation (Gerber *et al.*, 2010). Recent policies have aimed to apply partial or complete grazing bans, progressively, over 70 million hectares in Inner Mongolia (Kemp *et al.*, 2013). Overall, China is spending US$2 billion a year on grassland management and related poverty-alleviation programmes (ibid.).

Deforestation caused by the expansion of rangeland systems into forested areas leads to biodiversity loss and greenhouse gas emissions. It has been estimated that 13 million hectares were deforested for pasture establishment in Latin America between 1990 and 2006 (Opio *et al.*, 2013). Around one-third of greenhouse gas emissions from beef production in Latin America and the Caribbean during this period have been attributed to pasture expansion (ibid). At the time, Brazil and Costa Rica's policies included incentives and subsidies/credits to establish pastures on deforested land (Gerber *et al.*, 2010). However, as noted above, deforestation for grazing-land expansion in Latin America is likely to be coming to an end (Letourneau *et al.*, 2012; FAO, 2013a). For example, in Costa Rica, policies have recently addressed forest protection and recovery through the establishment of national parks and protected areas accounting for more than 35 percent of the total forest cover in 2005 (Gerber *et al.*, 2010). Deforestation remains an issue in Asia and Africa, although it appears to be declining in Asia.

Potential for diversification of livelihoods from grasslands. There is growing acknowledgment of the importance of preserving vital ecosystem services, including the provision of habitat for plant and animal biodiversity, pollination, climate regulation and the supply of potable water (Noble *et al.*, 2014). In some areas it may be possible for grassland-based livestock to co-exist with the

provision of carbon sequestration services, conservation of grassland to improve water flow in rivers or generation of electricity from wind turbines (Antle and Stoorvogel, 2011; de Jode and Hesse, 2011; Grassland Foundation, 2005; Neely and De Leeuw, 2011; World Bank, 2009). Co-use of land may require livestock to be kept at lower stocking rates, but could potentially generate higher economic returns from grassland than livestock alone. It requires careful management and functioning markets for non-livestock outputs.

4 Mixed farming systems

4.1 Overview

Mixed farming involves the integration of livestock and crop production into one system. Livestock provide manure to fertilize the soil and (in some cases) draught power for agricultural work. Crops provide feed for the animals. Mixed-rainfed systems are found particularly in temperate areas of Europe and North America, in humid and subhumid areas of Latin America and the Caribbean and Africa, in semi-arid areas of Africa and in South Asia. Mixed-irrigated systems are predominantly found in East and South Asia. Mixed farming systems account for a large share of global livestock production, making a particularly significant contribution to milk and ruminant-meat production (Figure 2B2).

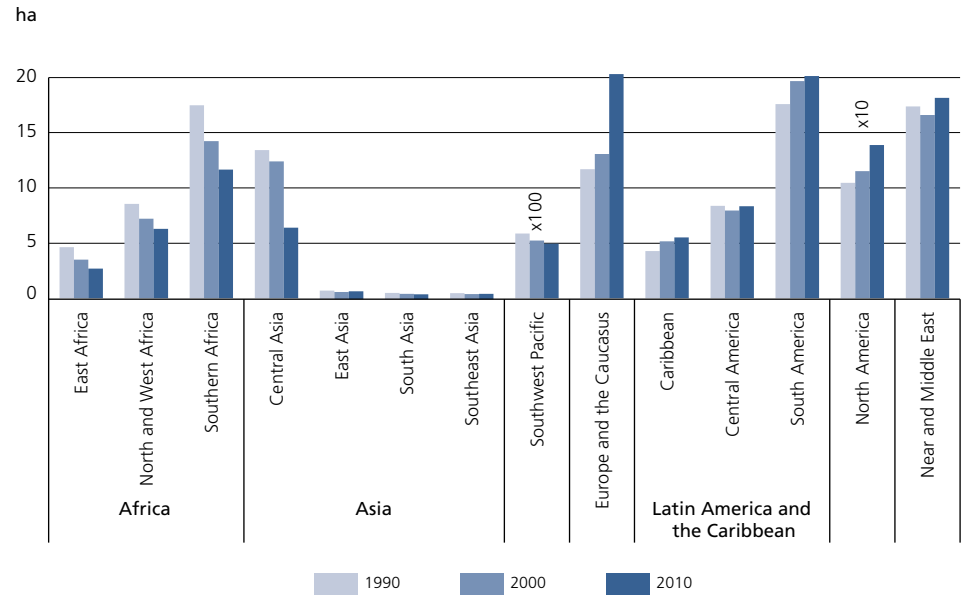
In the developed regions of the world, mixed farms are mainly intensive and production tends to be specialized. A narrow range of breeds with high production potential are increasingly used. There has been a trend towards landless production, especially for monogastric animals. In developing countries, both intensive and extensive mixed farming systems are dominated by small-scale production. Intensive mixed systems are generally market oriented. Depending on the circumstances, they may use either locally adapted breeds or cross-breeds (exotic × locally adapted). Extensive mixed farms, particularly those in marginal areas of developing countries, are predominantly subsistence or semi-subsistence oriented, with weak integration into the market. The breeds kept in these systems are mainly locally adapted, and multipurpose livestock production (meat and milk, meat and traction, etc.) remains important.

4.2 Main trends

Stagnation in developed countries. Projections suggest that most of the future growth in developed-country livestock output will be in poultry and pig production (OECD/FAO, 2014), which is concentrated mostly in landless systems. It is likely that, due to scarcity and costs of water and feed, mixed farming systems will intensify without changing into landless systems. These resource constraints will result in stagnation or even a decrease in the output of livestock products from these systems. There are indications of long-term trends towards larger farm sizes and ageing farming populations in developed countries. However, the impact of these trends is not yet clear. There are also some important nuances – including, in some countries, persistence of small and larger farms while medium-sized farms slowly disappear, and shifts in the social groups entering and leaving farming – that may affect livestock production and productivity in unexpected ways (Australian Bureau of Statistics, 2012; DEFRA, 2012; Mulet-Marquis and Fairweather, 2008; USDA, 2014).

Persistence of smallholders in developing countries. The prevalence of small-scale production in both intensive and extensive mixed farming systems in developing countries is expected to persist, as a result of continuing fragmentation of land (Steinfeld *et al.*, 2010). Agricultural land area per person economically active in agriculture has decreased over recent decades in all developing regions except Latin America and the Caribbean, reaching 0.6 ha in South and Southeast Asia, where farms are smallest (Figure 2B5). Farm sizes in Latin America and the Caribbean are expected to grow. In small mixed farms, livestock are an important source of income; it has been estimated that they typically contribute 5 to 20 percent of total household income in mixed-rainfed systems and 25 to 35 percent in mixed-irrigated systems (Steinfeld *et*

FIGURE 2B5
Agricultural land available per person economically active in agriculture



Source: FAOSTAT.

al., 2010). Smallholder mixed farming systems are predicted to remain the main producers of ruminants until 2050 (Herrero *et al.*, 2014).

Increasing pressure on intensive mixed systems in developing countries. Although consumption growth, integration into markets and new life opportunities encourage intensification and commercialization, intensive systems in developing countries are coming under increasing pressure from land fragmentation, limited resources and increasing input costs (feed and drugs). Increasing concentration of animal populations also makes disease control more challenging. It is expected that during the period to 2030 growth in crop productivity will drastically slow or even end (Herrero *et al.*, 2012). Climate change is a major challenge to sustainability and even irrigated systems are facing problems of water shortage. In Africa, semi-arid mixed-rainfed systems in the Sahel, arid and semi-arid grazing systems in East Africa and mixed and grazing systems in the Great Lakes Region may be severely affected by climate change (Thornton, 2014). Notwithstanding these various pressures, mixed systems are expected to survive, and in extensive systems productivity gains may be possible (Herrero *et al.*, 2012).

Environmental impacts. Well-managed mixed farming systems are recognized as being relatively benign in environmental terms. However, intensification, with increasing inputs and stocking rates, can lead to more severe impacts on the environment, particularly through increased demand for concentrate feeds. Over the 2000 to 2030 period, rainfed croplands are predicted to expand by 4.3 million km^2 (Letourneau *et al.*, 2012), with part of this expansion resulting from a growing need for livestock feed. The first SoW-AnGR identified several environmental problems associated with

irrigated mixed farming, including waterlogging, salinization of soils, the effects of dam building and issues linked to the disposal surplus of water.[2] These problems persist and may increase if livestock production in mixed systems continues to intensify.

References

Alexandratos, N. & Bruinsma, J. 2012. *World agriculture towards 2030/2050: the 2012 revision*. ESA Working paper No. 12-03. Rome, FAO (available at http://www.fao.org/docrep/016/ap106e/ap106e.pdf).

Antle, J.M. & Stoorvogel, J.J. 2011. *Economic, environmental and social impacts of rangeland soil carbon sequestration in the U.S. Northern Plains*. Report prepared for the Big Sky Carbon Sequestration Partnership Deliverable ED5.

Aklilu, Y. & Catley, A. 2010. *Livestock exports from the Horn of Africa: An analysis of benefits by pastoralist wealth group and policy implications*. Medford, MA, USA, Feinstein International Center (available at http://fic.tufts.edu/assets/LivestockExports.pdf).

Australian Bureau of Statistics. 2012. *Australian farming and farmers*. Canberra (available at http://tinyurl.com/lkq4lyb).

Birthal, P.S., Taneja, V.K. & Thorpe, W. (eds). 2006. *Smallholder livestock production in India: opportunities and challenges*. Proceedings of an ICAR–ILRI international workshop held at National Agricultural Science Complex, DPS Marg, Pusa, New Delhi 110 012, India, 31 January – 1 February 2006. New Delhi, National Centre for Agricultural Economics and Policy Research – Indian Council of Agricultural Research and Nairobi, ILRI (available at http://tinyurl.com/mckf8a3).

Costales, A.C., Pica-Ciamarra, U. & Otte, J. 2010. Social consequences of mixed crop–livestock systems in developing countries. *In* H. Steinfeld, H.A. Mooney, F. Schneider & L.E. Neville, eds. *Livestock in a changing landscape. Volume 1. Drivers, consequences and responses*, pp. 249–268. Washington, DC, Island Press.

Cuéllar, A.D. & Webber, M.E. 2008. Cow power: the energy and emissions benefits of converting manure to biogas. *Environmental Research Letters,* 3 (July-September 2008) 034002 (available at http://iopscience.iop.org/1748-9326/3/3/034002/fulltext).

DEFRA. 2012. *Agriculture in the United Kingdom*. London, Department for Environment, Food and Rural Affairs (available at http://tinyurl.com/pp9h5bw).

de Haan, C., Gerber, P. & Opio, C. 2010. Structural change in the livestock sector. *In* H. Steinfeld, H.A. Mooney, F. Schneider & L.E. Neville, eds. *Livestock in a changing landscape. Volume 1. Drivers, consequences and responses*, pp. 35–50. Washington, DC, Island Press.

De Jode, H. & Hesse, C. 2011. *Strengthening voices: how pastoralist communities and local government are shaping strategies for adaptive environmental management and poverty reduction in Tanzania's drylands*. IIED, Kimmage DSC and Tanzania Natural Resource Forum (available at http://pubs.iied.org/G03105.html).

FAO. 2007a. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2009. *The State of the Food and Agriculture. Livestock in the balance*. Rome (available at http://www.fao.org/docrep/012/i0680e/i0680e.pdf).

FAO. 2011. *World Livestock 2011. Livestock in food security*. Rome (available at http://www.fao.org/docrep/019/i3440e/i3440e.pdf)

FAO. 2012. *Biofuel co-products as livestock feed. Opportunities and challenges,* edited by H.P.S. Makkar, Rome (available at http://www.fao.org/docrep/016/i3009e/i3009e.pdf).

FAO. 2013a. *World Livestock 2013. Changing disease landscapes*. Rome (available at http://www.fao.org/docrep/019/i3440e/i3440e.pdf).

FAO. 2013b. *Edible insects. Future prospects for food and feed security*. Rome (available at http://www.fao.org/docrep/018/i3253e/i3253e.pdf).

FAO, IDF & IFCN. 2014. *World mapping of animal feeding systems in the dairy sector*. Rome (available at http://www.fao.org/publications/card/en/c/3fe753e2-9f1f-4397-acde-2bd25afb95b7/).

[2] FAO, 2007, pages 174–176.

PART **2**

FAO/ILRI. 2011 *Global livestock production systems v.5 2011*. Map downloaded from GIS system (available at http://tinyurl.com/nnvbhpo).

FAOSTAT. FAO Statistical database (available at http://faostat3.fao.org/faostat-gateway/go/to/home/E) (accessed 30 October 2014).

Galyean, M.L., Ponce, C. & Schutz, J. 2011. The future of beef production in North America. *Animal Frontiers*, 1: 29–36.

Gerber, P., Mooney, H., Dijkman, J., Tarawali, S. & Haan, C. de. 2010. *Livestock in a changing landscape. Volume 2. Experiences and regional perspectives.* Washington, DC, Island Press.

Gerosa, S. & Skoet, J. 2012. *Milk availability: trends in production and demand and medium-term outlook*. ESA Working paper No. 12-01. Rome, FAO (available at http://www.fao.org/docrep/015/an450e/an450e00.pdf)

Grassland Foundation. 2005. *Economic benefits of grassland protected areas*. Lincoln, Nebraska, USA, Grassland Foundation.

Guyomard, H., Manceron, S. & Peyraud, J.L. 2013. Trade in feed grains, animals, and animal products: Current trends, future prospects, and main issues. *Animal Frontiers,* 3(1): 14–18.

Herrero, M., Havlik, P., McIntire, J., Palazzo, A. & Valin, H. 2014. *African livestock futures: realizing the potential of livestock for food security. Poverty reduction and the environment in sub-Saharan Africa*. Geneva, Switzerland. Office of the Special Representative of the UN Secretary General for Food Security and Nutrition and the United Nations System Influenza Coordination (UNSIC) (available at http://tinyurl.com/nj6tr8a).

Herrero, M., Thornton, P.K., Notenbaert, A., Msangi, S., Wood, S., Kruska, R., Dixon, J. Bossio, J., van de Steeg, J., Freeman, H.A, Li X. & ParthasarathyRao, P. 2012. *Drivers of change in crop-livestock systems and their potential impacts on agro-ecosystems services and human wellbeing to 2030.* A study commissioned by the CGIAR Systemwide Livestock Programme. Nairobi, ILRI (available at http://tinyurl.com/kupbsau).

Kemp, D.R, Guodong, H., Xiangyang, H., Michalka, D.L., Fuiange, H., Jianging, W. & Yingjung, Z. 2013. Innovative grassland management systems for environmental and livelihood benefits. *PNAS*, 110(21): 8369–8374.

Lambin, E.F. & Meyfroidt. P. 2011. Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences of the United States of America*, 108(9): 3465–3472.

Letourneau, A., Verburg, P.H. & Stehfest, E. 2012. A land-use systems approach to represent land-use dynamics at continental and global scales. *Environmental Modelling & Software*, 33: 61–79.

Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M.S. & Bernabucci, U. 2010. Effects of climate changes on animal production and sustainability of livestock systems. *Livestock Science,* 130 (1–3): 57–69 (10th World Conference on Animal Production [WCAP]).

Noble, I.R., Huq, S., Anokhin, Y.A., Carmin, J., Goudou, D., Lansigan, F.P., Osman-Elasha B. & Villamizar, A. 2014. Adaptation needs and options. *In* C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea & L.L. White, eds. *Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York USA, Cambridge University Press.

Millen, D.D. & Arrigoni, M.D.B. 2013. Drivers of change in animal protein production systems: Changes from "traditional" to "modern" beef cattle production systems in Brazil. *Animal Frontiers,* 3(3): 56–60.

Mulet-Marquis, S. & Fairweather, J. 2008. *New Zealand farm structure change and intensification.* Research Report No. 301. Lincoln, New Zealand, Lincoln University Agribusiness and Economics Research Unit (available at http://www.lincoln.ac.nz/documents/4322_rr301_s14339.pdf).

Neely, C. & De Leeuw, J. 2011. Home on the range: the contribution of rangeland management to climate change mitigation. *In* E. Wollenberg, M-L. Tapio-Bistrom, M. Grieg-Gran & A. Nihart, eds, *Climate change mitigation and agriculture*, pp. 333–346. Abingdon, UK and New York, USA, Earthscan, Routledge.

OECD/FAO. 2014. *OECD-FAO Agricultural Outlook 2014*. Paris, OECD Publishing (available at http://www.agri-outlook.org/).

Opio, C., Gerber, P., Mottet, A., Falcucci, A., Tempio, G., MacLeod, M., Vellinga, T., Henderson, B. & Steinfeld, H. 2013. *Greenhouse gas emissions from ruminant supply chains – a global life cycle assessment.* Rome, FAO (available at http://www.fao.org/docrep/018/i3461e/i3461e.pdf).

Robinson, T.P., Thornton P.K., Franceschini, G., Kruska, R.L., Chiozza, F., Notenbaert, A., Cecchi, G., Herrero, M., Epprecht, M., Fritz, S., You, L., Conchedda, G. & See, L. 2011. *Global livestock production systems*. Rome, FAO and Nairobi, ILRI (available at http://www.fao.org/docrep/014/i2414e/i2414e00.pdf).

Robinson, T.P., Wint, G.R.W., Conchedda G., Van Boeckel, T.P., Ercoli, V. Palamara, E., Cinardi, G., D'Aietti, L., Hay, S.I. & Gilbert, M. 2014. Mapping the global distribution of livestock. *PLoS ONE*, 9(5): e96084. doi:10.1371/journal.pone.0096084.

Seré, C. & Steinfeld, H. 1996. *World livestock production systems. Current status, issues and trends.* FAO Animal Production and Health Paper 127. Rome, FAO (available at http://www.fao.org/docrep/004/W0027E/W0027E00.HTM).

Settele, J., Scholes, R., Betts, R., Bunn, S., Leadley, P., Nepstad, D., Overpeck, J.T. & Taboada, M.A. 2014. Terrestrial and inland water systems. *In* C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea & L.L. White, eds. *Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects*. *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, USA, Cambridge University Press.

Steinfeld, H., Mooney, H.A., Schneider, F. & Neville, L.E. 2010. *Livestock in a changing landscape. Volume 1. Drivers, consequences, and responses*. Washington, DC, Island Press.

Thornton, P.K. 2014. Impacts of climate change on length of growing period. *In* K. Sebastian, ed. *Atlas of African research and development*, pp 56–57. Washington DC, International Food Policy Research Institute (IFPRI) (available at http://tinyurl.com/mc8vzeh).

Thornton, P.K., Jones, P.G., Owiyo, T., Kruska, R.L., Herrero, M., Kristjanson, P., Notenbaert, A., Bekele, N. & Omolo, A., with contributions from Orindi, V., Otiende, B., Ochieng, A., Bhadwal, S., Anantram, K., Nair, S., Kumar, V. & Kulkar, U. 2006. *Mapping climate vulnerability and poverty in Africa.* Report to the Department for International Development, Nairobi, ILRI (available at http://www.imagineindore.org/resource/21.pdf).

USDA. 2014. *2012 Census of Agriculture United States: summary and state data*. Washington, DC, United States Department of Agriculture (available at http://tinyurl.com/pd3gak7).

Watershed Organisation Trust. 2013. *Livestock systems, vulnerability and climate change*. Pune, India (available at http://tinyurl.com/ncuz7oc).

World Bank. 2009. *Mongolia: the economic value of the Upper Tuul Ecosystem*. December 2009. Washington DC, IBRD/World Bank (available at http://tinyurl.com/q929uzw).

Section C

Effects of changes in the livestock sector on animal genetic resources and their management

1 Overview and regional analysis

As described above in Sections A and B, the livestock sector in many parts of the world is undergoing rapid transformation, driven by both demand-side and supply-side factors. This section aims to describe the effects that these changes are having on animal genetic resources (AnGR) and their management. The first SoW-AnGR noted, in particular, that the intensification of the livestock sector was having a major influence on AnGR management and leading to the more widespread use of a narrow range of international transboundary breeds, often exotic to the countries where they were being used. It noted that locally adapted breeds retained an important role in more traditional production systems, but that the sustainable use of AnGR in these systems was being disrupted by a number of factors, including inappropriate policies, climate change and degradation of natural resources or problems with access to these resources. On the more positive side from the perspective of maintaining AnGR diversity, it noted that cultural roles, demand for environmental services and the emergence of new niche markets were to some extent stimulating the use of locally adapted breeds and that there was potential scope for expanding these uses. It also noted the potential future significance of locally adapted AnGR in the context of climate change and other threats to the sustainability of high external input systems and the use of high-output breeds.

With the aim of obtaining more detailed information on how these broad trends are playing out at national level, the country-report questionnaire for the second SoW-AnGR[1] included questions on the main drivers of change identified in the first SoW-AnGR (see Table 2C1). Countries were asked both to describe the effects of the drivers and to provide scores for the extent of their impacts on AnGR and their management during the preceding ten years and for predicted impacts for the next ten years.

The quantitative responses are summarized in Figure 2C1. With regard to impacts over the last ten years, six of the 15 drivers – changes in demand (quantity and quality), changes in imports, factors affecting the popularity of livestock keeping, policy factors and changes in state of grazing lands – received an average score of more than 1.5 (midway between "low" and "medium"). Most of the other drivers scored between 1 and 1.5. The exceptions were changes in livestock's cultural roles and the replacement of livestock functions. The low scores for these two drivers may reflect the fact that in a number of countries these changes had largely played out more than ten years ago. The high score for quantitative changes in demand coincides with the conclusion drawn in the first SoW-AnGR that this major driver of livestock-sector trends is having a substantial effect

[1] For further information on the reporting process, see "About this publication" in the preliminary pages of this report.

PART **2**

TABLE 2C1

Drivers of change explored in the country-report questionnaire

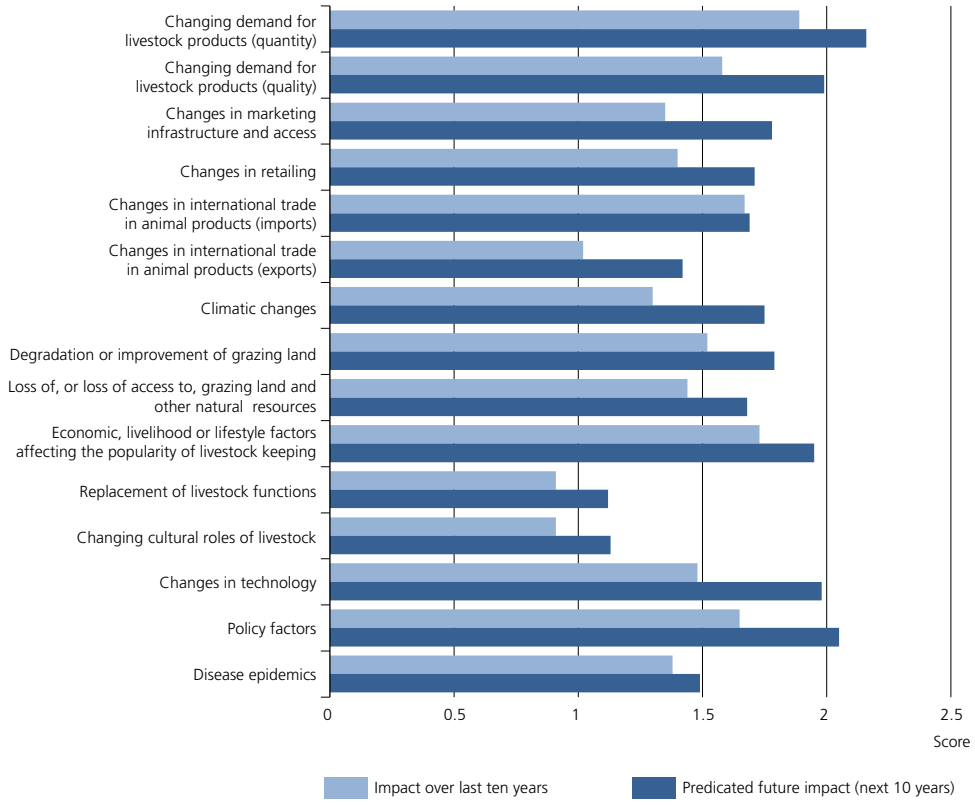
Drivers	Explanatory notes provided in the questionnaire
Changing demand for livestock products (quantity)	Changes in the quantity of product demanded by the market. For example, population growth, urbanization and higher incomes may have increased demand for meat, eggs and milk. Another possibility is that increasing availability of alternative products may have reduced demand for some livestock products.
Changing demand for livestock products (quality)	Changes in the type of products demanded by consumers (e.g. greater or lower demand for convenience foods, healthier products, animal welfare friendly products, environmentally friendly products, traditional products or other niche-market products).
Changes in marketing infrastructure and access	Changes that improve or reduce livestock keepers' access to markets for their products (e.g. better transport, better access to market information).
Changes in retailing	Changes in how animal products are retailed (e.g. expansion of supermarkets).
Changes in international trade in animal products (imports)	Increases or decreases in the importation of animal products into the country. [Respondents were reminded that imports and exports of genetic material were covered in a separate section of the questionnaire.]
Changes in international trade in animal products (exports)	Increases or decreases in the extent to which the county's livestock sector is oriented towards production for export. [Respondents were reminded that imports and exports of genetic material were covered in a separate section of the questionnaire.]
Climatic changes	Departures from the climatic patterns observed in preceding decades. These might include changes in the average temperature and levels of rainfall or changes in the frequency of events such as droughts, floods and hurricanes. [Respondents were advised that they did not have to decide whether these changes are attributable to human-induced climate change. For the future period, respondents were requested to base their answers on their knowledge of AnGR management in the respective country and its vulnerability to the effects of climate change as predicted by the best-available climatic models for the country.]
Degradation or improvement of grazing land	Changes to grazing land that make it less or more suitable for grazing livestock (e.g. erosion, changes in the species composition of the flora).
Loss of, or loss of access to, grazing land and other natural resources	Situations in which grazing lands, arable land used for fodder production or other resources such as water, are lost (e.g. because of urban or industrial development) or in which livestock keepers' access to such resources is restricted (e.g. changes in regulations may mean that pastoralists are not permitted to use certain grazing lands).
Economic, livelihood or lifestyle factors affecting the popularity of livestock keeping	This refers, for example, to changes in the availability of alternative employment activities outside livestock keeping, changes in the relative attractiveness of livestock keeping in economic terms or changes in lifestyles or lifestyle aspirations that make livestock keeping less or more attractive as an activity.
Replacement of livestock functions	Situations in which particular livestock functions are replaced by alternatives. For example: draught animal power may be replaced by mechanical power; livestock's savings and insurance functions may be replaced by banks and insurance companies.
Changing cultural roles of livestock	Changes to the roles of livestock in cultural practices and events (e.g. ceremonies, festivals, shows and sports).
Changes in technology	Technological developments and changes in access to technologies within the livestock sector (e.g. in the fields of animal health, feeding, housing, reproduction or genetics).
Policy factors	This refers to policies that affect the livestock sector. [Respondents were directed to the relevant section of the first SoW-AnGR for further information.]
Disease epidemics	Outbreaks of animal diseases: these may, for example, pose a threat to at-risk breeds (either directly or because of culling programmes). AnGR and their management may also be affected by other types of disruption associated with epidemics and their management (restrictions on marketing animal products, restrictions on animal movements, etc.).

on AnGR management, and with widespread concerns that economic and demand-related factors pose a threat to AnGR diversity (FAO, 2009a). Qualitative changes in demand scored somewhat lower, but their impact is predicted to increase considerably in the future.

The relatively high score given to the effects of imports of animal products presumably reflects the impact of competition on national livestock sectors. The impact of export trade is reported to have been relatively low, but the significance of this driver is predicted to rise

FIGURE 2C1

Past and predicted future impacts of the drivers of change on animal genetic resources and their management



Notes: Each country provided a score for the level of past and predicted future impact. The scores were converted into numerical values (none = 0; low = 1; medium = 2; high = 3).
Source: Country reports, 2014.

substantially in the future – the largest proportional increase (40 percent) among all the drivers considered. Factors affecting the popularity of livestock keeping as a livelihood activity (lifestyle changes, alternative employment opportunities, etc.) were not stressed particularly heavily as drivers of change in the first SoW-AnGR, but received the second highest average score in the country-report responses. Given that in many countries there is a tendency for small-scale livestock keepers (generally regarded as "guardians" of AnGR diversity) to move out of the sector (FAO, 2009b), the effect of this driver on AnGR is likely to be mainly negative in terms of maintaining diversity, although in some circumstances growth of interest in livestock keeping as a hobby or "alternative" lifestyle may contribute to the ongoing maintenance of non-mainstream AnGR.

The relatively high score received by policy factors coincides with the conclusion drawn in the first SoW-AnGR that livestock-sector policies

can have a significant effect on AnGR management. As discussed above in Section A, a wide range of policy areas and types of policy instruments can affect AnGR management. Over the last decade or so, discussions of general objectives of livestock-sector development have increasingly emphasized the importance of improving the efficiency of production, particularly with regard to reducing the amount of greenhouse gas emitted per unit of food produced (Steinfeld *et al.*, 2006; FAO, 2009b). There has been a tendency to regard smallholder and pastoralist systems as relatively inefficient, which if translated into concrete policies could potentially have a negative effect on livestock diversity by de-emphasizing the production systems that tend to favour the maintenance of a diverse range of AnGR. Recent years have, however, seen some alternative views put forward regarding the nature of "efficiency" in livestock production systems, including arguments related to the need to take a broader range of livestock products and services into account on the output side and the need to consider a wider range of inputs and environmental impacts (see Box 2C1). It remains to be seen whether arguments of this kind will have a significant effect on future policies.

It is interesting to note that the effects of all the drivers considered in the country reports are predicted to be greater in the future than in the past. Apart from above-noted increase in the significance of export trade, the drivers whose impact is expected to show the greatest increases are climate change (35 percent increase) (see Box 2C2 for an example), technological changes (33 percent) and changes related to marketing access and infrastructure (32 percent increase).

There are a number of regional differences in the significance of the various drivers (Table 2C2). For example, in Africa, there is predicted to be a big increase (relative to that in other regions) in the impact of drivers related to demand, marketing and retailing. This is consistent with: i) the predicted increase in demand for animal products in Africa (see Section A above); and ii) the major scope for change that exists in the management of AnGR in this region. Given this background, the finding may not be particularly surprising. However, it highlights the increasingly dynamic nature of AnGR management in the region and – given that drivers in this category are commonly regarded as threats to AnGR diversity – the need for action to ensure that changes are managed sustainably. The effects of policies and technological changes are also predicted to increase substantially in this region. This might again be interpretable as an unsurprising response to a dynamic period of development, but given the potential of both policies and the use of technology to have both positive and negative effects on AnGR diversity, it again highlights the need to ensure appropriate management, including monitoring programmes for trends in the size and structure of breed populations. Africa also generally has higher future scores for environment-related drivers (climatic changes, drivers related to grazing land, disease) than other regions. Some of these drivers (climatic changes and degradation of grazing land) also have relatively large predicted increases in their effects.

In Asia, the predicted future impacts of demand- and marketing-related drivers are mostly similar to those in Africa. The difference between the two regions is that, in Asia, most of these drivers received similar scores for their past and future impacts. A big jump in the impact of export trade is, however, predicted for Asia.

In the Southwest Pacific, drivers related to the environment and natural resources stand out in terms of their predicted future increases in impact. However, in absolute terms, the scores for these drivers are not particularly high relative to other regions. From relatively low levels in the past, the impacts of cultural change, technological change and policy factors are predicted to increase substantially.

The situation in Europe and the Caucasus is relatively stable in terms of differences between past and future impacts. The largest predicted changes

Box 2C1

Efficiency and multifunctionality in extensive livestock systems

It is sometimes argued that extensive livestock production systems are relatively harmful to the environment because of their low efficiency in terms of transforming inputs into animal products (milk and meat), which results in a relatively high carbon footprint. Recently, however, some studies assessing environmental impacts of different production systems have tried to consider other livestock functions such as manure production, draught power and insurance and savings.

If multifunctionality is taken into account, the environmental efficiency of extensive dairy systems may appear comparable, if not superior, to that of more intensive systems. For example, Weiler *et al.* (2014) estimated the carbon footprint of a Kenyan smallholder dairy system to be 1.1 kg CO_2-e (carbon dioxide equivalent) per kg milk if calculations include the allocation of emissions to a range of livelihood benefits. This amounts to half the carbon footprint estimate obtained if emissions are allocated only to food products (milk and meat) and falls within the range of results for intensive systems in OECD countries (0.8–1.3 kg CO_2-e per kg milk).

Vigne (2014) compared the efficiency (or "transformity") of different dairy production systems in terms of gigajoules of solar energy per joule of product and estimated that, despite lower production levels, the efficiency of extensive dairy systems in Mali (490 GJ of solar energy/J of product) was comparable to that of semi-intensive systems in western France (410–500 GJ of solar energy/J of product) and much more efficient than that of the intensive systems studied in Réunion (1 210 GJ of solar energy/J of product). The same study also concluded that the inputs used in the extensive systems (consisting mainly of locally available raw materials) had a higher renewability (44 percent of total resources consumed) than those of the semi-intensive and intensive systems studied (21 percent and 24 percent, respectively).

Both studies underline the necessity of incorporating multiple livestock functions into life-cycle assessments and other methodologies for estimating the environmental impact of production systems.

Box 2C2

Shift of livestock species as a result of climate change: an example from Ethiopia

Pastoral areas of Ethiopia have experienced substantial increases in temperature in recent years. Southern, southwestern and southeastern areas have undergone a decline of 15 to 20 percent in spring and summer rainfall since the mid-1970s. Yosef *et al.* (2013) report the findings of a survey of 200 pastoralists in the Afar, Oromiya and Somali Regions of Ethiopia that assessed livelihood diversification and cattle and dromedary population dynamics. Official surveys indicate a decline of 50 to 70 percent in the cattle population over the last 20 years in most of the districts covered by the study. Conversely, the dromedary population increased by between 10 and 200 percent, depending on the district. A large majority of the cattle owners interviewed stated that they intended to reduce the number of cattle they kept. One district was an exception, in that a majority reported an interest in increasing the number of cattle kept by crossing their animals with breeds that have better resistance to drought and disease. All interviewees indicated their desire to increase the number of dromedaries in their herds. Dromedaries were reported to provide a better source of income than cattle, sheep or goats. Based on the results of the survey, the authors conclude that the observed species shift could pose a threat to indigenous cattle breeds in the near future.

TABLE 2C2

Past and predicted future impacts of livestock sector trends and drivers on animal genetic resources and their management

Regions	Africa			Asia			Southwest Pacific			Europe and the Caucasus			Latin America and the Caribbean			North America			Near and the Middle East			World		
	Past	Future	Δ	Past	Future	Δ	Past	Future	Δ	Past	Future	Δ	Past	Future	Δ	Past	Future	Δ	Past	Future	Δ	Past	Future	Δ
Changing demand for livestock products (quantity)	1.9	2.5	0.6	2.2	2.4	0.2	2.3	2.1	-0.2	1.6	1.7	0.1	1.9	2.1	0.2	2	2	0	2.3	2.4	0.1	1.9	2.2	0.3
Changing demand for livestock products (quality)	1.4	2.1	0.7	1.9	2.1	0.2	1.9	1.9	0	1.6	1.9	0.3	1.6	2	0.4	2	2	0	1.6	1.6	0	1.6	2.0	0.4
Changes in international trade in animal products (imports)	1.7	1.7	0	1.9	1.8	-0.1	1.3	1.3	0	1.7	1.7	0	1.6	1.8	0.2	1	1	0	1.6	1.4	-0.2	1.7	1.7	0.0
Changes in international trade in animal products (exports)	0.9	1.5	0.6	1.2	1.8	0.6	0.4	0.9	0.5	1.2	1.4	0.2	1.1	1.6	0.5	2	2	0	0.4	0.4	0	1.0	1.4	0.4
Changes in marketing infrastructure and access	1.3	2.1	0.8	1.7	2.1	0.4	0.9	1.4	0.5	1.4	1.5	0.1	1.4	1.8	0.4	1	1	0	1	1.3	0.3	1.4	1.8	0.4
Changes in retailing	1.3	1.9	0.6	1.6	1.9	0.3	1.3	1.6	0.3	1.5	1.6	0.1	1.4	1.7	0.3	1	1	0	1.1	1.1	0	1.4	1.7	0.3
Economic, livelihood or lifestyle factors affecting the popularity of livestock keeping	1.8	2.2	0.4	1.9	2	0.1	1.6	2	0.4	1.9	2	0.1	1.5	1.7	0.2	2	2	0	0.6	0.7	0.1	1.7	2.0	0.2
Changing cultural roles of livestock	0.9	1.2	0.3	1.5	1.5	0	1	1.7	0.7	0.7	0.9	0.2	0.7	1	0.3	1	1	0	1	1	0	0.9	1.1	0.2
Replacement of livestock functions	0.9	1.4	0.5	1.4	1.6	0.2	0.6	0.7	0.1	0.9	0.8	-0.1	0.9	1.1	0.2	0	0	0	0.6	0.6	0	0.9	1.1	0.2
Climatic changes	1.7	2.2	0.5	1.5	1.8	0.3	0.7	2	1.3	0.7	1.1	0.4	1.6	2.1	0.5	1	2	1	1.3	1.3	0	1.3	1.8	0.5
Degradation or improvement of grazing land	1.9	2.3	0.4	1.8	2	0.2	0.9	1.6	0.7	1.1	1.2	0.1	1.6	1.9	0.3	0	0	0	1.3	1.6	0.3	1.5	1.8	0.3
Loss of, or loss of access to, grazing land and other natural resources	1.9	2.1	0.2	1.7	1.7	0	1	2	1	0.9	1.1	0.2	1.6	2	0.4	2	2	0	0.7	0.7	0	1.4	1.7	0.2
Disease epidemics	1.8	1.7	-0.1	1.7	1.7	0	0.7	1.3	0.6	1.1	1.4	0.3	0.7	1.1	0.4	0	2	2	1.9	1.3	-0.6	1.4	1.5	0.1
Changes in technology	1.2	2.1	0.9	1.7	2.1	0.4	0.7	1.6	0.9	1.7	1.8	0.1	1.8	2.2	0.4	3	3	0	1.7	1.3	-0.4	1.5	2.0	0.5
Policy factors	1.5	2.1	0.6	1.7	2	0.3	1.1	1.7	0.6	2.1	2.3	0.2	1.5	2.1	0.6	2	2	0	1.4	1.4	0	1.6	2.1	0.4

Note: Each country provided a score for the level of past and predicted future impact. The scores were converted into numerical values (none = 0; low = 1; medium = 2; high = 3). Dark orange = increase of 1 or more in average score from past to predicted future; light orange = increase between 0.6 and 1; dark yellow = increase between 0.3 and 0.6; light yellow = no change or increase of less than 0.3; pale blue = decrease of less than 0.3; medium blue = decrease of 0.3 or more.
Source: Country reports, 2014.

are in the impacts of climatic changes, animal diseases (perhaps to some degree connected to climatic change) and qualitative changes in demand. The driver with the most impact (both in the past and predicted for the future) is policy. This probably reflects the significance of AnGR-focused policies (i.e. policies specifically aiming to promote conservation and sustainable use) in the European Union (EU) and in some other European countries (see Part 3 Section F). This is the only region where quantitative changes in demand do not have the highest or joint highest impacts (both past ten years and predicted future).

Latin America and the Caribbean reports a pattern of past impacts that is roughly similar to those of Asia and Africa. Predicted changes from the past to the future indicate a moderate degree of dynamism, but changes in the impacts of demand and market-related drivers are generally less dramatic than in Africa. The biggest increase in impact is predicted in the policy field. Moderate increases are predicted across a range of different drivers, including those related to the environment and natural resources, exports, marketing infrastructure and qualitative changes in demand.

In the Near and Middle East, the past and future impacts of most drivers are predicted to be similar. The largest predicted increases are in the impacts of changes in marketing infrastructure and access and changes in the state of grazing land. The impact of several drivers is predicted to decrease, including, in sharp contrast to other developing regions, technological changes. The impact of disease epidemics is predicted to decline because of improvements to veterinary provisions in some countries.

2 Specific effects on animal genetic resources management – examples at country level

As noted above (see also Part 1 Section F), it is generally considered that rising demand for livestock products drives production-system changes that tend to lead to the wider use of a narrow range of breeds (those suitable for use in industrial or other high-input systems) and constitute potential threats to the survival of other breeds because of replacement (see Box 2C3) or in some cases indiscriminate cross-breeding. This analysis is generally borne out by the descriptions provided in the country reports. The report from Suriname, for example, notes that producers' desire for "quick" improvements in production has led to the introduction of exotic breeds with high yield potential, even though this has created problems associated with higher expenses for feed, housing and overall management. Despite these problems, there is reportedly "a reluctance or in some cases inability" to switch back to using locally adapted breeds. The report from Niger mentions that the effects of greater demand for livestock products, driven by population growth and urbanization, have included the emergence of a new layer of rich farmers and the impoverishment of thousands of small-scale livestock keepers that raise locally adapted breeds.

As described above in Section A, changes in income levels and lifestyles can lead to changes in the types of animal-source food sought by consumers. For example, urbanization and rising incomes tend to lead to an increase in demand for convenience foods, often mass-produced and sold by large retailers. However, a certain level of affluence, and changing fashions, may lead to growing interest in speciality food products, potentially including those that are more traditional or perceived to be so. Social and environmental concerns may start to exert greater influence on consumers' choice of products. The first SoW-AnGR noted that the homogenization of consumer demand posed a potential threat to AnGR diversity, while the emergence of niche markets offered a potential means of keeping "non-mainstream" breeds in use. The establishment of "new" niche markets for animal products has tended to be a developed-country phenomenon. However, a number of examples from developing countries have been recorded (LPP *et al.*, 2010) (see also Part 1 Section D). Moreover, in many developing countries,

Box 2C3

Animal genetic resources management in Iceland: will exotic breeds substitute locally adapted breeds?

Iceland has only one breed for most species of livestock. The roots of these breeds can be traced back to the settlement of Iceland. They are believed to have been subject to extremely limited cross-breeding with exotic breeds. Icelandic breeds are unique in that their diversity, in terms of traits such as colour, is greater than that of other livestock breeds.

Leadersheep,
a unique strain of the Iceland breed of sheep

Photo credit: Jon Eiriksson.

The utilization and breeding of these breeds today appears to be stable and sustainable, and this has been the case for a long time. There is organized, ongoing breeding work in cattle, sheep and horses, under the overall control of the Farmers Association of Iceland. Livestock breeding programmes are subject to special legislation that defines the rules of the programmes and provides for governmental funding to support breeding centres and pedigree and performance recording. There are no signs that the genetic diversity of these stocks is anything but well maintained. However, the healthy and stable state of locally adapted Icelandic breeds is threatened by recent changes in national demand for livestock products. Icelandic consumers' demand for cheaper domestic products has been prominent in recent years, and the pressure can be expected to continue in the near future.

The country's well-organized livestock breeding industry has achieved considerable success in terms of increasing the efficiency of production in recent years and this has led to lower food prices. However, it is possible that demand for more efficient production could lead to Icelandic breeds being unable to maintain their positions in the face of competition from imported higher-performing breeds. The importation of exotic cattle breeds, a subject of discussion in recent years, would completely change the position of the Icelandic cattle population.

Source: Adapted from the country report of Iceland.

long-standing preferences for the taste of products from native breeds continue to influence customer choice. While these general tendencies are widely recognized, the scale and precise nature of their effects on AnGR diversity remain unclear, particularly in developing countries.

The country reports provide a number of examples of the influence of qualitative changes in consumer demand on AnGR management. The report from Slovenia, for example, notes that increasing demand for organic, animal-welfare friendly, environmentally friendly and traditional products means that more emphasis is being given to indigenous breeds. It also predicts that the influence of these consumer demands on AnGR and their management will be higher in the next ten years than in the past. The report from the United States of America mentions that the establishment of new local or regionally based markets will create opportunities for product branding that support the use of at-risk breeds. It also notes that in the case of chickens, consumer demand for "naturally" grown meat has affected the development of new lines, enhancing diversity at commercial level, and that, in some states, animal-welfare regulations may

lead to the development of new genetic lines for cage-free production.

Among developing countries, the report from Kenya notes that indigenous chickens are increasingly being raised for organic meat production. Some other country reports – including those from Bhutan, Namibia and Nepal – note some degree of increasing interest in speciality or high-quality products and a potentially positive effect on demand for locally adapted breeds. The report from Malawi mentions that increasing consumer preference for products from locally adapted breeds is expected to have both positive and negative effects on the sustainable use of AnGR. One the one hand, livestock keepers will be motivated to continue raising locally adapted breeds. One the other, there may be pressure to sell high-quality breeding stock for slaughter. With regard to homogenization of demand and its effects on AnGR, the report from Suriname notes a link to international trade: importation of poultry-meat products has affected consumer tastes and this has led to a strong shift towards the use of exotic breeds.

The effects that changes to marketing infrastructure and market access are reported to be having on AnGR management are also diverse. The most straightforward effect of improving market access is to expose more livestock keepers to the influence of consumer demand in the relevant markets. This can magnify the above-described demand-related effects, either to the cost or to the benefit of AnGR diversity. The potential for negative effects on diversity as a consequence of locally adapted breeds increasingly being replaced by exotic breeds as market access increases is noted, for example, in the country reports from India and Kenya. Conversely, some reports (e.g. Bhutan and South Africa) note the potentially positive effect of increasing access to speciality markets. Specific campaigns to promote the marketing of speciality products or those from particular production systems (e.g. produced by smallholders) have the potential to benefit AnGR diversity. This may occur as a result of a deliberate attempt to promote conservation (see Part 4 Section D) or as a side-effect of efforts to promote livelihood development. The country report from the Netherlands, for example, notes the "potential positive impact of marketing of regional products and labelled products through specific supply chains." Advances in communication technologies are creating new marketing opportunities for some livestock keepers. For example, the report from the Republic of Korea mentions that online marketing has created links between producers and consumers and provides a marketing channel for products from native AnGR.

Several country reports, both from developing and developed countries, mention that ongoing concentration of retailing in the hands of supermarkets is negatively affecting AnGR diversity because of, *inter alia*, demand for more uniform products. However, in a number of countries there is also reported to be increasing interest on the part of supermarkets and other retailers in labelling schemes related to geographical origin, product quality, animal welfare and so on. The country report from South Africa, for example, mentions labelling schemes for grass-fed beef, free-range mutton, Karoo lamb and Klein Karoo ostrich.

Some country reports note that the import of animal products or the demands of export markets are influencing AnGR management. The precise consequences are not always clear. However, in some cases (e.g. Sierra Leone), competition from imports is reported to be discouraging livestock keeping and leading to a decline in animal populations and negative consequences for AnGR. The report from Ghana mentions the negative effects of "unfair competition from imported products" on the local pig and poultry sectors. There is, however, some uncertainty about future trends. The report from Senegal, for example, notes the potential need to ensure that the country's livestock sector is able to meet increasing local demand in the event of rising import prices. On the export side, the country report from South Africa mentions that growing emphasis on animal welfare and sustainable production in export markets is creating opportunities for marketing certified products from

locally adapted breeds. The report from Lesotho notes that export demand for wool and mohair are driving the development of breeding programmes for fibre-producing species.

Production-system trends driven by environmental changes also potentially affect demand for different types of AnGR. Where production systems become "harsher" as a result of climate change, resurgent disease problems, etc., the roles of locally adapted breeds may become increasingly important and demand for them may increase (or decline more slowly). The country report from Barbados, for example, notes that the cost of adapting production environments to provide appropriate conditions for exotic breeds is likely to increase. The report from Brazil, states that climate change is likely to increase interest in the use of locally adapted breeds for cross-breeding, although their low levels of production may hamper the implementation of such strategies. The report from South Africa highlights the effect of climate change on the incidence of diseases and parasites and the roles of resistant or tolerant locally adapted breeds such as tick-tolerant Nguni cattle and native goats that are resistant to internal parasites and cowdriosis. Other reports that mention increasing interest in locally adapted breeds as a result of climate change include those from Rwanda, Solomon Islands and Sudan.

Major environmental changes may make it more difficult to raise some breeds in the geographical areas where they have traditionally been kept and may even lead to shifts in the species raised in a given area. Developments of this kind may pose a threat to some breeds. While immediate threats to specific breeds are rarely reported (possibly because of inadequate monitoring programmes – see Part 3 Section B), many country reports mention the threat that climate change poses to livestock production, and in some cases to AnGR diversity, via the increased prevalence of climatic disasters and disease outbreaks or via more gradual changes to production systems. The report from Mongolia, for example, states that

"Occurrences of natural disasters have become frequent, which ... [adversely affects] AnGR through tremendous death of livestock. For instance, the harsh winter disaster of 2010 resulted in 10.2 million livestock losses, equivalent to 20 percent of the national herd … As the pastoral livestock system is vulnerable to any changes, climate change … will have an adverse impact on … [the system's] AnGR through [effects on] feed and water resources in the future."

Degradation or loss of grazing land is noted as a problem in several country reports. In some cases, climate change is mentioned as a contributing factor. Specific effects on AnGR management are again rarely mentioned. However, the report from Bhutan states that the quality of pastures has declined over the years, with reduced carrying capacity leading to further overgrazing, and that this may require a reduction in the use of low-producing breeds and more emphasis on high-yielding breeds. The report from the Islamic Republic of Iran notes that the main grazing area of the Systani cattle breed, wetlands in the eastern part of the country, have been affected by the construction of a dam in neighbouring Afghanistan.[2] It further notes that some Systani herds were transferred to another part of the country as part of efforts to conserve the breed. Adverse effects of rangeland degradation on locally adapted breeds are also noted in the country report from China. The report from Peru notes that rangeland degradation has led many people, particularly those living at high elevations and keeping camelids and sheep, to sell their land and animals and migrate to towns and cities. The desire to minimize the rangeland degradation caused by livestock keeping can also affect breed choice. For example, the country report

[2] Other problems affecting this area and threatening the grazing lands of the Systani cattle are reported to include reduced precipitation (apparently caused by climate change), expansion of agricultural lands, inefficient irrigation, inappropriate cropping patterns, introduction of non-native aquatic plants and overexploitation of pastures (UNDP, 2014).

from South Africa mentions the case of the Nguni cattle breed, which is considered to be much less harmful to degraded grazing areas than exotic breeds.

In addition to the effects of pasture degradation *per se*, several country reports note that loss of grazing land as a result of the expansion of other land uses is affecting AnGR management. For example, the report from Sri Lanka states that the conversion of grazing land into human settlements, cropland and wildlife parks is limiting the feed resource base for livestock. Some reports (e.g. those from Austria, Bulgaria, India and Kenya) note that developments of this kind are a threat to locally adapted breeds. The report from Peru mentions that commercially oriented quinoa production has fuelled an expansion of cropland and changes in production methods that have affected access to land for camelid husbandry. It also notes that water resources in the lands used by indigenous communities are often appropriated or contaminated by mining operations. The report from the Plurinational State of Bolivia also mentions the effect that expanding quinoa production has had in terms of the loss of pastureland used by camelids and sheep. The report from Ethiopia links the expansion of cropland into grazing areas to the growth of the human population and notes that effects on livestock include a reduction in household herd/flock sizes, poor resistance to disease and interbreeding among breeds as animals move in search of feed.

The impact of replacement of livestock roles and functions on AnGR and their management received a relatively low score in comparison to some other drivers of change (Figure 2C1, Table 2C2). However, changes of this type can have a major effect on demand for specific breeds and species. Among effects of this type, the decline of locally adapted breeds because of the replacement of draught animal power with mechanized power is by far the most commonly mentioned in the country reports (see also Part 1 Section D), although little information is provided about effects on specific breeds.

The report from Burkina Faso mentions that a decline in the savings and insurance roles of livestock is having a negative effect on locally adapted AnGR. However, several other countries indicate that livestock continue to play an important role in the provision of services of this kind. Several country reports mention that the cultural roles of livestock are declining and that in some cases that this is having a substantial effect on AnGR and their management. The report from Sri Lanka, for example, notes that exchange of livestock at the time of marriages used to be a widespread practice and that this helped to distribute livestock and maintain their diversity, but that this practice has disappeared. It also notes that concerns about animal welfare have led to some animal sports (e.g. cock fighting) being prohibited by law and that sacrificing animals at religious events is in decline because of societal disapproval, with the consequence that breeding of the types of animal used in these events is in decline. At the same time, the cultural roles of livestock remain important in many countries and in some cases are being built upon as a means of promoting the sustainable use and conservation of potentially threatened breeds (see Part 4 Section D for examples).

Some new functions are emerging that potentially increase demand for breeds that might be threatened with extinction if they had to continue relying on their traditional roles. The use of livestock in the management of landscape and wildlife habitats, for example, is creating significant demand for some locally adapted breeds in Europe (see Part 1 Section D and Part 4 Section D for examples).

The influence of economic, livelihood or lifestyle factors on the popularity of livestock keeping as an activity and on the type of livestock keeping practised is noted in a number of country reports. Consequences for AnGR management are not always described in detail. However, a number of different effects are noted. For example, several reports from European countries note a decline in the number of small farms and a declining interest in livestock keeping, particularly among young people. This trend is generally regarded

as a threat to AnGR diversity, as the production systems that have traditionally maintained a wide range of locally adapted breeds are tending to disappear. Several country reports from developing countries note the ongoing popularity of livestock keeping. However, a few (e.g. China and Eritrea) mention that changes to traditional production systems and lifestyles is threatening the survival of locally adapted breeds. The country report from the Islamic Republic of Iran notes specifically that the populations of Murkhoz goats and Bactrian camels in the western part of the country are decreasing sharply because of changes in the lifestyles of local people. The report from India offers a more general comment on the popularity of livestock keeping:

> *"New generations are losing interest in livestock keeping because of changes in lifestyle aspirations and alternative opportunities available in the country … Livestock keeping is becoming less profitable. Average herd/flock size is decreasing."*

Technological advances can affect AnGR and their management in multiple ways. Various livestock management technologies can help to create conditions in which exotic breeds can be introduced into areas where they would otherwise not flourish. The country report from Kenya, for example, notes that improved animal husbandry and management practices are leading to more widespread use of exotic breeds. Reproductive technologies, such as artificial insemination and embryo transfer, can make it easier to introduce breeds into new areas and to cross-breed with them. The country report from Zambia, for example, states that more livestock keepers are being trained in artificial insemination and that this has led to increased demand for specialized dairy cattle. Reproductive technologies can play valuable roles in AnGR management, but if breed introductions and cross-breeding are badly managed, problems can be exacerbated by their use. Indiscriminate cross-breeding and breed replacement are among the factors most frequently mentioned in the country reports as causes of genetic erosion (see Part 1 Section F).

Several country reports (e.g. China, Ghana, the Philippines and the Republic of Korea) mention the positive roles that new technologies play in various aspects of AnGR management, including characterization, genetic improvement and conservation. However, the country reports provide little detailed information on the current or predicted future effect of the introduction of genomic technologies (see Part 4 Sections B and C) on the utilization of different types of AnGR. Potential effects of the use of these technologies on the utilization of at-risk or non-mainstream breeds are discussed in Box 2C4.

Box 2C4

The potential influence of genomics on the utilization of at-risk breeds

Introducing genomic selection into a breeding programme reduces the generation interval and allows an increase in genetic progress. However, it requires a large investment and is only applied in breeds with a large critical mass in terms of population size. This may actually increase the gap in production performance between at-risk breeds and the main breeds targeted by commercial breeding programmes and hence potentially increase the risk of breed extinctions.

However, genomics may help motivate efforts to conserve at-risk breeds by facilitating the discovery and utilization of the valuable characteristics these breeds may harbour. Genetic analysis may reveal unique alleles or unique combinations of alleles (haplotypes) that are not present in mainstream commercial breeds. Moreover, the introgression of parts of chromosomes responsible for valuable traits identified in at-risk breeds into commercial breeds is potentially greatly facilitated by genomic selection (Odegard *et al.*, 2009; Amador *et al.*, 2010).

Policy factors are among the drivers reported in the country reports to be having the greatest effect on AnGR and their management, with a considerable increase in their importance predicted for the coming ten years relative to the past (Table 2C2). Impacts on AnGR vary greatly. On the one hand, policies directed at promoting the sustainable use, development and conservation of AnGR can provide valuable support to efforts to prevent breeds from becoming extinct and to maintain diversity. On the other hand, policies can constrain certain types of livestock production and thereby threaten the associated AnGR. Policies may also promote breed replacement, either directly or by promoting production system changes that lead to the introduction of exotic (or other alternative) breeds. Changes in the types of breeds and crossbreeds utilized is an inevitable consequence of the evolution of the livestock sector and these changes are always likely to be affected by a range of policies that are not all favourable to AnGR diversity. As with other drivers of change, there is a need to ensure that the impacts that policies have on diversity are monitored and that, if necessary, action is taken to adjust them or to promote by other means the conservation and sustainable use of breeds that are adversely affected.

The country reports mention a range of different policy-related factors affecting AnGR management. Several note AnGR-focused policies that are benefiting or are expected to benefit the sustainable use, development and conservation of these resources. However, some suggest that policies focus on rapidly increasing the output of animal products lack sufficient emphasis on longer term sustainable management. Some reports mention broader livestock-sector policies that are expected to influence AnGR management: for example, those related to environmental protection, animal welfare, rangeland management not, but and disease control. However, little detailed information on the effects of these policies is provided. Further discussion of the state of national and international policies and legal frameworks on AnGR management can be found in Part 3 Section F.

One issue that was recognized in the first SoW-AnGR as a potential future influence on AnGR management was the question of rising input prices. Although information on the effects of this driver was not specifically requested in the country-report questionnaire, it was mentioned in some responses. Rising feed costs are, for example, noted as a factor influencing AnGR management in the country reports from Barbados and Kiribati. The report from Ghana notes that high production costs are among the factors leading to the closure of many of the country's pig and poultry farms.

References

Amador, C., Fernández, J. & Meuwissen, T.H.E. 2013. Advantages of using molecular coancestry in the removal of introgressed material. *Genetics Selection Evolution*, 13 (available at http://www.gsejournal.org/content/45/1/13).

Country reports. 2014. Available at http://www.fao.org/3/a-i4787e/i4787e01.htm.

FAO. 2009a. *Threats to animal genetic resources – their relevance, importance and opportunities to decrease their impact*. Commission on Genetic Resources for Food and Agriculture. Background Study Paper No. 50. Rome (available at ftp://ftp.fao.org/docrep/fao/meeting/017/ak572e.pdf).

FAO. 2009b. *The State of the Food and Agriculture. Livestock in the balance*. Rome (available at http://www.fao.org/docrep/012/i0680e/i0680e.pdf).

LPP, LIFE Network, IUCN–WISP & FAO. 2010. *Adding value to livestock diversity – Marketing to promote local breeds and improve livelihoods*. FAO Animal Production and Health Paper. No. 168. Rome (available at http://www.fao.org/docrep/012/i1283e/i1283e00.htm).

Odegard, J., Yazdi, M.H., Sonesson, A.K. & Meuwissen, T.H.E. 2009. Incorporating desirable genetic characteristics from an inferior into a superior population using genomic selection. *Genetics*, 181: 737–745.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V. Rosales, M. & de Haan, C. 2006. *Livestock's long shadow: environmental issues and options.* Rome, FAO (available at ftp://ftp.fao.org/docrep/fao/010/a0701e/a0701e00.pdf).

PART **2**

UNDP. 2014. *Hamoun wetlands. Current situation and the way forward*. Tehran, United Nations Development Programme in the Islamic Republic of Iran (available at http://tinyurl.com/oucualv).

Vigne, M. 2014. *Efficiency of extensive livestock systems in harsh environments*. Cirad Perspective 25. Paris, Cirad Agricultural Research for Development (available at http://tinyurl.com/opo2ajm).

Weiler, V., Udo, H.M.J., Viets, T, Crane, T.A. & De Boer, I.J.M. 2014. Handling multi-functionality of livestock in a life cycle assessment: the case of smallholder dairying in Kenya. *Current Opinion in Environmental Sustainability*. 8: 29–38.

Yosef, T., Mengsitu, U., Solomon, A., Mohammed, Y.K. & Kefelegn, K. 2013. Camel and cattle population dynamics and livelihood diversification as a response to climate change in pastoral areas of Ethiopia. *Livestock Research for Rural Development*, 25(9) 2013 (available at http://www.lrrd.org/lrrd25/9/yose25166.htm).

Section D

Livestock sector trends and animal genetic resources management – conclusions

The analysis presented in Section A indicates that while growth may be slowing, global demand for animal-source foods is expected to continue increasing, and indications are that much of this demand growth will be met by production from large-scale landless systems. Meat consumption has expanded very quickly in Latin America, but future expansion is expected to be strongest in South Asia and Africa. The same regions are projected to be the main centres of growth in milk consumption. These are both very resource-constrained regions, where there are still many small-scale livestock keepers and pastoralists and where small-scale milk production has historically been strong. Growth in demand is widely viewed as one of the main drivers of change in AnGR management, and experiences from other regions suggest that dramatic increases in demand create major challenges to the sustainable use of livestock diversity.

Despite the spread of "industrial" and other intensive production systems, the livestock sector in most developing countries remains far from homogeneous. Mixed farming and grassland production systems continue to provide a substantial proportion of output, particularly in the case of ruminants. Livestock continue to play multiple roles in the livelihoods of many poor people. In some circumstances, small-scale commercially oriented producers contribute significantly to meeting growing demand for animal-source food. Production environments remain diverse in climatic and agro-ecological terms, and in many circumstances isolating animals from harsh environmental conditions is impractical. The demands placed on AnGR therefore remain diverse. However, given the evolving (in some cases rapidly evolving) nature of livestock production systems and the fact that knowledge of breed characteristics often remains inadequate, ensuring that breeds and crosses are well-matched to their production environments and to the demands placed on them is challenging. In terms of breed survival, rapid change may mean that a breed's existing role disappears rapidly and that it declines towards extinction before new roles for it can emerge or national authorities recognize the threat and take action to promote its conservation.

In addition to "demand-side" drivers, livestock production is being affected by physical changes affecting the agro-ecosystems in which it takes place. Current changes are, on the whole, creating greater challenges for livestock-keeping livelihoods. Climate change, in particular, is likely to create increasing problems over the coming years and decades. The importance of livestock biodiversity as a resource with which to adapt production systems to future changes and as a source of resilience in the face of greater climatic variability is likely to increase. Climate change, however, also poses threats to the sustainable management of AnGR.

Another widespread trend with important implications for AnGR management is the movement of people out of livestock keeping as a livelihood activity and into alternative employment. In most countries, small-scale livestock keeping is unlikely to disappear in the short or medium term. However, the pull of economic activities outside livestock keeping and of non-livestock

keeping lifestyles often adds to constraints at production-system level in reducing the economic and social attractiveness of livestock keeping. Where trends of this type are strong, AnGR associated with particular traditional types of livestock keeping or with particular communities may be threatened.

In developed countries, industrial and other intensive production systems are already dominant and several traditional livestock functions have become very marginal. Many locally adapted breeds remain at risk of extinction. However, some developments have begun to create roles for breeds that are not competitive in terms of the supply of mass-market products. The most significant trends of this type are probably the growth of niche markets for various kinds of traditional or ethically produced products and the increasing use of grazing animals in the management of wildlife habitats. Given that many developing countries have sizeable middle classes and that many livestock production systems in developing countries provide important regulating and habitat ecosystem services,[1] it is possible that developments such as niche marketing and payment for environmental services might have an increasing influence on AnGR management in the future. There are, however, many constraints to the successful implementation of such schemes in developing countries.

The evolution of livestock production systems is affected not only by economic forces and the state of the physical environment, but also by public policies. The country reports suggest that policy factors have a major effect on AnGR and their management and that this effect is likely to increase in the future. A wide range of policies may be relevant, some focused specifically on AnGR management, but others targeting other aspects of livestock keeping, rural development, consumer protection and the environment. Many may be put in place with no thought to their effects on AnGR diversity. The current state of policy frameworks, their implementation and their effects on AnGR is discussed in Part 3 Section F. There are some positive developments, such as the increasing number of countries developing national strategies and action plans for AnGR. However, weak policies and programmes are still regarded as significant drivers of genetic erosion in a number of countries (see Part 1 Section F). The future of broad livestock-sector policies may be influenced by arguments regarding the nature of efficiency in livestock systems.

Policies that aim to support the sustainable management of AnGR require a long-term perspective. Understanding livestock-sector trends is therefore a vital element of AnGR management planning (FAO, 2009; 2010; 2013). The country-reporting exercise may have helped countries to review the influence of livestock-sector trends on their AnGR and to prioritize actions that need to be taken to address future demands, threats and opportunities within different production systems and affecting different breeds or breed categories. In other countries, the reporting process may have highlighted gaps in knowledge that make it more difficult to plan effectively. Where this is the case, efforts need to be made to collect and analyse the relevant information, perhaps as part of the process of developing or updating a national strategy and action plan for AnGR.

[1] See Box 1D1 in Part 1 Section D for explanation of these terms.

References

FAO. 2009. *Preparation of national strategies and action plans for animal genetic resources*. FAO Animal Production and Health Guidelines. No. 2. Rome (available at http://www.fao.org/docrep/012/i0770e/i0770e00.htm).

FAO. 2010. *Breeding strategies for sustainable management of animal genetic resources*. FAO Animal Production and Health Guidelines. No. 3. Rome (available at http://www.fao.org/docrep/012/i1103e/i1103e.pdf).

FAO. 2013. In vivo *conservation of animal genetic resources*. FAO Animal Production and Health Guidelines. No. 14. Rome (http://www.fao.org/docrep/018/i3327e/i3327e00.htm).

Part 3

THE STATE OF CAPACITIES

Introduction

This part of the report presents an analysis of capacities in the management of animal genetic resources for food and agriculture (AnGR), based on the information provided in the country reports. In contrast to the country-reporting process for the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR), the country reports were prepared using a standard questionnaire. One hundred and twenty-eight reports were submitted using the questionnaire. Therefore, except where otherwise stated, the analysis is based on a self-selecting sample of 128 countries. The country coverage, including the possibility that non-reporting countries may have lower levels of capacity than those that reported, needs to be borne in mind when interpreting the findings. The regions and subregions used in the analysis are those that were defined for the purpose of the first SoW-AnGR. It should be noted that in some subregions the proportion of responding countries is relatively low and thus the above-noted potential for sampling bias to affect subregional-level statistics may be more marked.[1]

The analytical approach varies from section to section according to the nature of the information provided in the country reports. The first section presents an analysis of the state of human and institutional capacity in AnGR management. This is followed by sections describing the state of characterization, inventory and monitoring, breeding programmes, conservation programmes and the use of reproductive and molecular biotechnologies. The final section covers legal and policy frameworks affecting AnGR and their management. This section is divided into three major subsections, addressing frameworks at international, regional and national levels. The latter subsection draws on responses to a survey on policy and legal frameworks conducted by FAO in 2013.

Much of the analysis in Sections B, C, D and E is based on the breed concept. As discussed in the introduction to Part 1, there is no universally accepted means of determining whether a given livestock population should be considered a distinct breed. In the country-reporting process (as is the case with ongoing reporting of breed-related data to the Domestic Animal Diversity Information System [DAD-IS][2] – see Part 1 Section B) each country determined for itself how to interpret the breed concept. Thus it needs to be borne in mind that the unit of analysis upon which the reported figures are based may vary from country to country. It should also be noted that – as the objective is to assess national capacities – the unit of analysis for the breed-related data presented in this part of the report is the national breed population (i.e. a given breed within a given country), rather than the breed as a whole. So-called transboundary breeds (see Part 1 Section B) have national populations in more than one country. The country-report questionnaire requested respondents to indicate the number of breeds

[1] For further information on the country-reporting process and on the regional and subregional classifications, see "About this publication" in the preliminary pages.

[2] http://fao.org/dad-is

present in their respective countries and to indicate how many are considered "locally adapted" and how many "exotic" (see Part 1 Section B for definitions). Unless otherwise stated, figures indicating the proportion of national breed populations subject to various types of management activity are based on this sample.

Section A

Institutions and stakeholders

1 Introduction

The first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007a) concluded that in most parts of the world the institutional framework for animal genetic resources (AnGR) management was inadequate. Improvements in this field are targeted in Strategic Priority Area 4 of the Global Plan of Action for Animal Genetic Resources (FAO, 2007b) – Policies, Institutions and Capacity-building (see Box 3A1).

This section describes the state of human and institutional capacities in AnGR management at national, regional and international levels. The analysis is based largely on country reports, reports from regional focal points and networks for AnGR management and reports

Box 3A1
Strategic Priority Area 4 of the Global Plan of Action for Animal Genetic Resources

Strategic Priority Area 4: Policies, Institutions and Capacity-building

Implementation at national level

SP 12 Establish or strengthen national institutions, including national focal points, for planning and implementing animal genetic resources measures, for livestock sector development

SP 13 Establish or strengthen national educational and research facilities

SP 14 Strengthen national human capacity for characterization, inventory, and monitoring of trends and associated risks, for sustainable use and development, and for conservation

SP 18 Raise national awareness of the roles and values of animal genetic resources

SP 20 Review and develop national policies and legal frameworks for animal genetic resources

Implementation at regional level

SP 17 Establish Regional Focal Points and strengthen international networks

Implementation at international level

SP 15 Establish or strengthen international information sharing, research and education

SP 16 Strengthen international cooperation to build capacities in developing countries and countries with economies in transition

SP 19 Raise regional and international awareness of the roles and values of animal genetic resources

SP 21 Review and develop international policies and regulatory frameworks relevant to animal genetic resources

SP 22 Coordinate the Commission's efforts on animal genetic resources policy with other international forums

SP 23 Strengthen efforts to mobilize resources, including financial resources, for the conservation, sustainable use and development of animal genetic resources

Note: SP = Strategic Priority; "the Commission" = the Commission on Genetic Resources for Food and Agriculture.

from international organizations whose work is relevant to the implementation of the Global Plan of Action.[1]

2 Institutional capacities at country level

2.1 Basic recommended institutional framework for animal genetic resources management

In adopting the Global Plan of Action for Animal Genetic Resources countries affirmed the need for effective national institutions to support the sustainable management of AnGR. The Global Plan of Action specifically calls for the establishment or strengthening of National Focal Points for the Management of Animal Genetic Resources and for these bodies to be strongly linked to stakeholder networks. Recommendations for the development of institutional frameworks at national level were further elaborated in guidelines endorsed by the Commission on Genetic Resources for Food and Agriculture in 2011 (FAO, 2011a). The basic elements of this recommended framework are an officially nominated National Coordinator for the Management of Animal Genetic Resources, a National Focal Point (the National Coordinator and his or her support staff) and a multistakeholder National Advisory Committee (see Boxes 3A2 and 3A3). It is also recommended that each country develop a national strategy and action plan for AnGR as a vehicle for implementing the Global Plan of Action at national level (FAO, 2009).

As of July 2014, officially nominated National Coordinators were in place in 173 countries (Figure 3A1), up from 144 in 2006 (FAO, 2006). A majority of National Coordinators are based within ministries responsible for agriculture or rural development. However a number work for research institutions, universities or other relevant organizations (Figure 3A2). National Advisory Committees were in place in 78 countries (Figure 3A3).

Box 3A2
Elements of the recommended national institutional framework for the management of animal genetic resources

National Coordinator for the Management of Animal Genetic Resources: the government-nominated person who coordinates the national implementation of the Global Plan of Action for Animal Genetic Resources and leads the development and operation of a national network of stakeholders. He or she is the contact person for communication with FAO on matters relating to the implementation of the Global Plan of Action for Animal Genetic Resources and with global and regional animal genetic resources networks.
National Focal Point for the Management of Animal Genetic Resources: the National Coordinator for the Management of Animal Genetic Resources and his or her support staff within the institution responsible for coordinating activities concerning the management of animal genetic resources.
National Advisory Committee: a multistakeholder body, incorporating both scientific and policy expertise, that provides guidance on the development of the national animal genetic resources programme.

Source: FAO, 2011a.

2.2 Country-report analysis

The country-report questionnaire requested countries to provide a score (none, low, medium or high) for the state of their capacities and provisions in each of the following areas:

- education (the state of tertiary education in all areas of AnGR management);
- research (the state of research in all areas of AnGR management);
- awareness (the extent to which all stakeholders in agriculture, rural development and environmental management are aware of the roles and values of AnGR);

[1] See "About this publication" in the preliminary pages of the report for more information on the reporting process.

Box 3A3

The role of the National Coordinator for the Management of Animal Genetic Resources

The recommended activities of National Coordinators include the following:

Policy development

- Facilitating and supporting the development and revision of policy and legal frameworks in the field of animal genetic resources management, including national strategy and action plans for animal genetic resources.
- Contributing to the development and revision of other relevant policy and legal instruments such as national strategy and action plans on conservation and sustainable use of biological diversity and national livestock-development strategies.

Strengthening animal genetic resources management

- Coordinating the implementation of the National Strategy and Action Plan for Animal Genetic Resources.
- Coordinating and supporting the planning, implementation, monitoring and evaluation of conservation, surveying and monitoring and breed development strategies.
- Coordinating the identification of research priorities in animal genetic resources management.
- Coordinating the mobilization of financial and other resources to support implementation of the National Strategy and Action Plan for Animal Genetic Resources.

Communication and cooperation

- Facilitating communication on animal genetic resources management between the National Focal Point for the Management of Animal Genetic Resources and relevant ministries and other national bodies such as the National Focal Point for the Convention on Biological Diversity.[1]
- Developing and supporting national stakeholder networks in the animal genetic resources sector.
- Communicating with FAO and with Regional Focal Points and National Focal Points in other countries, and cooperating in activities organized at regional and international levels.

Education and public awareness

- Raising awareness of animal genetic resources issues via conferences, exhibitions, books, brochures, posters, the internet, television, radio, etc.

Global reporting

- Updating national data in the Domestic Animal Diversity Information System (DAD-IS) (or regional database if applicable) on a regular basis.
- Coordinating progress reporting on the implementation of the Global Plan of Action for Animal Genetic Resources.

Intergovernmental processes

- Participating in country delegations to the sessions of the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture, the Commission on Genetic Resources for Food and Agriculture and other relevant intergovernmental bodies.
- Contributing to the development of country negotiating positions.
- Communicating with other National Coordinators to develop regional positions.
- Debriefing government officials following meetings and coordinating implementation of actions recommended by intergovernmental bodies.

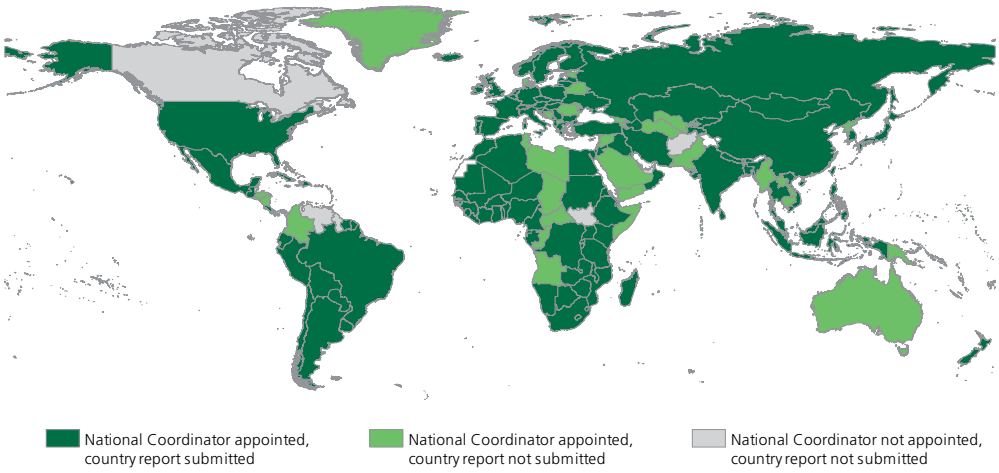
Source: FAO, 2011a.

[1] https://www.cbd.int/information/nfp.shtml

- infrastructure (the extent to which the organizational and physical infrastructure needed to deliver services related to AnGR management is in place);
- stakeholder participation (the extent to which individual stakeholders and stakeholder organizations, particularly livestock keepers and their organizations, are involved in and can influence collaborative AnGR

FIGURE 3A1

Submission of country reports and nomination of National Coordinators for the Management of Animal Genetic Resources



Note: Figure refers to National Coordinators appointed as of July 2014. The country report of Morocco was not prepared in the standardized format and thus could not be included in the quantitative analysis.

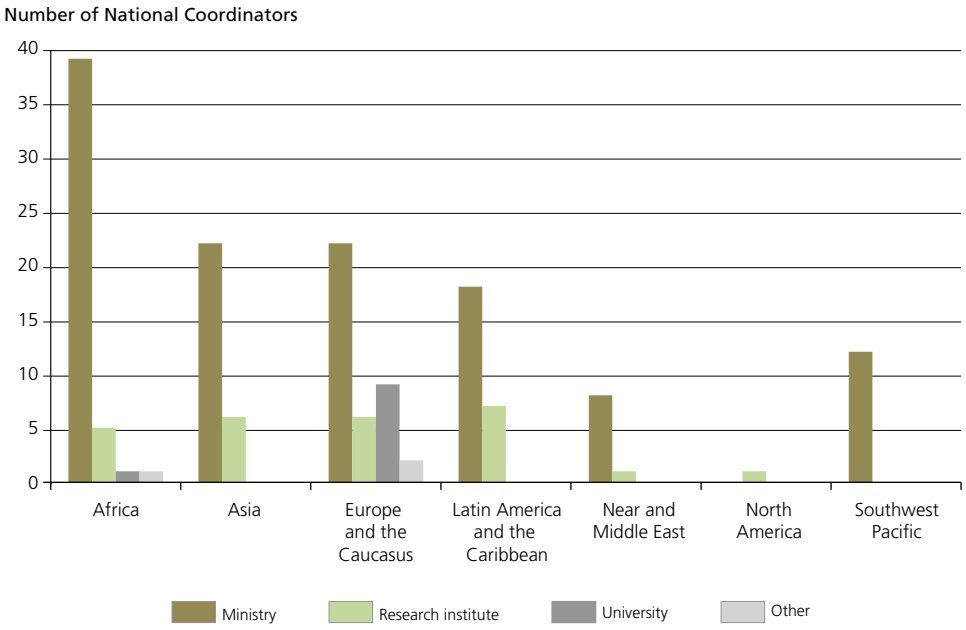
management activities at local and national levels);

- policies (the extent to which the country [i.e. national or regional government] has established policy initiatives, strategies, programmes or plans that promote the sustainable use, development and conservation of AnGR);
- policy implementation (the extent to which the country's policy initiatives, strategies, programmes or plans promoting the sustainable use, development and conservation of AnGR are being successfully implemented);
- laws (the extent to which the country has put in place a legal framework that is conducive to the sustainable use, development and conservation of AnGR and that protects livestock breeders/owners' rights to manage AnGR as they deem appropriate); and
- implementation of laws (the extent to which the country's laws conducive to the sustainable use, development and conservation of AnGR are being successfully implemented).

With regard to policies and laws, the questionnaire recognized that the type of framework required would vary from country to country, i.e. that elaborate frameworks are not necessarily required in all circumstances. In assigning their scores, countries were asked to focus on the extent to which their legal and policy measures are sufficient to ensure the sustainable use, development and conservation of AnGR in their particular national circumstances. The responses are summarized region by region in Figure 3A4. Differences at subregional level are shown in Figures 3A5, 3A6 and 3A7. Detailed findings within each thematic area are shown in Figures 3A9, 3A10 and 3A11.

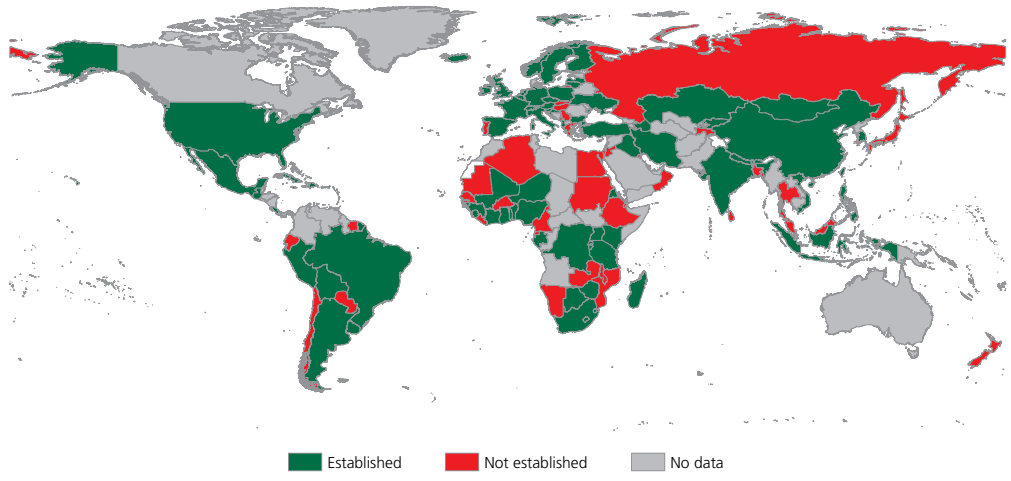
The scores shown in Figure 3A4 indicate that in almost all aspects of the institutional framework for AnGR management, North America and Europe and the Caucasus have higher levels of capacity than other regions. Asia has medium to low levels of capacity (average scores between 1 and 2) across all the elements of institutional

FIGURE 3A2
Employment affiliations of National Coordinators for the Management of Animal Genetic Resources



Source: DAD-IS (http://fao.org/DAD-IS) (accessed September 2014).

FIGURE 3A3
Status of National Advisory Committees for Animal Genetic Resources



Source: Country reports, 2014.

capacity covered. In other developing regions, at least some elements of institutional capacity are at very low levels (average scores between 0 and 1).

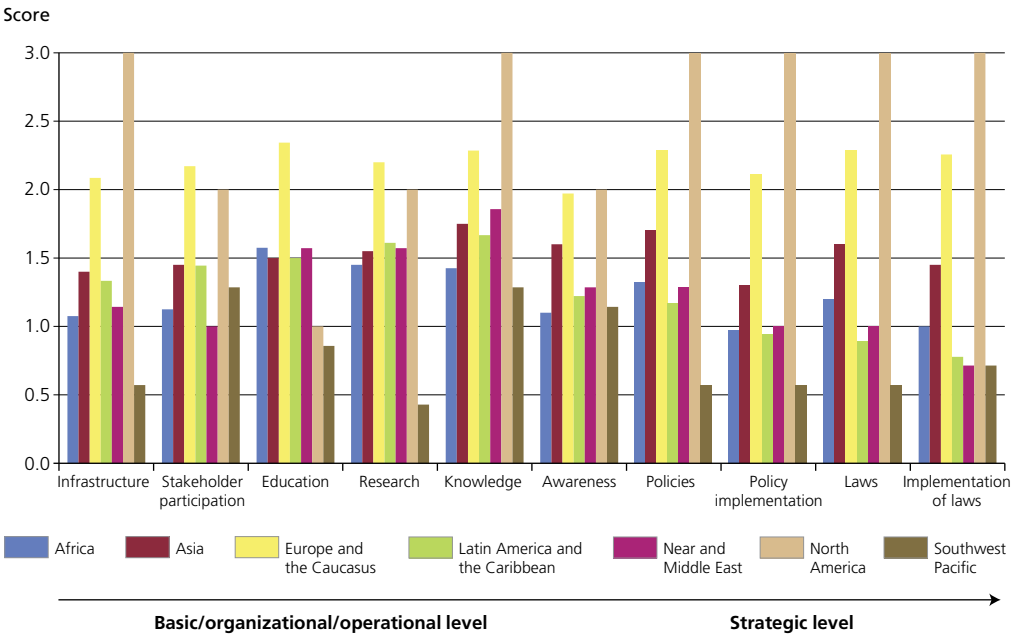
The country-report questionnaire also required responding countries to report on the progress they had made in implementing the various elements of the Global Plan of Action. These responses were used to calculate indicators for progress made at the level of strategic priority areas and at the level of individual strategic priorities (see Box 3A1 and Table 3F1 in Part 3 Section F) (FAO, 2014). National-level indicators for Strategic Priority Area 4 (Policies, Institutions and Capacity-building) are shown in Figure 3A8.

Infrastructure and stakeholder participation

Organized AnGR-management activities that involve action at farm (or holding) level (e.g. *in situ* conservation) are dependent on the active involvement of livestock keepers. They will often also require the participation of a range of other stakeholders (suppliers of livestock services, processers of livestock products, veterinary authorities, research institutions, local government authorities, nature conservation agencies, tourism operators and so on) (FAO, 2010; 2013). Other activities, such as surveying and monitoring of population sizes, may not require such a high level of commitment on the part of livestock keepers, but are nonetheless dependent on their participation. Again, they are also likely to require the cooperation of a range of different stakeholders (FAO, 2011b). While circumstances will

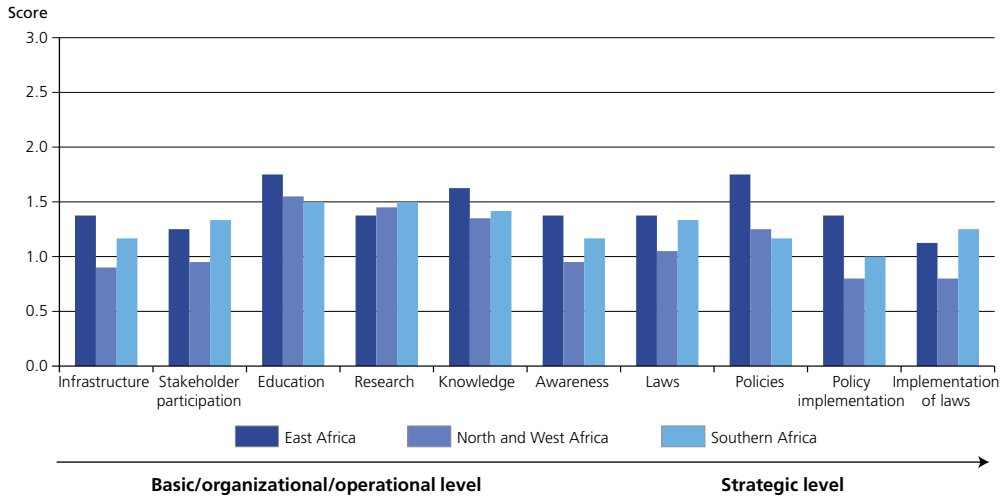
FIGURE 3A4

Overview of the state of institutions in animal genetic resources management



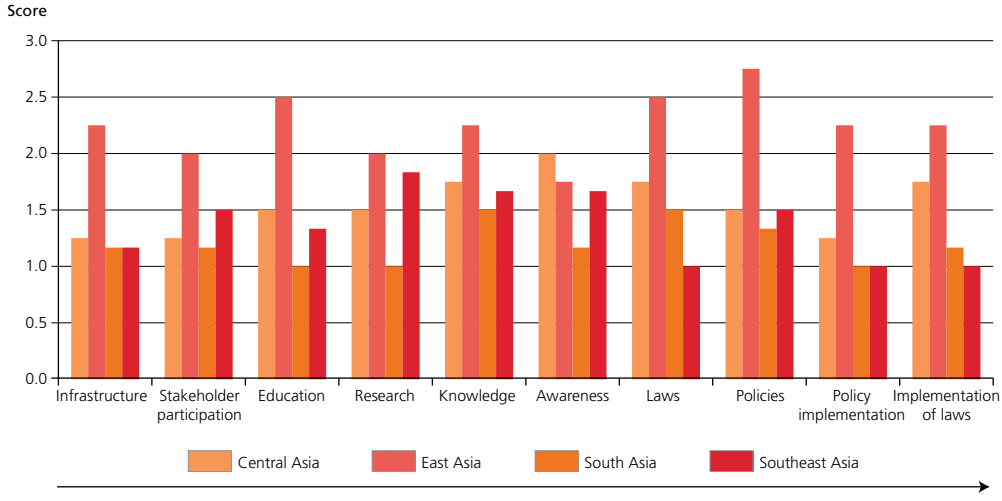
Note: Each country provided a score for the state of institutions in each area. The scores were converted into numerical values (none = 0; low = 1; medium = 2; high = 3).
Source: Country reports, 2014.

FIGURE 3A5
State of institutions in animal genetic resources management – Africa



Note: Each country provided a score for the state of institutions in each area. The scores were converted into numerical values (none = 0; low = 1; medium = 2; high = 3).
Source: Country reports, 2014.

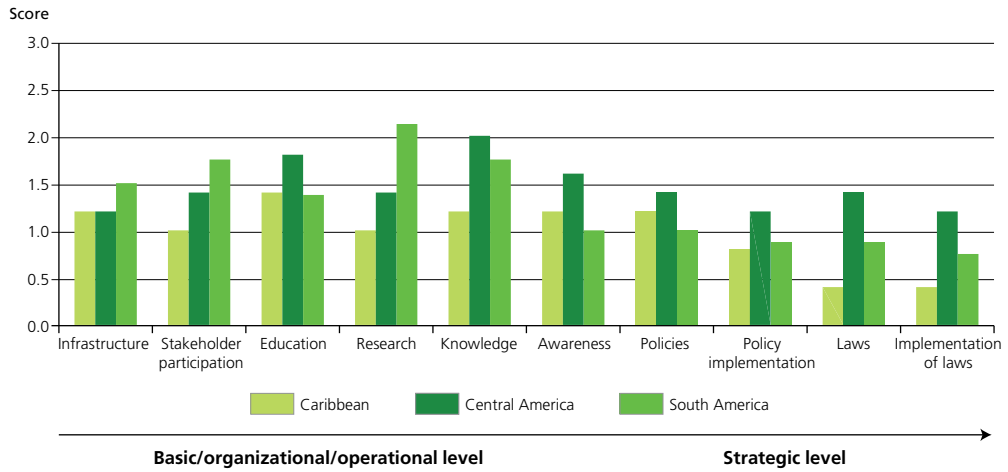
FIGURE 3A6
State of institutions in animal genetic resources management – Asia



Note: Each country provided a score for the state of institutions in each area. The scores were converted into numerical values (none = 0; low = 1; medium = 2; high = 3).
Source: Country reports, 2014.

FIGURE 3A7

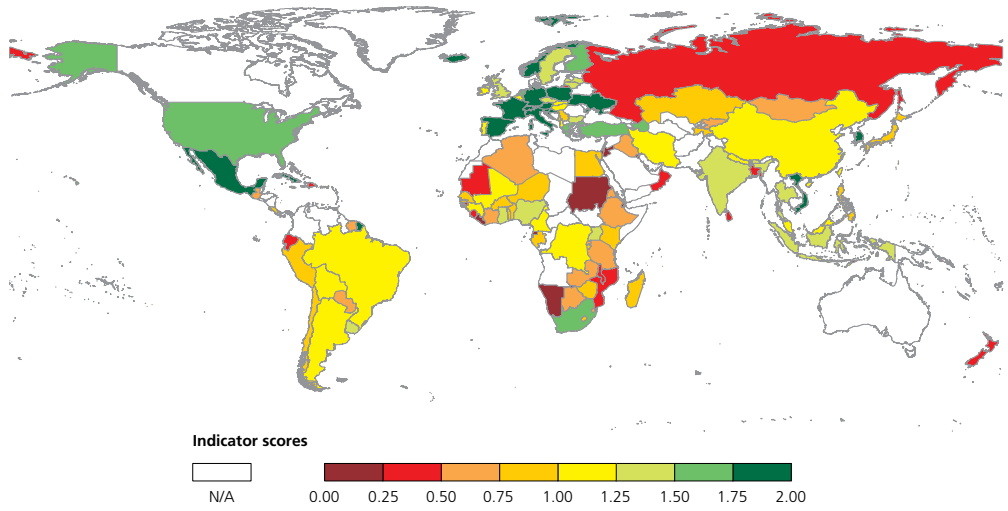
State of institutions in animal genetic resources management – Latin America and the Caribbean



Note: Each country provided a score for the state of institutions in each area. The scores were converted into numerical values (none = 0; low = 1; medium = 2; high = 3).
Source: Country reports, 2014.

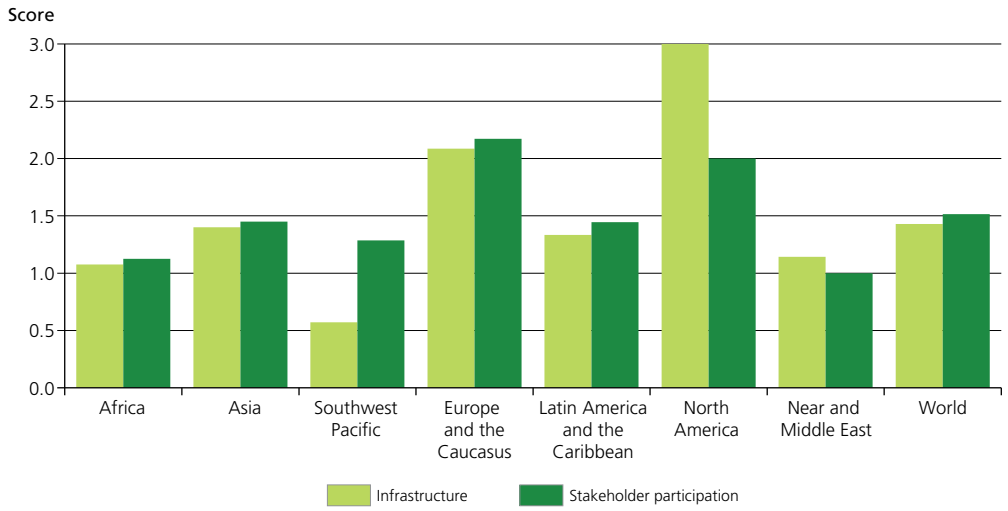
FIGURE 3A8

Indicators for the implementation of Strategic Priority Area 4 of the Global Plan of Action for Animal Genetic Resources



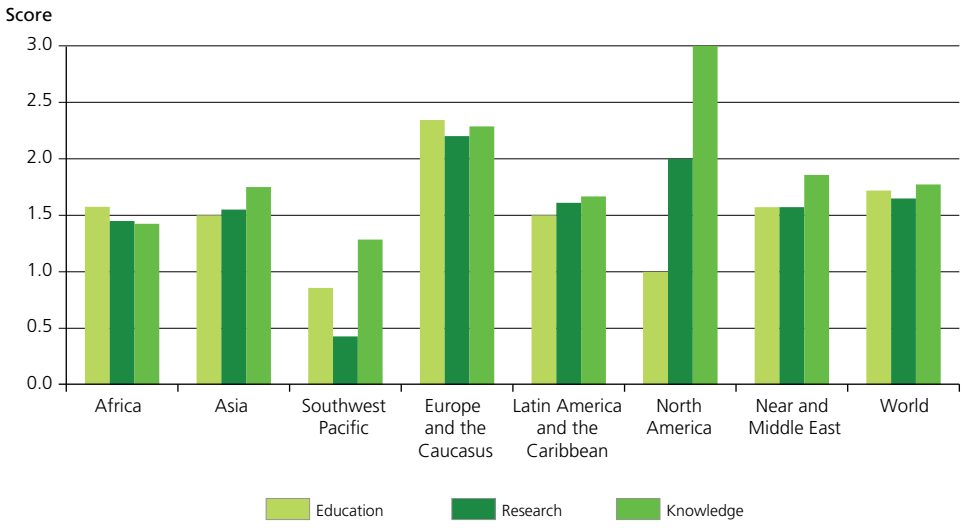
Note: Indicator scores are divided into eight evenly distributed classes between a minimum score of 0 and a maximum score of 2. A score of 2 means that all actions covered by the indicator have been implemented fully. A score of 0 means that no action has been taken.
Scores calculated based on self-assessments provided in country reports.
Strategic Priority Area 4 = Policies, Institutions and Capacity-building.
Source: Country reports, 2014.

FIGURE 3A9
State of infrastructure and stakeholder participation



Note: Each country provided a score for the state of institutions in each area. The scores were converted into numerical values (none = 0; low = 1; medium = 2; high = 3).
Source: Country reports, 2014.

FIGURE 3A10
State of education, research and knowledge



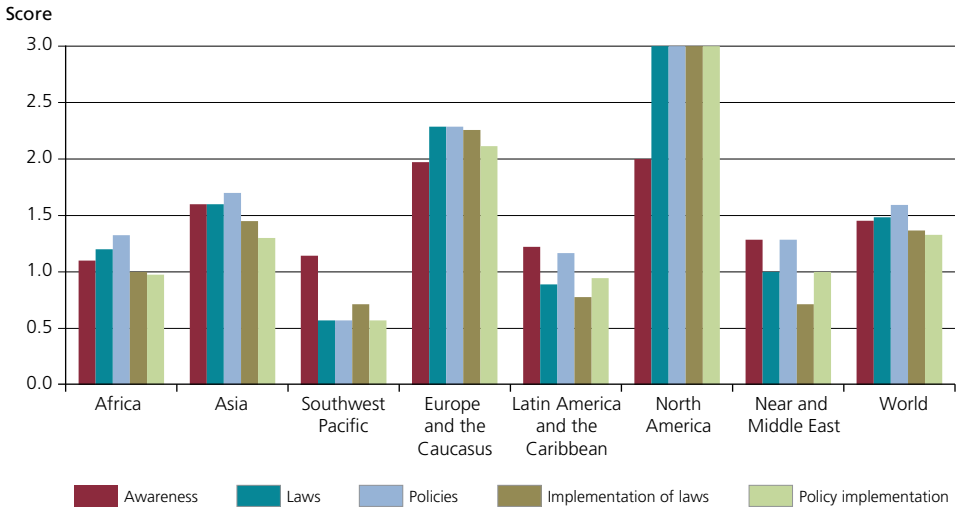
Note: Each country provided a score for the state of institutions in each area. The scores were converted into numerical values (none = 0; low = 1; medium = 2; high = 3).
Source: Country reports, 2014.

vary from country to country, a top-down approach in which little attention is paid to stakeholders' objectives and concerns – particularly those of livestock keepers – is unlikely to be successful.

Effective stakeholder participation in AnGR management is likely to depend on the existence of a degree of organizational infrastructure, whether in the form of stakeholder groups such as breeders' associations or in the form of mechanisms that facilitate the involvement of individual stakeholders (consultative and participatory planning processes, etc.). Various elements of AnGR management are also dependent on the availability of a certain level of physical and technical infrastructure (e.g. laboratory facilities to enable cryoconservation and transport infrastructure to facilitate service delivery and marketing initiatives).

The country reports indicate that in all regions apart from North America and Europe and the Caucasus, both stakeholder involvement and physical and organizational infrastructure remain at low to medium levels of development (Figure 3A9). Even in developed regions, it appears that provisions in these fields still need to be strengthened. In North America, for example, infrastructure is very well developed, but the level of stakeholder participation is reported only to be medium. Many developing countries report that a lack of government support and funding constrains efforts to improve stakeholder participation. Some examples of initiatives in this field are nonetheless described in the country reports. For example, Uganda reports that livestock-keeper groups influence activities at local level and are gradually acquiring national recognition. The country is in the process of establishing a "Livestock Genetic Platform", via which stakeholders will be able to contribute to discussions on AnGR management.

FIGURE 3A11
State of policy development



Note: Each country provided a score for the state of institutions in each area. The scores were converted into numerical values (none = 0; low = 1; medium = 2; high = 3).
Source: Country reports, 2014.

Many countries, particularly in Africa, note that a lack of funding for infrastructure development is a problem. For example, the country report from the United Republic of Tanzania mentions poor road links to livestock-keeping areas. While European countries generally have well-developed infrastructure in place, some remote areas in this region remain poorly served by road networks. This can constrain surveying and monitoring activities, access to markets and the provision of veterinary services. The country report from Albania notes that in mountainous areas infrastructural developments associated with tourism have inadvertently helped AnGR conservation to flourish.

Education, research and knowledge

A lack of knowledge of AnGR and their management can be a serious constraint to the sustainable use, development and conservation of these resources. Some country reports note specific constraints or problems that have arisen because of a lack of knowledge. Swaziland's report, for example, mentions that indigenous knowledge related to livestock keeping and the maintenance of AnGR diversity has not been documented and that this is a constraint to the development of breeding programmes and other AnGR management strategies. In Sri Lanka, lack of knowledge is reported to lead to the slaughter of valuable breeding animals and to indiscriminate cross-breeding. Inability to distinguish between breeds has reportedly led to the near extinction of some of the country's breeds (e.g. the Kottukachchiya goat).

The state of education, research and knowledge, as reported in the country reports, is summarized in Figure 3A10. As in most areas of AnGR management, the highest levels of provision and capacity are reported from the developed regions of the world, although levels differ markedly between countries even in these regions. In most developing regions, education, research and knowledge are at medium to low levels, with the Southwest Pacific reporting the lowest levels across all categories.

While a number of countries report various educational courses and training activities related to livestock production, relatively little information is provided on the state of education more specifically related to AnGR management, i.e. breeding (genetic improvement), conservation, characterization, etc. Educational initiatives targeting AnGR management as a distinct topic appear to be restricted mainly to Europe and not to be very widespread. The livestock production study programme of University of Montenegro's Biotechnical Faculty is reported to include a course in "Animal genetic resources (sustainable use and conservation)". The country report from the Netherlands notes that in addition to university-level programmes, biodiversity and genetic resources are also included in the curriculum at primary and secondary school levels.

AnGR-related research activities are widely reported from all regions of the world. Nonetheless, many barriers to effective research efforts remain to be overcome, especially in developing countries. For example, the country report from Kyrgyzstan notes that a lack of funding and resources (laboratories and technical knowledge) and the absence of governmental support have reduced research capacity. A lack of young scientists entering the field is noted as constraint to research in some country reports (e.g. Barbados and Liberia).

State of awareness, policies and policy development, and laws and their degree of implementation

Awareness of the roles and values of AnGR among policy-makers is an important prerequisite for the development of appropriate institutions for their management. Awareness among the general public may also help to push the issue up the political agenda. Awareness among livestock keepers and development practitioners should lead to more sustainable approaches to AnGR management (providing such approaches are not constrained by other factors such as a lack of resources). Policies and laws can have a major influence on AnGR management. However, the

specific types of instruments and the levels of intervention required will depend on the specific circumstances in the respective country. Legal and policy frameworks are discussed in detail in Part 3 Section F. Country-report responses related to the state of awareness, laws, policies, implementation of laws and policy implementation are summarized in Figure 3A11.

The country reports indicate that in all regions there is a need to increase awareness of the roles and values of AnGR. Awareness of the significance of locally adapted breeds and the need to conserve those that are at risk of extinction may in fact be even lower than suggested by the data presented in Figure 3A11. For example, the country report from Germany notes that awareness is high only in relation to economically important breeds and that there is significantly less awareness of issues related to the management of breeds that are at risk of extinction. Despite such concerns, a certain basic awareness of the significance of sustainably managing AnGR is apparently widespread at governmental level, given the very large number of countries that have appointed National Coordinators for the Management of Animal Genetic Resources (see Subsection 2.1).

Legal and policy frameworks are well developed in North America and Europe and the Caucasus, but less so in other regions. It should be recalled (see above) that high scores do not necessarily indicate elaborate legal or policy measures in the field of AnGR management. They indicate that existing legal and policy frameworks are appropriate to the needs of the respective country. For example, the United States of America reports a relatively non-interventionist approach in many AnGR-related fields of policy and legislation (see Part 3 Section F), but indicates that this creates a conducive framework for effective AnGR management. The state of implementation of laws and policies is at a high level in North America and a medium to high level in Europe and the Caucasus. However, in other regions there seem to be major weaknesses in implementation. It is possible that the low scores in this field are in part accounted for by a lack of laws or policies to implement,[2] but in most regions the level of implementation appears to lag behind the level of "on-paper" provision.

A number of different awareness-raising activities (exhibitions at agricultural shows, television programmes on AnGR-related topics, etc.) are mentioned in the country reports. There are some indications that these have led to positive outcomes in terms of AnGR management. The country report from South Africa, for example, notes that intensified awareness-raising efforts targeting the "developing-farmer" and communal sectors have led to additional breeds, including the Zulu sheep, Tankwa goat and Afrikaner cattle, being characterized and conserved.

Integration of the management of animal genetic resources with the management of plant, forest and aquatic genetic resources

In view of growing interest in managing the various elements of biodiversity for food and agriculture in a more integrated way, the country-report questionnaire included a subsection devoted to this topic. Countries were requested to provide information on the extent to which AnGR management is integrated with the management of plant, forest and aquatic genetic resources for food and agriculture by providing a score (none, limited or extensive) for the extent of collaboration in various aspects of genetic-resources management. They were also requested to describe the nature of any collaboration reported and, if relevant, to describe any benefits obtained by pursuing a collaborative approach. The results of the scoring exercise are summarized in Table 3A1.

The average scores for the extent of collaboration between the subsectors of genetic resources management are rather low. However, there is a lot of variation between countries in terms of the levels of collaboration reported. While 20 percent of countries report no collaboration

[2] All reporting countries were included in the analysis of the level of implementation regardless of their reported level of "on-paper" provision.

in any of the areas of management considered, there are a number of reports of "extensive" integration. In the case of "joint national strategies or action plans" (some countries specified that they were referring to legal instruments), 16 percent of countries indicate an extensive level of integration. There are also some reports of integrated activities in fields such as marketing.

TABLE 3A1

Reported extent of collaboration in the management of the various subsectors of genetic resources for food and agriculture

Regions and subregions	Number of countries	Field of collaboration							
		Joint national strategies or action plans	Characterization	Genetic improvement	Product development and/or marketing	Conservation strategies, programmes or projects	Awareness-raising	Training activities and education	Mobilization of resources
Africa	**40**	**0.6**	**0.7**	**0.4**	**0.5**	**0.6**	**0.6**	**0.6**	**0.4**
East Africa	8	0.4	0.8	0.3	0.3	0.5	0.3	0.5	0.3
North and West Africa	20	0.6	0.7	0.4	0.5	0.6	0.6	0.6	0.4
Southern Africa	12	0.8	0.5	0.6	0.6	0.6	0.7	0.5	0.4
Asia	**20**	**1.0**	**0.6**	**0.5**	**0.4**	**0.5**	**0.6**	**0.5**	**0.5**
Central Asia	4	0.8	0.5	0.8	0.2	0.0	0.0	0.2	0.0
East Asia	4	1.0	0.6	0.6	0.6	1.0	1.5	0.4	0.8
South Asia	6	0.7	0.5	0.3	0.2	0.7	0.7	0.8	0.3
Southeast Asia	6	1.3	0.8	0.6	0.6	0.4	0.4	0.4	0.7
Southwest Pacific	**7**	**0.4**	**0.3**	**0.4**	**0.3**	**0.3**	**0.4**	**0.1**	**0.1**
Europe and the Caucasus	**35**	**1.0**	**0.5**	**0.3**	**0.5**	**0.7**	**0.9**	**0.7**	**0.7**
Latin America and the Caribbean	**18**	**0.8**	**0.3**	**0.4**	**0.3**	**0.6**	**0.9**	**0.7**	**0.6**
Caribbean	5	0.2	0.0	0.0	0.0	0.0	0.4	0.4	0.0
Central America	5	1.0	0.4	0.8	0.6	0.6	0.8	0.6	0.8
South America	8	1.0	0.5	0.4	0.4	0.9	1.3	0.9	0.9
North America	**1**	**0.0**	**0.0**	**0.0**	**0.0**	**1.0**	**1.0**	**1.0**	**0.0**
Near and Middle East	**7**	**0.4**	**0.1**	**0.3**	**0.0**	**0.1**	**0.3**	**0.1**	**0.1**
World	**128**	**0.8**	**0.5**	**0.4**	**0.4**	**0.6**	**0.7**	**0.6**	**0.5**

Note: Countries provided a score (none, limited or extensive) for the level of collaboration in each category of activity. The scores were converted into numerical values (none = 0; limited = 1; extensive = 2). The figures shown in the table are average scores for the respective categories.
Source: Country reports, 2014.

For example, the country report from Poland mentions the "Kurpie model", an NGO initiative to promote agricultural biodiversity, under which indigenous livestock breeds and plant varieties have been reintroduced and promoted for use in organic agriculture and sustainable development in the northeastern part of the country. Plant and animal products from the scheme are jointly marketed in shops in the capital city.

Most countries did not report specific institutions or stakeholder bodies that coordinate activities across the various subsectors of genetic resources. Some country reports note that the fact that different types of genetic resources are addressed by different ministries is a constraint to collaboration and coordination. Nonetheless, a number of coordinating structures or bodies of various types are mentioned in the country reports, including ministerial or interministerial committees (e.g. Finland and Gabon), foundations (e.g. France), genetic resources centres (e.g. Brazil, Norway and Sweden) and genetic resources networks (e.g. the Plurinational State of Bolivia). In other countries, particular stakeholders play an integrating role with regard to specific aspects of genetic resources management (e.g. gene banking or research).

In addition to the above-mentioned concern about lack of coordination between government ministries, the main constraints to integrated approaches to genetic resources management noted in the country reports are lack of funds, insufficient training of staff working in relevant institutions, lack of sensitization and education among stakeholders and the general public, lack of national-level strategies and legislation, and lack of coordination between administrative and field levels. Some country reports suggest that relatively small-scale initiatives, such as integrated projects and workshops, could be a means of fostering collaboration on a larger scale.

The main potential benefits of an integrated approach foreseen in the country reports are: in administrative terms, savings in time and costs; and, at field level, more efficient and sustainable use of natural resources and the reduction of conflicts related to resource use.

3 Institutional frameworks at subregional and regional levels

3.1 Regional focal points and networks for the management of animal genetic resources

Collaboration between countries at regional level can facilitate action in many areas of AnGR management. The Global Plan of Action for Animal Genetic Resources calls for the establishment of regional focal points for the management of AnGR and for the strengthening of international networks (see Box 3A1). Detailed advice on the establishment and operation of regional focal points is provided in FAO's guidelines on *The development of institutional frameworks for the management of animal genetic resources* (FAO, 2011a). As of mid-2014, the following focal points and networks were in operation:

- Asian Animal Genetic Resources Network;
- European Regional Focal Point for Animal Genetic Resources;
- Regional Focal Point for Latin America and the Caribbean;
- Sub-Regional Focal Point for West and Central Africa; and
- Animal Genetic Resources Network Southwest Pacific.

As part of the reporting process for the second SoW-AnGR, regional focal points and networks were invited to report on regional-level activities contributing to the implementation of the Global Plan of Action. Reports were received from Asia, Europe, Latin America and the Caribbean and the Southwest Pacific.[3] The reports can be accessed at http://www.fao.org/3/a-i4787e/i4787e03.htm. Regional focal points and networks also participated in the previous round of

[3] For information on the reporting process, see "About this publication" in the preliminary pages of this report.

reporting on the implementation of the Global Plan of Action (FAO, 2012).[4]

The European Regional Focal Point is the longest-established and most active network. During the period since the adoption of the Global Plan of Action (2007), it has been active in the implementation of all four of the Plan's strategic priority areas. In the field of characterization inventory and monitoring (Strategic Priority Area 1), actions have included work on the establishment of a regional information system for AnGR (the European Farm Animal Biodiversity Information System – EFABIS) and efforts to harmonize risk-status and endangerment criteria. In the field of sustainable use and development (Strategic Priority Area 2), actions have included contributing to discussions related to the European Union's legal framework on access and benefit-sharing. In the field of conservation (Strategic Priority Area 3), actions have included organizing training activities, providing support to a number of conservation projects and, in 2014, the establishment of the European Gene Bank Network for Animal Genetic Resources (EUGENA) (see Box 3D8 in Part 3 Section D). In the field of policies, institutions and capacity-building (Strategic Priority Area 4), actions have included contributing to discussions on the development of the European Union's legal and policy frameworks in areas relevant to AnGR management.

The Regional Focal Point for Latin American and the Caribbean was established in 2007. Its main activity has been the organization of a number of regional workshops for National Coordinators. Priorities for the future are reported to include seeking financial support for the organization of training courses and for collaborative activities at regional and/or bilateral levels. In the Southwest Pacific, an online network for discussion, dissemination of information and communication between National Coordinators has been established. Other activities have included characterization and conservation projects for locally adapted pigs and chickens, involving a number of countries. In 2012, the recently established Sub-Regional Focal Point for West and Central Africa reported a number of priorities for future action. However, it did not participate in the 2014 round of reporting. The Asian Animal Genetic Resources Network, established in late 2013, has agreed an organizational structure and intends to focus on information exchange, the provision of assistance and technical advice, and the mobilization of funds.

3.2 Other collaborative activities at regional and subregional levels

The focal points and networks discussed above exist specifically to strengthen the implementation of the Global Plan of Action at regional level. However, a range of other players also contribute to this goal. The roles of regional political and economic unions and communities (e.g. the European Union and the subregional economic communities of Africa) in the establishment of regional-level legal and policy instruments relevant to AnGR management are discussed in Part 3 Section F. Regional and subregional-level AnGR management activities can also be organized or supported by non-governmental organizations (NGOs), intergovernmental organizations (e.g. UN agencies) or research organizations (e.g. the centres of the Consultative Group on International Agricultural Research[5] – CGIAR). Countries can also enter directly into collaborative activities with their regional neighbours.

While the analysis presented in the *Synthesis progress report on the implementation of the Global Plan of Action* (FAO, 2014) indicates that international collaboration is one of the elements of the Global Plan of Action in which least progress has been made, a number of countries report that they have participated in collaborative activities at regional level. For example, in

[4] Reports were received from Europe, Latin America and the Caribbean, the Southwest Pacific, and West and Central Africa. The Asian Animal Genetic Resources Network was not in operation at the time. All regional progress reports are available on FAO's web site: http://www.fao.org/ag/againfo/programmes/en/genetics/Reporting_system_2007-11.html#secondo

[5] http://www.cgiar.org

response to a specific question about regional *in situ* conservation projects, more than 40 percent of countries indicate that they have contributed to the development and implementation of such programmes. A somewhat lower number (approximately 30 percent) report that they have contributed to "international cooperative inventory, characterization and monitoring activities involving countries sharing transboundary breeds and similar production systems", many of which are likely to have been at regional level. Collaboration in these fields is more advanced in developed regions than elsewhere in the world.

The level of international cooperation within Europe is greatly increased by the above-described work of the European Regional Focal Point. However, a number of examples of bilateral collaboration, or collaboration involving small groups of countries, are also reported. In the Americas, Brazil, Canada and the United States of America have cooperated in the development of an information system for the management of data related to conservation activities. The main other reported initiative involving countries from Latin America and the Caribbean is the REGENSUR Platform created by the Southern Cone Cooperative Program for Technological Development in Agri-Food and Agroindustry (PROCISUR) of the Inter-American Institute for Cooperation on Agriculture of the Organization of American States, which in 2010 expanded its mandate to include animals and micro-organisms in addition to plants. Collaborative work is envisaged in the fields of sustainable use, conservation, policies and capacity-building, the aim being to reinforce the implementation of national strategies and action plans for AnGR in the countries of the Southern Cone of South America. Regional-level initiatives in Africa have mostly been implemented under the auspices of the African Union Interafrican Bureau for Animal Resources (AU-IBAR).

AnGR-focused NGOs working at regional or subregional levels are reported mainly from Europe. Examples include Safeguard for Agricultural Varieties in Europe (SAVE Foundation) (see Box 3A4) and the Danubian Countries Alliance of Genes in Animal Species (DAGENE). Research organizations active at regional level include the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) (mandate covering all Arab states), whose activities include inventory and characterization studies, breeding programmes, AnGR-related training activities and awareness-raising in the fields of conservation and sustainable use.

4 Institutional frameworks and stakeholders at international level

A range of different entities contribute to the institutional framework for the management of AnGR at international level (i.e. global or spanning more than one region). As at regional level, these include intergovernmental organizations, NGOs and research organizations. International policy and legal frameworks developed by global intergovernmental bodies such as the Convention on Biological Diversity (CBD), FAO and the World Intellectual Property Organization (WIPO) are discussed in Part 3 Section F.

The international instrument most directly focused on AnGR management is, clearly, the Global Plan of Action for Animal Genetic Resources, which was negotiated under the auspices of FAO's Commission on Genetic Resources for Food and Agriculture. The Commission is responsible for overseeing the implementation of the Global Plan of Action and FAO plays the leading role globally in terms of both supporting and monitoring implementation. FAO's activities are described in Boxes 3A5 and 3A6. The Commission provides an intergovernmental forum for ongoing discussion of issues relevant to the management of AnGR and other biodiversity for food and agriculture.

The ongoing work of both WIPO and the Secretariat of the CBD also supports the implementation of the Global Plan of Action in various ways. Both bodies submitted reports on their activities as part of the second SoW-AnGR reporting process. WIPO's report notes, in particular,

Box 3A4

Facilitating the establishment of institutional frameworks for animal genetic resources management – lessons from a project in Bulgaria

As part of the Swiss Agency for Cooperation-funded programme Linking Nature Protection and Sustainable Rural Development,[1] Safeguard for Agricultural Varieties in Europe (SAVE) Foundation was invited to help address the institutional framework for animal genetic resources management in Bulgaria.

In 2014, SAVE undertook two missions to Bulgaria: the first to meet stakeholders and gain an overview of the state of conservation measures for indigenous breeds at risk, both at policy level and on the ground; and the second to facilitate stakeholder meetings. These meetings addressed both technical matters related to the genotyping of livestock populations and matters related to the development of effective institutions and policies. Among the latter, the following topics received particular attention:

- the need to improve communication among stakeholders;
- the need to unify scattered animal genetic resources-related policy and regulatory provisions, so that the overall strategy is clarified and any contradictions can be addressed;
- the need for thematic workshops that help ensure that all stakeholders have the same level of knowledge; and
- the need to revise subsidy programmes on the basis of recommendations from the European Regional Focal Point for Animal Genetic Resources and the results of genotyping studies.

Stakeholders from all levels, government to farmers, attended the meetings and participated actively in the discussions. SAVE's role in this context was to make recommendations based on the discussions, with implementation then taking place at national level.

Experiences from this project and from SAVE's previous work in similar capacities show that the involvement of all stakeholders in discussions of institutional frameworks helps to create a transparent approach that allows everyone to participate in the planning of future activities and adds sustainability to the process.

Provided by Elli Broxham, SAVE Foundation.

[1] http://www.swiss-contribution.admin.ch/bulgaria/en/Home/Projects/Project_Detail?projectinfoID=214077

its *Patent landscape report on animal genetic resources* (WIPO, 2014) and ongoing negotiations taking place in the Intergovernmental Committee on Intellectual Property and Genetic Resources, Traditional Knowledge and Folklore.[6] The report from the CBD Secretariat notes, *inter alia*, work taking place under the Global Taxonomy Initiative,[7] efforts to promote the ecosystem approach, work related to the Nagoya Protocol on Access and Benefit Sharing, work related to the Convention's Article 8(j) (Traditional Knowledge, Innovations and Practices) and the periodic publication of the *Global Biodiversity Outlook*.[8]

As discussed in Part 3 Section F, the Secretariats of the CBD and the Commission have agreed a joint work plan with the aim of promoting synergies in efforts to implement the CBD's Strategic Plan for Biodiversity 2011–2020 and the Commission's Multi-Year Progamme of Work.

Another UN body that contributes to the implementation of the Global Plan of Action, and submitted a report on its activities, is the International Atomic Energy Agency (IAEA), which assists countries through the transfer of nuclear-related technologies and complementary tools. AnGR-related technologies that feature in IAEA's work include molecular genetic testing, hormone monitoring and artificial insemination.

The main international research organizations with mandates relevant to the management

[6] http://www.wipo.int/tk/en/igc
[7] https://www.cbd.int/gti/
[8] https://www.cbd.int/gbo/

Box 3A5

FAO's role in the management of animal genetic resources

FAO's role in animal genetic resources (AnGR) management focuses on supporting countries in their implementation of the Global Plan of Action for Animal Genetic Resources, particularly by:

- raising awareness and promoting AnGR-related issues;
- collaborating with international bodies and organizations addressing sectoral and cross-sectoral issues of relevance to AnGR management;
- developing and maintaining a global information and communication structure for AnGR – the Domestic Animal Diversity Information System (DAD-IS) and the Domestic Animal Diversity Network (DAD-Net);
- supporting the establishment of National and Regional Focal Points;
- coordinating inter-regional activity;
- monitoring the implementation of the Global Plan of Action;
- overseeing the preparation of policy and technical guidelines;
- assisting countries with the development of national capacity in AnGR management;
- developing project and programme proposals; and
- mobilizing donor resources.

For further information see: http://www.fao.org/ag/angr.html

of AnGR are Bioversity International, the International Center for Agricultural Research in the Dry Areas (ICARDA) and the International Livestock Research Institute (ILRI). The latter two organizations undertake a range of activities relevant to the implementation of the Global Plan of Action, including characterization studies, work on the establishment of community-based breeding programmes and provision of support to policy development. Bioversity's AnGR-related work focuses mainly on economic valuation (see Part 4 Section E). All three organizations submitted reports on their activities as part of the second SoW-AnGR reporting process.

The number of international NGOs actively supporting the implementation of the Global Plan of Action is limited. Only a few organizations in this category submitted reports as part of the second Sow-AnGR reporting process: Heifer International; the International Committee for Animal Recording; the League for Pastoral Peoples; and Rare Breeds International. The missions of these organizations (along with those of other relevant international and regional organizations) are shown in Table 3A2.

A number of NGOS and civil society organizations have also taken on a campaigning role at international level. The emergence of the concept of "Livestock Keepers' Rights", for example, was discussed in the first SoW-AnGR[9] (recent developments are described in Box 3A7). Another issue that has become increasingly prominent in the work of civil society organizations in recent years is the development of so-called biocultural community protocols in livestock-keeping communities (see Part 4 Section D – particularly Box 4D3).

5 Changes since 2005

Table 3A3 compares the scores for the state of capacity and provision presented above in Subsection 2 to the equivalent figures from the first SoW-AnGR process,[10] taking into account the 109 countries that participated in both reporting processes. It is important to note that the figures are not directly comparable. Aside from the inevitable element of subjectivity involved in such scoring exercises, the scores used in the first SoW-AnGR were allocated on the basis of the textual descriptions presented in the country reports rather than being directly assigned by the

[9] FAO, 2007a, page 291.

[10] FAO, 2007a, Figures 44 to 46 and Table 58 (pages 205–213).

Box 3A6
The Domestic Animal Diversity Network (DAD-Net)

Established in 2005 by FAO's Animal Production and Health Division, DAD-Net is a moderated global electronic discussion forum where information and experiences on issues relevant to the management of animal genetic resources can be discussed informally. Membership is open to anybody interested in animal genetic resources management and is particularly relevant to National Coordinators for the Management of Animal Genetic Resources and their stakeholder networks, decision-makers, academics and non-governmental organizations. Topics discussed include training and education opportunities, research and technological developments and technology transfer. As of October 2014, the DAD-Net had 2 500 members, from 185 countries. Regional subgroups have been established for Asia and the Pacific, Latin America and Caribbean, East Africa, North Africa, West and Central Africa, and Eastern Europe and Central Asia.

For further information see https://dgroups.org/fao/dad-net\

countries themselves.[11] While the figures therefore have to be interpreted with some caution, the global trends over the 2005 to 2014 period have been positive (scores increased) or neutral (scores stayed the same) in all aspects of the institutional framework considered. The figures indicate declines in some areas of capacity in some regions, most commonly in Latin America and the Caribbean. These declines are clearly matters of some concern, but are perhaps accounted for by overly generous allocation of scores during the first SoW-AnGR process.

At international level, the major change since 2005 has been the adoption of the Global Plan of Action for Animal Genetic Resources. Implementation of most of the Global Plan of Action's strategic priorities takes place mainly at national level (see Table 3F1 in Part 3 Section F). As described above, activities related to the development of institutional frameworks fall mainly within Strategic Priority Area 4 of the Global Plan of Action (see Box 3A1). The *Synthesis progress report on the implementation of the Global Plan of Action* (FAO, 2014) includes an analysis of the progress made (as reported in the country reports) in the implementation of the various elements of the Global Plan of Action since its adoption in 2007.

[11] Countries had the opportunity to request amendments during the reviewing process.

Many examples of improvements to institutional frameworks are reported. However, relative to the amount of work that remains to be done in order to establish effective institutional frameworks in all countries, progress has been modest. On the positive side, the number of countries having a National Coordinator for the Management of Animal Genetic Resources in place is higher (in 2014) than ever before. The number of countries that have developed or are in the process of developing national strategies and action plans for AnGR (see Part 3 Section F) is also encouraging given that national plans targeting AnGR management in a holistic sense were rare prior to the adoption of the Global Plan of Action. Thirty-percent of country reports note an increase in national funding for AnGR management since 2007.

Given that at the time the first SoW-AnGR was prepared, only one regional focal point for AnGR (Europe) was in operation, the existence of four additional regional focal points and networks represents a significant step forward. However, there is clearly scope for further improvement, both in terms of the coverage of regional and subregional focal points and in terms of the level of activity of existing focal points.

The number of international organizations substantially involved in promoting the sustainable use, development and conservation of AnGR has not

TABLE 3A2

Organizations supporting animal genetic resources management at regional and international levels

Organization name and web link	Type	Description of mission
African Union Interafrican Bureau for Animal Resources (AU-IBAR) http://www.au-ibar.org/	IGO	To provide leadership in the development of animal resources for Africa through supporting and empowering African Union Member States and Regional Economic Communities.
Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) http://www.acsad.org/	IGO	To develop plant varieties and animal breeds resistant to drought and integrated management of water resources, preserve the environment and biodiversity and combat desertification.
Bioversity International http://www.bioversityinternational.org/	CGIAR	To deliver scientific evidence, management practices and policy options to use and safeguard agricultural biodiversity to attain sustainable global food and nutrition security.
The Secretariat of the Convention of Biological Diversity (CBD) www.cbd.int/secretariat/	UN	To support the goals of the Convention: - the conservation of biological diversity - the sustainable use of its components - the fair and equitable sharing of benefits arising from the use of genetic resources.
Danubian Countries Alliance of Genes in Animal Species (DAGENE) http://www.dagene.eu/	NGO	To preserve genetics in the Danube river basin.
European Federation of Animal Science (EAAP) www.eaap.org/	NGO	To promote the improvement, organization and enlightened practice of animal production by scientific research, the application of science and cooperation between the national animal production organizations, scientists and practitioners of member countries.
Heifer International www.heifer.org/	NGO	To eradicate poverty and hunger through sustainable, values-based holistic community development through distributing animals, along with agricultural and values-based training, to families in need around the world as a means of providing self-sufficiency.
International Atomic Energy Agency (IAEA) – Joint FAO/IAEA Division www.iaea.org/	UN	To support Member States in the peaceful application of nuclear science and technology in a safe and effective manner to provide their communities with more, better and safer food and agricultural produce while sustaining natural resources.
International Centre for Agricultural Research in the Dry Areas (ICARDA) www.icarda.cgiar.org/	CGIAR	To improve the livelihoods of the resource-poor across the world's dry areas.
International Committee for Animal Recording (ICAR) www.icar.org/	NGO	To promote the development and improvement of the activities of performance recording and the evaluation of livestock.
International Livestock Research Institute (ILRI) http://www.ilri.org/	CGIAR	To improve food security and reduce poverty in developing countries through research for better and more sustainable use of livestock.
League for Pastoral Peoples and Endogenous Livestock Development (LPP) http://www.pastoralpeoples.org/	NGO	To support pastoral societies and other small-scale livestock keepers to pursue their own vision of development through research, technical support, advisory services and advocacy, including endogenous development built on local knowledge, institutions and resources.
NORDGEN - Nordic Genetic Resource http://www.nordgen.org/	IGO	To safeguard the sustainable use of plants, farm animals and forests, securing the broad diversity of genetic resources linked to food and agriculture through conservation and sustainable use, solid documentation and information work and international agreements.
Rare Breeds International http://www.rarebreedsinternational.org/	NGO	To prevent the loss of diversity in global farm animal genetic resources.
Safeguard for Agricultural Varieties in Europe (SAVE Foundation) http://www.save-foundation.net/	NGO	A European umbrella organization for the promotion and coordination of activities for the *in situ* conservation of at risk breeds of domestic animals and cultivated plant varieties.
World Intellectual Property Organization www.wipo.int/	UN	To lead the development of a balanced and effective international intellectual property system that enables innovation and creativity for the benefit of all.

Note: CGIAR = Consultative Group on International Agricultural Research; IGO = intergovernmental organization; NGO = non-governmental organization; UN = United Nations. For information on FAO's work in this field see Box 3A5.

Box 3A7
Livestock Keepers' Rights

"Livestock Keepers' Rights" is a concept developed by civil society (including non-governmental organizations and herders' associations) during the "Interlaken Process".* It is based on the rationale that many breeds in developing countries disintegrate because of the loss of the customary rights of livestock keepers to sustain their livestock on common property resources, as well as policies that are adverse to small-scale livestock keepers. Livestock Keepers' Rights are a set of principles that would support and encourage livestock keepers to continue making a living from their breeds and thereby achieve the combined effect of conserving diversity and improving rural livelihood opportunities.

The term Livestock Keepers' Rights was first coined during the 2002 World Food Summit, in allusion to the Farmers' Rights enshrined in the International Treaty on Plant Genetic Resources for Food and Agriculture. In a series of consultations and workshops held with hundreds of livestock keepers from more than 20 countries in Karen (Kenya) in 2003, Bellagio (Italy) in 2006, Yabello (Ethiopia) in 2006, Sadri (India) and Addis Ababa (Ethiopia) in 2007, Livestock Keepers' Rights were elaborated into a much more comprehensive concept than Farmers' Rights. Rather than representing legal rights, they correspond to development principles that would help livestock keepers continue to conserve biodiversity.

Principles and rights

During a workshop with legal experts held in Kalk Bay, South Africa, in December 2008, the rights were further refined and subdivided into principles and rights:

"Principle 1: Livestock Keepers are creators of breeds and custodians of animal genetic resources for food and agriculture ...

Principle 2: Livestock Keepers and the sustainable use of traditional breeds are dependent on the conservation of their respective ecosystems ...

Principle 3: Traditional breeds represent collective property, products of indigenous knowledge and cultural expression of Livestock Keepers ...

Based on these principles articulated and implicit in existing legal instruments and international agreements, Livestock Keepers from traditional livestock keeping communities and/or adhering to ecological principles of animal production, shall be given the following Livestock Keepers' Rights:

1. Livestock Keepers have the right to make breeding decisions and breed the breeds they maintain.
2. Livestock Keepers shall have the right to participate in policy formulation and implementation processes on animal genetic resources for food and agriculture.
3. Livestock Keepers shall have the right to appropriate training and capacity building and equal access to relevant services enabling and supporting them to raise livestock and to better process and market their products.
4. Livestock Keepers shall have the right to participate in the identification of research needs and research design with respect to their genetic resources, as is mandated by the principle of Prior Informed Consent.
5. Livestock Keepers shall have the right to effectively access information on issues related to their local breeds and livestock diversity."

The Declaration on Livestock Keepers' Rights that emerged from the Kalk Bay Workshop references these principles and rights to existing international agreements and legal frameworks such as the Convention on Biological Diversity, the United Nations Convention to Combat Desertification, the Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration on Animal Genetic Resources, the Universal Declaration of Human Rights, the International Covenant on Economic, Social and Cultural Rights, the United Nations Declaration on the Rights of Indigenous Peoples, the Convention on the Protection and Promotion of the Diversity of Cultural Expressions, the Convention

(Cont.)

*"The Interlaken process" was the process that culminated in the adoption of the Global Plan of Action for Animal Genetic Resources in Interlaken, Switzerland in 2007.

Box 3A7 *(Cont.)*
Livestock Keepers' Rights

(No. 169) concerning Indigenous and Tribal Peoples in Independent Countries, the Declaration on the Rights of Persons belonging to National or Ethnic, Religious and Linguistic Minorities and other pertinent instruments.

The Declaration was signed by a large number of individuals and organizations. Subsequently, the participants of the International Technical Expert Workshop on Access and Benefit Sharing in Animal Genetic Resources for Food and Agriculture, held in Wageningen, the Netherlands, in December 2010, recommended that "Livestock Keepers' Rights should be addressed."

Livestock Keepers' Rights are frequently referred to as a potential tool for protecting the rights of livestock keepers in a context where scientists and industries are making increasing use of the intellectual property rights system to protect their advances in breeding and associated technologies. However, their scope is not restricted to the right to breed, save and exchange genetic material. It encompasses a broader approach that would strengthen small-scale livestock keepers and support them in making a living in their traditional agro-ecosystems.

The discussion about Livestock Keepers' Rights may be revived once The Nagoya Protocol on Access and Benefit-Sharing is ratified, as the Protocol requires its Contracting Parties to share monetary and non-monetary benefits arising from the utilization of traditional knowledge associated with genetic resources, and from the utilization of genetic resources held by indigenous and local communities, with these communities. As described above, non-monetary benefits, such as the participation of livestock keepers in policy formulation and implementation processes on animal genetic resources, training and capacity-building, access to services, marketing support, identification of research needs and access to information, are among the demands made in the Declaration on Livestock Keepers' Rights.

Provided by Ilse Köhler-Rollefson.
For further information see: Köhler-Rollefson and Wanyama, 2003; Köhler-Rollefson *et al.*, 2010a, Köhler-Rollefson *et al.*, 2010b; Köhler-Rollefson *et al.* 2012; FAO 2011c.

TABLE 3A3
Institutions and stakeholders – changes 2005 to 2014

	Africa			Asia			Southwest Pacific			Europe and the Caucasus			Latin America and the Caribbean			North America			Near and Middle East			World		
	n = 35			n = 18			n = 5			n = 29			n = 16			n = 1			n = 5			n = 109		
	2005	2014	Δ	2005	2014	Δ	2005	2014	Δ	2005	2014	Δ	2005	2014	Δ	2005	2014	Δ	2005	2014	Δ	2005	2014	Δ
Research	0.8	1.5	0.7	1.4	1.6	0.2	0.8	0.4	-0.4	2.1	2.3	0.2	1.6	1.8	0.2	3	2	-1	1.2	1.8	0.6	1.4	1.7	0.3
Knowledge	0.7	1.4	0.7	1.3	1.8	0.5	0.6	1.4	0.8	2.2	2.3	0.1	1.6	1.7	0.1	3	3	0	1	1.8	0.8	1.4	1.8	0.4
Awareness	0.9	1.1	0.2	1.5	1.7	0.2	0.4	1.2	0.8	2.2	2	-0.2	1.6	1.2	-0.4	2	2	0	1	1	0	1.5	1.5	0
Infrastructure	1	1.1	0.1	1.4	1.5	0.1	0.8	0.6	-0.2	2.1	2.2	0.1	1.8	1.4	-0.4	3	3	0	1.2	1	-0.2	1.5	1.5	0
Stakeholder participation	0.6	1.1	0.5	1	1.5	0.5	0.4	1.2	0.8	2	2.2	0.2	1.4	1.5	0.1	3	2	-1	0.4	0.8	0.4	1.2	1.5	0.3
Laws and policies	0.5	1.2	0.7	1.2	1.8	0.6	0.6	0.8	0.2	2	2.4	0.4	1.4	1.1	-0.3	3	3	0	0.8	1.2	0.4	1.2	1.6	0.4
Implementation of laws and policies	0.3	1	0.7	0.9	1.5	0.6	0.2	0.8	0.6	1.8	2.3	0.5	1	0.9	-0.1	3	3	0	0.6	0.9	0.3	0.9	1.4	0.5

Notes: This comparison is based on the country reports of 109 countries that reported for both the first and second SoWAnGRs. The date 2005 refers to the year in which the last country reports were submitted during the first reporting process (some reports were submitted as early as 2002). Scores: 0 = none; 1 = low; 2 = medium; 3 = high. In 2005, laws and policies were treated as a single category, while in 2014 they were scored separately. The 2014 scores for "laws and policies" and "implementation of laws and policies" shown in the table are averages of the scores for policies and the scores for laws. n= number of responding countries. Δ = difference in score between 2005 and 2014.

increased since 2005. However, four international organizations (AU-IBAR, IAEA, ILRI and the SAVE Foundation) report that their budgets for activities supporting AnGR-related activities have increased since the adoption of the Global Plan of Action.

6 Conclusions and priorities

In general, the conclusions drawn in the first SoW-AnGR remain valid. Without effective institutions, it is difficult to make progress in terms of strengthening AnGR management programmes. Major gaps and weaknesses in institutional frameworks still need to be addressed. The most positive development in recent years has probably been the more widespread establishment of specifically AnGR-focused structures and instruments, in particular National Focal Points (appointment of National Coordinators) and national strategies and action plans. These developments indicate that AnGR management has acquired at least a foothold on national political agendas. This is further illustrated by the large number of country reports submitted despite the short period of time available in which to prepare them. The development and strengthening of regional focal points and networks is another indicator of countries' interest in AnGR management.

While legal and policy frameworks are still reported to be far from adequate in many countries, they have been supplemented by a substantial number of new instruments over recent years (see Part 3 Section F for further discussion). However, effective implementation remains a problem for many countries. In many cases, the basic prerequisites for effective policy implementation – physical and organizational infrastructure, stakeholder participation, and knowledge and awareness of AnGR-related issues – remain weak or absent. The consequences of these weaknesses are evident in many of the areas of AnGR management discussed in the country reports. Aside from the ubiquitous lack of sufficient funding, lack of knowledge and technical skills, lack of stakeholder participation and inadequate or poorly implemented policies are among the main reported constraints to the establishment of effective AnGR management programmes in all fields from surveying and monitoring to conservation and genetic improvement.

References

Country reports. 2014. The reports can be accessed at http://www.fao.org/3/a-i4787e/i4787e03.htm.

FAO. 2007a. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2007b. *Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration*. Rome (available at http://www.fao.org/docrep/010/a1404e/a1404e00.htm).

FAO. 2009. *Preparation of national strategies and action plans for animal genetic resources*. FAO Animal Production and Health Guidelines. No. 2. Rome (available at: http://www.fao.org/docrep/012/i0770e/i0770e00.htm).

FAO. 2010. *Breeding strategies for sustainable management of animal genetic resources*. FAO Animal Production and Health Guidelines. No. 3. Rome (available at http://www.fao.org/docrep/012/i1103e/i1103e00.htm).

FAO. 2011a. *Developing the institutional framework for the management of animal genetic resources*. FAO Animal Production and Health Guidelines. No 6. Rome (available at: http://www.fao.org/docrep/014/ba0054e/ba0054e00.pdf).

FAO. 2011b. *Surveying and monitoring of animal genetic resources*. FAO Animal Production and Health Guidelines. No. 7. Rome (http://www.fao.org/docrep/014/ba0055e/ba0055e00.htm).

FAO. 2011c. *Report of the International Technical Expert Workshop: Exploring the Need for Specific Measures for Access and Benefit-Sharing Of Animal Genetic Resources for Food and Agriculture*. CGRFA-13/11/Circ.1. Commission on Genetic Resources for Food and Agriculture, Thirteenth Regular Session, Rome, 18–22 July 2011. Rome (available at http://www.fao.org/docrep/meeting/022/mb393e.pdf).

FAO. 2012. *Synthesis progress report on the implementation of the Global Plan of Action for Animal Genetic Resources – 2012*. Commission on Genetic Resources for Food and Agriculture, Fourteenth Regular Session, Rome 15–19 April 2013. CGRFA-14/13/Inf.15. Rome (available at http://www.fao.org/docrep/meeting/027/mg044e.pdf).

FAO. 2013. In vivo *conservation of animal genetic resources.* FAO Animal Production and Health Guidelines. No. 14. Rome (available at http://www.fao.org/docrep/018/i3327e/i3327e00.htm).

FAO. 2014. *Synthesis progress report on the implementation of the Global Plan of Action for Animal Genetic Resources – 2014*. Information Document, Eighth Session of the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture, Rome 26–28 November 2014. CGRFA/WG-AnGR-8/14/Inf.5. Rome (available at http://www.fao.org/3/a-at136e.pdf).

Köhler-Rollefson, I., Kakar, A.R., Mathias, E., Rathore, H.S. & Wanyama, J. 2012. Biocultural community protocols: tools for securing the assets of livestock keepers. *Participatory Learning and Action,* 65 (Biodiversity and culture: exploring community protocols, rights and consent): 109–118.

Köhler-Rollefson, I. Mathias, E., Singh, H., Vivekanandan, P. & Wanyama, J. 2010a. Livestock Keepers' Rights: The State of Discussion. *Animal Genetic Resources,* 47: 1–5 (available at http://www.fao.org/docrep/013/i1823t/i1823t00.pdf).

Köhler-Rollefson, I., Vivekanandan, P. & Rathore, H.S. 2010b. Livestock Keepers Rights and Biocultural Protocols: tools for protecting biodiversity and the livelihoods of the poor. *LEISA India,* 12(1): 35–36.

Köhler-Rollefson, I. & Wanyama, J. (eds.). 2003. *The Karen Commitment. Proceedings of a conference of indigenous livestock breeding communities on animal genetic resources. Karen, Kenya, 27–30 October 2003*. Bonn, Germany, German NGO Forum on Environment & Development (available at http://www.pastoralpeoples.org/docs/karen.pdf).

Mäki-Tanila, A. & Hiemstra, S.J. 2010. Regional issues on animal genetic resources: trends, policies and networking in Europe. *Animal Genetic Resources*, 47: 125–136 (available at http://www.fao.org/docrep/013/i1823t/i1823t00.pdf).

WIPO. 2014. *Patent landscape report on animal genetic resources*, by P. Oldham, S. Hall & C. Barnes. Geneva, Switzerland (available at http://tinyurl.com/q5xbd2y).

Section B

Characterization, inventory and monitoring

1 Introduction

Characterization, inventory and monitoring of animal genetic resources (AnGR) are essential to their sustainable management. Information on breeds' characteristics facilitates effective planning of how and where they can best be used and developed. Assessing risk status (the likelihood that breeds will become extinct if no remedial action is taken) is a key element of AnGR management at national level. This requires information on the size and structure (number of female and male breeding animals, proportion of females breeding pure, total number of herds, geographical distribution, etc.) of breed populations and how these change over time. A range of different approaches and specific tools are available for use in gathering information on the characteristics of individual animals and livestock populations (FAO, 2011a; 2011b; 2012). The state of the art in this field is described in Part 4 Sections A and B, the latter focusing specifically on molecular genetic tools.

This section provides an overview of the state of implementation of characterization, inventory and monitoring activities, based on the information provided in the country reports (see the introduction to Part 3 for an overview of the country coverage and the use of the national breed population as a unit of analysis). The country-report questionnaire included two subsections focused on characterization activities. The first of these requested countries to provide information on the extent to which their national breed populations have been subject to various types of characterization study (see Box 3B1). Countries were obliged to provide this information for the "big five" livestock species (cattle, sheep, goats, pigs and chickens). Providing information on other species was optional. The other subsection addressed countries' progress in implementing Strategic Priority Area 1 of the Global Plan of Action for Animal Genetic Resources (Characterization, Inventory and Monitoring of Trends and Associated Risks). In this subsection, countries were required to report on the state of development of institutional and organizational arrangements for activities in this field, as well as on the state of implementation of various activities. Countries also had the opportunity to describe constraints to the implementation of activities in this strategic priority area. Detailed analysis is provided in the *Synthesis progress report on the implementation of the Global Plan of Action for Animal Genetic Resources – 2014* (FAO, 2014a).

2 Development of national breed inventories

A national breed inventory is a comprehensive list of the breeds present in a country. Given that the breed is the unit of management for many AnGR-related activities, including conservation programmes, establishing a complete inventory is an important objective. Figure 3B1 presents a region by region summary of the reported state of countries' national breed inventories, including whether or not progress has been made since the adoption of the Global Plan of Action. The results show that while many countries have made progress in improving their inventories in

Box 3B1
Characterization – definitions of terms

Baseline survey of population size: A survey that obtains sufficient population data to determine a breed's risk status at national level. It provides a reference point for monitoring population trends.
Monitoring of population size: A systematic set of activities undertaken to document changes in population size and structure over time.
Phenotypic characterization: The process of identifying distinct populations and describing their morphological and production characteristics within given production environments; it includes the description of breeds' production environments and recording of their geographical distributions.
Genetic diversity studies based on pedigree: Studies that involve estimating genetic relationships among animals based on the probabilities of their sharing alleles from common ancestors. At breed level, average coefficients of inbreeding and/or kinships and their trends over time are the most commonly used measures.
Molecular genetic diversity studies within breed: Studies that involve the genotyping of individual animals within a breed for a set of molecular markers, for the purpose of evaluating diversity within the breed. At breed level, heterozygosity is the most simple and meaningful parameter used. Higher heterozygosity indicates higher diversity. Breed genetic structure can be studied by comparing observed and expected heterozygosity (predicted according to sample size and allelic frequencies) and by measuring relationships between animals (proportion of shared alleles across the markers). This provides information on possible population fragmentation or recent cross-breeding events important for the future of the breed.
Molecular genetic diversity studies between breeds: Studies that involve the genotyping of representative groups of animals from a group of breeds for the purpose of evaluating genetic similarity between the breeds. Genetic distance, a measure of the similarity of the allele frequencies between breeds, is a parameter commonly used to measure relationships between breeds. Introgression between populations can be detected by such studies.
Genetic variance components estimation: Use of pedigree and performance data to estimate which part of the phenotypic variance in a population is under genetic control.
Molecular genetic evaluation: The inclusion of molecular genetic information in the procedure for genetic evaluation. This may be limited to genotypes for a few specific genes or extended to the prediction of "genomic breeding values" by using information from large panels of single nucleotide polymorphisms (SNPs).

recent years, a majority (63 percent) still consider that their inventories are incomplete.

3 Baseline surveys and monitoring of population sizes

This subsection focuses on activities undertaken in order to obtain data on the size and structure of national breed populations. The term "baseline survey" is used to refer to an initial data-gathering exercise that provides sufficient data to allow a breed population's risk status to be assessed accurately; ongoing activities that provide the data needed to track a breed's risk status over time are referred to as "monitoring" (FAO, 2011b). The state of implementation of surveying and monitoring activities for the "big five" species, grouped by region and subregion, is presented in Table 3B1. Results broken down by species are presented in Tables 3B2 and 3B3.

The country-report data indicate that baseline surveys have been conducted for 53 percent of national breed populations belonging to the big five species; 44 percent of national breed populations are monitored regularly. It is important to note here that the world figures are greatly influenced (in a positive direction) by those from

TABLE 3B1

Coverage of baseline surveys and monitoring programmes for the big five species

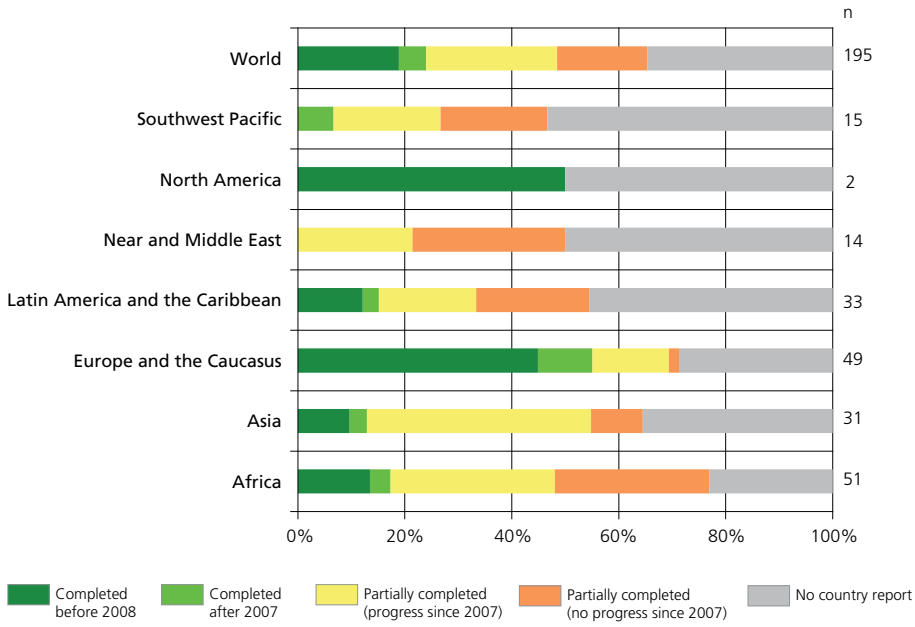
Regions and subregions	Number of countries	Number of national breed populations	Baseline survey of population size (%)	Regular monitoring of population size (%)
Africa	**40**	**1 317**	**45**	**23**
East Africa	8	289	62	22
North and West Africa	20	563	28	12
Southern Africa	12	465	54	36
Asia	**20**	**1 323**	**37**	**18**
Central Asia	4	165	83	38
East Asia	4	548	21	8
South Asia	6	276	50	9
Southeast Asia	6	334	31	31
Southwest Pacific	**7**	**216**	**30**	**16**
Europe and the Caucasus	**35**	**4 090**	**68**	**64**
Latin America and the Caribbean	**18**	**1 164**	**29**	**23**
Caribbean	5	142	42	35
Central America	5	324	33	32
South America	8	698	24	16
North America	**1**	**241**	**92**	**92**
Near and Middle East	**7**	**168**	**34**	**23**
World	**128**	**8 519**	**53**	**44**

Note: The number of national breed populations refers to the number reported in the country reports.
Big five species = cattle, sheep, goats, pigs and chickens.
Source: Country reports, 2014.

the Europe and the Caucasus region, which accounts for a large proportion (48 percent) of the total number of reported national breed populations in the big five species. In this region, the majority (64 percent) of national breed populations (all figures refer to the big five species) are monitored regularly. However, a substantial proportion of national breed populations (32 percent) have not been subject even to a baseline survey. The coverage of both baseline surveys and monitoring programmes is high (92 percent coverage) in North America. Elsewhere in the world, a few subregions – East Africa, Southern Africa and Central Asia – have a relatively high proportion (more than 50 percent) of national breed populations that have been subject to baseline surveys, but the overall figures for developing regions are low. The coverage of monitoring programmes also varies from subregrion to subregion: relatively high (more than 30 percent) in Southern Africa, Central Asia, Southeast Asia, the Caribbean and Central America, but low or very low elsewhere.

Country-report responses on the state of implementation of the Global Plan of Action show that approximately 45 percent of countries consider that they have fully implemented baseline surveys for breeds in all livestock species of economic importance. In contrast, almost 20 percent

FIGURE 3B1
Progress in the establishment of national breed inventories



Note: Countries were asked the following question: Which of the following options best describes your country's progress in building an inventory of its animal genetic resources covering all livestock species of economic importance? Response options were as follows: a. Completed before the adoption of the GPA; b. Completed after the adoption of the GPA; c. Partially completed (further progress since the adoption of the GPA); d. Partially completed (no further progress since the adoption of the GPA). The following definition was provided: "An inventory is a complete list of all the different breeds present in a country." GPA = Global Plan of Action for Animal Genetic Resources; n = number of countries.
Source: Country reports, 2014.

of countries report that no baseline surveys at all have been undertaken in any of their national breed populations. The remaining countries report partial coverage. In the case of monitoring programmes, 30 percent of countries report full coverage of breeds in all important livestock species, 30 percent report partial coverage and 40 percent report that they have no monitoring activities. Progress since the adoption of the Global Plan of Action has been encouraging, but unspectacular, overall. About 20 percent of countries report that the coverage of their monitoring programmes has increased since 2007. Approximately 30 percent report at least some new baseline surveys.

With regard to the state of organizational arrangements for monitoring programmes, almost 60 percent of countries report that they have allocated institutional responsibilities for monitoring programmes and about 35 percent that they have established protocols (details of schedules, objectives and methods) for such programmes.

4 Phenotypic and molecular genetic characterization

The level of implementation of various types of phenotypic and molecular genetic characterization study in the big five species is summarized in

TABLE 3B2
Coverage of baseline surveys and monitoring programmes for cattle

Regions and subregions	Dairy cattle			Beef cattle			Multipurpose cattle		
	Number of national breed populations	Baseline survey (%)	Monitoring (%)	Number of national breed populations	Baseline survey (%)	Monitoring (%)	Number of national breed populations	Baseline survey (%)	Monitoring (%)
Africa	**149**	**42**	**23**	**208**	**45**	**36**	**176**	**60**	**23**
East Africa	34	41	21	19	53	21	73	63	16
North and West Africa	67	28	18	79	23	11	66	45	18
Southern Africa	48	63	33	110	59	56	37	78	43
Asia	**68**	**54**	**37**	**119**	**40**	**29**	**142**	**36**	**8**
Central Asia	16	94	69	17	94	47	10	60	40
East Asia	10	90	70	27	48	30	60	7	0
South Asia	21	43	10	2	50	50	55	69	11
Southeast Asia	21	19	24	73	25	23	17	18	6
Southwest Pacific	**13**	**31**	**23**	**33**	**18**	**15**	**11**	**36**	**36**
Europe and the Caucasus	**206**	**86**	**80**	**425**	**84**	**85**	**219**	**82**	**80**
Latin America and the Caribbean	**103**	**35**	**31**	**247**	**40**	**34**	**65**	**31**	**23**
Caribbean	17	35	18	15	27	27	14	36	36
Central America	37	30	30	74	46	46	26	31	31
South America	49	39	37	158	39	30	25	28	8
North America	**15**	**73**	**73**	**59**	**93**	**93**	**4**	**100**	**100**
Near and Middle East	**19**	**47**	**26**	**7**	**14**	**14**	**19**	**37**	**32**
World	**573**	**59**	**48**	**1098**	**60**	**56**	**636**	**58**	**40**

Source: Country reports, 2014.

Figure 3B2 and Table 3B4. Because it was likely to be difficult for countries to provide precise information on the number of breed populations subject to specific types of study, the country-report questionnaire requested them to score the level of coverage, as follows: high (approximately >67 percent of breeds); medium (approximately 33 to 67 percent of breeds); low (approximately <33 percent of breeds); or none (no coverage). Figure 3B2 shows the proportion of answers falling into each category, broken down on the left by species and on the right by region. Table 3B4 presents a summary of the same data based on the average level of implementation at regional level.

Given that countries were not asked to provide precise breedwise data, the presentations do not reveal the exact proportion of breeds at global and regional levels subject to each type of study. There was clearly also some scope for differential interpretation of how much characterization work is necessary to qualify a breed as "characterized" as opposed to "non-characterized" under the scoring system. Moreover, it is possible that in some countries the

TABLE 3B3

Coverage of baseline surveys and monitoring programmes for sheep, goats, pigs and chickens

Regions and subregions	Sheep			Goats			Pigs			Chickens		
	Number of national breed populations	Baseline survey (%)	Monitoring (%)	Number of national breed populations	Baseline survey (%)	Monitoring (%)	Number of national breed populations	Baseline survey (%)	Monitoring (%)	Number of national breed populations	Baseline survey (%)	Monitoring (%)
Africa	**178**	**54**	**28**	**170**	**51**	**25**	**143**	**36**	**16**	**293**	**31**	**11**
East Africa	44	64	32	45	69	29	20	90	40	54	61	11
North and West Africa	73	41	15	65	37	17	69	25	7	144	13	5
Southern Africa	61	64	39	60	53	30	54	31	19	95	43	21
Asia	**224**	**58**	**15**	**189**	**37**	**15**	**194**	**25**	**15**	**387**	**29**	**19**
Central Asia	60	88	37	21	76	43	9	78	44	32	75	13
East Asia	75	31	1	78	18	5	114	18	10	184	18	7
South Asia	60	75	5	49	55	4	25	36	12	64	14	14
Southeast Asia	29	28	28	41	29	32	46	28	24	107	44	44
Southwest Pacific	**40**	**50**	**5**	**19**	**21**	**16**	**44**	**25**	**18**	**56**	**27**	**18**
Europe and the Caucasus	**957**	**80**	**80**	**327**	**81**	**76**	**334**	**89**	**84**	**1622**	**45**	**38**
Latin America and the Caribbean	**189**	**37**	**33**	**117**	**34**	**21**	**150**	**24**	**15**	**293**	**12**	**10**
Caribbean	24	50	46	22	45	41	26	38	31	24	50	38
Central America	42	26	26	35	34	34	36	33	31	74	24	24
South America	123	37	33	60	30	5	88	16	5	195	3	1
North America	**57**	**100**	**100**	**16**	**100**	**100**	**26**	**96**	**96**	**64**	**84**	**84**
Near and Middle East	**38**	**47**	**29**	**32**	**59**	**41**	**1**	**0**	**0**	**52**	**0**	**0**
World	**1683**	**85**	**72**	**870**	**73**	**55**	**892**	**65**	**54**	**2767**	**44**	**35**

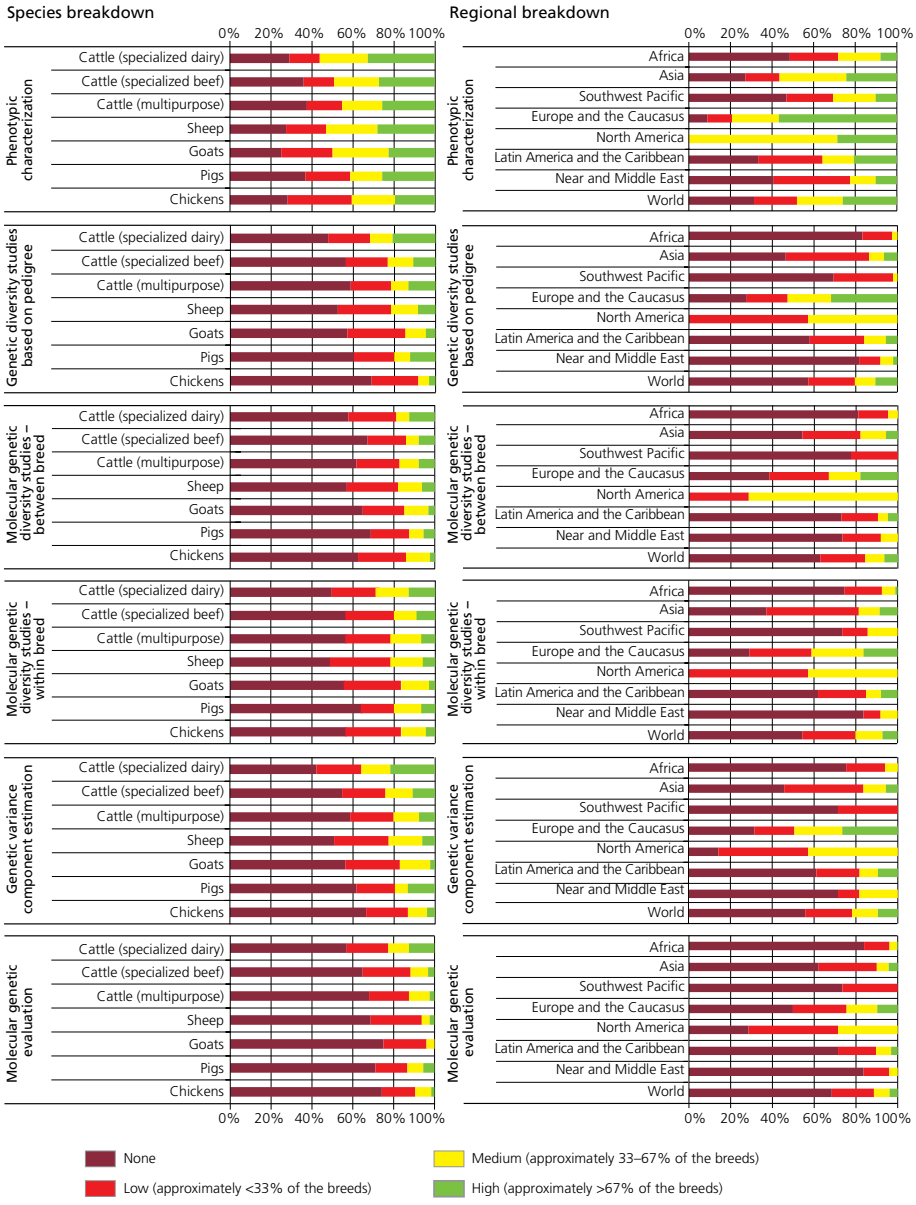
Source: Country reports, 2014.

reporting authorities were not aware of all relevant studies. Nonetheless, the country-level data appear to indicate many gaps in the coverage of characterization studies. For almost all combinations of species and type of study, a majority of countries report either no coverage or low coverage. Phenotypic characterization has been more widely implemented than the other activities. Across all categories, dairy cattle are more likely to have high or medium levels of coverage than other species (and other types of cattle). North America and Europe and the Caucasus, have higher levels of coverage than other regions, but many gaps in coverage remain even in these regions.

As noted in the introduction to this section, providing information on characterization activities targeting breeds other than the big five was not a compulsory element of the country-reporting process. Nevertheless, countries had the option of providing information on these species (equivalent to that provided for the big five). Results for buffaloes, horses, asses, dromedaries, rabbits,

FIGURE 3B2

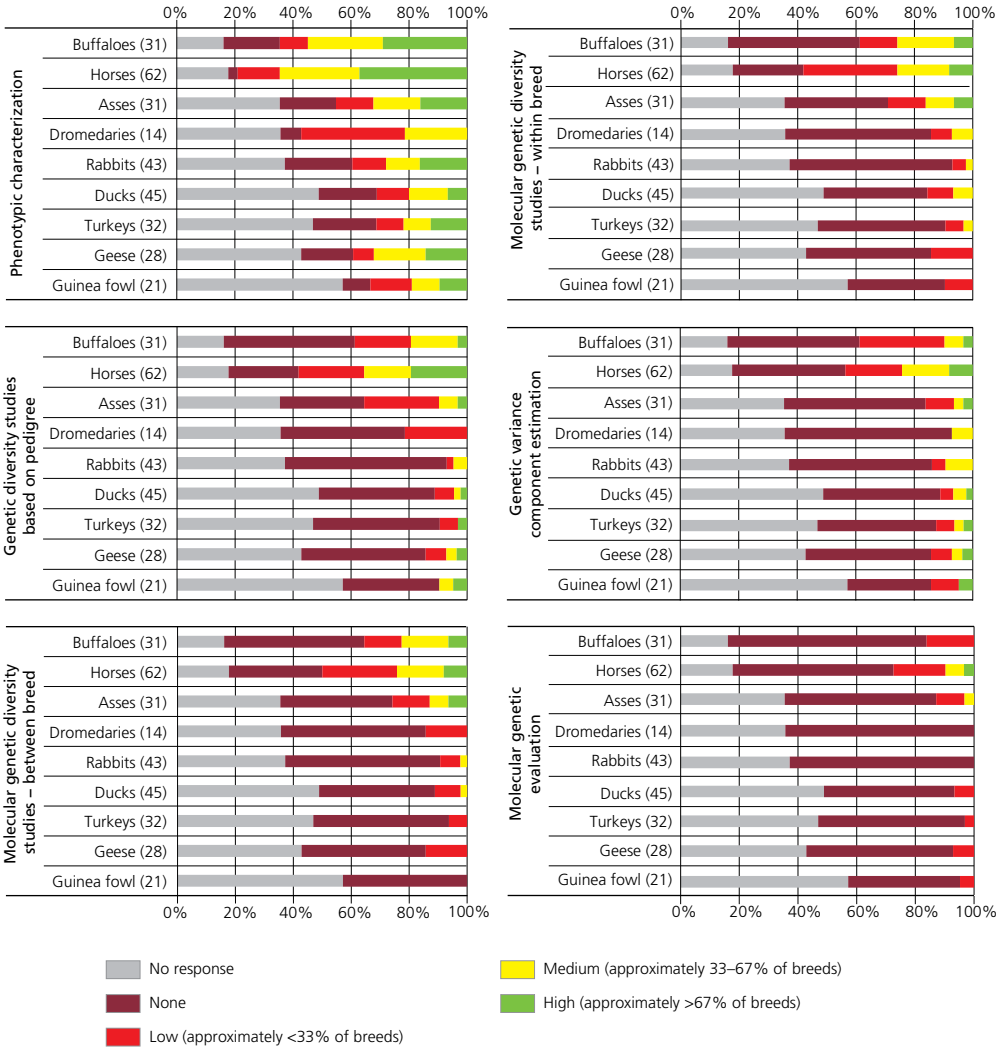
Characterization activities for the big five species – frequency of responses



Note: The bar charts show the proportion of responses falling into the none, low, medium and high categories of breed coverage (see legend). The charts on the left show the overall proportion of countries that provided the respective response for the respective species. The charts on the right show the proportion of answers (country × species combinations) from the respective region falling into the respective category.
Source: Country reports, 2014.

FIGURE 3B3

Characterization activities for "minor" species



Note: The figures refer only to countries that reported the presence of the respective species (number shown in brackets on the left for each species). The bars show the proportion of countries whose responses fell into the none, low, high and medium categories or that provided no information on the state of characterization in respective species.
Source: Country reports, 2014.

TABLE 3B4

Characterization activities for the big five species – average scores

Activity	Species	Africa	Asia	Southwest Pacific	Europe and the Caucasus	Latin America and the Caribbean	North America	Near and Middle East	World
Phenotypic characterization	Cattle (specialized dairy)								
	Cattle (specialized beef)								
	Cattle (multipurpose)								
	Sheep								
	Goats								
	Pigs								
	Chickens								
Genetic diversity studies based on pedigree	Cattle (specialized dairy)								
	Cattle (specialized beef)								
	Cattle (multipurpose)								
	Sheep								
	Goats								
	Pigs								
	Chickens								
Molecular genetic diversity studies – between breed	Cattle (specialized dairy)								
	Cattle (specialized beef)								
	Cattle (multipurpose)								
	Sheep								
	Goats								
	Pigs								
	Chickens								
Molecular genetic diversity studies – within breed	Cattle (specialized dairy)								
	Cattle (specialized beef)								
	Cattle (multipurpose)								
	Sheep								
	Goats								
	Pigs								
	Chickens								
Genetic variance component estimation	Cattle (specialized dairy)								
	Cattle (specialized beef)								
	Cattle (multipurpose)								
	Sheep								
	Goats								
	Pigs								
	Chickens								

(Cont.)

TABLE 3B4 *(Cont.)*

Characterization activities for the big five species – average scores

Activity	Species	Africa	Asia	Southwest Pacific	Europe and the Caucasus	Latin America and the Caribbean	North America	Near and Middle East	World
Molecular genetic evaluation	Cattle (specialized dairy)								
	Cattle (specialized beef)								
	Cattle (multipurpose)								
	Sheep								
	Goats								
	Pigs								
	Chickens								

0–0.5	0.5–1	1–1.5	1.5–2	2–2.5	2.5–3
Low		Medium		High	

Note: Scores provided by countries were converted into numerical values (none = 0; low = 1; medium = 2; high = 3). The colours indicate average scores for the countries of the respective region, as shown in the legend (border values assigned to the higher class).
Source: Country reports, 2014.

ducks, turkeys, geese and guinea fowl are shown in Figure 3B3. As with Figure 3B2, the bar charts indicate the proportion of responses (equivalent here to the proportion of countries) corresponding to each level of implementation. As providing information was not obligatory, a number of countries that reported the presence of a given species provided no indication of the level of implementation of characterization studies. The bar charts, therefore, in contrast to those for the big five, include a "no answer" category. The figure shows that, as in the case of the big five species, many gaps remain in the coverage of characterization studies. Phenotypic characterization has, again, been relatively widely implemented. Across the range of different activities, characterization of horses, and with some exceptions buffaloes, is more advanced than that of the other species.

Country reporting on the implementation of the Global Plan of Action indicates that many countries have made progress in AnGR characterization since 2007. In the case of both phenotypic and molecular genetic characterization, the majority of countries either report improvements or report that comprehensive studies had already been undertaken before 2007. Unfortunately, a substantial minority of countries remain at a low level of coverage and have not made any progress in recent years. Both the extent of coverage and the extent of progress are lower in the case of molecular genetic studies than in the case of phenotypic studies.

5 Constraints to characterization, surveying and monitoring

As noted above, the country-report questionnaire requested countries to provide information on the major barriers and obstacles preventing them from improving their inventory, characterization and monitoring programmes. Lack of funding was the most commonly mentioned constraint, followed by lack of human capacity (technical skills and knowledge). Other constraints mentioned included lack of infrastructure and technical resources (including for data management); lack of awareness on the part of policy-makers and livestock keepers; and lack of adequate policies and planning in the field

Box 3B2

China's second national animal genetic resources survey

China's first national survey of animal genetic resources began in 1976. The first phase was completed in 1984 and the results were published between 1986 and 1990. Another phase was implemented in 1995 and 1996, focusing on the southwestern mountainous area and Tibet, which had not been included in the first phase.

During the 1980s, China began to implement a reform and opening-up policy. The importation of exotic breeds and rapid development of intensive and large-scale production systems contributed to an unprecedented improvement in livestock production performances. However, these achievements were accompanied by a great threat to the diversity of China's animal genetic resources. As a result, the Ministry of Agriculture decided to carry out a second national survey. In 2003, the National Commission of Animal Genetic Resources organized experts to draft a technical manual in preparation for the second survey. The following year, four provinces were selected for a pilot survey. After two years of the pilot survey, the Implementation Plan for the National Survey on Animal Genetic Resources was finalized. In 2006, the plan was issued to provinces and regions nationwide by the Ministry of Agriculture, thereby formally launching the second survey.

It is estimated that more than 6 900 people from 30 provinces and autonomous regions nationwide were involved in the survey, with more than 45 million Yuan (approximately US$7.3 million) of central and local funds invested in the survey and the compilation of the findings. More than 1 200 animal breeds were surveyed and 21 300 photos of breeds were taken.

In 2010–2012, *The record of China's animal genetic resources* was finalized and published, based on the survey results. The publication consists of seven volumes and includes more than 2 100 pictures. A volume on bees and a volume on rabbits, deer and fur animals were published for the first time.

As a result of the survey, a number of previously unrecorded breeds were discovered and identified. These included breeds with distinctive characteristics, such as the Gaoligongshan pig and Piao chicken of the remote southwestern mountainous area. More than 540 indigenous breeds were described, more than twice the number recorded in the first survey.

The second survey revealed the precarious status of China's animal genetic resources. Nearly 300 indigenous breeds had declined in numbers, accounting for more than half of all breeds. Fifteen breeds had become extinct. 55 were endangered and 22 were on the brink of extinction, with the latter two categories accounting for 14 percent of the total.

Impacts of the second survey on policies have included the following:

- Since 2012, the annual regular budgetary allocation for the conservation of breeds has increased from 32 million Yuan to 50 million Yuan (more than US$8 million).
- To date, one in three provinces has launched regular budgetary allocation for the conservation of breeds on provincial priority lists. The annual budget varies from 4 million Yuan to 7 million Yuan (US$0.6 – US$1.1 million).
- In 2012, the Ministry of Agriculture issued the Twelfth Five Year Plan on the Conservation and Sustainable Utilization of Animal Genetic Resources, which includes plans to establish a national dynamic monitoring and early warning system.
- In February 2014, the Ministry of Agriculture re-issued the priority list for conservation. The number of breeds on the list has risen to 159.

Provided by Hongjie Yang.

Box 3B3

BushaLive – a collaborative project to characterize the Busha cattle of the Balkans

The BushaLive project, funded under the Funding Strategy for the Implementation of the Global Plan of Action for Animal Genetic Resources, targets the autochthonous Busha cattle breed of the Balkans, which survives in small, highly endangered, populations. The breed is hardy and well-suited to extensive farming, but has relatively low production yields. It is an important part of the local identity, but will be lost if conservation measures are not put in place to protect it. Stakeholders across the various nationalities and religions present in the Balkans share a common willingness to collaborate in conserving the breed.

Blood samples have been taken from 254 animals. The aim is to obtain unbiased estimates of diversity parameters, population history and the degree of admixture in the Busha population, using genome-wide marker data. Eight reference populations have been included. These represent possible sources of admixture and have also been subject to different levels of artificial selection. Four Busha strains sampled in former studies have also been included. These samples complement the newly collected material. Final conclusions will only be possible after completion of all the analyses. However, the results obtained so far show that locally well-adapted strains that have never been intensively managed and differentiated into standardized breeds show large haplotype diversity. This suggests the need for a conservation and recovery strategy that does not rely exclusively on searching for the original native genetic background, but rather on the identification and removal of common introgressed haplotypes.

Further information on each of the sampled animals has been collected via a comprehensive survey targeting their phenotypic characteristics and husbandry systems, as well as the products and services that they provide. This information, together with the genetic data, will be used to provide a basis for the development of a regional strategy for the management of the breed, spanning all stakeholder levels from farmers to governments. The project will also explore the potential for more effective marketing of the breeds' products. The next steps will be the establishment of basic recording systems and support for the development of breeding organizations and common breeding goals. The project will close with a stakeholder workshop for people working at all levels on the conservation of the breed. The event will provide an opportunity to pass on the information gathered and the strategies developed during the project to those who will use them in the future.

Provided by Elli Broxham, SAVE Foundation.

Photo credit: Elli Broxham.

Photo credit: Elli Broxham.

of characterization, surveying and monitoring. Some countries mentioned practical difficulties associated with the large size of the country or the location of livestock in remote areas, on small farms or in mobile production systems. A few countries mentioned problems associated with a lack of coordination – or a lack of willingness to share information – among stakeholders (e.g. breeders' associations and private companies).

6 Conclusions and priorities

The results presented above need to be treated with some caution because of possible missing data, and inter-country variations in interpretation of the scoring systems and the use of breed concept. Nonetheless, it is clear that in most regions of the world there are major gaps in the coverage of characterization activities and hence major gaps in knowledge about the characteristics of AnGR. Similarly, there are major gaps in programmes for monitoring trends in the size and structure of breed populations and hence the current risk status of many breeds is unknown. These gaps in knowledge inevitably hamper the sustainable use, development and conservation of AnGR. Weaknesses are particularly marked in the developing regions of the world. Research priorities in the field of characterization are discussed in Part 4 Sections A and B.

Strategic priorities for improving the state of inventory, characterization and monitoring are set out in the Global Plan of Action, which recognizes the fundamental importance of improving the state of knowledge of AnGR. Many countries have made some progress in implementing these priorities. However, progress is often constrained by a lack of human and financial resources. The need to strengthen capacity in this field is recognized in the Global Plan of Action as follows:

> *"Establish or strengthen, in partnership with other countries, as appropriate, relevant research, training and extension institutions, including national and regional agricultural research systems, to support efforts to characterize, inventory and monitor trends and associated risks, sustainably use and develop, and conserve animal genetic resources".*[1]

The evidence from the country reports suggests that this recommendation remains highly relevant.

Lack of funding is a widespread constraint to improving many aspects of the management of AnGR. The Global Plan of Action recognizes both the need for "substantial and additional financial resources" and the need for predictable allocation of such resources. The latter may be particularly significant for ongoing activities such as monitoring programmes. Unfortunately, the country reports indicate that improving funding is one of the elements of the Global Plan of Action for which least progress has been made to date (FAO, 2014a) (see Table 3F2 in Part 3 Section F).

While monitoring programmes are far from comprehensive in terms of breed coverage, in most species a majority of national populations are reported to be subject to regular population monitoring. Here there appears to be a discrepancy with the level of reporting of breed population data at international level, i.e. the entry by countries of their national data into the Domestic Animal Diversity Information System (DAD-IS) (see Part 1 Section B). For example, 78 percent of national breed population figures in DAD-IS were not updated once during the four years preceding the preparation of this report (FAO, 2014b). If data are available at national level, it is important that they are entered into DAD-IS so that global trends can be monitored more effectively.

Another issue that may require attention is the institutional framework for the surveying and monitoring of AnGR. The Global Plan of Action recognizes the need to "encourage the establishment of institutional responsibilities and infrastructure for monitoring of trends ..." Establishing an effective surveying and monitoring programme requires not only funds and human resources, but also clear allocation of responsibilities for overall

[1] Strategic Priority 13, Action 3.

coordination and for specific tasks (organization of surveys, provision of data to national authorities, etc.). Objectives, relevant to national data requirements and feasible in terms of national capacities, need to be defined and support from stakeholders needs to be ensured. The country reports indicate that some progress has been made in terms of improving institutional arrangements for surveying and monitoring, but that large gaps remain. Advice on the development of national strategies in this field, including institutional arrangements and stakeholder involvement, is provided in the FAO guidelines *Surveying and monitoring of animal genetic resources* (FAO, 2011b). The guidelines *Phenotypic characterization of animal genetic resources* and *Molecular genetic characterization of animal genetic resources* (FAO, 2011a; 2012) also provide advice on how to ensure that characterization studies are relevant to national requirements. All three guidelines provide practical advice on the organization of characterization and monitoring activities.

The country reports reveal gaps in implementation across all the activities discussed in this section. Specific priorities for action will depend on national circumstances. However, in many countries the basic task of establishing a full inventory of national breeds has not been completed. Similarly, for many recognized breeds, phenotypic characteristics – morphology, performance in specific production environments, degree of adaptedness to specific diseases or climatic challenges, and so on – have been inadequately studied. Gaps are particularly prominent in developing countries, which means that the characteristics of the locally adapted breeds of these countries have been poorly characterized and that the comparative performance of different breeds in the production conditions of these countries has been inadequately assessed. If these gaps are not addressed, it will be difficult or impossible to manage locally adapted breeds sustainably and ensure that their potential is realized.

References

Country reports. 2014. Available at http://www.fao.org/3/a-i4787e/i4787e01.htm.

FAO. 2011a. *Molecular genetic characterization of animal genetic resources*. FAO Animal Production and Health Guidelines. No. 11. Rome (available at http://www.fao.org/docrep/014/i2413e/i2413e00.htm).

FAO. 2011b. *Surveying and monitoring of animal genetic resources.* FAO Animal Production and Health Guidelines. No. 7. Rome (available at http://www.fao.org/docrep/014/ba0055e/ba0055e00.htm).

FAO. 2012. *Phenotypic characterization of animal genetic resources*. FAO Animal Production and Health Guidelines. No. 11. Rome (available at http://www.fao.org/docrep/015/i2686e/i2686e00.htm).

FAO. 2014a. *Synthesis progress report on the implementation of the Global Plan of Action for Animal Genetic Resources – 2014*. Information Document. Eighth Session of the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture. Rome 26–28 November 2014. CGRFA/WG-AnGR-8/14/Inf.5. Rome (available at http://www.fao.org/3/a-at136e.pdf).

FAO. 2014b. *Status and trends of animal genetic resources – 2014.* Information Document. Eighth Session of the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture, Rome, 26–28 November 2014. CGRFA/WG-AnGR-8/14/Inf. 4. Rome (available at http://www.fao.org/3/a-at135e.pdf).

Section C

Breeding programmes

1 Introduction

This section draws on the information provided in the country reports to present an analysis of the state of implementation of livestock breeding programmes and of capacity to implement them (see the introduction to Part 3 for an overview of the country coverage and the use of the national breed population as a unit of analysis). The state of the art in breeding programmes is described separately in Part 4 Section C. Breeding programmes were defined in the country-report questionnaire as follows:

"systematic and structured programmes for changing the genetic composition of a population towards a defined breeding goal (objective) to realize genetic gain (response to selection), based on objective performance criteria.

Breeding programmes typically contain the following elements:

- *definition of breeding goal;*
- *identification of animals;*
- *performance testing;*
- *estimation of breeding values;*
- *selection;*
- *mating; and*
- *transfer of genetic gain.*

Breeding programmes are usually operated either by a group of livestock breeders organized in a breeders' association, community-based entity or other collective body; by a large commercial breeding company; or by the government."

In addition to reporting on programmes of this type, countries also provided information on other activities and strategies aimed at improving the quality of their livestock populations in genetic terms, i.e. measures taken to promote cross-breeding or the wider use of breeds perceived to be more productive.

This section provides an update of the material on the state of capacity in genetic improvement programmes presented in the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007a).[1] The country-report questionnaire addressed the main themes covered in the first SoW-AnGR. However, because of the different reporting methods, most of the findings presented below are not directly comparable to those presented in the earlier publication.

2 Global overview

For each of the so-called "big five" species (cattle, sheep, goats, pigs and chickens), the majority of country reports indicate the presence of breeding programmes (Table 3C1). The figures are higher for cattle (around 90 percent each for the dairy, beef and multipurpose categories) than for the other species (around 80 percent in all cases). While the figures appear to show that breeding programmes are widespread, in some cases the activities referred to in the country reports do not seem to be breeding programmes in the strict sense of the term (see introduction). Many countries report the presence of breeding programmes, but also that some of the key elements of breeding programmes are not in place for any of their breeds. For this reason, the figures presented in the table need to be treated with some caution. It should also be noted that the figures merely

[1] FAO, 2007, Part 3 Section B (pages 215–241).

indicate the presence of at least one programme targeting the respective species. The numbers of breeds covered may be high or low, as may the effectiveness and reach of the programmes.

The regional breakdown presented in Table 3C1 shows that programmes for beef and dairy cattle are widespread in almost all regions and subregions (dairy cattle programmes in North and West Africa are the main exception). Gaps are more widespread in the case of multipurpose cattle (e.g. in South Asia, the Near and Middle East and Central America) and even more so in other species (e.g. sheep, pigs and chickens across most subregions of Africa; and sheep and goats in East Asia and the Southwest Pacific).

In the case of species other than the big five, the proportion of countries indicating that they have breeding programmes in place is generally low (Table 3C2). Only in the case of horses (74 percent), buffaloes (58 percent) and Bactrian camels (80 percent), do the majority of countries reporting the presence of the respective species indicate that they have breeding programmes in place.

TABLE 3C1

Proportion of countries reporting the existence of breeding programmes – regional breakdown

Regions and subregions	Number of countries	Dairy cattle	Beef cattle	Multipurpose cattle	Sheep	Goats	Pigs	Chickens
		%						
Africa	**40**	**76**	**90**	**82**	**58**	**75**	**57**	**56**
East Africa	8	88	100	86	50	88	50	63
North and West Africa	20	57	83	83	60	60	56	42
Southern Africa	12	92	91	78	58	92	64	75
Asia	**20**	**95**	**89**	**80**	**74**	**80**	**75**	**85**
Central Asia	4	100	100	100	100	100	50	100
East Asia	4	100	75	100	50	50	75	75
South Asia	6	100	100	60	80	83	100	83
Southeast Asia	6	83	83	75	67	83	67	83
Southwest Pacific	**7**	**100**	**100**	**100**	**67**	**40**	**86**	**86**
Europe and the Caucasus	**35**	**97**	**88**	**97**	**97**	**94**	**97**	**94**
Latin America and the Caribbean	**18**	**100**	**100**	**80**	**94**	**89**	**100**	**83**
Caribbean	5	100	100	75	100	100	100	60
Central America	5	100	100	60	100	100	100	80
South America	8	100	100	100	88	75	100	100
North America	**1**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Near and Middle East	**7**	**83**	**100**	**67**	**86**	**71**	**0**	**86**
World	**128**	**91**	**93**	**87**	**79**	**81**	**80**	**79**

Note: The figures and bars represent the number of countries indicating the presence of breeding programmes (at least one) as a proportion of the number of countries reporting the presence of the respective species.
Source: Country reports, 2014.

TABLE 3C2
Proportion of countries reporting the existence of breeding programmes – species breakdown

Species	Number of countries reporting presence	Percentage of countries with breeding programmes (at least one)
Dairy cattle	116	91
Beef cattle	103	93
Multipurpose cattle	103	87
Sheep	123	79
Goats	126	81
Pigs	112	80
Chickens	126	79
Horses	62	74
Ducks	43	40
Rabbits	43	44
Buffaloes	31	58
Turkeys	31	45
Asses	30	0
Geese	28	43
Guinea fowl	20	30
Dromedaries	14	29
Quails	14	36
Ostriches	13	31
Pigeons	11	9
Deer	8	0
Alpacas	7	0
Llamas	6	33
Muscovy ducks	6	33
Bactrian camels	5	80
Yaks	5	40
Guinea pigs	4	0

Source: Country reports, 2014.

3 Stakeholder involvement

The systematic implementation of breeding programmes requires stable organizational structures. Programmes can be organized by public-sector bodies, by the private sector, by non-governmental organizations (NGOs) or via collaborative efforts involving more than one sector. Table 3C3 summarizes the information provided in the country reports regarding the sectors and groups of stakeholders that operate breeding programmes (i.e. take the leading or organizational role in the operation of such programmes). For the purposes of this analysis, the private and non-governmental sectors are divided into the following categories:

- national commercial companies (companies based in the respective reporting country);
- external commercial companies (companies based outside the reporting country);

TABLE 3C3

Extent of involvement of different stakeholder groups as operators of breeding programmes

Regions and subregions	Number of countries	Government	Livestock keepers organized at community level	Breeders' associations or cooperatives	National commercial companies	External commercial companies	NGOs	Others
		%						
Africa	**40**	**52**	**29**	**32**	**17**	**6**	**15**	**9**
East Africa	8	58	24	26	15	4	13	7
North and West Africa	20	49	28	37	11	9	19	8
Southern Africa	12	54	33	29	28	4	11	10
Asia	**20**	**83**	**38**	**43**	**30**	**22**	**28**	**11**
Central Asia	4	94	60	40	40	37	40	0
East Asia	4	75	29	43	36	39	29	0
South Asia	6	83	45	26	16	0	37	6
Southeast Asia	6	77	23	57	32	20	13	30
Southwest Pacific	**7**	**47**	**40**	**45**	**45**	**60**	**43**	**6**
Europe and the Caucasus	**35**	**37**	**9**	**76**	**25**	**20**	**17**	**14**
Latin America and the Caribbean	**18**	**60**	**33**	**57**	**55**	**26**	**29**	**25**
Caribbean	5	70	29	15	24	13	3	3
Central America	5	60	29	74	80	17	54	20
South America	8	54	38	72	59	40	29	41
North America	**1**	**0**	**71**	**100**	**86**	**57**	**0**	**100**
Near and Middle East	**7**	**78**	**43**	**20**	**24**	**20**	**24**	**18**
World	**128**	**54**	**27**	**51**	**29**	**19**	**21**	**14**

Note: The figures refer to the percentage of countries (among those reporting the respective species) in which the respective stakeholder group operates breeding programmes averaged over seven species/categories, i.e. the "big five" species (cattle, sheep, goats, pigs and chickens), with the three categories of cattle breeds (dairy, beef and multipurpose) treated separately.
Source: Country reports, 2014.

- breeders' associations or cooperatives (membership organizations in which individual livestock breeders join together to pursue common goals);
- NGOs (NGOs that are not breeders' associations: e.g. those involved in promoting rural development); and
- livestock keepers organized at community level (community-level structures, whether traditional or newly established, that enable livestock keepers to act collectively to organize genetic improvement activities).

At global level, the most frequently reported operators of breeding programmes are governments and breeders' associations. However, there are major differences between regions in terms of the reported significance of these two categories. Breeders' associations are frequently reported

in Europe and the Caucasus and North America, but much less so in most developing regions. Latin America and the Caribbean (or more specifically the Central and South America subregions) is a partial exception to this pattern. Conversely, government-operated programmes are reported more frequently in all developing regions (most particularly in Asia and the Near and Middle East) than in Europe and the Caucasus and North America. No government-operated programmes are reported in the latter region. Programmes operated by national and external commercial companies are reported from all regions of the world (most frequently the Southwest Pacific, North America, and Central and South America). The species involved are most commonly chickens, pigs or dairy cattle (see supplementary tables A3C1, A3C6 and A3C7).[2] Programmes operated by livestock keepers organized at community level are quite widely reported across all developing regions. However, the country reports generally provide little information about the nature of these programmes. Programmes operated by NGOs are reported in most regions, but with relatively low frequency in most cases (highest levels in Central America, the Southwest Pacific and Central Asia).

Whatever sector takes the leading role in organizing a breeding programme, a range of different tasks need to be addressed. A variety of different stakeholders may be involved in each of these tasks, either in terms of planning (e.g. identifying breeding goals and planning how the programme will be organized) or in terms of practical implementation (e.g. recording animals' performance, undertaking genetic evaluations or delivering artificial insemination services). These activities can be thought of as the "building blocks" of breeding programmes. Some of these building blocks can serve a number of different purposes, i.e. they can contribute not only to breeding programmes, but also to other aspects of livestock development. For example, animal identification can facilitate disease control, prevention of livestock theft and the delivery of support payments (FAO, 2015). Performance recording can play a role in herd management. Thus, the building blocks may be in place even if no breeding programmes are yet in operation.

Countries were asked both to provide information on the level of implementation of the various building blocks of breeding programmes and to report on the level of involvement of different stakeholders in their implementation. Because some of these activities can be undertaken by individual livestock keepers, and because of the prominent role of research organizations in undertaking some of them, these two stakeholder categories were included in the list of options provided in the country-report questionnaire. Countries were asked to provide scores for the level of involvement of the various categories. The responses (with respect to the big five species) are summarized in Figure 3C1.

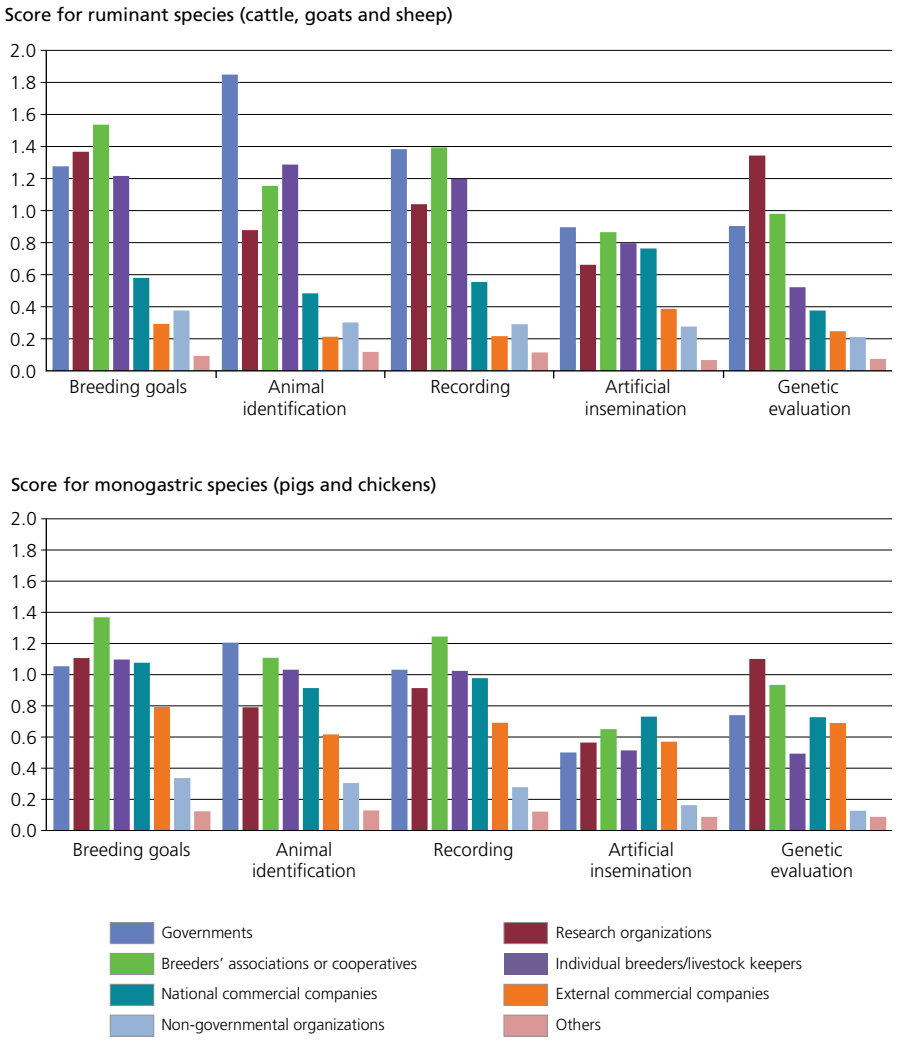
Governments, research organizations, breeders' associations and individual livestock breeders/keepers are reported to play relatively prominent roles across all activities, both in ruminants and monogastrics. In the case of commercial companies, involvement in most activities is markedly higher in monogastrics and dairy cattle than in other types of livestock. The role of NGOs is reported to be limited across all categories of activity. The global figures conceal some regional differences. As in the case of the figures presented in Table 3C3, the roles of breeders' associations are generally more prominent than those of governments in developed regions, while the opposite is the case in developing regions.

Figure 3C2 shows the distribution of countries where breeders' associations are reported either to operate breeding programmes or to have some involvement in implementing the elements of breeding programmes. As noted above, the term "breeding programme" appears not to have been interpreted uniformly across all the country reports and the same may be true of the phrase "operating a breeding programme". It is therefore possible that the number of countries shown to have programmes operated by breeders' associations (i.e. as green rather than yellow on the map) may be an overestimate.

[2] Supplementary tables for Part 3 are provided on CD ROM and at http://www.fao.org/3/a-i4787e/i4787e197.pdf

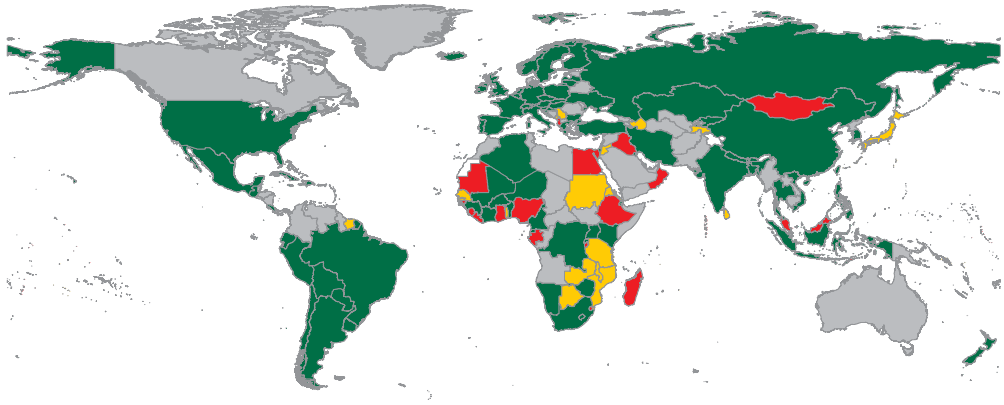
FIGURE 3C1

Stakeholder involvement in breeding-related activities in ruminants and monogastrics – global averages



Note: Countries provided scores (at species level) for the level of stakeholder involvement in each activity. Answering the question was optional (the number of responses varied from species to species). The scores were converted into numerical values (none = 0; low = 1; medium = 2; high = 3). The figures shown are global averages for the respective groups of species.
Source: Country reports, 2014.

FIGURE 3C2
Involvement of breeders' associations in breeding programmes and elements of breeding programmes



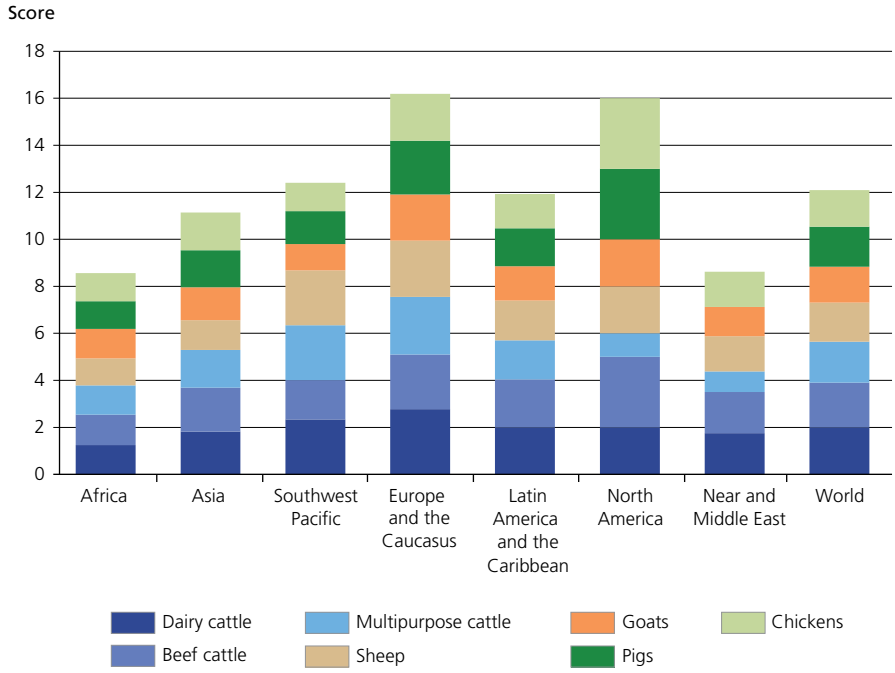
Source: Country reports, 2014.

4 Educational, research and organizational capacities

The successful development and operation of breeding programmes requires a high level of technical capacity and knowledge on the part of the stakeholders involved. Many country reports mention limited knowledge on the part of livestock keepers and technicians as a significant constraint to the implementation of breeding programmes. Analysis of country-report responses on the general state of education and training in the field of animal genetic resources (AnGR) is presented in Part 3 Section A. However, countries were also asked specifically to provide scores (none, low, medium or high) for the state of education and training in the field of animal breeding. The responses are summarized in Figure 3C3. The global cumulative score of 12 out of a potential maximum of 21 illustrates that there is a major deficit in the provision of education and training in this field. Africa and the Near and Middle East are the regions reporting the lowest levels of provision. Responses related to the state of implementation the Global Plan of Action for Animal Genetic Resources reveal a similar picture (Figure 3C4). Approximately 31 percent of reporting countries consider that their provision of training and technical-support programmes for the breeding activities of livestock-keeping communities is at an adequate level; 43 percent report that they have some programmes of this type in place, but that they require improvement; 26 percent report that they have no such programmes. Moreover, 39 percent report that they have made no progress in terms of improving provisions since the Global Plan of Action was adopted in 2007.

Countries were also asked to report on the state of their research activities in the field of animal breeding, again by providing a score. The responses are summarized in Figure 3C5. On a global scale, as in the case of training,

FIGURE 3C3
State of training in the field of animal breeding



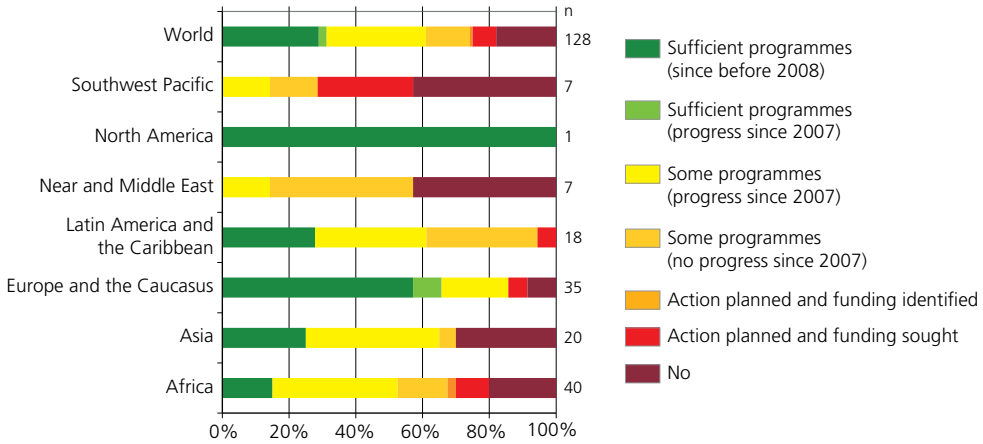
Note: Each country provided a score for the level of provision with respect to each species. The scores were converted into numerical values (none = 0; low = 1; medium = 2; high = 3) and an average score calculated for the respective species × region combinations (countries where the respective species was not reported to be present were excluded from the calculations). The length of each bar corresponds to the cumulative average scores across all species for the respective region. The maximum potential score is 21 (3×7).
Source: Country reports, 2014.

there is a major gap between the current level of research activity and the potential maximum (high level of research in all countries for all species). In practice, the effect of this shortfall is likely to be reduced by the diffusion of research results from one country to another. However, the concentration of research in certain regions or countries may increase the likelihood that some production systems and species are inadequately covered. Moreover, there may be constraints to the diffusion of knowledge, particularly into less-developed countries. Scores for the state of research are highest in North America and Europe and the Caucasus, and lowest in Africa.

As noted above, breeding programmes are complex undertakings that involve a range of different tasks. Establishing a successful breeding programme requires not only the technical capacity to undertake these tasks, but also organizational structures that enable these tasks to be carried out systematically and on a sufficiently large scale. This is likely to require substantial and well-organized involvement of the livestock keepers that raise the respective breeds. Countries were asked to report (again by providing a score) on the level of livestock-keeper organization with respect to animal breeding (taking all the various elements of breeding programmes into account). The responses are summarized in Table 3C4. Scores

FIGURE 3C4

State of implementation of training and technical support programmes for the breeding activities of livestock-keeping communities



Note: Countries were asked the following question: Have training and technical support programmes for the breeding activities of livestock-keepers been established or strengthened in your country? Response options were as follows: a. Yes, sufficient programmes have existed since before the adoption of the GPA; b. Yes, sufficient programmes exist because of progress made since the adoption of the GPA; c. Yes, some programmes exist (progress has been made since the adoption of the GPA); d. Yes, some programmes exist (but no progress has been made since the adoption of the GPA); e. No, but action is planned and funding identified; f. No, but action is planned and funding is sought; g. No. GPA = Global Plan of Action for Animal Genetic Resources; n = number of responding countries.
Source: Country reports, 2014.

for the level of organization are highest in Europe and the Caucasus, Latin America and the Caribbean and North America and lowest in Africa, the Southwest Pacific and the Near and Middle East.

5 Breeding methods and activities

An overview of the status of breeding programmes is presented above (Subsection 2). This subsection presents an analysis of the level of implementation of the various elements of breeding programmes and of the types of programmes that are in operation, specifically the prevalence of programmes that involve cross-breeding.

Countries were asked to indicate the number of exotic and locally adapted breed populations for which breeding goals have been defined and in which the following activities are being implemented:

- animal identification;
- recording of pedigrees;
- recording of animal performance;
- use of artificial insemination (AI);
- implementation of genetic evaluation following the classic approach (i.e. not including the use of genomic information);
- implementation of genetic evaluation including the use of genomic information; and
- management of genetic variation by maximizing the effective population size or minimizing the rate of inbreeding.

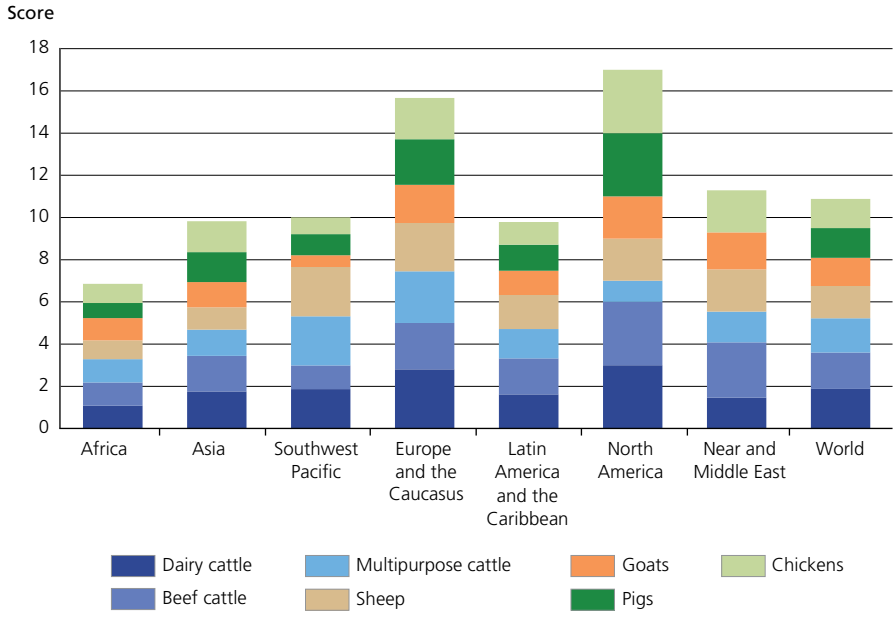
The findings are presented in Table 3C5 (broken down by region), in Table 3C6 (broken down by species) and in the supplementary tables.[3]

The figures presented in the tables show that no breeding goal has been defined for almost half of all reported national breed populations.

[3] Supplementary tables for Part 3 are provided on CD ROM and at http://www.fao.org/3/a-i4787e/i4787e197.pdf

FIGURE 3C5

State of research in the field of animal breeding



Note: Each country provided a score for the level of provision with respect to each species. The scores were converted into numerical values (none = 0; low = 1; medium = 2; high = 3) and an average score calculated for the respective species × region combinations (countries where the respective species was not reported to be present were excluded from the calculations). The length of each bar corresponds to the cumulative average scores across all species for the respective region. The maximum potential score is 21 (3×7).
Source: Country reports, 2014.

There are also major gaps in the breed coverage of other fundamental breeding-programme elements, such as animal identification and the recording of pedigrees and performance. Even where activities are reported, their impacts may be limited. The figures give no indication of the level of coverage within the breed population. Given that the management of locally adapted breeds is generally considered to be neglected relative to that of exotic breeds, it is interesting to note that in many cases (i.e. species × technique combinations) coverage is higher among locally adapted breeds than among their exotic counterparts. Two points should be noted in this regard. First, where continuously imported exotic breeds are concerned, the national population is likely to benefit from the effects of breeding programmes operating in other countries, i.e. stakeholders may consider that there is no need to establish a breeding programme at national level (the disadvantage may be a lack of fine-tuning to the needs of local production systems).[4] Second, some of the exotic breeds reported may be present in very small numbers, having been imported by hobbyists or on an

[4] Some locally adapted breeds are present in more than one country. However, international transfers of "improved" breeding animals and genetic material are dominated by a limited number of breeds. In the case of local breeds (i.e. breeds present in only one country) as opposed to transboundary breeds, importing genetic material is not an option as far as straight-breeding is concerned.

TABLE 3C4

Level of organization of livestock keepers with respect to animal breeding activities

Regions and subregions	Number of countries	Dairy cattle	Beef cattle	Multipurpose cattle	Sheep	Goats	Pigs	Chickens
Africa	**40**	**0.8**	**0.6**	**0.8**	**0.7**	**0.7**	**0.6**	**0.7**
East Africa	8	0.9	0.6	0.6	0.3	0.6	0.4	0.9
North and West Africa	20	0.6	0.5	1.0	0.7	0.7	0.6	0.6
Southern Africa	12	1.0	0.8	0.6	0.8	0.8	0.7	0.7
Asia	**20**	**1.5**	**1.1**	**0.6**	**0.9**	**1.0**	**1.2**	**1.3**
Central Asia	4	1.5	0.5	1.0	1.3	1.0	0.3	1.3
East Asia	4	2.5	2.3	0.5	1.0	1.3	2.3	1.8
South Asia	6	0.7	0.2	1.0	0.5	0.7	0.5	0.8
Southeast Asia	6	1.5	1.7	0.0	1.0	1.2	1.7	1.5
Southwest Pacific	**7**	**0.7**	**0.9**	**0.6**	**0.7**	**0.7**	**1.1**	**1.1**
Europe and the Caucasus	**35**	**2.7**	**2.3**	**1.9**	**2.4**	**1.9**	**2.2**	**1.7**
Latin America and the Caribbean	**18**	**1.9**	**1.5**	**0.9**	**1.4**	**1.1**	**1.3**	**1.4**
Caribbean	5	1.8	0.4	0.2	1.2	1.2	1.2	1.0
Central America	5	1.6	1.6	1.2	1.2	1.4	1.4	1.4
South America	8	2.1	2.1	1.1	1.6	0.9	1.4	1.8
North America	**1**	**3.0**	**3.0**	**2.0**	**2.0**	**2.0**	**3.0**	**1.0**
Near and Middle East	**7**	**0.6**	**0.1**	**0.3**	**0.6**	**0.4**	**0.0**	**0.9**
World	**128**	**1.6**	**1.3**	**1.1**	**1.3**	**1.1**	**1.2**	**1.2**

Note: Each country provided a score for the level of organization with respect to each species. The scores were converted into numerical values (none = 0; low = 1; medium = 2; high = 3). The figures shown in the table are average scores for the countries of the respective region.
Source: Country reports, 2014.

experimental basis. These populations may not be intended for use as production animals and therefore the absence of breeding programmes for them may not be particularly significant.

Across almost all the activities covered in Table 3C5, Europe and the Caucasus, North America and the Southwest Pacific[5] are well ahead of the other regions in terms of breed coverage, at least where locally adapted breeds are concerned. Artificial insemination is a partial exception to this rule, a fact that is probably explained, in part, by the species imbalance in the regional figures, i.e. the developed regions have relatively more breeds belonging to species other than cattle. The use of genomic information in genetic evaluation is reported to be very limited everywhere except the Southwest Pacific (because of the responses from New Zealand) and North America. The species breakdown (Table 3C6) shows that for most of the activities described, the highest coverage is in dairy

[5] New Zealand accounts for 56 percent of all the breed populations (cattle, sheep, goats, pigs and chickens) reported from the region and almost all of them are covered by the various breeding-programme elements considered.

TABLE 3C5

Level of implementation of breeding-programme elements and techniques – regional breakdown

Regions	Number of national breed populations		Animal identification		Pedigree recording		Performance recording		Artificial insemination	
	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted
			%							
Africa	671	646	48	45	30	29	22	26	37	28
Asia	374	949	48	33	31	24	40	30	40	24
Southwest Pacific	150	66	47	66	41	56	39	61	40	32
Europe and the Caucasus	2 051	2 039	58	78	47	74	41	70	33	32
Latin America and the Caribbean	690	474	37	50	36	35	30	31	31	32
North America	19	222	26	69	26	51	26	46	26	49
Near and Middle East	69	99	30	26	23	16	28	16	20	19
World	**4 024**	**4 495**	**51**	**59**	**40**	**51**	**36**	**49**	**35**	**30**

Regions	Number of national breed populations		Breeding goal defined		Genetic evaluation (classic approach)		Genetic evaluation including genomic information		Management of genetic variation	
	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted
			%							
Africa	671	646	34	39	15	24	9	6	16	13
Asia	374	949	47	26	21	22	6	7	13	11
Southwest Pacific	150	66	48	70	61	54	61	54	53	57
Europe and the Caucasus	2 051	2 039	55	73	29	47	5	8	26	51
Latin America and the Caribbean	690	474	28	30	12	27	4	4	5	8
North America	19	222	26	98	26	40	26	34	26	58
Near and Middle East	69	99	30	18	19	16	1	15	12	5
World	**4 024**	**4 495**	**45**	**53**	**24**	**35**	**8**	**9**	**20**	**32**

Note: The figures refer to the proportion of breeds (national breed populations) belonging to the big five species (cattle, goats, sheep, pigs and chickens) covered by the respective breeding-programme elements and techniques. They provide no indication of population coverage within breeds.
Source: Country reports, 2014.

cattle breeds, beef cattle breeds and sheep breeds. Artificial insemination is again an exception, with multipurpose cattle and pigs having higher coverage than sheep. Chicken breeds have relatively low levels of coverage across all activities, probably reflecting the domination of the chicken subsector by a few high-output breeds and the large number of breeds raised either in backyard systems or by hobbyists.

Countries were also asked to indicate the prevalence (in terms of the number of exotic and locally adapted breed populations covered) of breeding programmes involving straight-breeding only and those involving

TABLE 3C6
Level of implementation of breeding-programme elements and techniques – species breakdown

Species	Number of national breed populations		Animal identification		Pedigree recording		Performance recording		Artificial insemination	
	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted
			%							
Dairy cattle	348	225	69	81	56	68	54	64	81	73
Beef cattle	558	540	76	81	63	76	55	64	65	59
Multipurpose cattle	165	471	84	49	63	37	47	38	78	47
Sheep	605	1 078	76	73	65	65	49	60	28	24
Goats	342	528	61	62	47	46	44	42	27	19
Pigs	401	491	53	56	50	45	47	46	50	33
Chickens	1 605	1 162	23	43	12	36	14	39	10	13

Species	Number of national breed populations		Breeding goal defined		Genetic evaluation (classic approach)		Genetic evaluation including genomic information		Management of genetic variation	
	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted
			%							
Dairy cattle	348	225	45	66	29	54	14	26	29	42
Beef cattle	558	540	54	66	34	51	13	17	25	38
Multipurpose cattle	165	471	61	37	34	28	24	7	33	27
Sheep	605	1 078	60	60	36	41	7	4	31	39
Goats	342	528	49	44	26	27	8	4	25	31
Pigs	401	491	51	45	33	36	11	13	25	29
Chickens	1 605	1 162	33	50	10	25	3	4	9	26

Note: The figures refer to the proportion of breeds (national breed populations) covered by the respective breeding-programme elements and techniques. They provide no indication of population coverage within breeds.
Source: Country reports, 2014.

both straight-breeding and cross-breeding. The responses are summarized for the big five species in Table 3C7. As in the case of the overview figures presented above (Subsection 2) the figures in both categories may be overestimates if a strict definition of the term "breeding programme" is applied. While it is clear that cross-breeding strategies are being pursued in all the regions of the world, in all species and in both breed categories, the nature of these strategies and the extent to which they are linked to straight-breeding programmes is not always clear.

The descriptions provided in the country reports indicate that a strategy of cross-breeding locally adapted breeds or "non-descript" populations with exotic breeds (often through the use of artificial insemination) is being widely pursued in developing countries. In many cases this strategy is being promoted by the country's government as a means of rapidly increasing national output of livestock products.

TABLE 3C7

Proportion of breeds reported to be subject to breeding programmes applying straight/pure-breeding and cross-breeding

Straight/pure-breeding only	Dairy cattle		Beef cattle		Multipurpose cattle		Sheep		Goats		Pigs		Chickens	
	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted
	%													
Africa	38	30	51	46	70	24	24	39	26	38	30	33	25	39
Asia	32	42	15	30	57	43	19	55	24	33	44	17	28	31
Southwest Pacific	10	33	12	38	22	100	0	7	0	0	8	17	0	36
Europe and the Caucasus	42	64	54	48	32	55	54	51	56	56	47	42	12	41
Latin America and the Caribbean	43	53	38	43	0	23	26	27	14	14	20	11	6	27
North America	0	0	0	0	n/a	0	n/a	0	n/a	0	0	0	0	0
Near and Middle East	17	29	0	50	25	13	14	21	27	38	n/a	0	26	21
World	**38**	**48**	**43**	**39**	**40**	**39**	**40**	**45**	**35**	**39**	**35**	**27**	**14**	**35**
Straight/pure-breeding and cross-breeding	**Dairy cattle**		**Beef cattle**		**Multipurpose cattle**		**Sheep**		**Goats**		**Pigs**		**Chickens**	
	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted	Exotic	Locally adapted
	%													
Africa	57	58	77	54	80	30	36	23	40	32	46	35	25	36
Asia	51	58	31	37	81	15	33	17	47	13	23	15	31	10
Southwest Pacific	80	33	56	63	100	100	96	100	58	86	69	61	81	50
Europe and the Caucasus	23	30	33	37	50	25	26	26	21	11	42	34	30	21
Latin America and the Caribbean	37	47	33	24	40	28	43	37	42	29	39	29	24	12
North America	100	100	100	100	n/a	100	n/a	100	n/a	100	100	100	0	100
Near and Middle East	33	57	0	50	50	33	21	21	18	14	n/a	0	0	0
World	**42**	**47**	**42**	**45**	**64**	**25**	**33**	**30**	**34**	**21**	**41**	**33**	**30**	**23**

Note: n/a indicates that no breed belonging to the respective species and breed category is reported from the respective region. The term "breeds" in the heading refers to national breed populations.
Source: Country reports, 2014.

Well-planned cross-breeding can be an effective means of pursuing this objective. However, if not well planned, the anticipated benefits may not be realized. The extent to which the cross-breeding activities referred to in the country reports form part of organized strategies is not always clear, neither is the extent to which such strategies, where they are in place, are effectively implemented. Consequences in terms of production levels (and in terms of livelihoods, genetic diversity and the environment) are often unmonitored. In all developing regions, a large proportion of countries (75 percent in Africa, 50 percent in Asia, 85 percent in the Southwest

Pacific, 70 percent in Latin America and the Caribbean and 85 percent in the Near and Middle East) report that they have not undertaken an assessment of the impact of the use of exotic breeds.[6]

6 Breeding policies

A majority of countries report that they have national policies in place to support breeding progammes or influence their objectives (Figure 3C6). Dairy cattle breeding (75 percent of countries) is more frequently targeted than the breeding of any other species or type of animal. Chickens are the least targeted species among the big five (53 percent of countries). A number of countries in all regions except North America report the presence of breeding programmes but the absence of any policies in this field. A few countries, in contrast, report that they have no breeding programmes in place, but nonetheless have policies. In the case of most species, breeding policies are more prevalent in developed regions than elsewhere. These policies vary in terms of how much they aim to influence the objectives and implementation of breeding programmes. Some countries (e.g. the United States of America) leave decision-making very much in the hands of the private sector, while others (e.g. European countries, to varying degrees) take a more interventionist approach. Chicken-breeding policies are comparatively rare in Europe and the Caucasus (partly accounting for the low overall coverage of policies targeting this species). Asia has a high level of coverage in several species: 80 percent or higher in dairy and multipurpose cattle, goats, pigs and chickens. Latin America and the Caribbean has a similarly high level of coverage in the case of dairy cattle.

The reported policies vary in terms of their objectives and in terms of the extent to which they are being successfully implemented. As noted above, a number of countries are seeking to promote greater use of exotic breeds and cross-breeding. If not well planned and implemented, policies of this type can contribute to the erosion of locally adapted breeds (see Part 1 Section F).

The Global Plan of Action for Animal Genetic Resources subsumes breeding programmes within the broader field of sustainable use and development (Strategic Priority Area 2) and calls for "national sustainable use polices"[7] and "species and breed development strategies"[8] that take a long-term perspective and consider, *inter alia*, the need to maintain sufficient genetic diversity. Implementation of these elements of the Global Plan of Action is moderately well advanced in terms of the number of countries having sustainable use policies in place (more than 50 percent of reporting countries). Considerable progress since the adoption of the Global Plan of Action in 2007 is reported. A majority of countries (close to 60 percent) also report that they have "long-term sustainable use planning" in place for at least some species and breeds. These figures, however, clearly also indicate that large gaps remain in the coverage of sustainable use policies. National breeding policies are discussed in greater detail in the regional overviews presented below.

7 Regional overviews

7.1 Africa

Breeding programmes in Africa are often based on governmental farms from which breeding animals and/or genetic material are distributed to livestock keepers. The main reported constraints to the development of more effective programmes in this region are a lack of funding, a lack of technical knowledge at all levels and a lack of organizational structures, particularly with respect to livestock-keeper participation in activities

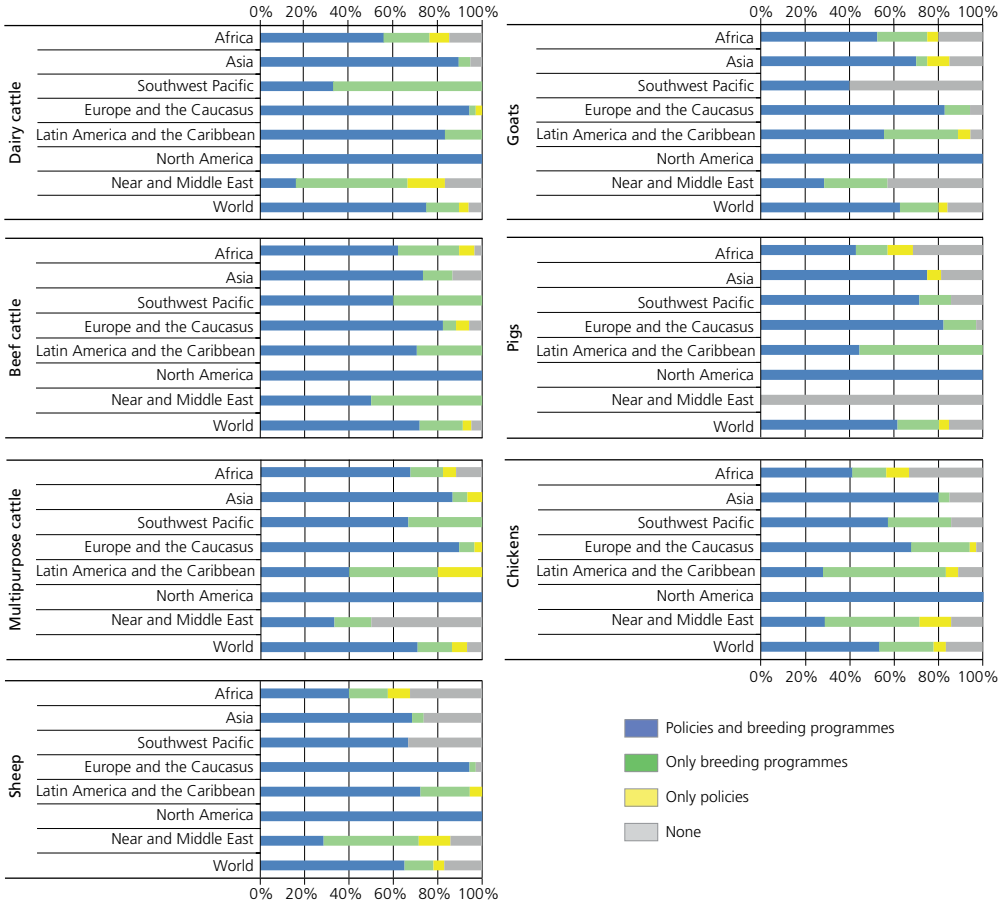
[6] Figures refer to responses to a specific question addressing this topic included in the section of the country-report questionnaire addressing the state of implementation of the Global Plan of Action.

[7] FAO, 2007b, Strategic Priority 3.

[8] FAO, 2007b, Strategic Priority 4.

FIGURE 3C6

Proportion of countries reporting breeding programmes and policies supporting breeding programmes



Note: Proportions refer to the proportion of countries reporting the respective species, i.e. countries not reporting the respective species are excluded from calculations.
Source: Country reports, 2014.

such as animal identification and performance recording.

The development of breeders' associations and their involvement in the operation of breeding programmes have generally been limited in Africa, although they are playing an increasing role in some countries. The country report from South Africa, for example, notes that 72 breed societies "set standards and assist with evaluations" within the framework of the country's national animal-recording and improvement schemes, operated by its Agricultural Research Council's Animal Production Institute. The report from Namibia mentions that breed societies "ensure

Box 3C1
Sheep breeding in Tunisia

In Tunisia, the genetic improvement of sheep is monitored by the Farming and Pasture Office (OEP). Growth records are currently collected in only 109 flocks, via a simplified process involving four weighings. Registered breeds are the Barbarine tête Noire (9 flocks), Barbarine tête Rousse (58 flocks), Noire de Thibar (32 flocks), Queue Fine de l'Ouest (5 flocks) and D'man (5 flocks). The number of registered flocks declined substantially after 2011: firstly, because of civil disturbances, which led to several farms being dissolved, and secondly, because of an attempt to reduce costs. The number of weighings was also reduced as a cost-saving measure. Registered flocks account for roughly 25 000 ewes, a small fraction of the national stock, which was estimated at 3 800 000 ewes in 2011 (Direction Générale de la Production Animale, 2011). Future breeding stocks are selected on the basis of conformation, health and daily-growth traits. Candidate rams and replacement ewes are then sold to breeders and institutional farms nationwide to spread genetic gain. Occasionally, the best rams are used for artificial insemination. On average, genetic gains for growth traits have been roughly 10 percent of the mean over the last decade. The Sicilo-Sarde dairy breed was recently added to the recording system (five flocks accounting for 100 ewes each). This breed's population size had declined drastically to a few thousand ewes, but has increased to around 29 000 ewes in the last five years following an increase in the price of milk and the establishment of a breed association in the region of Béja in the north of Tunisia. The establishment of breed associations for other breeds is being encouraged, with the aim of supporting breeders, improving breed conservation and alleviating the financial burden on the state, which entirely finances existing improvement programmes. A further objective is to better involve researchers in the characterization and genetic evaluation of breeds and thereby provide a basis for the implementation of robust and durable improvement programmes appropriate for the production systems in the various regions of the country.

Provided by Boulbaba Rekik, National Coordinator for the Management of Animal Genetic Resources, Tunisia.

that their breeders identify animals correctly, determine whether animal recording should be mandatory … and decide whether genetic evaluations should be undertaken." Nonetheless, the majority of the country's livestock keepers are reported not to be involved in any structured breeding programmes. In some countries, breeders' associations have been established, but their practical activities remain at a low level. Rwanda reports that breeders' associations participate in the country's "livestock working group" and that their advice is taken into consideration in the setting of breeding goals. They also play a limited role in animal identification, performance recording and the provision of artificial insemination services in some species.

Some countries report efforts to establish community-based breeding programmes. Where successful examples of programmes of this kind are reported, they are mainly operated by international research institutions or development NGOs. In Ethiopia, for example, the International Livestock Research Institute (ILRI) and the International Center for Agricultural Research in Dry Areas (ICARDA) have both established some community-based breeding programmes for small ruminants.

Cross-breeding of locally adapted breeds with high-output exotic breeds (often via the use of artificial insemination) is widely reported. The extent to which these efforts are organized or promoted by the government varies from country to country, as does the extent to which steps are taken to minimize the risk of indiscriminate cross-breeding. The country report from Uganda notes that Boer goats (a breed originally imported from South Africa) are raised on government farms and bucks made

available to goat keepers for cross-breeding with their indigenous animals. Goat keepers are trained in how to avoid indiscriminate cross-breeding and also in performance-recording techniques.

7.2 Asia

The design and implementation of breeding programmes in Asia is generally very dependent on the public sector, with research organizations often playing a significant role (Table 3C3). Nonetheless, approaches to the implementation of breeding programmes vary greatly across the region and there are many specificities at country and subregional levels.

In Central Asia, policies that foster cross-breeding with exotic breeds are widespread. In the Islamic Republic of Iran, for example, cross-breeding has been heavily used in dairy cattle, and to a lesser extent in sheep to improve meat production and in goats to improve milk production. The Iranian country report notes that breeding policies will in future continue to promote cross-breeding in dairy cattle, but that in beef cattle, sheep and goats the intention is to give greater attention to the genetic potential of locally adapted breeds. While in some countries livestock keepers are organized into breeders' associations and cooperatives that participate in the implementation of breeding programmes, this is not the case everywhere in the subregion. The country report from Kazakhstan notes that the intention is to concentrate breeding activities on large collective farms. The country also intends to establish a well-organized system for the use of imported genetic material (Box 3C2).

In East Asia, breeding programmes for the main livestock species are in place in the majority of countries. Programmes are government driven, but livestock keepers are well organized in most countries (Tables 3C3 and 3C4). Breeding programmes in Mongolia are less well developed than those in the other reporting countries in this subregion. The country reports two major constraints to the establishment of breeding programmes: the difficulty of organizing pedigree and performance recording in its extensive production systems, where livestock are unconfined and mating is usually uncontrolled; and livestock keepers' reluctance to participate in government-driven breeding programmes.

In South and Southeast Asia, governments are also generally quite active in the development of breeding policies and in the implementation of breeding programmes. However, the presence of large numbers of small-scale livestock keepers and the lack of breeders' associations lead to difficulties with the organizational aspects of breeding programmes. Breeding strategies in these subregions usually have a strong focus on cross-breeding with high-output exotic breeds. Governments often facilitate the distribution of breeding material from such breeds. While breeding policies in several countries in these subregions have successfully contributed to increasing production levels, a lack of attention to locally adapted breeds has led to their genetic erosion via indiscriminate cross-breeding and breed replacement. Commercial companies are implementing breeding programmes in some countries, mainly in pigs and chickens. These programmes operate on a small scale, but their importance seems to be growing. The country report from Malaysia, for example, states that future progress will depend on the private sector becoming the main driver of breeding programmes.

7.3 Southwest Pacific

In New Zealand and Australia,[9] breeding programmes are long established and very well developed. Attention is focused largely on the development and improvement of a narrow range of species and breeds. Breeders' associations and livestock keepers' cooperatives play key roles. Breeding programmes are organized by these bodies, and a large proportion of livestock keepers participate in them. Government and research institutions support some activities, but decision-making lies in the hands of the livestock keepers.

[9] Australia did not submit a country report as part of the second SoW-AnGR process. However, it prepared a country report at its own initiative in 2012.

Box 3C2
Kazakhstan's plan for the development of the beef-cattle industry

Kazakhstan is implementing the "Master Plan for the Development of the Beef Cattle Industry till 2020" with the aim of ensuring the country's supply of protein for human consumption. The main objectives are to:

- increase the numbers of specialized beef cattle;
- increase the proportion of pedigree cattle in the herd (from 8 percent to 20 percent); and
- increase slaughter weights and dressing percentage.

It is planned to import 72 000 animals from highly productive beef breeds. During the period between 2010 and early 2014, 45 000 pedigree beef animals were imported from the United States of America (34 percent), Australia (22 percent), Canada (14 percent), the countries of the European Union (21 percent) and the Russian Federation (8 percent). The programme aims to increase the population of female beef cattle to 1.5 million head by 2020, with annual delivery of more than 900 000 animals for slaughter and annual beef production of more than 200 000 tonnes.

To accomplish these objectives, the Government of Kazakhstan is considering, *inter alia*, introducing:

- preferential credit and subsidies for the purchase of imported pedigree cattle;
- investing in farm machinery and equipment;
- providing interest-rate subsidies for selective breeding;
- decreasing the costs of forage production; and
- subsidizing the construction of modern feedlots.

The imports have led to some negative consequences, such as deaths of cattle from exotic disease, and reduced reproductive and productive rates because of the need to acclimatize to the new production environment.

It is planned to bring the share of imported cattle in the total beef breeding herd up to 40 to 50 percent. Currently, imported livestock are used both for pure-breeding and for cross-breeding. Positive results have been obtained by crossing the Kazakh White-headed breed with the Hereford, the Auliyekol with the Charolais, and the zonal type "Zhetysu" with the Limousin. Negative impacts on locally adapted breeds are possible if massive uncontrolled cross-breeding occurs.

Provided by Talgat Karymsakov, National Coordinator for the Management of Animal Genetic Resources, Kazakhstan.

In the small island countries of the Southwest Pacific, breeding programmes are rare and where they exist are in their early stages of development (it should be noted in this context that given the small size of these countries attempting to establish independent breeding programmes is not necessarily an appropriate strategy). Livestock-keeper organizations are not well developed and the few breeding programmes mentioned in the country reports are government driven. Private companies are sometimes involved, but there is little participation on the part of individual breeders. The most commonly reported activity is the importation and distribution of exotic breeds to replace locally adapted breeds or for cross-breeding with them. The country report from Samoa describes plans to involve large commercial farms as multipliers within a pyramidal breeding system as a means of meeting demand for breeding animals. The multipliers will be supplied with breeding animals from government-run nucleus farms, and in turn supply individual farmers.

7.4 Europe and the Caucasus

In the majority of the countries of Europe and the Caucasus, the livestock sector is well developed, and breeding programmes are long established and well organized (Tables 3C4 and 3C5 and Figure 3C6). In most European countries, breeders' associations are well organized and play a key role in the operation of breeding programmes (Table 3C3). In a number of countries

Box 3C3

Using exotic genetics in the dairy sector – experiences from Poland

Cattle breeding work undertaken in Poland after the Second World War focused on dual-purpose cattle. All breeds were used for both milk and meat production. The majority of cattle belonged to the Black and White and Red and White lowland breeds, with the Polish Red breed also making up a substantial proportion of the population. In this period, only 20 percent of the cattle population was kept on large-scale farms, while farms keeping one or two cows accounted for 40 percent (Trela and Choroszy, 2010).

The first national programme for the evaluation and selection of bulls for use in artificial insemination was introduced in 1971. Initially, the breeding value of the bulls was estimated using contemporary comparison. Best Linear Unbiased Prediction (BLUP) was introduced in 1985, and BLUP-Animal Model in 1991. The Programme on Genetic Improvement of Cattle Performance, introduced in 1972, with a timeframe running till 1990, underlined the importance of artificial insemination, including the use of imported semen (which came mainly from the United States of America, Canada and Western Europe).

Before 1985, very little genetic progress was achieved within the national breeding scheme and therefore there was an urgent need for an alternative approach. The "Programme on Cattle Breeding and Production to 2000", adopted in 1986, for the first time accepted backcrossing with Holstein-Friesian bulls as a way of developing a specialized dairy population. This was to be complemented by ongoing improvement of pure-bred dual-purpose cattle. Backcrossing with Holstein-Friesians presented an opportunity to benefit from the high genetic potential of this specialized dairy breed and to rapidly enhance the genetic value of the national cattle stock. Over time, as farmers' demand for high-performing dairy stock grew, the development of the herd-book population became dependent on the import of Holstein-Friesian semen. However, the general use of Holstein-Friesian semen was not promoted, as a large part of the cattle population was kept in small herds (up to five cows) under modest husbandry conditions.

After the introduction of the market economy in 1990, the rapid development of the dairy processing sector facilitated the development of specialized dairy production and as a result backcrossing with Holstein-Friesians became widespread. The greater availability of imported semen contributed to this development. As a result of long-term continuous backcrossing, the active Black and White cattle population was completely replaced with the Holstein-Friesian genotype. This led to the recognition of a new breed, the Polish Holstein-Friesian, for which herd books were established in 2005 by the Polish Federation of Cattle Breeders and Dairy Farmers.

To maintain the genetic resources of the traditional dual-purpose types of Polish cattle, the Polish Black and White and the Polish Red and White, were included in the genetic resources conservation programme, as had been already been done for the Polish Red and Whitebacked breeds. This enabled the continued production of semen for use on farms where conditions are not suitable for the highly demanding Polish Holstein-Friesian cows.

The widespread use of Holstein-Friesian semen resulted in the transformation of the dual-purpose population into a specialized dairy breed, and enabled an increase in national milk production while reducing the number of cows (5.5 million in 1985 and 2.4 million in 2013). In 2013, the average milk yield of the Polish Holstein-Friesian Black and White variety was 7 588 kg and that of the Red and White variety was 6 936 kg, while those of the Polish Black and White and the Polish Red and White breeds were 4 659 kg and 4 610 kg respectively (PFHBPM, 2013). It is clear that cross-breeding with an exotic highly specialized dairy breed has positively affected overall milk production. However, high performance was accompanied by decreased fertility, higher somatic cell counts, poor leg conformation and reduced herd-life (Pokorska *et al.*, 2012), problems that are common in the Holstein-Friesian population worldwide. To address these issues, the breeding goals within the programme were substantially widened in 2007. Moreover, in some commercial herds limited cross-breeding with Montbeliarde or Swedish/Norwegian Red cattle was initiated to improve health and robustness.

Provided by Elżbieta Martyniuk, National Coordinator for the Management of Animal Genetic Resources, Poland.

(e.g. the Netherlands, Norway and the United Kingdom) the government's role in breeding programmes is largely restricted to providing support to breeders' associations via research activities. Generally, governments supervise and monitor the implementation and performance of breeding programmes. They implement animal-identification schemes in which all livestock keepers have to participate regardless of whether or not they are members of breeders' associations. They also support breeders' associations by coordinating their work. Some countries (e.g. France and Spain) provide subsidies to support the work of breeders' associations. Breeders' associations organize and implement performance and pedigree recording, set and review breeding goals, ensure the consistency of activities contributing to the genetic improvement of the breed and, where they have the capacity, implement genetic evaluations. Research institutes and universities support breeders' associations and governments in the theoretical and methodological aspects of genetic evaluation, as well as working on the development and refinement of breeding methods. There is, however, some variation across the region. In some countries, particularly in the Caucasus and parts of southeastern Europe, breeding programmes are relatively undeveloped, livestock-keeper organization is limited and breeders' associations are rare.

Commercial companies are active in the region's dairy cattle and pig-breeding sectors and dominate the poultry-breeding sector. They control most of the market for genetic resources in these sectors and work with a narrow range of breeds and lines. As a result of this focus, their roles in breeding programmes for locally adapted breeds of pigs, chickens and dairy cattle are usually limited.

Many European countries rely, to varying degrees, on the use of imported genetics. A number of countries report that this poses a threat to the survival of some of their locally adapted breeds (see Part 1 Section F). However, in some countries it has proved possible to combine a programme of development based on the use of exotic breeds with measures that ensure that locally adapted breeds are maintained and that appropriate genetic resources for use in more marginal production environments remain available (see, for example, Box 3C3).

7.5 Latin America and the Caribbean

In Latin America and the Caribbean, breeding programmes are diverse in terms of the stakeholder groups involved in organizing and implementing them. Depending on the country and the species, breeding programmes may be operated by governments, breeders' associations, commercial companies or livestock keepers organized at community level. However, some stakeholders are more important that others in terms of the implementation of specific breeding-programme elements. Governments are very active in the operation of animal-identification schemes. Breeders' associations and individual livestock keepers are heavily involved in the definition of breeding goals and in the recording of performance data. Artificial insemination is mainly delivered by commercial companies. Research institutions are heavily involved in genetic evaluations.

In the Caribbean, breeding programmes are less developed than in Central and South America. Governments are the main operators of the few breeding programmes that are in place. The importation of exotic genetic material for cross-breeding with locally breeds is widespread. The best-developed breeding programmes are in the dairy-cattle sector, which is characterized by a relatively high level of livestock-keeper organization and the presence of commercial companies. The country report from Suriname, for example, notes that dairy cooperatives actively participate in the definition of breeding goals and also facilitate the provision of artificial insemination services. The report from Trinidad and Tobago mentions that a national commercial dairy company provides artificial insemination to some dairy farms, although on an irregular basis, and also records production data for some farms.

Box 3C4
Beef cattle breeding in Brazil

As well as having the largest commercial cattle herd in the world, Brazil is currently the world's largest exporter of beef. In recent decades, breeding programmes have been at the forefront of beef-sector development and have achieved a marked increase in the productivity of beef breeds.

In 2003, when Brazil prepared its country report for the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture*, there were 16 breeding programmes operating in the beef sector,[1] and they all remain operational. Thirteen programmes target various Zebu breeds, with the objective of increasing reproductive efficiency and growth rate using classical breeding techniques allied with modern biotechnologies. Two further programmes are the Breeding Programme for Zebu Cattle (PMGZ) and GENEPLUS. PMGZ is run by the Brazilian Zebu Breeders' Association, which identifies superior animals by calculating expected progeny differences (EPDs) for weight and weight gain at various ages, as well as for fertility traits and reproductive efficiency, based on a national database covering all Zebu breeds. GENEPLUS provides zebu breeders with EPDs for various production and reproductive traits. The oldest Brazilian herd book, created in 1906, the Collares Herd Book, is responsible for the registration of British and continental cattle breeds, and operates PROMEBO, a genetic evaluation programme for seven *Bos taurus* breeds, which provides yearly sire summaries with EPDs for weights and reproductive traits.

One of the main successes has been a switch from selection for qualitative traits (e.g. ear size in Zebu cattle) to selection for quantitative traits with a more direct link to productivity. Since 2003, the number of animals recorded in the database of the PMGZ programme has risen from 1.5 million animals to 3.6 million animals, with 230 000 new animals entering the database each year. GENEPLUS today covers five Zebu breeds and four composite breeds, as well as two European breeds. Its database, which covered about 700 000 animals in 2003, now covers more than 2.5 million animals. Despite the successes, breeding programmes in Brazil still face many constraints. In the poorer regions of the country, the main constraints are:

- a lack of farmer awareness and commitment to recording animal performance;
- a low level of education among livestock keepers; and
- the cost of recording for smallholders, especially in the case of locally adapted breeds.

Future priority objectives for breeding programmes include, in addition to continuing to increase meat production, increasing dam longevity and meat quality. In Zebu cattle, meat tenderness is fundamental to maintaining export levels, especially exports to countries with higher quality requirements.

Provided by Arthur Mariante, National Coordinator for the Management of Animal Genetic Resources, Brazil.

[1] See FAO 2007a, Box 31 (page 231).

The majority of breeding programmes in Central and South America are implemented by breeders' associations or commercial companies. Breeders' associations generally receive support from the public sector, mainly via the work of research institutions, which are involved not only in genetic evaluation, but also on definition of breeding goals, in performance recording and in the organizational aspects of breeding programmes. Commercial companies – mainly national, but in some cases international – are very active in the region and operate breeding programmes for dairy and beef cattle, pigs and chickens, and to a lesser extent goats. The country report from Costa Rica notes that experiences gained in the implementation of cattle-breeding programmes are used to guide the development of programmes for small-ruminant species.

Cross-breeding strategies are reported to be quite widespread in Latin America (Table 3C7).

Companies and research institutes have developed composite lines, mostly in beef cattle, but also in other species. Cross-breeding with exotic breeds (using both imported genetic material and genetic material sourced from within the region), and to a lesser extent with composite lines developed in the region, is widely used as a method of increasing production levels. Brazil reports a major increase in livestock productivity over recent years, brought about by the implementation of well-developed breeding programmes (Box 3C4). Research organizations at national and regional levels, as well as universities and breeders' associations, are responsible for the majority of Brazil's breeding programmes. In other countries (e.g. Chile, Ecuador and Paraguay), improvement of animal performance has been based on the importation of genetic material and efforts to establish breeding programmes for various livestock species are currently ongoing. Peru and the Plurinational State of Bolivia have established breeding programmes aimed at improving fibre quality in llamas and alpacas. Bolivian programmes include some operated by community-owned companies, the main such company, COPROCA, involves 1 200 camelid keepers. Peru reports breeding programmes for several "minor" species, including rabbits, ducks and guinea pigs.

7.6 North America

In the United States of America, breeding programmes are technologically advanced and widely implemented in all the main livestock species. Cross-breeding strategies are widespread (Table 3C7). Breeders' associations and individual livestock keepers are the main stakeholders involved in the operation of breeding programmes (Table 3C3). National and international commercial companies play a major role in cattle, pig and chicken breeding programmes. Advanced technologies such as genomic selection are widely used in dairy cattle breeding (see supplementary table A3C8).[10] Decision-making regarding breeding activities rests with livestock keepers or commercial companies. Federal and state research organizations may develop means of evaluating traits that the livestock industry deems important, but responsibility for adapting and utilizing such approaches lies with the industry.

7.7 Near and Middle East

The coverage and state of development of breeding programmes in the Near and Middle East are very limited. The programmes that do exist mainly involve sheep and goats and are based on governmental farms or breeding stations. The involvement of livestock keepers is very limited (see Box 3C5 for example). Selected animals, raised on governmental farms or imported, are distributed to livestock keepers with the aim of increasing production levels. Artificial insemination programmes operate on a limited scale.

Box 3C5
Sheep breeding in Jordan

Jordan's sheep-breeding programmes are conducted on a very limited scale. Breeding stations distribute some selected rams to livestock keepers, without measuring the animals' productivity under field conditions and without monitoring. The majority of these rams are selected phenotypically, without genetic-evaluation programmes.

A national animal identification and registration system is in place, but there is no performance and pedigree recording at the livestock-keeper level. To establish a breeding programme at national level, animal identification needs to be linked to performance and pedigree information. Establishing such a programme would require well-qualified staff and good collaboration among stakeholders.

Source: Adapted from Jordan's country report.

[10] Supplementary tables for Part 3 are provided on CD ROM and at http://www.fao.org/3/a-i4787e/i4787e197.pdf

PART 3

8 Changes since 2005

As noted in the introduction to this section, many of the data presented above are not directly comparable to those presented in the first SoW-AnGR. However, in both reporting processes countries provided information on the number of breeds subject to various breeding-related activities. The list was slightly expanded for the second reporting process, but results for the activities covered in both processes are presented in Figure 3C7 (for cattle breeds).

Because the first reporting process was not based on a structured questionnaire,[11] comparable figures are available for only 35 countries.[12] The results show that – at least as far as the 35 countries are concerned – the proportion of cattle breeds covered by all the various breeding-related activities reported upon has expanded since the time of the first SoW-AnGR reporting process. Is should, however, be noted that there are some differences between the pattern of development in OECD countries and that in non-OECD countries. In particular, coverage of genetic evaluation has increased much more sharply in OECD countries (46 percent to 70 percent) than in non-OECD countries, where it has remained almost stable at around 32 percent. Given the progress made in the implementation of other breeding-programme elements, addressing the coverage of genetic evaluations would appear to be the logical next step towards the more widespread establishment of effective breeding programmes.

[11] During the first SoW-AnGR process, countries were provided with predefined tables or "tabulation tools", intended to facilitate the collection and analysis of information during the preparation of their country reports. Some countries included the completed tables in their country reports, while others did not.

[12] Albania, Argentina, Austria, Bangladesh, Benin, Brazil, Burundi, Cameroon, Croatia, Cyprus, Democratic Republic of the Congo, Ethiopia, Gambia, Ghana, Greece, Guatemala, Iceland, Latvia, Lesotho, Madagascar, Malaysia, Mexico, Namibia, Norway, Paraguay, Republic of Korea, Senegal, Slovakia, Slovenia, Swaziland, Sweden, Togo, Ukraine, United Republic of Tanzania and Uruguay.

9 Conclusions and priorities

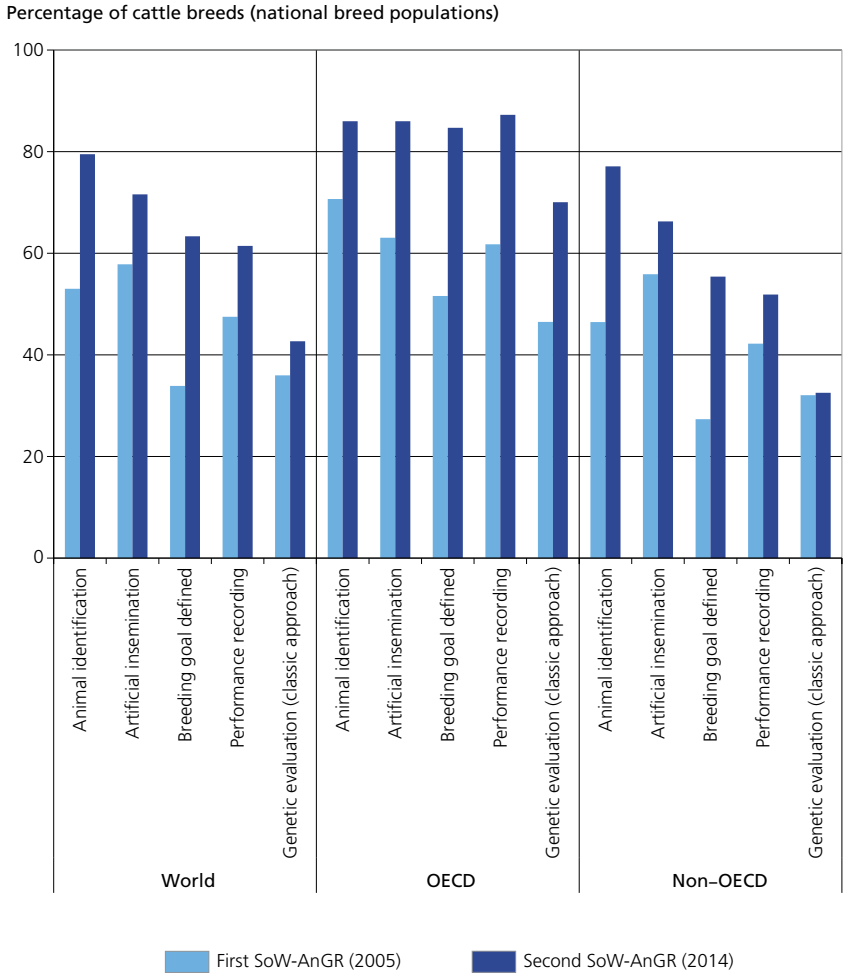
While the majority of countries report that they have at least some breeding progammes in place, the reported levels of implementation of the various elements of breeding programmes suggest that these programmes are often in a very rudimentary state – or in some cases non-existent in the sense of organized progammes involving the establishment of breeding goals, recording of performance, etc.

The involvement of stakeholder groups in the organization and implementation of breeding programmes varies greatly from region to region. In Africa, Asia and the Near and Middle East, governments are the main players, while in North America, Europe and the Caucasus, Australia and New Zealand, responsibility for operating breeding programmes lies mainly in the hands of breeders' associations and commercial companies, with various degrees of support from governments and research organizations, depending on the country. The involvement of breeders' associations and commercial companies is also relatively well developed in parts of Latin America.

The first SoW-AnGR concluded that, where they existed, government-operated breeding programmes in developing countries tended to have limited impact because of a lack of interaction with livestock keepers. However, it also concluded that there were many constraints to the emergence of the "developed-country" model based on breeders' associations and involving minimal governmental support, particularly with regard to the organizational structures needed to facilitate the involvement of individual livestock keepers and the relatively high levels of knowledge and technical skills required. The information provided in the country reports suggests that a number of these preconditions have still not been met in many countries. While there are some reported examples of progress, livestock-keeper organization frequently remains poorly developed, as do education and training in the field of livestock breeding.

Many countries have put policies in place aimed at improving the state of livestock breeding.

FIGURE 3C7
Implementation of breeding tools in cattle (2005 and 2014)



Note: The figure is based on information reported by the 35 countries (9 OECD and 26 non-OECD) that provided the relevant information in both State of the World (SoW-AnGR) reporting processes. The figures represent the percentage of cattle breeds (national breed populations) in which the tools are used. Note that they may be used only in part of the population within these breeds.

In many developing countries, in particular, these policies focus mainly on the introduction of exotic breeds for use in cross-breeding, sometimes with little attention to the establishment of breeding programmes. Utilizing the genetic progress already made in exotic breeds has obvious attractions for countries seeking rapidly to boost their output of livestock products. The difficulty lies in the fact that while increasing the availability of exotic genetic material may be relatively straightforward, ensuring that it is used appropriately is more challenging.

PART **3**

While interest in expanding the use of exotic breeds is practically universal in developing countries, a number have also recognized the need to take greater advantage of the characteristics of their locally adapted breeds, particularly given the challenges associated with climate change and the ongoing need for livestock that are suitable for use by small-scale producers and in low-input production systems. In this context, improving the productivity of locally adapted breeds through the implementation of breeding programmes is, at least in theory, an appealing option, both because of the potential to derive benefits directly from increasing livestock productivity and because it may help to keep the breeds in use and hence available as resources for the future. However, for the reasons noted above, implementing such programmes is often challenging. Only a small number of developing countries report the successful establishment of community-based breeding programmes in medium- or low-input production systems.

On the positive side, the evidence provided in the country reports suggests that the level of implementation of several of the main elements of breeding programmes – in terms of the number of breeds covered – has increased in recent years. Major gaps, nonetheless, remain in all developing regions. Even where activities are reported to have become more widespread in terms of breed coverage, they may remain very restricted in terms of the proportion of the population covered within each breed. Animal identification appears to be the area where the most progress has been made, probably because of its multiple roles in livestock development.

As noted in the first SoW-AnGR, developing a national breeding strategy can be very challenging, particularly given that the information needed in order to assess the relative costs and benefits of different approaches is often unavailable. The existence of these knowledge gaps underlines the importance of strengthening efforts to characterize breeds and their production environments (see Part 3 Section B and Part 4 Sections A and B) and the need to keep track of trends and drivers of change in the livestock sector (see Part 2).

Countries have a range of different short- and longer-term objectives and often have to deal with a diverse range of production systems. Identifying specific priorities at national and production-system levels is therefore a matter for countries themselves. The information provided in the country reports suggests that, in more general terms, priorities will often include capacity-building at all levels from livestock-keepers to policy-makers, as well as strengthening the organizational structures needed in order to implement successful breeding programmes. Livestock-keeper involvement is frequently a weak point in existing programmes.

References

Country reports. 2014. Available at http://www.fao.org/3/a-i4787e/i4787e01.htm.

Direction Générale de la Production Animale. 2011. *Enquête de structure*. Tunis, Ministère de l'Agriculture.

FAO. 2007a. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2007b. *Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration.* Rome (available at http://www.fao.org/docrep/010/a1404e/a1404e00.htm).

FAO. 2015. *Development of integrated multipurpose animal recording systems*. FAO Animal Production and Health Guidelines. Rome (in press).

PFHBPM. 2013. *Analiza i podsumowanie wyników oceny wartości użytkowej bydła w 2013r.* Polska Federacja Hodowców Bydła i Producentów Mleka.

Pokorska, J., Kułaj, D. & Ormian, M. 2012. Przyczyny brakowania krów rasy polskiej holsztyńsko-fryzyjskiej odmiany czarno-białej użytkowanych w fermie wielkotowarowej. *Roczniki Naukowe Polskiego Towarzystwa Zootechnicznego*, 8(2): 17–24.

Trela, J. & Choroszy, B. 2010. Wkład Instytutu Zootechniki Państwowego Instytutu Badawczego w rozwój i doskonalenie krajowej populacji bydła mlecznego. *Wiadomości Zootechniczne,* R. XLVIII (2010), 4: 3–30.

Section D

Conservation programmes

1 Introduction

This section presents a review of the state of conservation programmes based on information provided in the country reports (see the introduction to Part 3 for an overview of the country coverage and the use of the national breed population as a unit of analysis). Conservation actions are commonly grouped into three categories: *in situ* conservation; *ex situ in vivo* conservation; and *ex situ in vitro* conservation (see Part 4 Section D for a discussion of the state of the art in conservation methods). These categories were defined in the country-report questionnaire as follows:

- ***In situ* conservation**: support for continued use by livestock keepers in the production system in which the livestock evolved or are now normally found and bred.
- ***Ex situ in vivo* conservation**: maintenance of live animal populations not kept under their normal management conditions (e.g. in zoological parks or governmental farms) and/or outside the area in which they evolved or are now normally found.
- ***Ex situ in vitro* conservation**: conservation under cryogenic conditions including, *inter alia*, the cryoconservation of embryos, semen, oocytes, somatic cells or tissues having the potential to reconstitute live animals at a later date.

The section is structured as follows. Subsection 2 presents an overview of the state of conservation programmes worldwide. Subsections 3 and 4 discuss *in situ* conservation programmes in more detail, including an analysis of the types of activities undertaken and whether they are managed by the public or private sectors. Subsection 5 discusses *ex situ in vitro* conservation programmes in greater depth, including an analysis of the types of material stored and the breed coverage. Subsection 6 presents a region by region overview of the state of conservation programmes. Subsection 7 presents an analysis of changes in the state of conservation programmes since the time the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007a) was prepared. The final subsection presents some conclusions and discusses priority actions that need to be taken in order to improve the state of conservation programmes worldwide.

2 Global overview

A comprehensive assessment of the state of global provision of conservation programmes would require breed-by-breed data on the presence or absence (and if present the effectiveness) of the various types of conservation programme that can be implemented, as well as on the risk status of the respective breeds. Requiring the inclusion of breedwise data on conservation activities in the country reports was not considered to be feasible (the major gaps that exist in risk-status data are discussed in Part 1 Section B). The country-report questionnaire therefore requested countries to provide scores (none, low, medium or high) for the extent to which their breed populations are covered by each of the three categories of conservation programmes. Given that some breeds may be in so secure state that they do not need to be included in a conservation programme, countries were asked to focus particularly on at-risk breeds. The main objective, as stated in the questionnaire, was to obtain an indication of the extent

to which the countries' programmes meet the objective of minimizing the risk of breed extinction. Countries where all breeds are regarded as secure had the option of indicating this as an explanation for the absence of programmes in a given category.

The majority (82 percent) of country reports indicate the presence of *in situ* conservation programmes for breeds belonging to at least one species. However, there is a lot of variation across the regions and subregions of the world (Table 3D1). *In situ* conservation programmes are reported by all countries in Europe and the Caucasus, Central Asia, East Asia and North America. North and West Africa (65 percent) and Central America (60 percent) are the subregions in which the lowest proportions of countries report the presence of *in situ* conservation programmes. It should be noted that these figures simply indicate the presence of conservation programmes. They provide no indication of how many breeds are targeted or how effective the programmes are.

Ex situ conservation programmes are less common than *in situ* programmes: 60 percent and 54 percent of countries report *ex situ in vivo*

TABLE 3D1
Proportion of countries reporting conservation activities

Regions and subregions	Number of countries	*In situ* conservation programmes	*Ex situ in vivo* conservation programmes	*Ex situ in vitro* conservation programmes
		%		
Africa	**40**	**70**	**48**	**30**
East Africa	8	75	63	50
North and West Africa	20	65	40	20
Southern Africa	12	75	50	33
Asia	**20**	**90**	**80**	**65**
Central Asia	4	100	50	50
East Asia	4	100	100	100
South Asia	6	83	83	33
Southeast Asia	6	83	83	83
Southwest Pacific	**7**	**71**	**29**	**14**
Europe and the Caucasus	**35**	**100**	**69**	**86**
Latin America and the Caribbean	**18**	**83**	**72**	**61**
Caribbean	5	100	80	60
Central America	5	60	40	60
South America	8	88	88	63
North America	**1**	**100**	**100**	**100**
Near and Middle East	**7**	**71**	**71**	**29**
World	**128**	**84**	**63**	**55**

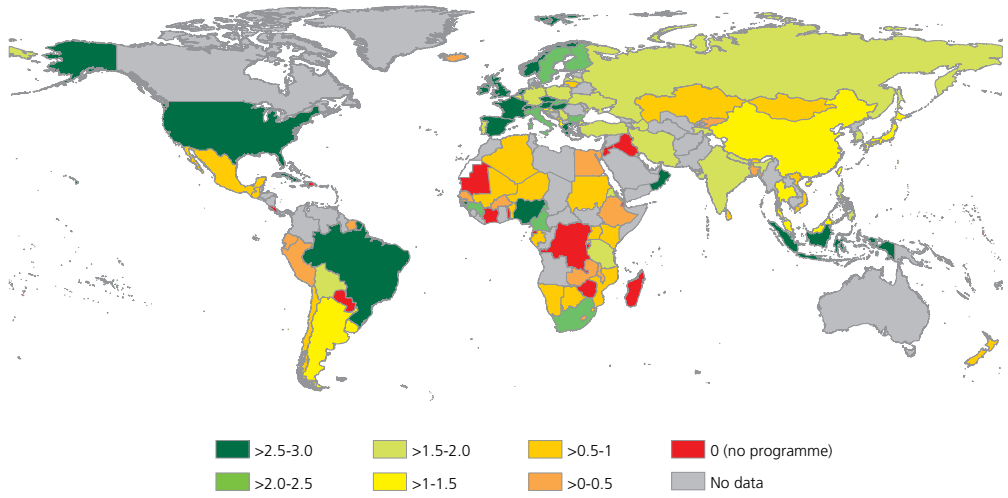
Note: Figures refer to the proportion of countries reporting conservation activities for at least one species.
Source: Country reports, 2014.

and *ex situ in vitro* programmes, respectively. The figures are particularly low in the Southwest Pacific (29 percent and 14 percent). However, 100 percent of East Asian countries report the presence of both types of programme.

While the overall figures indicate that conservation programmes are widespread, the country-report responses regarding the level of breed coverage indicate that in many countries programmes are far from comprehensive. This is illustrated, for example, by Figure 3D1, which shows average national breed coverage scores for *in situ* programmes at country level (taking into account the so-called "big five" species – cattle, chickens, pigs, sheep and goats). A more detailed breakdown, covering all three categories of conservation programme, is presented in Figure 3D2. High scores for breed coverage (i.e. comprehensive conservation programmes for a given species at national level) are rare globally: 23 percent in the case of *in situ* programmes; 7 percent in the case of *ex situ in vivo* programmes; and 8 percent in the case of *ex situ in vitro* programmes.[1] The regional breakdown shows that the main exceptions are the coverage of *in situ* and *ex situ in vitro* programmes in North America and to a lesser extent in Europe and the Caucasus. The breed coverage of *ex situ in vivo* programmes is generally low even in developed regions, where this type of programme appears to be a low priority relative to the other two categories. This is probably explained by the fact that if effective *in situ* and *ex situ in vitro* programmes are in

[1] Cases where the species is absent or all breeds are considered secure are excluded from these calculations.

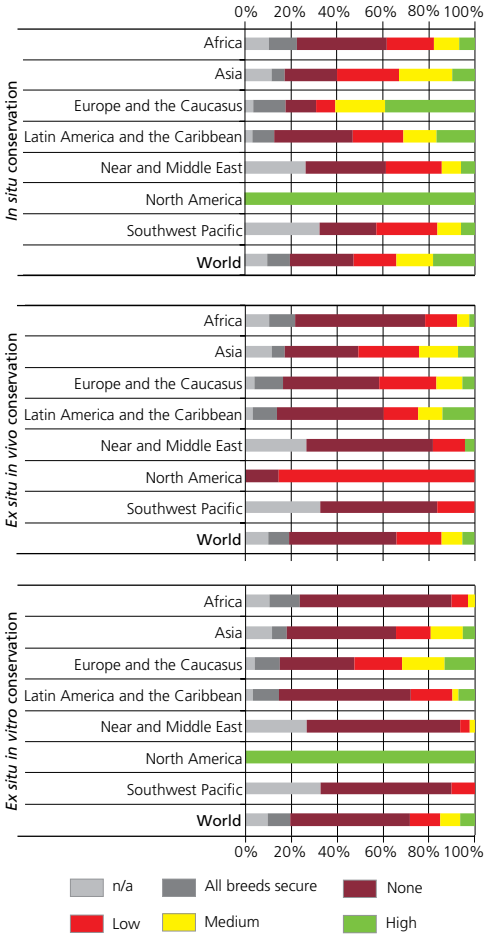
FIGURE 3D1
Coverage of *in situ* conservation programmes for the big five livestock species



Note: Coverage indicates the reported extent to which country's breeds are covered by conservation programmes. Coverage was scored none (0), low (1), medium (2) or high (3) for each of the big five species (cattle, sheep, pigs, chickens and goats), with beef, dairy and multipurpose cattle treated separately, i.e. a total of seven categories. Countries could specify that no programmes are implemented in a given category because all breeds are secure. The average scores are calculated based on the scores for all the species/categories reported to be present in the country, with the exception of those in which all breeds are reported to be secure. Sierra Leone is shown on the map as having no data (grey) because for all the species/categories reported present, the option "no programmes implemented because all breeds are secure" was chosen.
Source: Country reports, 2014.

FIGURE 3D2

Breed coverage in conservation activities for the big five species – frequency of responses



Note: The bar charts show the proportion of answers (country × species combinations) from the respective region falling into the various categories of breed coverage (none, low, medium and high) as well as those for which no programmes are reportedly needed because all breeds are secure. Cases where the respective species is not reported to be present in the country are assigned to a separate category (n/a). The big five species comprise cattle, goats, sheep, pigs and chickens.
Source: Country reports, 2014.

operation for a given breed, the addition of an *ex situ in vivo* programme may not provide much additional benefit in terms of reducing extinction risk (see Part 4 Section D). In all categories, high scores are more common in Latin America and the Caribbean and in Asia than in other developing regions.

Table 3D2 shows that, while in some regions breed coverage within a given category of programme is at a similar level across all species, in other regions some species are more comprehensively covered than others. For example, in the case of *in situ* programmes, sheep, pigs and multipurpose cattle have the highest average scores in Europe and the Caucasus, dairy cattle in Latin America and the Caribbean, chickens in Asia and small ruminants in the Near and Middle East. In the case of *ex situ in vitro* programmes, the global totals indicate a higher level of coverage for cattle and sheep than for other species, although there are again some regional variations. Subregional breakdowns showing the three categories of conservation programme are presented in Tables 3D3, 3D4 and 3D5.

In addition to providing information on the big five species, countries also had the option of providing information on other species. The responses are summarized in Table 3D6. Countries that have programmes were probably more likely to respond than those that do not, so it is possible that the relatively high proportion of responding countries indicating the presence of conservation programmes and the relatively high breed coverage scores for these species are overestimates. Some of these species are widely distributed, but were only reported on by a few countries. In absolute terms, the number of countries reporting the presence of conservation programmes for some of these species is very low (e.g. eight countries report *in situ* programmes for asses, eight for geese, six for turkeys and ten for ducks).

TABLE 3D2

Breed coverage in conservation activities for the big five species – average scores

Conservation programmes	Species	Africa	Asia	Southwest Pacific	Europe and the Caucasus	Latin America and the Caribbean	North America	Near and Middle East	World
In situ conservation	Cattle (specialized dairy)								
	Cattle (specialized beef)								
	Cattle (multipurpose)								
	Sheep								
	Goats								
	Pigs								
	Chickens								
Ex situ in vivo conservation	Cattle (specialized dairy)								
	Cattle (specialized beef)								
	Cattle (multipurpose)								
	Sheep								
	Goats								
	Pigs								
	Chickens								
Ex situ in vitro conservation	Cattle (specialized dairy)								
	Cattle (specialized beef)								
	Cattle (multipurpose)								
	Sheep								
	Goats								
	Pigs								
	Chickens								

0–0.5	0.5–1	1–1.5	1.5–2	2–2.5	2.5–3
Low		Medium		High	

Note: Scores provided by countries were converted into numerical values (none = 0; low = 1; medium = 2; high = 3). The colours indicate average scores for the countries of the respective region, as shown in the legend (border values assigned to the higher category).
Source: Country reports, 2014.

3 *In situ* conservation programmes – elements

In situ conservation programmes can include a wide range of different activities. The country-report questionnaire requested countries to indicate which activities (from a predefined list) form part of their *in situ* programmes and to indicate whether these activities are operated by the public or private sectors (or both). The twelve potential activities considered in the questionnaire are listed below (grouped into four categories for the purposes of analysis and discussion):

TABLE 3D3

Proportion of countries reporting *in situ* conservation programmes

Regions and subregions	Number of countries	Dairy cattle	Beef cattle	Multi-purpose cattle	Sheep	Goats	Pigs	Chickens
		%						
Africa	**40**	**37**	**54**	**59**	**51**	**56**	**41**	**47**
East Africa	8	57	60	86	43	57	50	38
North and West Africa	20	45	50	64	63	60	50	57
Southern Africa	12	17	55	25	42	50	27	42
Asia	**20**	**67**	**77**	**71**	**79**	**68**	**67**	**78**
Central Asia	4	100	100	75	100	75	50	75
East Asia	4	33	67	100	50	75	100	100
South Asia	6	60	0	100	80	40	75	80
Southeast Asia	6	67	83	25	83	83	50	67
Southwest Pacific	**7**	**67**	**60**	**67**	**67**	**40**	**71**	**71**
Europe and the Caucasus	**35**	**78**	**64**	**90**	**97**	**85**	**89**	**77**
Latin America and the Caribbean	**18**	**67**	**73**	**50**	**72**	**56**	**61**	**47**
Caribbean	5	100	100	100	80	80	80	60
Central America	5	33	50	33	60	60	60	40
South America	8	60	75	20	75	38	50	43
North America	**1**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Near and Middle East	**7**	**50**	**50**	**33**	**71**	**71**	**0**	**43**
World	**128**	**59**	**64**	**68**	**74**	**67**	**65**	**61**

Note: The proportions are calculated by dividing the number of countries reporting *in situ* programmes for the respective species by the number of countries reporting the presence of breeds in need of conservation, i.e. countries where the respective species is not reported or where all breeds belonging to the species are reported to be secure are excluded from the calculations.
Source: Country reports, 2014.

Activities focused on increasing demand for breed products and services

1. *Promotion of niche marketing or other market differentiation (including promotion via association of breeds with products having geographical indications or other indicators of origin):*[2] efforts to promote the marketing of a breed's products to a subgroup of consumers who have particular preferences regarding, for example, product quality, the type of production system (e.g. high animal welfare or organic) or the association of products with particular geographical regions or traditions.
2. *Promotion of at-risk breeds as tourist attractions*: the establishment of specific tourist attractions featuring at-risk breeds (e.g. farm parks) or efforts to promote the keeping of at-risk breeds as elements of attractive landscapes that appeal to tourists.

[2] Geographical indications or other indicators of origin are schemes that protect (via the regulation of labelling, etc.) the names of agricultural products and foods originating from a particular geographical area or that are produced in a particular way (e.g. using traditional methods and ingredients).

TABLE 3D4

Proportion of countries reporting *ex situ in vivo* conservation programmes

Regions and subregions	Number of countries	Dairy cattle	Beef cattle	Multi-purpose cattle	Sheep	Goats	Pigs	Chickens
		%						
Africa	**40**	**26**	**46**	**37**	**34**	**29**	**17**	**9**
East Africa	8	29	60	71	14	43	0	13
North and West Africa	20	33	50	27	38	20	23	7
Southern Africa	12	17	36	25	42	33	18	8
Asia	**20**	**67**	**64**	**43**	**63**	**61**	**60**	**67**
Central Asia	4	50	33	25	50	50	50	50
East Asia	4	33	75	100	50	100	100	100
South Asia	6	80	100	80	80	40	50	80
Southeast Asia	6	83	67	0	67	67	50	50
Southwest Pacific	**7**	**33**	**20**	**33**	**33**	**20**	**14**	**29**
Europe and the Caucasus	**35**	**42**	**44**	**48**	**59**	**44**	**50**	**58**
Latin America and the Caribbean	**18**	**42**	**64**	**33**	**50**	**44**	**50**	**35**
Caribbean	5	50	67	75	60	60	60	20
Central America	5	33	33	33	40	40	40	40
South America	8	40	75	0	50	38	50	43
North America	**1**	**0**	**100**	**100**	**100**	**100**	**100**	**100**
Near and Middle East	**7**	**17**	**0**	**33**	**43**	**29**	**0**	**14**
World	**128**	**39**	**49**	**41**	**50**	**41**	**39**	**37**

Note: The proportions are calculated by dividing the number of countries reporting *ex situ in vivo* programmes for the respective species by the number of countries reporting the presence of breeds in need of conservation, i.e. countries where the respective species is not reported or where all breeds belonging the species are reported to be secure are excluded from the calculations.
Source: Country reports, 2014.

3. *Use of at-risk breeds in the management of wildlife habitats and landscapes*: situations in which animals belonging to at-risk breeds are used deliberately to alter the environment (usually the vegetation) to create habitats suitable for wildlife or landscapes that are considered desirable by humans.
4. *Promotion of breed-related cultural activities*: the promotion of cultural activities such as shows, festivals and sporting events in which at-risk breeds play a role.

Activities focused on incentivizing and supporting livestock keepers

5. *Incentives or subsidy payment schemes for keeping at-risk breeds*: schemes under which livestock keepers receive payment (e.g. from the government) for keeping at-risk breeds.
6. *Recognition award programmes for breeders*: schemes in which breeders that make a particular contribution to the conservation and sustainable use of a breed or breeds are honoured or recognized in some way (e.g. a programme of annual awards).

TABLE 3D5

Proportion of countries reporting *ex situ in vitro* conservation programmes

Regions and subregions	Number of countries	Dairy cattle	Beef cattle	Multi-purpose cattle	Sheep	Goats	Pigs	Chickens
		%						
Africa	**40**	**20**	**32**	**24**	**6**	**9**	**7**	**0**
East Africa	8	43	60	43	0	0	0	0
North and West Africa	20	9	22	14	7	7	8	0
Southern Africa	12	17	27	25	8	17	9	0
Asia	**20**	**50**	**54**	**29**	**42**	**50**	**33**	**33**
Central Asia	4	50	33	25	50	50	0	25
East Asia	4	33	67	100	50	100	100	100
South Asia	6	40	0	40	40	20	25	20
Southeast Asia	6	67	67	0	33	50	17	17
Southwest Pacific	**7**	**33**	**20**	**33**	**33**	**20**	**0**	**0**
Europe and the Caucasus	**35**	**74**	**58**	**76**	**76**	**56**	**57**	**35**
Latin America and the Caribbean	**18**	**50**	**60**	**23**	**35**	**29**	**24**	**7**
Caribbean	5	50	67	25	40	40	20	0
Central America	5	75	50	50	25	25	25	0
South America	8	33	63	0	38	25	25	14
North America	**1**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Near and Middle East	**7**	**0**	**0**	**17**	**14**	**14**	**0**	**0**
World	**128**	**44**	**47**	**41**	**39**	**34**	**29**	**17**

Note: The proportions are calculated by dividing the number of countries reporting *ex situ in vitro* programmes for the respective species by the number of countries reporting the presence of breeds in need of conservation, i.e. countries where the respective species is not reported or where all breeds belonging the species are reported to be secure are excluded from the calculations.
Source: Country reports, 2014.

7. *Extension programmes to improve management of at-risk breeds*: programmes that target the keepers of at-risk breeds with advice on how to manage them.
8. *Awareness–raising activities on the potential of specific at-risk breeds*: activities that provide livestock keepers (or potential livestock keepers) with information on the potential (e.g. unique traits that may be valuable in particular circumstances) of specific at-risk breeds that might otherwise be overlooked.

Activities focusing on breeding programmes

9. *Conservation breeding programmes:* breeding programmes that maintain breed-specific traits and limit inbreeding.
10. *Selection programmes for increased production or productivity in at-risk breeds:* genetic improvement programmes for at-risk breeds that aim to increase their production and/or productivity and thereby promote their ongoing use by livestock keepers.

TABLE 3D6
Level of breed coverage in conservation programmes for "minor" species

Species	Number of countries reporting breeds	Number of countries reporting on existance of conservation programme	*In situ* conservation		*Ex situ in vivo* conservation		*Ex situ in vitro* conservation	
			Programmes reported (%)	Score	Programmes reported (%)	Score	Programmes reported (%)	Score
Buffaloes	31	21	81	1.9	62	1.3	52	1.0
Horses	62	47	81	2.1	45	0.9	55	0.9
Asses	30	16	50	1.3	38	0.6	25	0.4
Dromedaries	14	5	60	0.8	20	0.3	20	0.3
Rabbits	43	20	55	1.2	25	0.6	5	0.1
Ducks	43	16	63	1.4	50	0.9	13	0.1
Turkeys	31	12	50	1.0	42	0.6	17	0.2
Geese	28	12	67	1.6	42	0.7	8	0.1
Guinea fowl	20	6	67	1.0	33	0.7	17	0.2

0–0.5	0.5–1	1–1.5	1.5–2	2–2.5	2.5–3
Low		Medium		High	

Note: The percentages are calculated relative to the number of countries that provided information on the presence or absence of conservation programmes for the respective species. The scores for breed coverage are averages for the responding countries. Scores were converted into numerical values (none = 0; low = 1; medium = 2; high = 3). The colours indicate score categories as shown in the legend (border values assigned to the higher category).
Source: Country reports, 2014.

Activities focusing on community-level participation and empowerment

11. *Community-based conservation programmes:* programmes in which the local people are the primary stakeholders responsible for the development and implementation of the activities undertaken to conserve their animal genetic resources (AnGR).
12. *Development of biocultural protocols:* a biocultural protocol is a document that is developed after a community undertakes a consultative process to outline their core cultural and spiritual values and customary laws relating to their traditional knowledge and resources.

For further discussion of the elements of *in situ* conservation programmes, see Part 4 Section D and FAO (2013). The various listed activities are not necessarily completely distinct from each other. In particular, a community-based conservation programme is likely to include one or more of the other activities. Moreover, many of the activities are also not necessarily confined to conservation programmes, i.e. they can be implemented for a variety of reasons associated with livestock and rural development, environmental management, etc. The intention in the country-report questionnaire was to identify activities that are part of conservation programmes, i.e. deliberately being used to reduce the risk of genetic erosion or breed extinction. The information provided in the country reports was not always sufficient to determine whether or not this was the case.

The country-report responses are summarized in Tables 3D7 (species breakdown) and 3D8 (regional breakdown). It should be recalled that the figures only indicate the presence of a given activity as an element of conservation programmes within a given country for a given species. The activities are not necessarily widespread or well developed. The data presented in Figures 3D1 and 3D2 and in Table 3D2 indicate that, at least in developing regions, the majority of reported conservation activities are likely to be being undertaken only on a limited scale.

Globally, the most commonly reported activity is the implementation of conservation breeding programmes (74 percent of responses),[3] followed by the promotion of niche marketing (68 percent), awareness-raising activities (63 percent), extension activities aimed at improving the management of at-risk breeds (53 percent) and breeding programmes aimed at increasing productivity in at-risk breeds (51 percent).

The popularity of niche marketing as an element of conservation programmes may be because of its potential to become self-sustaining, eventually removing the need for support from government or other external sources. Niche marketing is reported to be widespread in conservation programmes for all species, although relatively uncommon in programmes for multipurpose cattle. The regional breakdown shows that this approach is less widespread in conservation programmes in Africa and in the Near and Middle East than in other regions. While traditional products from locally adapted breeds are popular in many countries and often command premium prices, establishing a new niche market for products from a breed that is at risk of extinction is challenging. Opportunities are likely to be greater where a substantial number of consumers can afford to pay premium prices and where appropriate legal frameworks are in place (see Part 3 Section F).

[3] Each response refers to the conservation programme for a given species within a given country (taking the big five species into account and treating the three categories of cattle breeds separately).

Other conservation activities in the category "increasing demand for products and services for at-risk breeds" are far less widely reported than niche marketing. This may, in part, be accounted for by the fact that the number of breeds for which these activities are potentially relevant is lower. For example, use in landscape management is mainly relevant for grazing animals and only in certain locations. It may also be because the "demand" in question is, to varying degrees, for public goods, and therefore the activities are unlikely to become self-sustaining on the basis of market demand. Some livestock-related cultural and touristic activities can generate income for the keepers of at-risk breeds (trekking with ponies or other animals, charging for entrance to farm parks, etc.), but others accrue to the general public or to the local tourism industry more broadly. Conservation grazing is typically organized by public authorities or on a smaller scale by NGOs.

The second most commonly reported element in this category is the promotion of AnGR-related cultural activities. This is reported with roughly the same frequency across the big five species. However, it is reported far more frequently in Europe and the Caucasus than elsewhere. Promotion of breeds as tourist attractions is somewhat less frequently reported overall. Again there are no major differences in the frequency with which it is reported in the various big five species, and Europe and the Caucasus is again the region where the activity is most frequently reported. It is also relatively frequently reported in North America and to a lesser extent in Latin America and the Caribbean and Asia. However, it is mentioned in very few of the reports from Africa, the Southwest Pacific and the Near and Middle East.

Use of livestock in the management of wildlife habitats and landscapes is reported to be used as an element of *in situ* conservation programmes in only 24 percent of countries that have such programmes. Unsurprisingly, this activity is more commonly reported among types of livestock that are kept in grazing systems (i.e. cattle and small-ruminants among the big five, plus, in

TABLE 3D7

Proportion of countries reporting the use of elements of *in situ* conservation – species breakdown

In situ conservation programmes elements		Average across species	Dairy cattle	Beef cattle	Multi-purpose cattle	Sheep	Goats	Pigs	Chickens
Increasing demand for breed products and services	Promotion of niche marketing	68	75	68	57	64	72	72	66
	Promotion as tourist attractions	35	28	37	37	40	37	34	33
	Use in the management of wildlife habitats and landscapes	24	19	28	30	30	28	22	13
	Promotion of breed-related cultural activities	43	33	43	45	45	49	45	43
Incentivization and support for livestock keepers	Incentives for keeping at-risk breeds	42	39	33	46	47	44	47	37
	Recognition and/or awards for breeders	45	54	47	45	48	43	41	39
	Extension to improve the management of at-risk breeds	53	42	47	57	64	58	53	50
	Awareness-raising activities	63	51	62	66	69	66	66	60
Breeding programmes	Conservation breeding	74	61	75	79	78	80	77	66
	Selection to increase production/productivity	51	42	52	55	57	54	53	44
Community-level participation and empowerment	Community-based conservation	48	46	42	48	53	49	53	46
	Biocultural community protocols	17	12	18	16	19	20	16	20

Note: Figures indicate the proportion of countries with *in situ* conservation programmes for any of the big five species.
Source: Country reports, 2014.

particular, horses). Potential synergy between AnGR conservation and wildlife conservation/landscape management arises because locally adapted breeds, including those that are at risk of extinction, are often well suited to grazing in harsh environments and may have other characteristics (including links to local culture) that make them suitable for use in conservation grazing. This activity is again much more commonly reported in Europe and the Caucasus than in other regions. The reports from several European countries, including Finland, Germany, Hungary, the Netherlands and the United Kingdom, note that locally adapted breeds play important roles

TABLE 3D8

Proportion of countries reporting the use of elements of *in situ* conservation – regional breakdown

In situ conservation programmes elements		World	Africa	Asia	Southwest Pacific	Europe and the Caucasus	Latin America and the Caribbean	North America	Near and Middle East
Increasing demand for breed products and services	Promotion of niche marketing	68	43	75	83	78	74	100	47
	Promotion as tourist attractions	35	6	33	3	66	26	43	7
	Use in the management of wildlife habitats and landscapes	24	4	16	3	49	23	0	7
	Promotion of breed-related cultural activities	43	25	38	19	69	31	14	33
Incentivization and support for livestock keepers	Incentives for keeping at-risk breeds	42	13	35	27	84	13	0	7
	Recognition and/or awards for breeders	45	30	47	34	59	38	100	27
	Extension to improve the management of at-risk breeds	53	41	43	60	74	37	43	34
	Awareness-raising activities	63	43	63	67	83	48	100	31
Breeding programmes	Conservation breeding	74	67	74	32	87	72	43	60
	Selection to increase production/productivity	51	34	53	29	65	54	100	27
Community-level participation and empowerment	Community-based conservation	48	41	75	53	47	35	29	39
	Biocultural community protocols	17	17	24	7	16	23	0	7

Note: The figures correspond to the number of countries reporting the respective activity divided by the number of countries reporting *in situ* conservation for the respective species, averaged over the big five species. The big five species comprise cattle, goats, sheep, pigs and chickens.
Source: Country reports, 2014.

in the management of landscapes in national parks and other scenic areas.

The country reports indicate that conservation programmes for each of the big five species frequently include awareness-raising activities. These activities are quite widespread in all regions. However, they are particularly widespread in North America and Europe and the Caucasus and relatively rare in Africa and the Near and Middle East. Reported awareness-raising activities extend beyond those aimed at livestock keepers to include those aimed at consumers or the general

public. There is therefore some overlap with the above-described "demand-creation" category, as consumers may become interested in buying products from at-risk breeds.

In Europe and the Caucasus, consumers and the general public are the main targets of the reported awareness-raising activities, whereas in Asia and Africa activities commonly focus on encouraging livestock keepers to avoid indiscriminate cross-breeding of locally adapted breeds. Among examples of awareness-raising directed at the general public, the country report from Japan mentions that some breeds have been designated as "national monuments". Channels for awareness raising include museums and zoos (country report of Germany) and schools (country reports of Italy and the Czech Republic), as well as a range of print and electronic media. Social awareness is reported to be increasing in some countries, and in some cases has led to government intervention to support conservation. For example, Mongolia's country report notes that in response to public concerns, the government has taken steps to help conserve the reindeer kept by the Dukha people, establishing a support programme that will include veterinary extension, financial support and technical advice on reindeer-antler craft.

Extension activities are a relatively common element of conservation programmes for all the big five species and in all regions (more so in Europe and the Caucasus and the Southwest Pacific than elsewhere). The above-described reindeer-focused programme in Mongolia is one example. In developed regions, some conservation-related extension activities involve the provision of advice to hobby farmers (see Box 3D3 for example), a group that may be interested in raising at-risk breeds but lack experience in animal husbandry and breeding.

Recognition and award schemes for livestock keepers are also reported with moderate frequency. Frequency of reporting is similar in each of the big five species, but more common in North America and Europe and the Caucasus than elsewhere.

The provision of economic incentives to livestock keepers raising at-risk breeds is widely used in Europe and the Caucasus as a core element of *in situ* conservation programmes, but is very rare in other regions. The Southwest Pacific is a partial exception because, in New Zealand, the Rare Breeds Conservation Society of New Zealand, which is the main operator of conservation programmes in the country, gives small grants to livestock keepers raising at-risk breeds. This is the only reported case in which financial incentives are paid by a private institution rather than by the government of the respective country. Many European Union member countries use allocations from the European Union Rural Development Programme to support the conservation of AnGR by providing payments to those keeping at-risk locally adapted breeds. Reported examples from other regions include the provision of financial support to the keepers of some locally adapted breeds of cattle goats and chickens in Indonesia.

Both breeding programmes involving conservation breeding and those that aim to increase the productivity of at-risk breeds are widely reported as elements of *in situ* conservation programmes. Conservation breeding is the more widely reported. While it is more frequently reported in Europe and the Caucasus than elsewhere, it is also reported quite frequently in some developing regions. Governmental farms and nucleus herds play a key role in these activities in most regions. In the case of both types of programme, there are no major differences in frequency between species. In some cases, the information provided in the country reports from Africa, Asia and Latin America and the Caribbean suggests that conservation breeding programmes and breeding programmes focusing on improving performance are not clearly distinguished. Some of the programmes referred to as "conservation breeding programmes" aim to contribute to conservation by improving the production traits of the targeted breeds.

Community-based conservation is more commonly reported in Asia than in any other region (75 percent compared to an average of 48 percent).

Box 3D1

Implementing a conservation programme – experiences from China

In 1995, China's Ministry of Agriculture launched a regular budgetary allocation for breed conservation. The annual budget started at 4 million Yuan and increased year by year to reach 54 million Yuan in 2012. In 2013, when the total sum dropped slightly to 50 million Yuan, 156 conservation projects were granted. In addition to training and administrative activities, these projects supported the conservation of more than 100 indigenous breeds. Any private or state-owned farm or company engaged in breed protection can apply to the Ministry of Agriculture for permission to participate in the programme, provided that it:

- is involved in the husbandry of indigenous breeds on the national priority list (under particular circumstances, "newly identified" breeds and/or breeds from underdeveloped provinces may be included, even if these breeds are not on the list);
- is located in the area of origin of the respective breed;
- puts forward appropriate conservation proposals; and
- is equipped with basic installations and technicians.

Every September, the National Commission for Animal Genetic Resources organizes a group of experts to evaluate applications. About 100 project proposals are selected each year. The National Commission and the group of experts monitor the implementation of the projects and provide training and technical guidance. Conservation farms that are provided with subsidies have to submit reports to the National Commission shortly before the end dates of their projects, i.e. every December. These reports, along with the results of the monitoring activities, are important factors in determining whether support will continue in the following year.

Because funding is limited, priorities have to be set. Prioritization criteria include importance to animal production and food security, special genetic characteristics and risk category.

In 2000, the Ministry of Agriculture issued the first National Animal Genetic Resources Priority List, consisting of 78 indigenous breeds. The list was revised in 2006 and 2014, with the number of breeds rising to 138 and then to 159. As the central government has a limited budget, it encourages provincial governments to formulate provincial priority lists, with the aim of motivating them to contribute. The central government subsidizes breeds on the national list and provincial governments subsidize breeds on the provincial lists.

Conserving breeds is a long-term task, and in practice the list of farms and companies applying for conservation projects remains relatively fixed from year to year. For this reason, the Ministry of Agriculture has adopted a strategy of designating State Certified Conservation Farms (one or two per breed on the national priority list). The "state certified" designation does not indicate that the farms are state owned. In fact, most of them are private. The Ministry and the farm enter into a contract under which the Ministry commits to providing subsidies and technical support, while the farm agrees to undertake conservation measures. To date, the Ministry has certified 160 such farms (covering 130 out of the 159 breeds on the national priority list), as well as six gene banks. In addition to these actions by the central government, some provinces have certified provincial conservation farms for the conservation of breeds that are on the respective provincial priority lists but not on the national list.

Provided by Hongjie Yang.

As noted above, this activity clearly overlaps with others. Box 3D2 provides an example of the successful involvement of a community in *in situ* conservation activities. Biocultural community protocols (see Box 4D3 in Part 4 Section D) are not widely reported (17 percent overall). Initiatives of this kind are a relatively new phenomenon and relevant only in certain circumstances.

Box 3D2

Dyeing sheep wool naturally in 35 colours: indigenous production systems and associated traditional knowledge – a case from Argentina

The women of the Qom ethnic group of the province of Formosa, Argentina, practise artisanal handicrafts using wool from the local sheep, which has traditionally been raised in a "backyard" production system. Because of the coarseness of the wool, the items produced include carpets and tapestries. The women and children take responsibility for managing the small animals, while the men attend to the cattle. The flocks are small. Twice a year, the animals are sheared by the women, who collect the wool and process it according to their needs.

For generations, Qom women have preserved local knowledge of how to use natural dyes extracted from bark, roots, leaves, fruits and insects. Efforts have been made to identify the natural materials used by the women throughout the handicraft production chain, with the aim of improving the quality and utilization of these materials, and thereby to improve the entire production chain and empower the women. Thirty-five colours obtained from natural sources and used to dye fibres have been identified. Phenotypic, production and genetic characterization studies, along with studies of population dynamics, are being undertaken in the local sheep population, whose fleeces possess unique characteristics that make them suitable for the type of fabric production practised locally for generations.

Women's associations, in the form of artisan centres, have played a participatory and permanent role in the innovation process, evaluating the impact that the interventions are having on their production activities. They have improved the quality of the craft products, and thereby achieved greater market penetration. The process has contributed to improving the women's visibility as social actors and to strengthening their political involvement and participation. Today, the artisan centres lead the innovation of the production process, transforming an artisanal practice associated with the past and the older generations into an innovative and dynamic livelihood activity that involves young people and opens new employment perspectives for the region's indigenous communities.

Provided by Sebastián de la Rosa.

4 *In situ* conservation programmes – the roles of the public and private sectors

In most countries where *in situ* conservation programmes exist, public institutions are directly involved in the implementation of most of the reported activities (Figure 3D3). Involvement of the private sector is more unevenly distributed. In Africa and Asia, public institutions are the main operators of all the *in situ* conservation activities reported, except for the promotion of breed-related niche-market products. In Europe and the Caucasus and Latin America and the Caribbean, involvement of the public and private sectors is reported with roughly equal frequency. In Europe and the Caucasus, private institutions are most commonly involved in the development of niche marketing of breed-related products and in the promotion of breed-related cultural and touristic activities. The involvement of public institutions is prominent in the fields of extension and awareness-raising and in the implementation of conservation breeding programmes.

In the United States of America, Australia[4] and New Zealand, public institutions play a minor role in the implementation of *in situ* conservation activities. The country report from the United States of America, for example, indicates that public-sector activity in the field of conservation

[4] Australia did not provide a country report as part of the second SoW-AnGR reporting process. However, it published a report as an independent initiative in 2012.

Box 3D3

The conservation network for the Finnish Landrace chicken

The Finnish Landrace chicken breed is descended from several landrace chicken populations that existed in Finland before industrialized egg production began. By the late 1990s, the breed was at risk because of cross-breeding with exotic breeds. Twelve different lines or families survived in remote villages. These populations now represent the core of the conservation programme, established in 1998 with the aim of maintaining the breed's purity and its genetic and phenotypic diversity. The programme is based on a network of more than 300 hobby breeders and is coordinated by MTT Agrifood Research Finland. New breeders are welcome to join the network. When they do so, they sign a contract with MTT Agrifood Research Finland, agreeing to follow the rules of the programme.

Network members submit annual reports to MTT, providing information on, *inter alia*, the number of breeding females and males that they have at the end of a year, brooding success, the phenotypic traits of their birds and eggs, and their sales of chicks and adult birds to other Landrace chicken breeders. MTT is responsible for maintaining the database, communication and information gathering. MTT organizes annual meetings and courses and provides advisory services. A four-member advisory group supports the coordination of the programme and provides expert practical advice to the network. Poultry farming organizations, such as the Finnish Poultry Association, as well as the Finnish Food Safety Authority EVIRA, contribute knowledge to the programme.

Photo credit: Kirsti Hassinen.

Currently, the hobby breeders in the network have more than 5 000 Finnish Landrace hens and breeding roosters. The modern trend of raising "city chickens" in urban areas has increased the popularity of the Landrace chicken. The various lines and families are kept apart to prevent crossing. The genetic diversity of the lines and the relationships among them are currently being investigated using whole-genome SNP (single nucleotide polymorphism) marker analysis. The studies should provide new information that will help in the implementation of the conservation work, possibly including the exchange of genetic material between some closely related lines.

Provided by Mervi Honkatukia, National Coordinator for the Management of Animal Genetic Resources, Finland.

is largely confined to the gene banking of cryoconserved material, while *in situ* conservation is handled largely by breeders' associations. Breeders' associations are also heavily involved in *in situ* conservation in Europe and the Caucasus and to some extent in South America. They manage breeding programmes focusing on conservation and/or performance improvement, and collaborate in the development of niche marketing and touristic and cultural activities (see Part 3 Section C for a general discussion of stakeholder involvement in breeding programmes). In some European countries (e.g. the Netherlands and the United Kingdom), breeders' associations are reported to be the primary stakeholders in *in situ* conservation, operating with some support from NGOs (see Box 3D3 for example) and government.

Globally, public institutions play a key role in breeding programmes focusing on conservation and/or performance improvement (Figure 3D3).

Box 3D4

Iberian pigs in Spain – sustained through product labelling

As described in a text box in the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture*,[1] the population size of the Iberian pig declined from the 1960s to the 1980s, after which time it recovered thanks to successful marketing efforts focusing on the quality of its meat. Unfortunately, the rising population eventually led to overproduction of Iberian breed products and triggered a sector crisis that led to a sharp decrease in the breed's population, which went from 4.1 million pigs marketed in 2008 to 2.0 million in 2013.[2]

To address these issues, Spain's Ministry of Agriculture introduced legislation[3] specifically regulating the labelling of all products from Iberian pigs. The aim is to provide consumers with clear information on the characteristics of the products, avoid product fraud and support farmers that produce high-quality Iberian pigs. The labels are defined so as to distinguish the quality of the products according to the genetic purity of the animals and the characteristics of the farming system. The labels are differentiated by colour, as follows:

- Black label: products from animals that are pure-bred Iberian and feed only on acorns in extensive farming systems in dehesa forests;
- Red label: products from Iberian–Duroc cross-bred animals (always at least 50 percent Iberian) that feed only on acorns in extensive systems in dehesa forests.
- Green label: products from pure-bred or cross-bred Iberian pigs (always at least 50 percent Iberian) that are fed on concentrates in extensive or outdoor intensive systems;
- White label: products from pure-bred or cross-bred animals fed on concentrates in intensive indoor systems.

Red, green and white labels have to clearly indicate the breed composition of the animals, specifying the percentage of Iberian breed genetics.

Photo credit: Plácido M. Rodríguez González, AECERIBER-Iberian Pig Breeders' Association of Spain.

[1] FAO, 2007, Box 20 Sustainable utilization of the Iberian pig in Spain – a success story (page 144).

[2] Data from Asociación interprofesional del cerdo ibérico (available in Spanish at http://www.cerdoiberico.es).

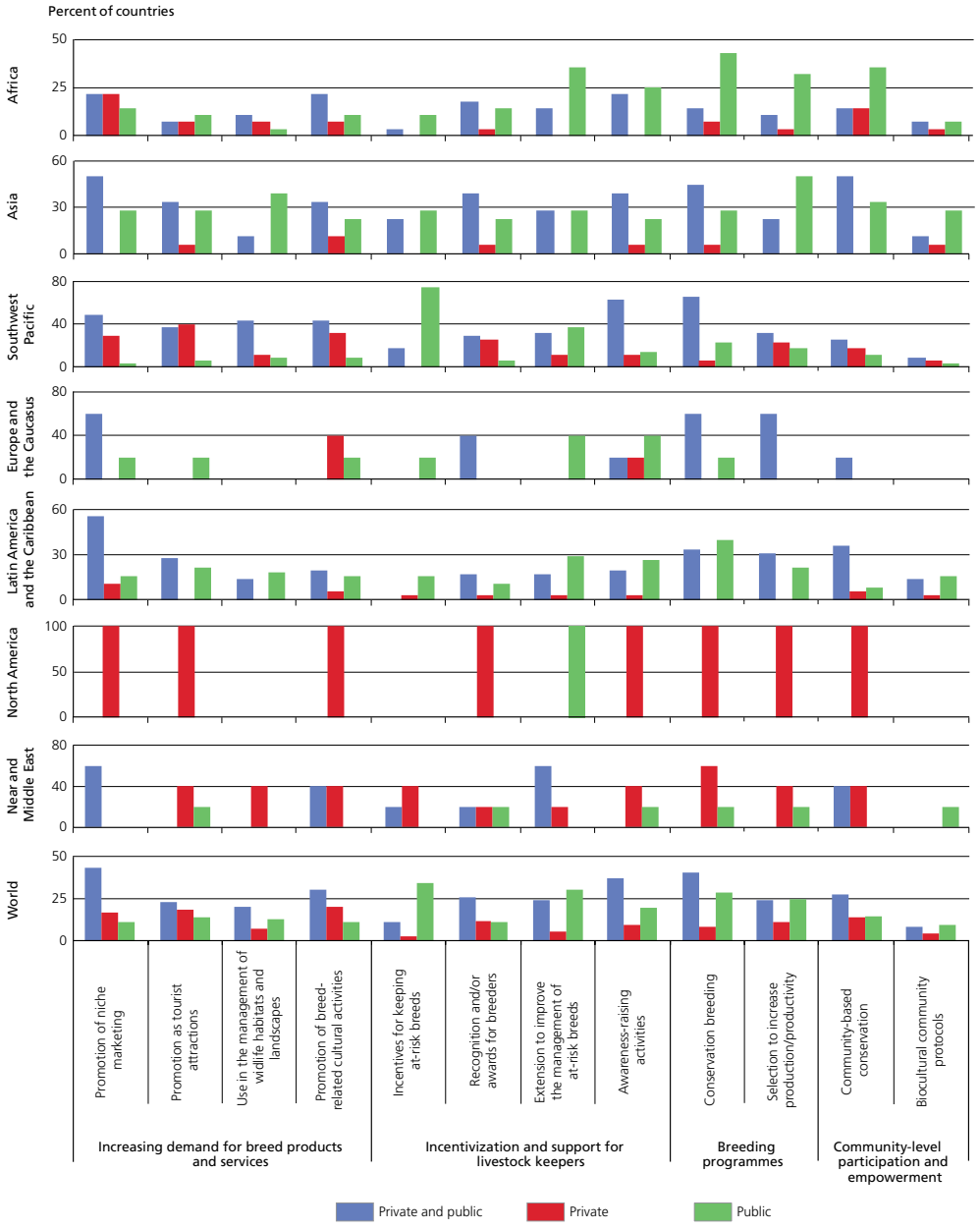
[3] Real Decreto 4/2014, de 10 de enero, por el que se aprueba la norma de calidad para la carne, el jamón, la paleta y la caña de lomo ibérico (available in Spanish at http://www.boe.es/diario_boe/txt.php?id=BOE-A-2014-318).

In the majority of African, Asian and to a lesser extent South American countries, national governments are the main, and usually only, operators of breeding programmes associated with *in situ* conservation. In the majority of the countries in these regions, governments manage nucleus farms where locally adapted and/or exotic animals are kept. These nucleus farms distribute breeding stock (males) to improve the wider livestock population. Schemes of this kind can play an important role in the conservation and development of at-risk breeds, although their impact is often limited by a range of organizational weaknesses and resource-related constraints (see Part 3 Section C and Part 4 Section C).

The provision of funding is a key element of the public sector's role in AnGR conservation. For example, governments may provide financial support for *in situ* conservation activities carried out by breeders' associations, cooperatives, livestock

FIGURE 3D3

Involvement of public and private institutions in the implementation of *in situ* conservation programme elements



Source: Country reports, 2014.

keepers organized at community level or NGOs. They may also provide direct financial incentives to livestock keepers who keep at-risk breeds. Payments of this kind play an important role in Europe and the Caucasus and in some countries in Asia, but are almost absent in the rest of the world. Governments also play a key role in extension activities aimed at improving the management of at-risk breeds. This role is significant even in countries such as the United States of America, where the government generally has little involvement in *in situ* conservation.

5 *Ex situ in vitro* conservation programmes

Almost half (45 percent) of reporting countries indicate that they have an operational *in vitro* gene bank for AnGR. A further 32 percent report that they have plans to develop one (Figure 3D4). In addition to being present in the United States of America, gene banks are widely reported in Europe and the Caucasus (71 percent of reporting countries), East Asia (100 percent), Southeast Asia (67 percent) and South America (63 percent). Note that a higher percentage of countries report the presence of *ex situ in vitro* conservation programmes (Table 3D1) than report gene banks (Figure 3D4 and Table 3D9). The discrepancy is accounted for mainly by the fact that some countries that do not have gene banks report the storage of cryopreserved genetic material for use in research or breeding programmes or for conservation purposes within the framework of small-scale projects.

Table 3D10 shows the percentage of national breed populations (big five species) reported to be cryoconserved in each region and subregion. The figures show that despite the large number of countries that have established gene banks, only a small proportion of national breed populations are conserved: 27 percent in cattle; 23 percent in sheep; 20 percent in goats; 18 percent in pigs; and 6 percent in chickens. The United States of America is the only reporting country where the majority of national cattle, sheep, goat and pig breed populations are conserved *in vitro*. The proportion of breed populations with sufficient material stored to allow them to be reconstituted in case of need is substantially lower (in most species fewer than half the cryoconserved breeds have a sufficient quantity of material stored).

Countries had the option of providing information on *ex situ in vitro* conservation in species other than the big five. The responses are summarized in Table 3D11. Note that answering the question was not compulsory and therefore it is possible that some countries that have genetic material from these species stored in their gene banks did not provide information. The reported proportion of buffalo breed populations with material stored is similar to that for cattle (although the absolute number is clearly much lower). In horses and rabbits, widely distributed species with a large number of reported breeds, the figures are substantially lower, at 8 percent and 9 percent, respectively. A similar proportion (but lower absolute numbers) is reported for asses. Material from several other mammalian species (dromedaries, Bactrian camels, alpacas, llamas and yaks) is reported to be stored in gene banks. These species do not have worldwide distribution and the total number of reported breeds is low. In all cases, material from between 10 and 30 percent of breed populations is reported to be stored in gene banks. In absolute terms, this amounts to a handful of breed populations in each species. In all "minor" mammalian species, the number of breed populations for which sufficient material is stored to allow them to be reconstituted is either low or none. The figures for "minor" avian species are almost all very low. Muscovy ducks are something of an exception (material from 43 percent of 21 reported breed populations stored – and in all cases in sufficient quantity to allow the breeds to be reconstituted).

Countries that have national gene banks were requested to provide further information on the contents of the collection, the operation of the gene bank (stakeholder involvement) and the

TABLE 3D9

Proportion of countries reporting the presence of *in vitro* gene banks, the storage of different types of genetic material, and plans for international collaboration in gene banking

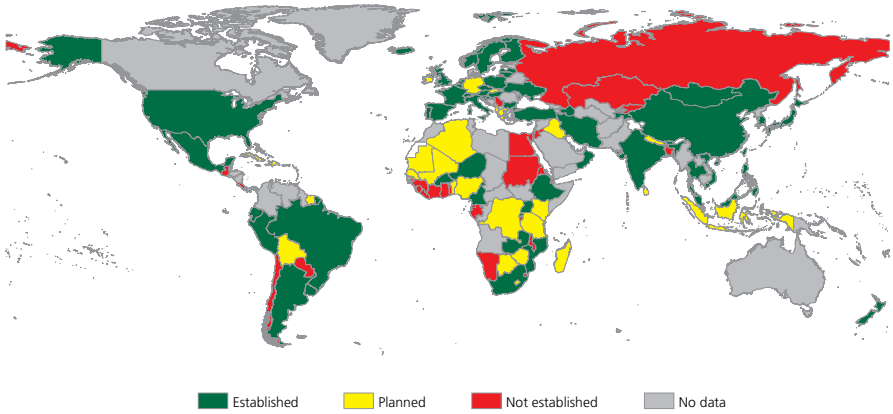
Regions and subregions	Number of countries	Countries reporting gene bank	Proportion of countries storing different types of genetic materials in their gene banks					Countries planning subregional or regional collaboration
			Semen	Embryos	Oocytes	Somatic cells	Isolated DNA	
		%						
Africa	**40**	**23**	**100**	**44**	**11**	**11**	**22**	**33**
East Africa	8	38	100	67	0	0	0	13
North and West Africa	20	15	100	33	33	0	33	40
Southern Africa	12	25	100	33	0	33	33	33
Asia	**20**	**60**	**100**	**67**	**42**	**42**	**67**	**30**
Central Asia	4	50	100	50	50	0	50	25
East Asia	4	100	100	100	50	75	75	0
South Asia	6	33	100	0	0	0	100	17
Southeast Asia	6	67	100	75	50	50	50	67
Southwest Pacific	**7**	**14**	**100**	**100**	**0**	**0**	**0**	**14**
Europe and the Caucasus	**35**	**71**	**100**	**64**	**16**	**48**	**60**	**46**
Latin America and the Caribbean	**18**	**44**	**88**	**75**	**25**	**38**	**38**	**11**
Caribbean	5	40	100	50	0	0	0	20
Central America	5	20	100	100	0	0	0	0
South America	8	63	80	80	40	60	60	13
North America	**1**	**100**	**100**	**100**	**100**	**100**	**100**	**0**
Near and Middle East	**7**	**14**	**100**	**0**	**0**	**0**	**100**	**14**
World	**128**	**45**	**98**	**63**	**23**	**39**	**53**	**30**

Source: Country reports, 2014.

purposes for which the stored material is (or has been) used. Responses are summarized in Tables 3D9 and 3D12. Semen is by far the most commonly stored material, followed by embryos. However, isolated DNA, somatic cells and oocytes are stored in a substantial number of gene banks. There is some regional variation. For example, more than half the African countries reporting the presence of a gene bank indicate that they store no material other than semen. The use of gene banks to store material from breeds that are not currently regarded as being at risk of extinction is quite widespread (53 percent of responsee).[5] This material has the potential to serve as an ultimate backup should some major unexpected disaster strike the *in vivo* population, but it can also be used in less extreme circumstances, for example to introduce the genetic variation needed to a re-orientate a breeding programme in response to changing market demands (see FAO, 2012).

[5] Responses = country × species combinations.

FIGURE 3D4
State of development of *in vitro* gene banks for animal genetic resources



Source: Country reports, 2014.

While a gene bank is a strategic national resource, the most direct beneficiaries (or potential beneficiaries) are livestock breeders. The involvement of stakeholders from the breeding sector in the planning of the development and operation of the gene bank is therefore likely to be important in ensuring that it is well targeted and operates effectively (FAO, 2012). Only a minority of country reports indicating the presence of a gene bank state that livestock keepers or breeders' associations are involved in its operation.

The number of cases in which genetic material from gene banks is reported to have been used to increase the genetic variability in *in situ* or *ex situ* populations is rather limited (26 and 18 percent of responses, respectively) and the country reports generally do not provide detailed information on these cases. Only a very few cases of gene bank material being used to reconstitute extinct or nearly extinct breeds are reported and few details are provided. An example of the reconstitution of a discontinued research line from cryoconserved material is presented in Box 3D5. Only a minority of countries globally (around 30 percent) report that they are involved in international or regional collaboration in gene banking. These cases are discussed in the regional overviews below.

6 Regional overviews

6.1 Africa

In Africa, the main elements of *in situ* conservation are extension activities and breeding programmes focusing on conservation and/or improvement of performance. State farms play a central role. However, there are some differences between the subregions. Most notably, *in situ* conservation programmes in Southern Africa are more diverse than those in other subregions in terms of the elements they include. The private sector, including breeders' associations, is also more involved in conservation in this subregion than elsewhere in the region.

In vitro conservation is not widespread in Africa. The majority of countries report that they have no gene bank and the proportion of breeds covered is low (Table 3D9 and 3D10). However, several country reports mention plans to establish subregional gene banks in Africa. The report from Uganda, for example, mentions the

TABLE 3D10

Breed coverage of the big five species in gene banks

Region and subregions	Reported proportion of national breed populations conserved in gene banks					
		Cattle	Sheep	Goats	Pigs	Chickens
		%				
Africa	**Conserved**	**12**	**6**	**5**	**3**	**2**
	Enough material	**8**	**6**	**4**	**3**	**2**
East Africa	Conserved	14	0	0	0	0
	Enough material	12	0	0	0	0
North and West Africa	Conserved	12	10	5	4	0
	Enough material	12	10	5	4	0
Southern Africa	Conserved	9	5	8	4	5
	Enough material	0	5	5	4	5
Asia	**Conserved**	**32**	**24**	**24**	**19**	**19**
	Enough material	**15**	**9**	**11**	**10**	**10**
Central Asia	Conserved	19	10	14	0	0
	Enough material	12	7	10	0	0
East Asia	Conserved	40	40	31	24	32
	Enough material	26	20	15	14	16
South Asia	Conserved	32	7	8	4	6
	Enough material	9	2	4	0	0
Southeast Asia	Conserved	29	31	34	20	11
	Enough material	10	3	10	9	0
Southwest Pacific	**Conserved**	**0**	**0**	**0**	**0**	**0**
	Enough material	**0**	**0**	**0**	**0**	**0**
Europe and the Caucasus	**Conserved**	**40**	**27**	**28**	**27**	**5**
	Enough material	**23**	**10**	**12**	**12**	**3**
Latin America and the Caribbean	**Conserved**	**15**	**15**	**15**	**5**	**0**
	Enough material	**12**	**10**	**7**	**5**	**0**
Caribbean	Conserved	20	21	23	12	0
	Enough material	7	4	9	12	0
Central America	Conserved	4	0	9	0	0
	Enough material	4	0	9	0	1
South America	Conserved	22	19	15	6	0
	Enough material	17	15	5	5	0
North America	**Conserved**	**74**	**67**	**88**	**92**	**25**
	Enough material	**33**	**12**	**13**	**42**	**3**
Near and Middle East	**Conserved**	**4**	**0**	**0**	**0**	**0**
	Enough material	**4**	**0**	**0**	**0**	**0**
World	**Conserved**	**27**	**23**	**20**	**18**	**6**
	Enough material	**16**	**9**	**9**	**9**	**3**

Note: "Conserved" = some material stored in a gene bank; "Enough material" = enough material stored to allow the breed to be reconstituted.
Source: Country reports, 2014.

TABLE 3D11
Breed coverage of "minor" species in gene banks

Species	Total number of national breed populations reported	Proportion of national breed populations from which some material is stored in a gene bank (%)	Proportion of national breed populations from which sufficient material is stored in a gene bank to allow the breed to be reconstituted (%)
Horses	1 317	8	2
Rabbits	586	9	9
Ducks	311	3	2
Pigeons	285	0	0
Geese	278	0	0
Turkeys	127	1	1
Buffaloes	85	27	15
Asses	74	8	1
Guinea fowl	51	0	0
Dromedaries	45	13	0
Quails	43	2	0
Muscovy ducks	21	43	43
Ostriches	20	5	5
Deer	18	0	0
Guinea pigs	12	0	0
Alpacas	12	17	0
Llamas	11	18	0
Bactrian camels	7	14	0
Yaks	6	17	0

Note: The total number of national breed populations reported refers to the number reported in the country reports. The proportions are calculated relative to this total number of reported breeds. Providing information on the gene banking of material from these species was optional. It is possible that some countries that did not provide information also have some material from these species stored in their gene banks.
Source: Country reports, 2014.

objective of developing a gene bank in collaboration with Burundi, Kenya, Rwanda, South Sudan and the United Republic of Tanzania. The report from Togo mentions plans to collaborate with other countries of the Economic and Monetary Union of West Africa to create a regional bank or strengthen the capacity of the gene bank of the International Centre of Research and Development of Livestock in the Subhumid Zone, based in Burkina Faso. The report from South Africa mentions the intention to collaborate with other Southern African Development Community countries (Botswana, Mozambique, Namibia, Zambia and Zimbabwe).

6.2 Asia

In situ conservation programmes in Asia are government driven and focus primarily on extension activities and breeding programmes aimed at improving breeds' productivity. In East Asia, well-developed *in situ* conservation programmes are in place in some countries. Although there is some private-sector involvement, governments are the main operators. The most widespread *in situ* conservation activities in this subregion are awareness raising, conservation breeding programmes, promotion of niche market products and community-based conservation. In South and Southeast Asia, a lot of attention is paid to awareness-raising

TABLE 3D12
Characteristics and functions of national gene banks

Regions and subregions	Number of countries	Storage of not-at-risk breeds	Participation of livestock keepers/ breeders' association	Increasing genetic variability in *ex situ* populations	Increasing genetic variability in *in situ* populations	Reconstitution of extinct breeds
		%				
Africa	**9**	**35**	**30**	**31**	**33**	**4**
East Africa	3	17	17	11	17	0
North and West Africa	3	61	56	61	61	0
Southern Africa	3	28	17	22	22	11
Asia	**12**	**67**	**26**	**35**	**29**	**4**
Central Asia	2	67	42	58	67	0
East Asia	4	63	17	17	25	4
South Asia	2	67	25	0	8	0
Southeast Asia	4	71	25	54	21	8
Southwest Pacific	**1**	**0**	**0**	**0**	**0**	**0**
Europe and the Caucasus	**25**	**58**	**61**	**10**	**24**	**1**
Latin America and the Caribbean	**8**	**40**	**27**	**2**	**19**	**0**
Caribbean	2	42	0	0	0	0
Central America	1	33	50	0	0	0
South America	5	37	33	3	30	0
North America	**1**	**100**	**100**	**83**	**67**	**17**
Near and Middle East	**1**	**17**	**0**	**0**	**17**	**0**
World	**57**	**53**	**42**	**18**	**26**	**2**

Note: "Number of countries" = the number of countries that provided information on the characteristics of their national gene banks. The figures represent the proportion of responses (country × species combinations) that indicate the presence of the respective activity. The figures refer only to the big five species (cattle, sheep, goats, pigs and chickens).

activities. For example, the country reports from Indonesia and the Philippines mention the use of the internet and social media in addition to traditional means of promoting locally adapted breeds. Some attention is also given to the establishment of breeding programmes for at-risk breeds. The country report from India, for example, mentions several such schemes for small-ruminant breeds.

More than half (60 percent) of country reports from Asia indicate the presence of a gene bank. However, there are substantial differences between the subregions (Table 3D9). In general, the gene banks in East and Southeast Asia are more developed than those in the other two subregions. In every major species, the gene banks of East and Southeast Asia store material from a higher proportion of reported breed populations than those in Central and South Asia (Table 3D10).

East Asia has a higher proportion of its chicken breeds stored in gene banks than any other subregion or region in the world. This is mainly a result of the presence of well-developed gene

Box 3D5
Reconstituting a research pig line

Gene banks have an important role in backing-up research populations. Purdue University in the United States of America had developed a line of pigs that were either homozygous or heterozygous for both the Napole and Halothane genes, both of which negatively affect pork quality in animals with the homozygous recessive genotype. In 2003, Purdue decided to discontinue this population and chose to have samples of semen from three carrier boars frozen and banked by the National Animal Germplasm Program. In August 2007, the University decided to re-establish a population in which the recessive homozygous condition was present, so that it could be used to research meat quality. Samples of the semen stored with the National Animal Germplasm Program were therefore transferred back to Purdue and sows were inseminated. The results were a 100 percent pregnancy rate and an average litter size of 7.7 pigs. The resulting boars were genotyped, and 14 of 25 were found to be heterozygous for both genes. With the F2 population, several boars were homozygous for both mutant genes. This case was the first in which a livestock research line was cryopreserved, discontinued and then re-established using the cryopreserved material.

Source: Reproduced from FAO, 2012.

banks in China and Japan. Although gene banks are relatively uncommon in the reporting countries of Central and South Asia, some countries from these subregions report well-developed gene banks. The gene bank of the Islamic Republic of Iran, for example, includes genetic material in the form of semen, embryos, oocytes and isolated DNA from cattle, sheep, goats, horses, buffaloes, Bactrian camels and dromedaries. Material from the gene bank has been used to introduce genetic variability into *in situ* and *ex situ* populations. The gene bank of India includes semen and isolated DNA from cattle, sheep, goats, buffaloes, horses and asses. Cattle genetic material from the gene bank has been used to increase the genetic variability and population sizes of cattle breeds such as the Tharparkar, Sahiwal, Krishna Valley and Hariana. In Southeast Asia, Malaysia, the Philippines, Thailand and Viet Nam all report the presence of a gene bank, while Indonesia reports plans to develop one. These gene banks are used mainly for introducing genetic variability into breeding programmes involving *ex situ* populations. With regard to international collaboration in gene banking within the region, the country report from the Philippines mentions plans for collaboration between India, Pakistan and the Philippines in the *ex situ in vitro* conservation of buffaloes.

6.3 Europe and the Caucasus

In Europe and the Caucasus, *in situ* conservation programmes are well developed and generally involve a range of different elements (supplementary tables A3D1 to A3D7).[6] The majority of locally adapted breeds are well characterized and their population trends are monitored. Breeders' associations are widespread and conservation breeding programmes or those aiming to increasing the productivity of at-risk breeds are common. A lot of effort is put into awareness-raising activities and the methods used are diverse. The provision of direct financial incentives to the keepers of at-risk breeds is more common in this region than anywhere else in the world. The same is true for the use of at-risk breeds in the management of landscapes and wildlife habitats and their use in touristic activities. Niche marketing of breed products is well developed, facilitated by the existence of labelling schemes such as those operating in the European Union for protected designations of origin.

The majority of the countries in the region report well-established gene banks. However, the breed coverage of *ex situ in vitro* programmes remains far from complete: material from 40 percent of the

[6] Supplementary tables for Part 3 are provided on CD ROM and at http://www.fao.org/3/a-i4787e/i4787e197.pdf

Box 3D6

Conservation of the Gembrong goat of Bali (Indonesia): a breed brought close to extinction by nylon fishing line

Gembrong means "lots of hair" in Balinese. The Gembrong goat's long shiny white hair was the basis for one of the breed's traditional uses: the hair was used as a lure for fishing. The introduction of nylon line in the fishing industry reduced the profitability of raising Gembrong goats and the breed's population experienced a severe decline. Today (May 2014) only 56 animals remain. The Ministry of Agriculture, the Indonesia Institute of Science, local government and universities are giving serious attention to the task of saving the breed. A conservation programme has been set up, including both *in situ* and *ex situ* components. A budget was allocated to support feeding and shed repair for the main *in situ* population, which consists of 26 animals kept by one farmer at the eastern tip of Bali province. There is another small four-animal herd in East Java. A conservation breeding programme is being implemented, and currently six bucks have been selected for breeding to minimize inbreeding in the *in situ* population. The *ex situ* conservation component of the programme consist of an *in vitro* collection, with a target of 200 straws of frozen semen for 2014, kept at the Indonesia Agency for Agriculture Research and Development. In addition, two *ex situ* herds have been created: one 19-animal herd at the Goat Research Institute in North Sumatra and one small herd of 7 animals in the Taman Ujung National Park. The next step being considered is a cross-breeding/back-crossing programme to increase the population size while controlling inbreeding. The plan is to inseminate females of the Kacang breed with semen from Gembrong bucks, with the aim of generating, in five to ten years, an almost pure herd of Gembrong goats. However, the cost of the implementing this plan has been estimated to be almost US$400 000 in total, and its economic viability is under discussion.

Photo credit: I Made Londra.

Provided by Bess Tiesnamurti, Aron Batubara and I Made Londra.

reported cattle breed populations and less than 30 percent of reported sheep, goat and pig breed populations is stored in gene banks. Chickens are even less well represented, with material from only 5 percent of the reported breed populations included in gene banks (Table 3D10).

Two types of gene bank are reported in this region: centralized national gene banks (e.g. Poland and Spain) and dispersed gene banks managed by different stakeholders (breeders' associations, research institutions, NGOs or commercial companies) (e.g. Italy and the United Kingdom). Germany is planning to do develop a national gene bank in the form of a network of gene banks operated by different partners. Switzerland's establishment of a "virtual gene bank" in collaboration with the private sector is described in Box 3D7. Despite the generally

Box 3D7

Switzerland's virtual national gene bank – building on the work of the commercial sector

Switzerland is fortunate enough to have gene banks in place for a number of species, including cattle, pigs, goats and horses. These gene banks are run by commercial artificial insemination (AI) companies, except for the horse gene bank, which is run by the government.

Following the adoption of the Global Plan of Action for Animal Genetic Resources in 2007, Switzerland committed itself to, among other priorities, strengthening its *ex situ* conservation measures. At the time, however, it had no proper national gene bank in place. Moreover, building up the full infrastructure needed to run a gene bank is a very costly process.

In 1960, Swissgenetics, a private commercial company, started to freeze and stock semen from bulls belonging to various cattle breeds for AI, as well as for long-term storage. Since about 1975, Swissgenetics has been systematically storing bovine semen in its own gene bank. The existence of this long-established store of frozen semen, and the fact that the company was willing to cooperate, represented a big opportunity for the government. The obvious approach was to join forces to fulfil the objective of establishing a national gene bank.

The Swiss Federal Office for Agriculture (FOAG) found a very reliable partner in Swissgenetics. The company agreed to place the core semen collection at the disposal of the government and to provide backup facilities for long-term storage. FOAG agreed to compensate these efforts with an annual financial contribution.

The contractual arrangements were signed in 2010 for a period of ten years, extendable for further periods of ten years. It was concluded that 30 doses of already-frozen semen from bulls belonging to Swiss breeds would be assigned to the virtual national gene bank. Since 2010, 50 semen doses from each new Swiss bull entering the AI station have been allocated to the virtual gene bank's core collection. The organization administrates the doses using the CryoWEB software.[1] If necessary and mutually agreed, frozen semen from the core collection can be used for genetic-scientific or genetic-economic purposes or for the revitalization of breeds that are at risk of extinction. Swissgenetics also hosts the gene bank for goat breeds.

This collaboration between a commercial AI company and the government in building a virtual national gene bank has been very successful so far. In 2012, FOAG succeeded in establishing a similar contract with Suisag, a commercial pig AI company.

Provided by Catherine Marguerat, National Coordinator for the Management of Animal Genetic Resources, Switzerland.

[1] http://cryoweb.tzv.fal.de/

well-developed state of *ex situ in vitro* conservation in this region, several countries have no gene banks and have no plans to establish them (Figure 3D4). A network of gene banks involving 23 countries is being developed (Box 3D8).

6.4 Latin America and the Caribbean

In situ conservation programmes in Latin America and the Caribbean involve both government and private initiatives. The main elements of programmes in this region are breeding schemes focusing on conservation and/or performance improvement (in which governmental nucleus farms play a key role), promotion of niche-market products and awareness-raising activities. However, there is great diversity within the region in terms of the types of conservation activities undertaken (supplementary tables A3D1 to A3D7)[7] and in the levels of breed coverage (Figure 3D1). Breeders' associations exist in most countries, and where they exist are usually involved in conservation programmes. In some countries, *in situ* conservation programmes are in their first stages of

[7] Supplementary tables for Part 3 are provided on CD ROM and at http://www.fao.org/3/a-i4787e/i4787e197.pdf

development, while in others they are well established. Gene banks in the region usually consist of more than one separate collection managed by different stakeholders. Genetic material from both locally adapted and exotic breeds is usually stored, and collections are typically used both to support ongoing breeding programmes and for long-term conservation. Gene banks are common in South America, but scarce in Central America and the Caribbean. *Ex situ in vivo* conservation is relatively well-developed in the region.

6.5 Southwest Pacific

In the small island countries of the Southwest Pacific, *in situ* conservation programmes, if they exist at all, are in their early stages of development and focus mainly on pigs and chickens (Tables 3D2 and 3D3). The main activities undertaken within these programmes are awareness raising, promotion of niche marketing and breed-related cultural activities. In the case of pigs, there are some community-based conservation programmes. In Australia[8] and New Zealand, most *in situ* conservation activities are implemented by private institutions, with NGOs playing a key role. Despite the lack of government involvement, these programmes include a diverse range of elements. In New Zealand, the Rare Breeds Conservation Society of New Zealand implements all *in situ* conservation activities. It gives small grants to livestock keepers who raise at-risk breeds, manages herd books, distributes newsletters and organizes fairs, shows and field days for awareness-raising and educational purposes.

Gene banks are present only in Australia and New Zealand. In both countries, the banks are operated by private bodies rather than by the public sector. In New Zealand, the Rare Breeds Conservation Society of New Zealand, in collaboration with a private cryostorage facility, maintains a genetic repository at which genetic material from at-risk breeds is stored in the form of semen and embryos. The gene bank operates entirely on the basis of private funding. No information was provided in the country report about the number of breeds from which material is stored. A similar approach is taken in Australia, where breeding organizations and civil society organizations support *ex situ* conservation. *In vitro* programmes in Australia only include at-risk breeds with commercial potential. There are no gene banks in the small island countries of the region.

6.6 North America

In the United States of America, *in situ* conservation is largely undertaken by breeders' associations and other non-governmental bodies. The most widespread activities include awareness raising, promotion of niche-market products, recognition/award programmes for livestock keepers and breeding programmes to improve productivity. Government activity is largely confined to *ex situ in vitro* conservation. The country has a well-developed gene bank that includes genetic material from more than 150 breeds; 30 percent of the country's breeds have enough material stored to allow them to be reconstituted if needed (Table 3D10). The primary role of the programme is to serve as a backup of *in situ* livestock populations that can be drawn upon if national or industry need arises. However, the collection is also used to provide samples for use in genetic research, to reconstitute research populations, to add genetic variability to industry populations and to evaluate germplasm in a range of different physiological experiments.

6.7 Near and Middle East

In the Near and Middle East, *in situ* conservation programmes are generally in their early stages of development. Oman has a well-developed strategic plan for the conservation of dromedary, cattle, sheep, goat and chicken genetic resources. Initial efforts are focusing on the identification of at-risk breeds, raising awareness among livestock keepers and children about the state of the country's AnGR and increasing the skills and knowledge of livestock keepers and government officers. In the context of this plan, several

[8] Australia did not provide a country report as part of the second SoW-AnGR reporting process. However, it published a report as an independent initiative in 2012.

Box 3D8

Development of the European Gene Bank Network for Animal Genetic Resources

European countries have established national gene banks for *ex situ in vitro* conservation of animal genetic resources (AnGR) as a complementary strategy to *in situ* conservation. Although countries take responsibility for the development of gene bank collections at national level, there are clear advantages to collaboration between countries at regional, subregional or bilateral levels.

The European Regional Focal Point on Animal Genetic Resources (ERFP) has established a Working Group on *Ex Situ* Conservation of Animal Genetic Resources.[1] The main tasks of this Working Group are to:

1. exchange experiences and knowledge among European countries;
2. support the establishment, development, efficiency and effectiveness of European national gene banks; and
3. jointly develop a European strategy for gene banking, documentation and other related issues.

In 2013, the first steps were taken, under the umbrella of the ERFP, to officially establish the European Gene Bank Network for Animal Genetic Resources (EUGENA). The objective is to support *ex situ* conservation and sustainable use of AnGR in Europe under common terms of agreement. In this context, a national gene bank for AnGR is defined as a repository (or more than one repository collaborating in a network at national level) that undertakes *ex situ* conservation and sustainable use of AnGR and is held by a host institution authorized and/or recognized by a national authority to fulfil these tasks. There are ample opportunities for the development of a more efficient, rational and long-term regionally integrated approach to conservation at the European level. When resources are limited, it is important to set priorities and to avoid gaps and duplication of efforts. A regional approach could help to further develop and enhance the quality standards of national gene banks. A regional portal or documentation system could provide easy access to information about national collections.

The objectives of EUGENA are to:

- support gene banks in fulfilling their individual roles and objectives;
- improve the monitoring and assessment of AnGR kept in *ex situ* collections in European countries by sharing information;
- improve gene bank operations and procedures in European countries by sharing information;
- create synergies in *ex situ* conservation and sustainable use by promoting joint activities among European gene banks;
- increase the efficiency of *ex situ* conservation of transboundary breeds;
- promote the harmonization of acquisition and access terms for *ex situ* conservation across European countries;
- facilitate improvements in the quality of *ex situ* collections in European gene banks;
- create an element of the European research infrastructure to address the conservation and sustainable use of AnGR; and
- facilitate a European approach to international cooperation and exchange of AnGR in the context of the Nagoya Protocol on Access and Benefit Sharing.

A survey was undertaken to generate an overview of the key characteristics of national gene banks in Europe, including legal and institutional aspects, the history of the collections, their objectives and their documentation. The survey identified similarities and differences among countries and issues that needed harmonization at European level and was thus an important first step towards facilitating the further development of EUGENA.

National governments are expected to further rationalize their national strategies for the conservation and sustainable use of AnGR, including national gene banking strategies. At present, not all valuable genetic diversity under the custody of breeders and researchers has been cryoconserved for the long term in a national gene bank. Besides complementing and enhancing gene bank collections, there is also a need to promote future use of gene bank collections, including through better characterization and documentation of collections.

Provided by Sipke Joost Hiemstra, National Coordinator for the Management of Animal Genetic Resources, the Netherlands.

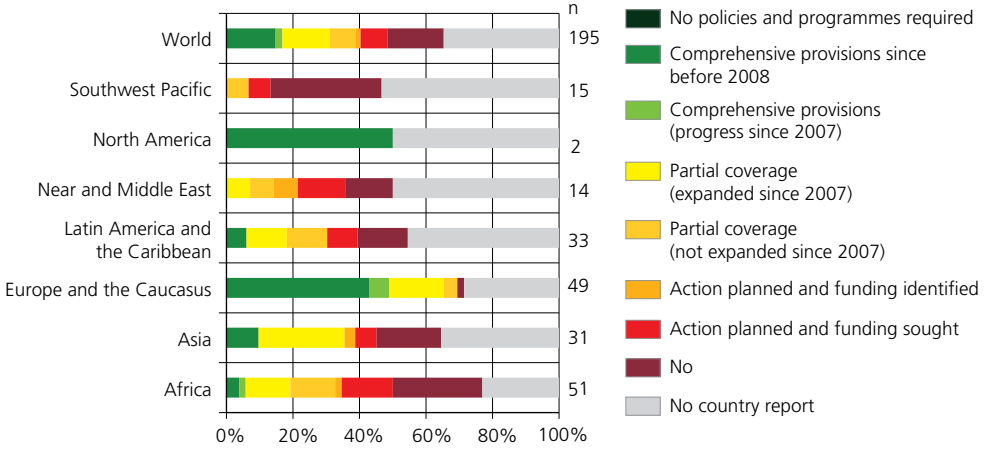
[1] http://www.rfp-europe.org/index.php?id=597

international agreements promoting the conservation and sustainable use of AnGR have been signed and four research centres or stations have been created in the country with the aim of conserving locally adapted breeds. Oman is also the only country in the region that reports a gene bank (semen and isolated DNA of two multipurpose cattle breeds are stored and are used for both conservation and breeding purposes).

7 Changes since 2007

Because of difference between the samples of reporting countries, it is difficult to present a direct comparison of the state of capacity in 2014 to that at the time the first SoW-AnGR was prepared. However, in addition to the detailed questions about the current state of conservation measures, the country-report questionnaire included some questions about the state of implementation of Strategic Priority Area 3 (Conservation) of the Global Plan of Action for Animal Genetic Resources (FAO, 2007b). Figure 3D5 summarizes the responses to a question about the state of conservation policies and programmes and whether they have been strengthened since 2007. The figure shows that a substantial number of countries report that they have improved the state of their conservation programmes since 2007. Improvements are more common in Asia and Europe and the Caucasus than in other regions. There are, however, a large number of countries (more than half) that report that they have no policies or programmes or that they have some provisions in place but have made no improvements since 2007. It appears that some countries interpreted this question more

FIGURE 3D5
State of conservation programmes and policies at country level and progress since 2007



Note: Countries were asked the following question: Does your country have conservation policies and programmes in place to protect locally adapted breeds at risk in all important livestock species? Response options were as follows: a. Country requires no policies and programmes because all locally adapted breeds are secure; b. Yes, comprehensive policies and programmes have been in place since before the adoption of the GPA; c. Yes, comprehensive policies and programmes exist because of progress made since the adoption of the GPA; d. For some species and breeds (coverage expanded since the adoption of the GPA); e. For some species and breeds (coverage not expanded since the adoption of the GPA); f. No, but action is planned and funding identified; g. No, but action is planned and funding is sought; h. No.
GPA = Global Plan of Action for Animal Genetic Resources; n = number of countries.
Source: Country reports, 2014.

strictly than the question about the presence of the various categories of conservation activity (Table 3D1). A possible explanation for the discrepancy is that some countries have some conservation measures in place but that these do not form part of an organized policy or programme.

According to the country reports, the main obstacle to the improvement of conservation measures is a lack of financial resources. Other frequently mentioned obstacles include a lack of skilled personnel, a lack of technical capacity, a lack of adequate information on AnGR, a lack of national policies and legal frameworks, and insufficient coordination among stakeholders.

8 Conclusions and priorities

Conservation programmes are more widespread than they were at the time the first SoW-AnGR was prepared. Only a minority of countries now report that they have no conservation activities. In terms of practical impacts, the country reports provide several examples of breeds formerly classified as at risk of extinction whose population sizes have increased as a result of successful conservation programmes (see Box 3D3 for example). There are nonetheless major gaps in the breed coverage of conservation programmes, particularly in developing regions and many countries report that they have made little or no progress in improving their conservation measures in recent years.

A wide range of different *in situ* conservation activities are reported. However, many are much more widely used in Europe and the Caucasus, and in some cases North America, than elsewhere in the world. While not all activities are relevant in all countries, there appears to be considerable scope for diversifying existing *in situ* conservation programmes. A number of these potential activities are, however, relatively complex to organize and/or require substantial funding. Reported constraints to the improvement of conservation programmes indicate that many countries need to strengthen the basic human capacities and institutional structures needed for effective AnGR management (see Part 3 Section A for further discussion). In some countries, however, the prerequisites for successful conservation programmes are largely in place and the main challenge is to strengthen the political will to act.

The breed coverage of *ex situ in vitro* conservation programmes is still very limited overall, and many countries have no gene banks. Many report that they have plans to establish gene banks, but lack of funding and lack of technical skills often remain significant constraints. Collaboration at regional or subregional level is a potential means of avoiding duplication in the use of resources, provided the relevant institutional and legal arrangements can be put in place. Interest in initiatives of this kind is reported from several regions and subregions. Country-report responses related to the organization and operation of gene banks suggest that in many cases more could be done with regard to the practical utilization of gene bank material to increase genetic variability within *ex situ* or *in situ* livestock populations. The involvement of breeders' associations and other livestock-sector stakeholders in the development and operation of gene banks is another area that may need strengthening.

References

Country reports. 2014. Available at http://www.fao.org/3/a-i4787e/i4787e01.htm.

FAO. 2007a. *The State of the World's Animal Genetic Resources for Food and Agriculture,* edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2007b. *The Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration.* Rome (available at http://www.fao.org/docrep/010/a1404e/a1404e00.htm).

FAO. 2012. *Cryoconservation of animal genetic resources.* FAO Animal Production and Health Guidelines No. 12. Rome (available at http://www.fao.org/docrep/016/i3017e/i3017e00.htm).

FAO. 2013. In vivo *conservation of animal genetic resources.* FAO Animal Production and Health Guidelines. No. 14. Rome (available at http://www.fao.org/docrep/018/i3327e/i3327e00.htm).

Section E

Reproductive and molecular biotechnologies

1 Introduction

This section presents a review and analysis of the use of reproductive and molecular biotechnologies, based on the information reported in the country reports (for more information on the coverage of the country reporting, see the introduction to Part 3). The biotechnologies on which countries were requested to provide information are listed in Box 3E1. The section is structured as follows: Subsection 2 presents a global overview of where and to what extent various molecular and reproductive biotechnologies are used in the livestock sector; Subsection 3 discusses stakeholder involvement in the delivery of biotechnology services in the livestock sector; Subsection 4 presents

Box 3E1
Glossary: biotechnologies

Artificial insemination (AI): The process by which sperm is placed into a female's uterus (intrauterine), or cervix (intracervical) using artificial means and with the intention of impregnating the female.
Embryo transfer: A step in the process of assisted reproduction in which embryos are placed into the uterus of a female with the intent of establishing a pregnancy.
Multiple ovulation and embryo transfer (MOET): A technology that enables a single female that usually produces only one or two offspring to produce a litter of offspring. It involves the stimulation of a female to shed large numbers of ova, natural mating or artificial insemination, collection of fertilized ova (either surgically, or non-surgically though the cervix) and transfer (usually non-surgically through the cervix) of the fertilized ova to recipient females.
Semen sexing: The separation of mammalian sperm into those bearing an X chromosome and those bearing a Y chromosome in order to be able to produce, via artificial insemination or *in vitro* fertilization, animals of a specified sex.
***In vitro* fertilization:** The process whereby an egg is fertilized with sperm outside the body of the animal before being re-implanted into the uterus.
Cloning: The process of creating genetically identical organisms by nuclear transplantation.
Genetic modification: The direct manipulation of an organism's genome using biotechnology.
Molecular genetic or genomic information: Information contained in a nucleotide-base sequence in chromosomal DNA or RNA, which may be used to estimate breeding values, in the selection of progeny, to detect carriers of diseases or for marker-assisted introgression of genes.
Transplantation of gonadal tissues: Ovarian tissue harvested from immature female chicks, frozen, thawed and transferred into other young females. Newly hatched chick testicular tissue harvested and transplanted successfully to host chicks, resulting in live offspring born from sperm derived from the donor testicular tissue. For further information, see FAO (2012).

region by region descriptions of the state of use of reproductive and molecular biotechnologies; Subsection 5 discusses changes since the time the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007) was prepared; and Subsection 6 presents some conclusions and future priorities.

2 Global overview

The country-report questionnaire requested countries to indicate the level of availability of a range of reproductive and molecular technologies by providing a score (by species): none; low (at experimental level only); medium (available to livestock keepers in some locations or production systems); or high (widely available to livestock keepers). Responding to the question was optional. Countries could provide information on any of the livestock species covered in the questionnaire.[1] The responses are summarized in Tables 3E1 and 3E2.

[1] The questionnaire (see http://www.fao.org/Ag/AGAInfo/programmes/en/genetics/Second_state.html) allowed for answers on the following species: alpaca, ass, Bactrian camel, buffalo, cattle, chicken, dromedary, duck, goat, goose, guinea pig, guinea fowl, horse, llama, Muscovy duck, ostrich, pig, pigeon, quail, rabbit, sheep, turkey and yak (domestic).

TABLE 3E1

Use of reproductive and molecular biotechnologies – regional breakdown

Regions and subregions	Number of countries	Artificial insemination	Embryo transfer	Molecular genetic or genomic information	Multiple ovulation and embryo transfer
		%			
Africa	**38**	**87**	**32**	**24**	**18**
East Africa	7	100	71	29	43
North and West Africa	19	74	16	21	11
Southern Africa	12	100	33	25	17
Asia	**16**	**100**	**94**	**81**	**81**
Central Asia	3	100	100	33	100
East Asia	3	100	100	67	100
South Asia	5	100	80	60	40
Southeast Asia	5	100	100	100	100
Southwest Pacific	**7**	**57**	**29**	**29**	**29**
Europe and the Caucasus	**35**	**100**	**89**	**80**	**69**
Latin America and the Caribbean	**17**	**100**	**82**	**59**	**76**
Caribbean	5	100	40	0	20
Central America	4	100	100	75	100
South America	8	100	100	88	100
North America	**1**	**100**	**100**	**100**	**100**
Near and Middle East	**6**	**100**	**33**	**50**	**17**
World	**120**	**93**	**64**	**55**	**51**

Note: The figures indicate the proportion of responding countries that reported the use of the respective technology at least at experimental level.
Source: Country reports, 2014.

Artificial insemination (AI) is the most widely used biotechnology, with 93 percent of reporting countries indicating that it is used at least to some extent. The only regions/subregions where this biotechnology is not reported to be used in all countries are the Southwest Pacific and North and West Africa. Embryo transfer is less widely reported, but is nonetheless used to some extent in a majority of countries. Countries that do not report the use of embryo transfer are more common in Africa, the Near and Middle East and the Southwest Pacific than in other regions. The use of semen sexing and *in vitro* fertilization is less commonly reported. Apart from North America, where all the technologies under consideration are used at least at experimental level, these two technologies are reported with medium frequency in Asia, Europe and the Caucasus, and Latin America and the Caribbean, and rarely in other regions. Few countries report the use of cloning, genetic modification or the transplantation of gonadal tissue. The use of molecular genetic or genomic information is reported with medium frequency overall, least frequently in Africa, the Southwest Pacific and Central Asia.

TABLE 3E2

Use of advanced reproductive and molecular biotechnologies – regional breakdown

Regions and subregions	Number of countries	Semen sexing	*In vitro* fertilization	Cloning	Genetic modification	Transplantation of gonadal tissue
		%				
Africa	**38**	**16**	**5**	**3**	**0**	**0**
East Africa	7	57	14	0	0	0
North and West Africa	19	5	5	0	0	0
Southern Africa	12	8	0	8	0	0
Asia	**16**	**63**	**75**	**56**	**44**	**25**
Central Asia	3	100	33	33	33	33
East Asia	3	67	100	67	67	33
South Asia	5	20	20	20	20	0
Southeast Asia	5	80	100	60	20	0
Southwest Pacific	**7**	**14**	**14**	**14**	**14**	**14**
Europe and the Caucasus	**35**	**60**	**54**	**20**	**11**	**14**
Latin America and the Caribbean	**17**	**47**	**65**	**24**	**24**	**6**
Caribbean	5	0	0	0	20	0
Central America	4	100	100	0	0	0
South America	8	50	88	50	38	13
North America	**1**	**100**	**100**	**100**	**100**	**100**
Near and Middle East	**6**	**17**	**17**	**0**	**0**	**0**
World	**120**	**40**	**39**	**19**	**14**	**10**

Note: The figures indicate the proportion of responding countries that reported the use of the respective technology at least at experimental level.
Source: Country reports, 2014.

TABLE 3E3

Level of availability of reproductive and molecular technologies for use in livestock production – big five species

Technology	Dairy cattle		Beef cattle		Multipurpose cattle		Sheep		Goats		Pigs		Chickens	
	n = 102		n = 77		n = 70		n = 78		n = 75		n = 71		n = 50	
	t	Score	t	Score	t	Score	t	Score	t	Score	t	Score	t	Score
Artificial insemination	98	2.5	70	2.1	67	2.2	56	1.6	54	1.4	63	2.2	33	1.4
Embryo transfer	70	1.6	49	1.7	40	1.6	32	1.4	25	1.2	19	1.5	3	1.0
Molecular genetic or genomic information	52	1.8	37	1.6	36	1.5	35	1.6	33	1.4	28	1.8	25	1.5
Multiple ovulation and embryo transfer	54	1.6	36	1.7	24	1.6	29	1.3	26	1.2	16	1.5	3	1.0
Semen sexing	46	1.8	29	1.8	22	1.7	7	1.3	6	1.0	11	1.2	5	1.0
In vitro fertilization	39	1.3	31	1.3	18	1.2	16	1.1	15	1.1	11	1.0	6	1.0
Cloning	14	1.4	12	1.4	7	1.0	11	1.0	10	1.0	7	1.0	4	1.0
Genetic modification	10	1.1	10	1.1	5	1.0	5	1.0	8	1.1	8	1.0	6	1.0
Transplantation of gonadal tissue	6	1.0	5	1.0	3	1.0	4	1.0	3	1.0	4	1.0	6	1.2

Note: Availability was scored on the following scale: none (0); low – at experimental level only (1); medium – available to livestock keepers in some locations or production systems (2); or high – widely available to livestock keepers (3); n = number of responding countries; t = number of responding countries reporting the use of the technology (scores 1, 2 or 3); scores shown are averages for the countries that reposted the use of the technology.
Source: Country reports, 2014.

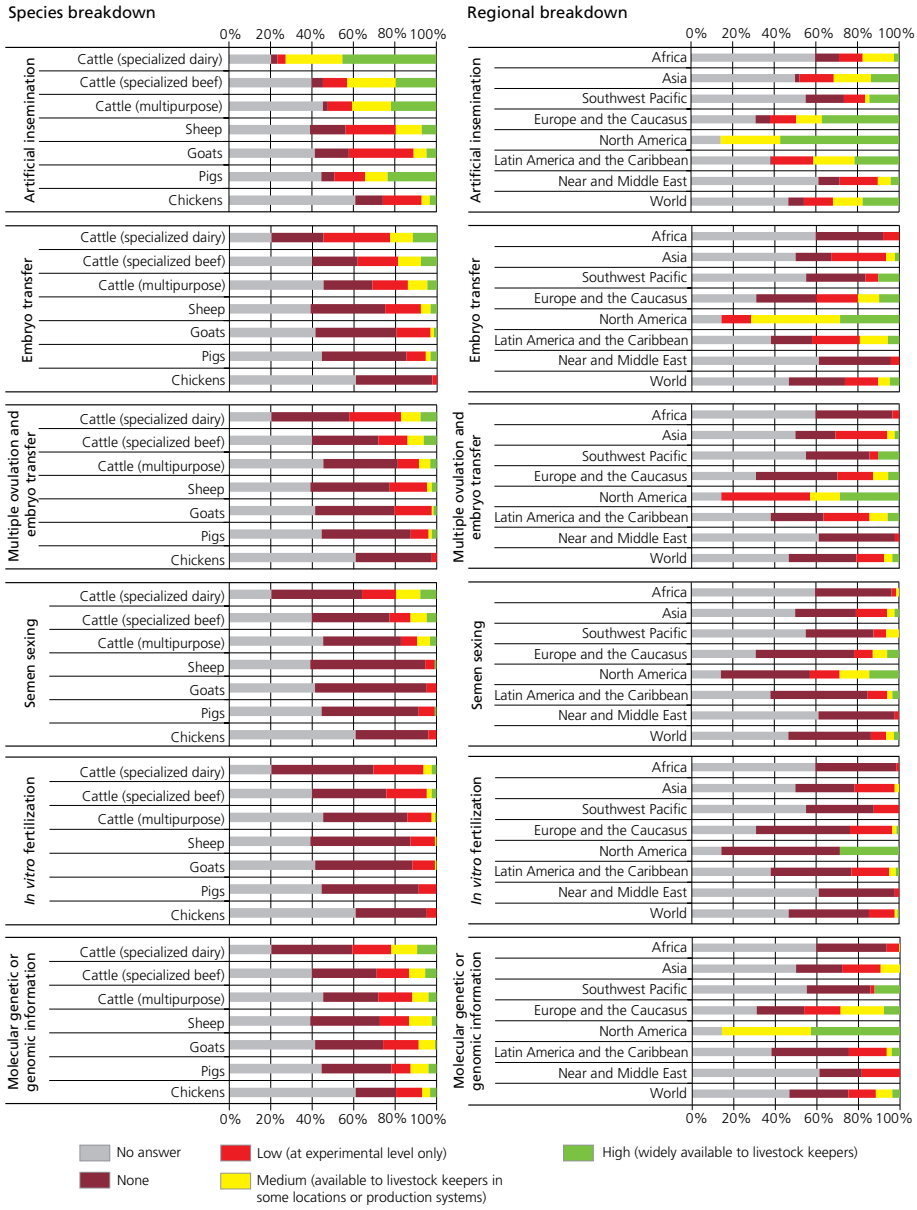
The figures shown in Tables 3E1 and 3E2 conceal big differences in the level of availability of the various technologies and in the extent of their use in different species and different production systems. Table 3E3 presents a species breakdown of the reported scores (see above) for the availability of different technologies. Figure 3E1 shows the frequency distribution of the availability scores by region. Production system differences are further discussed below (see Table 3E4).

As well as being the most widely reported biotechnology, AI also has the highest availability to livestock keepers in the countries where it is used. More than 40 percent of all reporting countries indicate that AI is widely available to livestock keepers raising dairy cattle (Figure 3E1). However, the figure is much lower for beef and multipurpose cattle and for pigs (less than 25 percent) and very low for other species.[2] Across all the other reproductive technologies considered, high and medium levels of availability are more commonly reported in cattle than in other species and more commonly in dairy cattle than in beef and multipurpose cattle. Where the use of molecular genetic or genomic information is concerned, high and medium scores are again most frequent in dairy cattle. However, they are relatively frequent also in sheep and pigs (roughly at the same level as beef and multipurpose cattle). For all technologies apart from AI, high and medium scores are a small minority of responses, indicating that in most countries they are used, if at all, only on an experimental basis.

[2] It is possible that these figures are underestimates given that some countries did not provide responses to the respective question. However, it seems likely that most countries with high levels of provision to report would have done so.

FIGURE 3E1

Level of availability of reproductive technologies



Note: The bar charts show the proportion of responses falling into the none, low, medium and high categories of breed coverage (see legend). The charts on the left show the overall proportion of countries that provided the respective response for the respective species. The charts on the right show the proportion of answers (country × species combinations) from the respective region falling into the respective category.

Source: Country reports, 2014.

In order to obtain an indication of differences between production systems in the level of use of AI – and in the sources of the semen used – countries were asked to indicate (by providing a score) the relative contributions of natural mating, AI using semen from locally adapted breeds, AI using nationally produced semen from exotic breeds and AI using imported semen to the total number of matings/inseminations within the various production systems present in the country. The production-system categories used in the questionnaire are shown in Box 3E2. The responses are summarized in Table 3E4.

The only species × production system combinations for which natural mating received an average score of less than 2 (approximately 33 to 66 percent of matings) were industrial systems (all species), dairy cattle (all systems except pastoralist), multipurpose cattle in small-scale peri-urban or urban systems and pigs in "ranching" systems (these are presumably pigs raised in outdoor systems that are not part of mixed farms). The averages conceal the extent of variation between regions and between countries within regions. Moreover, given the broad range of coverage represented by each category, the scores do not provide very precise estimates of the level of AI use. However, it appears that apart from the dairy sector and "industrial" systems, the use of natural mating is generally predominant.

There is some variation in the main sources of the semen used in different production systems and species. In the case of cattle, imported exotic semen has the highest average score in most production systems. In contrast, in the case of small ruminants, imported semen scores at a similar level to, or slightly lower than, the other sources. However, scores for AI with all types of semen are low in these species. In the case of pigs, the highest-scoring category in industrial systems, which are the main users of AI, is locally produced semen from exotic breeds.

Countries had the option of providing information on the use of biotechnologies in species other than the big five. While the data may not be complete, they suggest that the use of biotechnologies in these species is not widespread (Table 3E5). Horses are to some extent an exception (particularly in Europe and the Caucasus and South America). Of the 62 countries that report the presence of horses, 63 percent indicate that AI is used in this species. In the case of embryo transfer, 34 percent of these countries report that the technology is used in horses and 21 percent indicate the use of MOET. The use of molecular or genomic information in horses is reported by

Box 3E2
Glossary: production systems

Ranching or similar grassland-based production systems: Systems in which animals are grazed on privately owned grassland and/or fed largely on feed obtained from grassland.
Pastoralists systems: Systems in which livestock keepers move with their herds or flocks in an opportunistic way on communal land to find feed and water for their animals (either from or not from a fixed home base).
Mixed farming systems: Systems in which livestock keeping is integrated with other agricultural activities, together forming a whole. **Mixed systems (rural areas):** Mixed systems that do not fall into the category "small-scale urban or peri-urban" (see below).
Industrial systems: Large-scale landless production systems in which the production environment is highly controlled by management interventions. Landless systems are those in which livestock production is separated from the land where the feed given to the animals is produced.
Small-scale peri-urban systems: Small-scale (as judged by nationally relevant criteria) systems situated in or close to a city or large town from which products are supplied to the markets of the respective city or large town; these systems may be "landless" (backyard or scavenger) or, in peri-urban areas, may involve mixed farming.

TABLE 3E4

Level of use of artificial insemination and sources of semen

Species	Production system	Imported semen from exotic breeds	Nationally produced semen from exotic breeds	Semen from locally adapted breeds	Natural mating
		Score (0–3)			
Dairy cattle	Pastoralist	0.5	0.5	0.4	2.0
	Ranching	1.1	0.7	0.7	1.9
	Mixed farming	1.2	0.9	0.9	1.8
	Small-scale peri-urban	1.2	0.7	0.6	1.4
	Industrial	1.6	1.0	0.8	0.9
Beef cattle	Pastoralist	0.4	0.4	0.4	2.2
	Ranching	0.9	0.6	0.5	2.4
	Mixed farming	0.8	0.6	0.7	2.3
	Small-scale peri-urban	0.7	0.4	0.5	2.0
	Industrial	1.0	0.7	0.7	1.3
Multipurpose cattle	Pastoralist	0.4	0.4	0.4	2.3
	Ranching	0.8	0.6	0.8	2.2
	Mixed farming	1.0	0.6	1.0	2.2
	Small-scale peri-urban	1.0	0.6	0.7	1.7
	Industrial	1.0	0.8	0.8	1.0
Sheep	Pastoralist	0.1	0.2	0.2	2.4
	Ranching	0.2	0.3	0.3	2.6
	Mixed farming	0.3	0.3	0.4	2.7
	Small-scale peri-urban	0.2	0.2	0.3	2.3
	Industrial	0.2	0.4	0.4	1.9
Goats	Pastoralist	0.1	0.1	0.2	2.4
	Ranching	0.1	0.2	0.2	2.4
	Mixed farming	0.2	0.3	0.4	2.7
	Small-scale peri-urban	0.2	0.2	0.2	2.4
	Industrial	0.2	0.3	0.4	1.7
Pigs	Pastoralist	0.3	0.1	0.1	2.0
	Ranching	0.3	0.2	0.2	1.8
	Mixed farming	0.6	0.7	0.6	2.3
	Small-scale peri-urban	0.4	0.5	0.3	2.3
	Industrial	0.9	1.2	0.9	1.4

Note: The figures represent average scores for the extent to which artificial insemination and natural mating is used in the respective species in the respective production system. The following scoring system was used: none (0); low – approximately <33% of matings – (1); medium – approximately 33–66% of matings – (2); high – approximately >67% of matings – (3); or "production system not present in this country". Countries where a given species × production system combination does not exist were excluded from the calculation of the respective average score.
Source: Country reports, 2014.

TABLE 3E5

Use of reproductive and molecular technologies – selected "minor" species

Species	Number of countries reporting presence of the species	Artificial insemination	Embryo transfer	Molecular genetic or genomic information	Multiple ovulation and embryo transfer	Semen sexing	*In vitro* fertilization	Cloning	Genetic modification	Transplantation of gonadal tissue
	n	%								
Buffaloes	31	58	29	26	26	6	19	10	3	3
Horses	62	63	34	29	21	10	15	10	3	3
Asses	30	10	7	13	3	3	10	3	3	7
Dromedaries	14	14	14	21	14	0	14	0	7	0
Rabbits	43	19	5	9	5	0	2	2	2	2
Ducks	43	9	2	7	2	2	2	2	5	2
Turkeys	31	16	3	10	3	3	3	3	10	6
Geese	28	11	4	11	4	4	4	4	7	4
Guinea fowl	20	10	0	10	0	0	0	0	5	0

Note: Figures refer to the percentage of countries, among those reporting the presence of the respective species, reporting either low (at experimental level only), medium (available to livestock keepers in some locations or production systems) or high (widely available to livestock keepers) availability of the technology.
Source: Country reports, 2014.

29 percent of countries that report the presence of the species. The use of AI in buffaloes is also quite widely reported: of the 31 countries reporting the presence of the species, 58 percent indicate that AI is used.

The use of other biotechnologies in "minor" species is apparently limited and largely restricted to the experimental level. In the case of some species with limited geographical distributions, the use of molecular and reproductive technologies for research purposes is reported by some countries where the respective species are economically important. For example, research on AI in South American camelids is reported in the country reports from the Plurinational State of Bolivia and Peru. India and the Islamic Republic of Iran report research on AI, embryo transfer, MOET and *in vitro* fertilization in camels. The latter country also reports limited use of AI, embryo transfer and MOET for production purposes in Bactrian camels.

3 Stakeholders involved in service provision and research

The country-report questionnaire requested countries to indicate which stakeholders (from a list of options)[3] are involved in providing AI and embryo-transfer services to livestock keepers. The responses are summarized in Table 3E6. Globally, the public sector, breeders' associations or cooperatives and national commercial companies are the main players in the delivery of these services. However, there are major differences between regions. The public sector has no involvement in North America and also in many countries in Europe and the Caucasus and the Southwest Pacific, but is widely involved in service delivery in other regions. Breeders' associations frequently have a role in Europe and the Caucasus, Asia

[3] Public sector, breeders' associations or cooperatives, national non-governmental organizations, donors and development agencies, national commercial companies and external commercial companies.

and Latin America and the Caribbean, are less frequently involved in Africa and the Southwest Pacific and have no role in other regions. National commercial companies are widely involved in developed regions, somewhat less so in Latin America and the Caribbean and Asia, and quite rarely in other regions. In most regions, services are more frequently provided by national commercial companies (i.e. those based within the respective country) than by external companies. The involvement of NGOs is quite widespread in Asia, Africa and the Southwest Pacific, but less so elsewhere. Donors and development agencies have some involvement in the provision of services in all developing regions.

Countries were also asked to provide information on whether they are undertaking research on the biotechnologies discussed in this section. The responses are summarized in Tables 3E7 and 3E8. Where reproductive biotechnologies are concerned, research is most frequently reported in the more widely used technologies – AI followed by embryo transfer. Research on semen sexing and *in vitro* fertilization is less common and research on cloning and genetic modification even less so. The most common use of molecular genetic or genomic information in research is in the study of genetic diversity. Research on the use of molecular genetic or genomic information for prediction of breeding values and research on adaptedness traits are also reported quite frequently. There are major differences between the regions. Research in all the fields of biotechnology under consideration is being conducted in North America. In most cases, research is also reported from a large proportion of countries in Europe and the Caucasus, East Asia and South America. Research activities are discussed in more detail in the regional overviews below.

4 Regional overviews

4.1 Africa

AI is the main, and in most cases the only, reproductive or molecular technology used in livestock production in African countries (Tables 3E1 and 3E2). AI use is reported by all the countries of East and Southern Africa, and by 74 percent of the countries of North and West Africa. However, the level of availability of AI is very variable across subregions, species and production systems. Only four of the region's countries – Cameroon, Mauritius, South Africa (see Box 3E3) and Rwanda – report that AI is widely available to livestock keepers (and these responses refer only to its use in cattle). Many countries report that a lack of infrastructure and logistical and human capacity means that they are only in the early stages of establishing AI services. The country report from Benin, for example, notes that AI services were interrupted in 2010 because of a lack of liquid nitrogen.

The availability of AI is much higher in industrial and small-scale peri-urban and urban systems than in other systems. Many country reports, including those from Benin, the Gambia and South Africa (see Box 3E3), mention the preponderance of grassland systems as a constraint to the more widespread use of reproductive biotechnologies.

AI services in Africa are provided mainly by the public sector (Tables 3E6). The semen used may be imported or locally produced. In many countries, public institutions also provide AI technology and training to veterinarians and field technicians, who then deliver services. Governmental AI services are frequently provided in collaboration with livestock keepers' associations and NGOs. The provision of AI services to livestock keepers is usually subsidized. For example, the country reports from Botswana (see Box 3E4), Ethiopia and Lesotho mention that semen doses are provided to livestock keepers at subsidized prices.

The provision of AI services by private companies is much less widespread in Africa than provision by

TABLE 3E6

Stakeholder involvement in the provision of artificial insemination and embryo transfer services

Regions and subregions	Number of countries	Breeders' associations or cooperatives	Donors and development agencies	External commercial companies	National commercial companies	National non-governmental organizations	Public sector
		%					
Africa	**33**	**58**	**27**	**15**	**36**	**52**	**91**
	12	**8**	**8**	**0**	**17**	**17**	**58**
East Africa	7	57	43	14	43	71	100
	5	0	20	0	0	20	60
North and West Africa	14	57	36	29	50	50	86
	3	33	0	0	33	33	67
Southern Africa	12	58	8	0	17	42	92
	4	0	0	0	25	0	50
Asia	**16**	**75**	**50**	**38**	**69**	**56**	**100**
	15	**40**	**20**	**27**	**33**	**27**	**67**
Central Asia	3	100	33	67	67	33	100
	3	67	33	67	67	33	100
East Asia	3	67	100	67	100	67	100
	3	67	67	67	100	67	100
South Asia	5	60	40	0	60	60	100
	4	0	0	0	0	0	25
Southeast Asia	5	80	40	40	60	60	100
	5	40	0	0	0	20	60
Southwest Pacific	**4**	**50**	**50**	**100**	**50**	**50**	**50**
	2	**100**	**50**	**100**	**100**	**100**	**50**
Europe and the Caucasus	**35**	**83**	**9**	**66**	**91**	**26**	**55**
	29	**66**	**7**	**50**	**73**	**20**	**39**
Latin America and the Caribbean	**17**	**76**	**18**	**59**	**82**	**19**	**94**
	14	**57**	**7**	**64**	**86**	**7**	**64**
Caribbean	5	20	20	20	40	0	100
	2	0	0	50	50	0	50
Central America	4	100	25	50	100	33	100
	4	50	0	75	75	0	75
South America	8	100	13	88	100	25	88
	8	75	13	63	100	13	63
North America	**1**	**0**	**0**	**100**	**100**	**0**	**0**
	1	**0**	**0**	**100**	**100**	**0**	**0**
Near and Middle East	**6**	**0**	**17**	**17**	**33**	**0**	**100**
	2	**0**	**0**	**0**	**0**	**0**	**50**
World	**112**	**67**	**23**	**45**	**66**	**36**	**80**
	75	**48**	**11**	**41**	**58**	**20**	**53**

Note: = artificial insemination; = embryo transfer. "Number of countries" = the number of countries that report the availability of the respective technology at least at a low level for at least one species.
Source: Country reports, 2014.

TABLE 3E7

Proportion of countries reporting research on reproductive biotechnologies

Regions and subregions	Number of countries	Artificial insemination		Embryo transfer or MOET		Semen sexing		*In vitro* fertilization		Cloning	
		National	International	National	International	National	International	National	International	National	International
		%									
Africa	**40**	**43**	**30**	**30**	**23**	**8**	**0**	**8**	**3**	**3**	**0**
East Africa	8	50	25	63	50	13	0	13	13	0	0
North and West Africa	20	50	35	20	15	5	0	5	0	0	0
Southern Africa	12	25	25	25	17	8	0	8	0	8	0
Asia	**20**	**80**	**35**	**75**	**45**	**45**	**20**	**55**	**25**	**35**	**25**
Central Asia	4	75	25	75	25	50	25	50	0	25	0
East Asia	4	100	50	100	75	75	25	75	50	75	50
South Asia	6	83	17	67	33	17	0	33	17	17	0
Southeast Asia	6	67	50	67	50	50	33	67	33	33	50
Southwest Pacific	**7**	**29**	**14**	**29**	**14**	**14**	**14**	**14**	**14**	**14**	**14**
Europe and the Caucasus	**35**	**83**	**49**	**57**	**40**	**43**	**37**	**57**	**37**	**26**	**20**
Latin America and the Caribbean	**18**	**61**	**28**	**67**	**22**	**33**	**6**	**56**	**28**	**22**	**11**
Caribbean	5	40	20	20	0	0	0	0	0	0	0
Central America	5	60	0	80	0	60	0	60	20	0	0
South America	8	75	50	88	50	38	13	88	50	50	25
North America	**1**	**100**	**0**	**100**	**0**	**100**	**0**	**100**	**0**	**100**	**0**
Near and Middle East	**7**	**86**	**43**	**14**	**14**	**14**	**0**	**14**	**14**	**0**	**0**
World	**128**	**64**	**35**	**49**	**30**	**28**	**15**	**37**	**20**	**18**	**12**

Note: "National" refers to public or private research at national level and "international" refers to research undertaken as part of international collaboration.
Source: Country reports, 2014.

the public sector in terms of the number of countries where the respective sectors are involved. The role of external commercial companies is particularly limited (Table 3E6). However, in the East and North and West Africa subregions, national commercial companies provide AI services in a substantial percentage of countries. For example, AI services in Kenya are provided mainly by private providers (including cooperatives), with the public sector providing services only where there are no private-sector providers. The country report from Senegal mentions that the government provides AI material to private veterinarians who act as service providers, often grouped into associations or consortia so as to be more competitive and to better organize the zoning of the programme. These organizations are also reported to work with foreign companies to obtain inputs. In other countries, the government is in the process of trying to involve private companies in the provision of AI services (noted, for example, in the country report from Mauritania).

TABLE 3E8

Proportion of countries reporting research on molecular biotechnologies

Regions and subregions	Number of countries	Genetic modification		Use of molecular genetic or genomic information					
				for estimation of genetic diversity		for prediction of breeding values		for research on adaptedness	
		National	International	National	International	National	International	National	International
		%							
Africa	**40**	**0**	**0**	**33**	**25**	**15**	**18**	**18**	**18**
East Africa	8	0	0	50	38	13	13	25	25
North and West Africa	20	0	0	35	30	20	15	20	15
Southern Africa	12	0	0	17	8	8	25	8	17
Asia	**20**	**30**	**15**	**60**	**40**	**50**	**30**	**45**	**20**
Central Asia	4	25	0	50	25	50	50	25	0
East Asia	4	75	50	75	50	75	50	100	50
South Asia	6	17	0	67	33	17	0	17	0
Southeast Asia	6	17	17	50	50	67	33	50	33
Southwest Pacific	**7**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**
Europe and the Caucasus	**35**	**29**	**23**	**89**	**80**	**74**	**71**	**63**	**51**
Latin America and the Caribbean	**18**	**22**	**11**	**50**	**39**	**39**	**33**	**28**	**22**
Caribbean	5	0	0	0	0	0	0	0	0
Central America	5	20	0	40	20	20	20	0	0
South America	8	38	25	88	75	75	63	63	50
North America	**1**	**100**	**0**	**100**	**100**	**100**	**100**	**100**	**100**
Near and Middle East	**7**	**0**	**14**	**57**	**57**	**14**	**0**	**29**	**14**
World	**128**	**17**	**12**	**55**	**46**	**41**	**36**	**37**	**28**

Note: "National" refers to public or private research at national level; "international" refers to research undertaken as part of international collaboration.
Source: Country reports, 2014

Other biotechnologies such as embryo transfer and MOET are reported to be used in some countries, but this is usually only for experimental purposes (Figure 3E1). The country report from Rwanda, for example, mentions that research on embryo transfer is being implemented by the Rwanda Agriculture Board in collaboration with Japanese researchers. Another example is provided in the report from the United Republic of Tanzania, which mentions that research on embryo transfer is being undertaken at the country's Agriculture University and that preparations are under way to construct a MOET laboratory at the Mpwapwa Livestock Research Institute. A few countries in the region report the use of embryo transfer at farm or holding level, but only on a very limited scale.

Research in the field of biotechnology in Africa focuses mainly on improving AI techniques and extending the use of this technology to species other than cattle, embryo transfer techniques and the estimation of genetic diversity in various livestock populations (Tables 3E7 and 3E8). International collaboration in research

Box 3E3
The use of reproductive technologies in South Africa

South Africa currently has 32 registered reproduction centres that provide semen and embryo collection services, artificial insemination (AI) and embryo transfer in cattle, sheep, goats and horses. There are over 300 registered trained inseminators in the country (procedures for registration are regulated under the country's Animal Improvement Act of 1998). Some provide AI services to the smallholder sector, but most are either owners of commercial dairy farms or employed on such farms.

More extensive use of AI is restricted by the fact that most commercial beef and small-stock production takes place in extensive ranching systems. The commercial dairy sector is the largest user of reproductive biotechnologies (largely AI). Imported semen (mostly Holstein-Friesian), which is cheaper than nationally produced semen, is widely used. Genetic evaluations are conducted by breed societies to ensure high standards are maintained. Over the past ten years, the pig industry has moved towards the use of hybrid genetics and AI, which is provided by two companies. Imported embryos have been used to increase the numbers of Boran and Senepol cattle in the country, with varying degrees of success. Limited semen sexing and *in vitro* fertilization is done by a few registered service operators. Cloning (somatic cell nuclear transfer) has been limited to research, with one clone of a dairy cow having been successfully produced.

Source: Adapted from the country report of South Africa.

Box 3E4
The use of reproductive technologies in Botswana

The animal breeding section of the Department of Animal Production (DAP) coordinates and oversees artificial insemination (AI) in Botswana. The DAP has a network of 14 AI camps, to which livestock keepers can bring their cattle for insemination. DAP also offers courses at which participants learn how to perform AI so that they can use this technology on their own farms. Most of the people who attend the courses are owners or managers of dairy and beef cattle herds. The use of embryo transfer has also been explored. This technology has been applied experimentally on some farms, with very limited results.

Source: Adapted from the country report of Botswana.

is widely reported, including both collaboration between African countries and collaboration with countries from outside the region (European and Asian countries). Examples include collaboration in research on embryo transfer involving Rwanda and Japan and between Mozambique and South Africa (mentioned, respectively, in the country reports from Rwanda and Mozambique).

4.2 Asia

AI is the most widely used reproductive biotechnology in livestock production in Asia. Every country report from the region states that this technology is used (Table 3E1). Embryo transfer and MOET technologies are also used in a very large percentage of the Asian countries. However, in most cases they are reported to be used only at research level. Japan and the Republic of Korea are exceptions in this respect and report that embryo transfer is commonly used in livestock production. The use of molecular genetic or genomic information is also widely reported in the region, although less frequently in Central Asia. According to the country reports, molecular information is used mainly in research projects on genetic characterization and diversity and to a limited extent to detect regions in the genome involved in the regulation of animal performance. India reports extensive research on growth traits in native and broiler chickens and trait-based gene profiles for egg-quality traits. A few country reports explicitly mention the use of molecular techniques in breeding programmes. The country report from Japan, for example, mentions the use of genomic information in cattle breeding

programmes. The report from Indonesia mentions the use of marker-assisted selection in dairy and beef cattle and the report from Malaysia mentions its use in goats and cattle. The use of cloning technology for research purposes is mentioned in the country reports from India, Japan, the Republic of Korea and Thailand. The report from India notes that research institutions have successfully cloned buffaloes and sheep. The report from the Republic of Korea mentions that cloning has been used to restore native animal genetic resources (AnGR) threatened with extinction.

In every reporting country in Asia, government and public institutions are heavily involved in the provision of reproductive biotechnology services, either directly to livestock keepers or via breeders' associations or private veterinarians that provide the services to livestock keepers (Table 3E6). International donors, development agencies and NGOs also provide biotechnology services, mainly related to AI (see Box 3E5 for example). They also have a role in supporting research and in technical education, particularly in the less-developed countries of the region. For example, the country report from Bangladesh notes that NGOs play a key role in expanding the use of AI. The report from the Philippines mentions that Japan helped in the development of AI in the country and that the Republic of Korea provided support for the development of the cryopreservation facility of the Philippine Carabao Center. Private national and international companies also play a role in the provision of biotechnology services in some countries in the region, mainly in the dairy, pig and poultry sectors.

Country reports from East and Southeast Asia indicate research into almost all types of reproductive and molecular technology (Tables 3E7 and 3E8). In Central and South Asia, research is reported to be less wide ranging, but a majority of countries report research on AI, embryo transfer and MOET and on the estimation of genetic diversity. Many research projects in the region involve international collaboration, usually involving, on the one hand, Asian countries with relatively well-developed research programmes and, on the other, those where research capacity is more limited. Some collaboration with countries outside the region is also reported. The country report from Mongolia mentions collaboration with the Chinese Academy of Science in a research project on the improvement of embryo transfer and MOET in cattle, sheep and goats, and with the Russian Academy of Agriculture Science and the Chinese Academy of Science in a molecular study of the genetic diversity of Mongolian cattle and yaks.

4.3 Southwest Pacific

The countries of the Southwest Pacific region fall into two distinct groups with respect to the level of use of reproductive and molecular technologies and the amount of research conducted in these fields: New Zealand and Australia[4] on the one hand and the small Pacific island countries on the other.

The country report from New Zealand indicates that for most livestock species, molecular and reproductive technologies are widely available for use in production. It gives a score of 3 (widely available to livestock keepers) for the level of availability of AI, embryo transfer, MOET and use of molecular genetic or genomic information in the dairy and beef cattle and small-ruminant sectors. The same high level of availability is reported for AI and the use of molecular genetic or genomic information in the pig sector. National and international companies, as well as breeders' associations, are heavily involved in providing AI and embryo transfer services to livestock keepers (Table 3E6). The country also has a well-developed agricultural research sector, with extensive international links, that undertakes research into many of the technologies discussed in this section.

Half the country reports from the region's small island countries indicate that AI is used. This is mainly in the beef and, to a lesser extent,

[4] Australia did not provide a country report as part of the second SoW-AnGR process, but it produced a country report in 2012 at its own initiative.

Box 3E5

Artificial insemination in sheep and goats – an Indian experience

The Nimbkar Agricultural Research Institute (NARI), a non-governmental organization founded in 1968 in south-central Maharashtra State, India, has over the past 20 years established a centre of excellence in buck and ram semen freezing and artificial insemination (AI).

The establishment of AI services for goats was feasible because in Western Maharashtra, there were already many AI technicians who went around the villages to inseminate cows and buffaloes. The AI gun used in cows can also be used in goats; only a speculum is needed additionally.

Initially, buck semen was frozen in pellets, because no money was available to purchase costly equipment to fill, seal and print straws. NARI saw a funding opportunity when the Government of India's Department of Animal Husbandry announced an "Integrated Small Ruminant Development Project". In 2010, it was able to obtain a grant of 20 million rupees to set up a "state of the art centre".

Since 2012, it has been producing and supplying farmers with cryopreserved semen straws from three exotic and cross-bred goat breeds (Boer, cross-bred Damascus and Alpine × Beetal) for US$1.5 to US$2.5 per straw and one indigenous goat breed from south India (Osmanabadi) for about US$0.80 per straw. The Osmanabadi bucks are selected from villages in Maharashtra for fast growth and mother's high milk yield, as part of a village-level genetic improvement programme carried out by NARI under the All India Goat Improvement Project of the Indian Council of Agricultural Research. This programme, however, needs to be greatly expanded and strengthened. NARI's Centre currently has the capacity to freeze 150 000 straws of semen annually, which can be increased to 750 000 as demand increases.

So far, about 20 000 straws of buck semen have been produced and provided to farmers and AI technicians from Maharashtra, as well as from other states of India and from Nepal. The Maharashtra State Government procured 5 000 straws (4 000 Osmanabadi and 1 000 Boer) from NARI for its AI centres in five districts. Farmers from up to 100 km away also bring their does to NARI for AI. Technicians achieve a conception rate of more than 50 percent.

NARI provides three to five-day training courses in goat AI and management and has so far trained 900 inseminators, including some from distant parts from India and a few from other countries. Some women technicians trained by NARI have started successful AI enterprises and have found that there is overwhelming demand for AI, as good selected breeding bucks are not available.

One of the lessons learnt is that livestock owners are ready to pay for good-quality germplasm. NARI would like to help organizations in other parts of India to freeze semen of the goat breeds in their areas and popularize goat AI. The challenge is, however, to select genetically superior bucks to collect semen from. It is NARI's aim to provide semen more widely throughout India and at the same time to achieve economic viability for the AI centre.

Provided by Chanda Nimbkar.

dairy sectors (see supplementary tables).[5] The report from the Cook Islands notes that AI is not being used because it is cheaper to import live animals than semen. In the countries where they are available, AI services are provided by external commercial companies or international donor and development agencies, with governments playing a facilitating role. Some countries report the need to further foster the use of AI. For example, the country report from Samoa notes that the government is interested in increasing the use of AI and embryo transfer technologies in breeding programmes. However, it also notes that there is a great need to increase capacity and raise awareness in this field. No other molecular

[5] Supplementary tables for Part 3 are provided on CD ROM and at http://www.fao.org/3/a-i4787e/i4787e197.pdf

or reproductive technologies are reported to be used in the small island countries of the region and no research on such technologies is reported.

4.4 Europe and the Caucasus

In Europe and the Caucasus, commercial companies and breeders' associations are the major actors in the provision of AI and embryo transfer services (Table 3E6). The role of the public sector varies across the regions. Most often, it is involved in research and in regulation (e.g. evaluating semen quality and licensing companies for semen importation). In some cases it operates AI centres and services. The country report from France, states that the public sector was the main actor in the provision of reproductive technology services until 2010, after which the activity has been progressively taken over by veterinarians and the cooperative sector. External commercial companies are also significant service providers.

Most of the countries of the region report the widespread use of reproductive and molecular technologies (Tables 3E1 and 3E2). Research in the fields of genomics and the main reproductive biotechnologies is widespread. Research on cloning and genetic modification is less common (Tables 3E7 and 3E8). Research activities often involve international collaboration.

4.5 Latin America and the Caribbean

AI, embryo transfer, MOET, semen sexing, *in vitro* fertilization and molecular genetic and genomic information are reported to be used in a majority of countries in South and Central America (Tables 3E1 and 3E2). Brazil (see Box 3E6) and Mexico are the leading countries in their respective subregions, both in terms of the level of use of biotechnologies and in research. In Brazil, all the aforementioned technologies are used in cattle production. In the case of sheep, goats and pigs, AI, embryo transfer, molecular genetic and genomic information and MOET are used in production, but sexed semen and *in vitro* fertilization only in research. In most of the rest of the countries of South America, AI and embryo transfer, molecular genetic and genomic information and MOET are widely used in cattle and sheep production. In goats and pigs, AI is also widely used in production, but the use of embryo transfer, molecular genetic and genomic information and MOET is much less widespread (see supplementary tables).[6]

Research on biotechnologies is well developed in South America, mainly focusing on cattle and sheep; international collaboration in research is widespread (Table 3E7 and 3E8). The country reports from Peru and the Plurinational State of Bolivia mention research on optimizing the use of AI in llamas and alpacas. The reports from Argentina, Brazil and Uruguay mention research programmes on cloning and genetic modification.

In Central America, AI, embryo transfer and MOET are used in livestock production, although to a lesser extent than in South America (see supplementary tables).[6] These technologies are used more widely in cattle (mainly dairy cattle) than in other species. The country report from Mexico, for example, notes that these technologies are widely used in dairy cattle and that there is a federal government support programme that aims to spread the use of AI and embryo transfer in the livestock sector and to begin work on other technologies such as genomic selection. The country report from the Dominican Republic notes that the main providers of biotechnologies in the country are Brazilian and Mexican operators. Semen sexing and *in vitro* fertilization, and the use of molecular or genomic information in genetic evaluation, are reported to be undertaken for research purposes in dairy cattle in a few countries (e.g. Mexico and Costa Rica). Outside the dairy sector, the country report from Mexico mentions that genetic association studies are being implemented in beef cattle and sheep.

In the Caribbean subregion, biotechnologies are reported to be much less widely available than in the rest of the region (Tables 3E1 and 3E2). AI is used to a limited extent in cattle and sheep. Research on embryo transfer and MOET is

[6] Supplementary tables for Part 3 are provided on CD ROM and at http://www.fao.org/3/a-i4787e/i4787e197.pdf

Box 3E6

Biotechnologies for livestock production in Brazil – use and research

Artificial insemination: Although the use of artificial insemination (AI) is well established in Brazil, the growing use of fixed-time AI has given a new impulse to the use of this biotechnology. Currently, AI research focuses on the incorporation of fixed-time AI into different livestock-management systems.

Embryo transfer and MOET: The use of this technology in cattle production has gradually decreased, but research is still being undertaken with the aim of better selecting recipients and better maintaining pregnancies. There is ongoing research on the identification of molecular markers for use in selecting the best embryo donors. In other species, such as sheep, research focuses on synchronization protocols and ovarian superstimulation.

Semen sexing: Sexed semen is routinely used in Brazil for *in vitro* fertilization. However, there are still problems with its use in AI and embryo transfer.

***In vitro* fertilization:** Brazil is the biggest producer of *in vitro* fertilized cattle embryos in the world. Research focuses on oocyte donors, culture systems, oocyte quality, embryo quality and markers for embryo and oocyte selection. The cryopreservation of *in vitro* fertilized embryos and oocytes remains a major concern. Research is starting on *in vitro* fertilization protocols for sheep, goats, pigs and horses.

Cloning by nuclear transfer: Research in this area relates mainly to cell reprogramming (epigenetic studies) and transcriptome analysis of embryos, the objective being to increase the efficiency of the technique.

Genetic modification: Most research on genetic modification is being done in cattle. Nuclear transfer using transgenic cells is used to produce transgenic embryos. Due to the low efficiency of the technique, research is being done into the transfer of new DNA into the embryo or zygote using lentiviral and retroviral vectors. Genetic modification studies in goats have resulted in the birth of the first transgenic animal in Brazil.

Source: Adapted from the country report of Brazil.

being undertaken in a few countries (Table 3E7). The country report from Jamaica mentions that research was done on the feasibility of artificially inseminating locally adapted goats using semen from Boer goats, but that a relatively low pregnancy rate was achieved.

The reported involvement of stakeholder groups in the provision of biotechnology services in Latin America and the Caribbean is similar to that described above for Asia. Governmental institutions are relatively heavily involved in the provision of services in countries where livestock production is less well developed and for species kept mainly in less intensive systems. The reverse is true for commercial companies (Table 3E6). In Chile, for example, where AI is widely practised in cattle production, the use of this technology is fostered by the Institute of Livestock Development, but the main providers are commercial companies that import semen from exotic breeds. In Central and South America, breeders' associations play an important role in the provision of AI and to a lesser extent embryo transfer.

4.6 North America

In the United States of America, many biotechnologies are widely used in production (see Box 3E7). Services are provided primarily by the private sector. Extensive research into the use of biotechnologies is also conducted (Table 3E7 and 3E8). Newly developed technologies are quickly transferred to the private sector, where they are used not only by large companies, but also by independent breeders. National and external commercial companies are the main providers of AI and embryo transfer services to livestock keepers (Table 3E6).

4.7 Near and Middle East

In the Near and Middle East, AI is the only reproductive biotechnology reported to be available to livestock keepers (Table 3E1). It is used mainly in the dairy-cattle sector (supplementary table A3E1).[7]

[7] Supplementary tables for Part 3 are provided on CD ROM and at http://www.fao.org/3/a-i4787e/i4787e197.pdf

Box 3E7

Use of biotechnologies in livestock production in the United States of America

Dairy cattle: Sexed semen (female) is available from all large breeding companies and is widely used by dairy producers. Embryo transfer and *in vitro* fertilization are routinely used by breeders that provide bulls for artificial insemination (AI). A genomic evaluation system has been developed and nearly all bulls entering AI programmes have been subject to a genomic evaluation.

Beef cattle: Across the beef industry, the AI rate is low. Embryo transfer is used mainly by elite breeders to shorten generation intervals and increase the number of progeny from highly desirable bulls and cows.

Sheep: The sheep industry makes only limited use of AI, due to the limited success of transcervical AI using frozen semen. Embryo transfer is used mainly for importing new genetic resources. Marker-assisted selection is undertaken, mostly related to selection for disease resistance.

Goats: AI using frozen semen is widely used in the dairy-goat industry, but less so in the meat and fibre industries. There is some embryo transfer, mostly associated with the propagation of imported genetics.

Pigs: AI utilizing chilled extended semen is highly integrated into pig production systems. The use of embryo transfer is very limited, because of the very low efficiency of embryo freezing in pigs. Marker-assisted selection methodologies are starting to be used, and their use will expand as the accuracy of the marker panels is enhanced. Molecular modification methods are not currently utilized by the industry. Their development will depend on there being clear market signals that the use of genetic modified organisms is acceptable to consumers.

Chickens: Artificial insemination with fresh extended semen is used by chicken breeders. The advent of ovary transplantation represents a significant step in conserving poultry genetics. Marker-assisted selection is implemented by large breeding companies.

Source: Adapted from the country report of the United States of America.

AI is usually provided by public institutions, which distribute imported semen. However, a few countries report the involvement of private institutions. The country report from Egypt notes that private veterinarians provide AI services in cattle, buffalo and rabbits. The report from Sudan mentions that AI services were privatized in 2006 and that since then they have been provided by commercial companies.

Research in this field in the Near and Middle East is mainly related to AI and the estimation of genetic diversity, although the country report from Egypt also mentions that research on MOET, mainly for use in buffaloes, and on *in vitro* fertilization is being conducted by several institutions and universities. Some international collaboration in research is reported (Table 3E7 and 3E8). For example, the country report of Iraq mentions the involvement of the National Center for Genetic Resources Preservation of the United States of America in a study on the genetic diversity and structure of locally adapted breeds of cattle and sheep.

5 Changes since 2005

Table 3E9 presents a comparison of the level of availability (reported use at least at experimental level) of AI and embryo transfer reported in the country reports prepared (between 2002 and 2005) for the first SoW-AnGR to the level reported in 2014. The figures refer to the countries that provided the relevant information in both reporting processes. Use of both AI and embryo transfer has become more widespread in terms of the number of countries where they are used. However, as discussed above, in many countries, their use is restricted to particularly production systems or locations. In the case of embryo transfer, availability for use in production is often very limited.

Very few of the country reports prepared for the first SoW-AnGR indicated the use of molecular genetic or genomic information in breeding programmes. The use these technologies has

become considerably more widespread in recent years, but in many cases remains at experimental level.

6 Conclusions and priorities

The information provided in the country reports indicates major gaps in the availability of reproductive and molecular biotechnologies for use in the livestock sector. There has been some increase in their availability over recent years and, where availability of reproductive technologies is concerned, the gap between developed and developing countries appears to have narrowed to some extent. Nonetheless, with the exception of AI, many countries report no use of any reproductive biotechnologies and the proportion of countries where their use extends beyond the experimental level is generally very low, particularly for species other than cattle. In some cases, the use of biotechnologies is restricted because technical issues related to the efficiency of their use in certain species (or more generally) remain to be resolved (see Part 4 Sections B, C and D). The use of some is restricted by social or ethical concerns. In other cases, however, the use of potentially beneficial technologies is restricted by a lack of funding, lack of infrastructure, lack of trained personnel or a lack of organizational capacity.

A range of different stakeholders are involved in the provision of biotechnology services to livestock keepers. The private sector has at least some role in all regions and its role has increased over recent years in some developing countries. Nonetheless, the public sector continues to play the main role in the delivery of services in developing regions, particularly in more marginal locations and production systems.

Reproductive and molecular biotechnologies are powerful tools for the management of AnGR, particularly for characterization, monitoring, breeding and conservation. Improvements to infrastructure can help to make these technologies more widely available to livestock keepers. However, as some of these technologies allow very rapid changes in the genetic make-up of livestock populations, it is important to plan their use carefully and with adequate involvement of all relevant stakeholders. If their use is to become

TABLE 3E9

Changes in the level of use of reproductive biotechnologies since 2005

Regions	Artificial insemination			Embryo transfer		
	n	2005	2014	n	2005	2014
		%			%	
Africa	34	82	88	20	25	20
Asia	12	100	100	8	63	100
Southwest Pacific	5	40	60	4	0	25
Europe and the Caucasus	31	100	100	17	82	88
Latin America and the Caribbean	15	93	100	9	100	100
North America	1	100	100	1	100	100
Near and Middle East	5	100	100	2	50	50
World	**103**	**90**	**94**	**61**	**57**	**64**

Note: The analysis is based on the 103 countries that provided the relevant information during both the first and the second SoW-AnGR processes. "Use" refers to use at least at experimental level.
Source: FAO, 2007; Country reports, 2014.

more widespread, it is important that this takes place in the context of a comprehensive understanding of AnGR management that considers the pros and cons of applying such powerful tools and the need both to increase livestock production and productivity and to maintain genetic diversity.

References

Country reports. 2014. Available at http://www.fao.org/3/a-i4787e/i4787e01.htm.

FAO. 2007. *The State of the World's Animal Genetic Resources for Food and Agriculture,* edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2012. *Cryoconservation of animal genetic resources.* FAO Animal Production and Health Guidelines No. 12. Rome (available at http://www.fao.org/docrep/016/i3017e/i3017e00.htm).

Section F

Legal and policy frameworks

1 Introduction

This section is divided into three major subsections, respectively addressing international, regional and national (including where relevant subnational) legal and policy frameworks. As was the case in the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007a), the first two subsections are based mainly on a review of relevant literature, while the subsection on national frameworks is based on country reporting – in this case comprising both the main country reports (see introduction to Part 3) and responses to a separate survey on legal and policy frameworks conducted by FAO in 2013.[1]

2 International frameworks

The first SoW-AnGR described a number of international legally binding and non-binding instruments relevant to the management of AnGR.[2] This subsection presents an overview of developments since the time the first report was prepared.

2.1 Management of biodiversity

Developments related to the work of the Convention on Biological Diversity

The Convention on Biological Diversity (CBD)[3] remains the main legally binding international framework for the management of biodiversity. From the perspective of AnGR management, significant developments in recent years have included an in-depth review of the CBD's Programme of Work on Agricultural Biodiversity, as a result of which, in 2008, the Conference of the Parties (COP) to the CBD invited

> *"Parties, other Governments, relevant international and regional organizations, local and indigenous communities, farmers, pastoralists and plant and animal breeders to promote, support and remove constraints to on-farm and* in situ *conservation of agricultural biodiversity through participatory decision-making processes in order to enhance the conservation of plant and animal genetic resources, related components of biodiversity in agricultural ecosystems, and related ecosystem functions" (Decision IX/1).*

Under the same decision, the COP welcomed the launch of the first SoW-AnGR and the adoption of the Global Plan of Action for Animal Genetic Resources (FAO, 2007b; see below for more details). It invited stakeholders to ensure the effective implementation of the Global Plan of Action.

In 2010, the COP adopted the Strategic Plan for Biodiversity 2011–2010, along with the Aichi Biodiversity Targets (Decision X/2). Of particular significance to AnGR management is Target 13:

> *"By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity."*

[1] For further information on the reporting process, see "About this publication" in the preliminary pages.
[2] FAO, 2007a, Part 3 Section E, pages 275–284.
[3] http://www.cbd.int

The COP invited FAO and its Commission on Genetic Resources for Food and Agriculture (CGRFA)

> *"to contribute to the implementation of the Strategic Plan for Biodiversity 2011-2020 by refining targets for agricultural biodiversity, including at the ecosystem and genetic resources levels, and monitoring progress towards them using indicators" (Decision X/34).*

At the same meeting, the COP adopted the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity (CBD, 2011) (see Subsection 2.2 for further discussion).

In 2011, the second phase of the Joint Work Plan of the Secretariats of the CBD, FAO and the CGRFA, covering the period 2011 to 2020, was agreed upon. The key areas of work under this plan are assessments of biodiversity of relevance to food and agriculture, targets and indicators, best practices in the management of biodiversity, micro-organisms and invertebrates, access and benefit-sharing, enhancing implementation of the Strategic Plan for Biodiversity at national level, and climate change and genetic resources for food and agriculture (FAO, 2011a).

Developments related to the work of the Commission on Genetic Resources for Food and Agriculture

The CGRFA is the only permanent intergovernmental forum specifically addressing matters related to biodiversity for food and agriculture.[4] As far as AnGR management is concerned, the most significant development under the auspices of the CGRFA in recent years has been the adoption of the Global Plan of Action for Animal Genetic Resources. The process of preparing the first Sow-AnGR led to the development of draft strategic priorities for action for AnGR management (FAO, 2007c). This provided the basis for the negotiation of the Global Plan of Action by the CGRFA and its adoption by the International Technical Conference on Animal Genetic Resources for Food and Agriculture, held in Interlaken, Switzerland, in September 2007, along with the Interlaken Declaration on Animal Genetic Resources. Later in 2007, the Conference of FAO adopted a resolution endorsing the Global Plan of Action (FAO, 2007d).

The Global Plan of Action contains 23 strategic priorities for action, grouped into four strategic priority areas:

1. Characterization, Inventory and Monitoring of Trends and Associated Risks;
2. Sustainable Use and Development;
3. Conservation; and
4. Policies, Institutions and Capacity-building.

The strategic priorities, along with their main levels of implementation (national, regional or international) are shown in Table 3F1.

In 2009, the CGRFA agreed a timetable for monitoring the implementation of the Global Plan of Action, based on the preparation of periodical country progress reports (FAO, 2009a). The first round of reporting took place in 2012 (FAO, 2012). A further round of reporting followed as part of the reporting process for the preparation of the second SoW-AnGR. The outcomes are described in the various sections of Part 3, and in more detail in the *Synthesis progress report on the implementation of the Global Plan of Action for Animal Genetic Resources – 2014* (FAO, 2014a).

In 2013, the CGRFA agreed upon a set of targets and indicators to be used to monitor the implementation of the Global Plan of Action and another set to be used to monitor the status and trends of AnGR (FAO, 2013a; 2013b). The former set of indicators are referred to as "process indicators" and the latter as "resource indicators". The resource indicators are discussed in greater detail in Part 1 Section B.

The process-indicator framework includes indicators at the level of each strategic priority of the Global Plan of Action, as well as indicators at the level of the four strategic priority areas, with additional indicators for the overall state of collaboration and funding. The indicators can all be

[4] See FAO, 2007a, pages 276–277.

TABLE 3F1

Priority levels of implementation of the strategic priorities of the Global Plan of Action for Animal Genetic Resources

Implementation	Strategic Priority Area 1 Characterization, inventory and monitoring of trends and associated risks	Strategic Priority Area 2 Sustainable use and development	Strategic Priority Area 3 Conservation	Strategic Priority Area 4 Policies, institutions and capacity-building
National	**SP 1** Inventory and characterize AnGR, monitor trends and risks associated with them, and establish country-based early-warningand response systems	**SP 3** Establish and strengthen national sustainable use policies **SP 4** Establish national species and breed development strategies and programmes **SP 5** Promote agro-ecosystems approaches to the management of AnGR **SP 6** Support indigenous and local production systems and associated knowledge systems of importance to the maintenance and sustainable use of AnGR	**SP 7** Establish national conservation policies **SP 8** Establish or strengthen *in situ* conservation programmes **SP 9** Establish or strengthen *ex situ* conservation programmes	**SP 12** Establish or strengthen national institutions, including national focal points, for planning and implementing AnGR measures, for livestock sector development **SP 13** Establish or strengthen national educational and research facilities **SP 14** Strengthen national human capacity for characterization, inventory, and monitoring of trends and associated risks, for sustainable use and development, and for conservation **SP 18** Raise national awareness of the roles and values of AnGR **SP 20** Review and develop national policies and legal frameworks for AnGR
Regional			**SP 10** Develop and implement regional and global long-term conservation strategies	**SP 17** Establish Regional Focal Points and strengthen international networks
International	**SP 2** Develop international technical standards and protocols for characterization, inventory, and monitoring of trends and associated risks		**SP 11** Develop approaches and technical standards for conservation	**SP 15** Establish or strengthen international information sharing, research and education **SP 16** Strengthen international cooperation to build capacities in developing countries and countries with economies in transition **SP 19** Raise regional and international awareness of the roles and values of AnGR **SP 21** Review and develop international policies and regulatory frameworks relevant to AnGR **SP 22** Coordinate the Commission's efforts on AnGR policy with other international forums **SP 23** Strengthen efforts to mobilize resources, including financial resources, for the conservation, sustainable use and development of AnGR

Note: SP = Strategic Priority; AnGR = animal genetic resources.

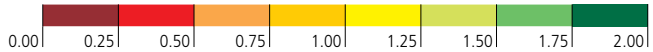
TABLE 3F2

Indicator scores for the implementation of the strategic priority areas of the Global Plan of Action for Animal Genetic Resources

Region	SPA 1	SPA 2	SPA 3	SPA 4	Collaboration	Funding
Africa	0.69	0.66	0.48	0.74	0.39	0.51
Asia	1.01	0.94	0.81	0.99	0.36	0.50
Europe and the Caucasus	1.48	1.31	1.29	1.43	1.03	0.54
Latin America and the Caribbean	0.89	0.90	0.77	0.91	0.33	0.65
Near and Middle East	0.57	0.33	0.22	0.35	0.25	0.38
North America	1.92	1.87	2.00	1.69	1.13	1.00
Southwest Pacific	0.57	0.37	0.25	0.23	0.11	0.38
World	**0.98**	**0.89**	**0.78**	**0.95**	**0.54**	**0.53**

Note: SPA = Strategic Priority Area (see Table 1F1). Indicator scores are divided into eight evenly distributed classes between a minimum score of 0 and a maximum score of 2. A score of 2 means that all actions covered by the indicator have been implemented fully. A score of 0 means that no action has been taken.

Indicator scores:



Source: FAO, 2014a.

calculated at national, regional and global levels. This was done for both the 2012 and the 2014 rounds of reporting (FAO, 2012; 2014a). Indicators for 2014 at strategic priority area level are summarized by region in Table 3F2 (country-level indicators for Strategic Priority Area 4 are shown in Figure 3A8 in Part 3 Section A). The figures show that implementation of the strategic priority areas is, on average, at a high level in North America and in Europe and the Caucasus, and at a medium or low level elsewhere. Implementation of Strategic Priority Area 4 (Conservation) is somewhat less advanced than that of the other strategic priority areas. The indicators for collaboration and funding are at a lower level than those for the strategic priority areas themselves.

Also in 2013, the CGRFA welcomed the idea of establishing a ten-year cycle for the preparation of state of the world reports for the various subsectors of genetic resources for food and agriculture. Following this cycle would mean that the next (third) SoW-AnGR would be published in 2025.

The Funding Strategy for the Implementation of the Global Plan of Action for Animal Genetic Resources was adopted by the CGRFA in 2009 (FAO, 2009a; 2009b). An FAO trust account was established for the receipt of voluntary contributions in support of the implementation of the Global Plan of Action. All trust account funds are dispersed to countries to support implementation activities at national or regional level. By 2011, US$1 million had been contributed to the trust account and the first call for proposals under the Funding Strategy was launched. In 2012, 13 projects, involving 30 countries, were chosen to receive funding.[5]

In addition to developments directly related to the implementation of the Global Plan of Action, the CGRFA has addressed a number of topics that are of relevance to AnGR management. For example, in 2013, the CGRFA adopted its Programme of Work on Climate Change and Genetic Resources for Food and Agriculture (FAO, 2013a). Also in 2013, it requested FAO to prepare *The State of the World's Biodiversity for Food and Agriculture*, which – it stressed – should focus on interactions between the

[5] For further details, see the Funding Strategy web site (http://www.fao.org/ag/againfo/programmes/en/genetics/first_call.html).

various sectors of genetic resources (animal, plant, forest, aquatic, micro-organism and invertebrate) and on cross-sectoral matters (ibid.).

Milestones and outputs for the CGRFA's work across all sectors of genetic resources and in cross-sectoral matters (access and benefit-sharing, climate change, biotechnology, biodiversity indicators and biodiversity and nutrition) are set out in its Multi-Year Programme of Work, which was adopted in 2007 and has been periodically revised (FAO, 2013a). In 2009, the CGRFA adopted a Strategic Plan in which it identified the processes and the partners that would be needed in order to achieve the milestones set out in the Multi-Year Programme of Work. A revised Strategic Plan, covering the period 2014 to 2023, was adopted in 2013 (ibid.).

2.2 Access and benefit-sharing

At the time the first Sow-AnGR was prepared, the main international instruments addressing access and benefit-sharing (ABS) issues were the CBD, the International Treaty on Plant Genetic Resources for Food and Agriculture (International Treaty) (FAO, 2009c) and, among "soft laws", the Bonn Guidelines on Access to Genetic Resources and Fair and Equitable Sharing of the Benefits Arising out of their Utilization (CBD, 2002).[6] While AnGR fall within the scope of the CBD, the specific characteristics and requirements of the AnGR subsector had received little attention in the development of international instruments related to ABS. There was a degree of concern about the potential effects that ABS frameworks might, directly or indirectly, have on the use of AnGR and other genetic resources for food and agriculture. In 2004, the CGRFA had recommended

> *"that FAO and the Commission contribute to further work on access and benefit-sharing, in order to ensure that it move in a direction supportive of the special needs of the agricultural sector, in regard to all components of biological diversity of interest to food and agriculture" (FAO, 2004).*

The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity entered into force on 12 October 2014. During the course of the negotiations on the Nagoya Protocol, the FAO Conference, at the recommendation of the CGRFA, invited the negotiators

> *"to explore and assess options … that allow for adequate flexibility to acknowledge and accommodate existing and future agreements relating to access and benefit-sharing" (FAO, 2009d).*

In 2011, the Commission decided to establish the Ad Hoc Technical Working Group on Access and Benefit-sharing for Genetic Resources for Food and Agriculture and mandated it to

> *"identify relevant distinctive features of the different sectors and sub-sectors of genetic resources for food and agriculture requiring distinctive solutions; taking into account the relevant distinctive features identified, develop options to guide and assist countries, upon their request, in developing legislative, administrative and policy measures that accommodate these features; and analyze, as appropriate, possible modalities for addressing access and benefit-sharing for genetic resources for food and agriculture, taking into account the full range of options, including those presented in the Nagoya Protocol" (FAO, 2011b).*

The Ad Hoc Working Group met in July 2012 in Longyearbyen (Svalbard), Norway (FAO, 2012).

Following the adoption of the Nagoya Protocol, the CGRFA launched a process aimed at the development of "Elements to Facilitate Domestic Implementation of Access and Benefit-Sharing for Different Subsectors of Genetic Resources for Food and Agriculture", intended as a voluntary tool to assist national governments with their work in this field (FAO, 2013a). The outcomes of the process were welcomed by the CGRFA at its Fifteenth Regular Session in 2015 (FAO, 2015).

[6] See FAO, 2007a, pages 277–278.

The Nagoya Protocol – scope and objectives

The Nagoya Protocol was adopted on 29 October 2010 by the Conference of the Parties (COP) to the CBD at its tenth meeting, held in Nagoya, Japan. The objective of the Nagoya Protocol is to further advance the third of the three objectives of the CBD: the fair and equitable sharing of benefits arising out of the utilization of genetic resources, including by appropriate access to genetic resources.

In general, the assumption when selling genetic material in the form of breeding animals, semen, embryos, etc., is that its value as a genetic resource is already reflected in its price, and that the buyer will be free to use it for further research and breeding (FAO, 2009d). However, following the adoption of the Nagoya Protocol, things could change. The point of departure of the Nagoya Protocol is the sovereign right of states over their natural resources (Article 3 of the CBD), which implies that the authority to determine access to genetic resources rests with national governments and is subject to national legislation. The sovereign right of states to determine access to genetic resources should not be confused with other categories of entitlement, such as the private ownership of an animal or genetic material. ABS measures may require that, even though an animal may be the private property of a livestock keeper or the common property of a community, certain conditions (e.g. related to the need for "prior informed consent") have to be met before it can be provided to a third party for research and development. Governments can, however, defer to providers and users to work out arrangements for the exchange of privately held genetic resources, and can choose not to require prior informed consent.

The Nagoya Protocol, in its preamble, explicitly recognizes the importance of genetic resources to food security, as well as

> *"the special nature of agricultural biodiversity, its distinctive features and problems needing distinctive solutions"*

and

> *"the interdependence of all countries with regard to genetic resources for food and agriculture as well as their special nature and importance for achieving food security worldwide and for sustainable development of agriculture in the context of poverty alleviation and climate change ..."*

In this regard, the Nagoya Protocol also acknowledges the fundamental role of the CGRFA and of the International Treaty.[7] In its operational provisions, the Nagoya Protocol requires its Parties to consider, in the development and implementation of their access and benefit-sharing legislation or regulatory requirements, the importance of genetic resources for food and agriculture and their special role for food security.[8] However, the Nagoya Protocol does not specify how, in practice, ABS measures might take these matters into account.

It is important to note that the Nagoya Protocol does not prevent its Parties from developing and implementing other relevant international agreements, including other specialized ABS agreements, provided that they are supportive of and do not run counter to the objectives of the CBD and the Nagoya Protocol.[9] The Nagoya Protocol does not apply with respect to genetic resources covered by and for the purpose of such specialized instruments.[10] The Nagoya Protocol does not require its Parties to apply their ABS legislation or policies to any, or all, of their genetic resources.

Main provisions of the Nagoya Protocol and their relevance to animal genetic resources management

The Nagoya Protocol covers genetic resources, including AnGR, that are provided by Parties that are the countries of origin of the respective resources or by Parties that have acquired the resources in accordance with the CBD. The Nagoya Protocol sets out core obligations for its Parties to take measures in relation to access to genetic resources, benefit-sharing and compliance. It also addresses:

- access to traditional knowledge associated with genetic resources;

[7] CBD, 2011, Preamble.
[8] CBD, 2011, Article 8(c).
[9] CBD, 2011, Article 4.2.
[10] CBD, 2011, Article 4.4.

- the sharing of benefits derived from the utilization of genetic resources and of traditional knowledge associated with genetic resources; and
- the compliance of utilization of genetic resources and traditional knowledge with applicable requirements to obtain prior informed consent, where applicable, and to establish mutually agreed terms.

The Nagoya Protocol does not define "access to genetic resources". Instead it relies on the CBD definition of "genetic resources"[11] and introduces the concept of "utilization" of genetic resources, which according to the Nagoya Protocol means "to conduct research and development on the genetic and/or biochemical composition of genetic resources, including through the application of biotechnology ..."[12] Thus, access to material that is not a genetic resource and access to a genetic resource for purposes other than research and development on its genetic and/or biochemical composition (e.g. access to milk for human consumption) are clearly outside the scope of the Nagoya Protocol. It remains to be seen whether, and to what extent, this definition of utilization proves to be useful in the AnGR subsector. Where, as in the case of AnGR, "research and development" and agricultural production occur in tandem, it may be difficult, in some situations, to distinguish "utilization" from activities related to production.

According to the Nagoya Protocol, access to a genetic resource for its utilization shall be subject to the prior informed consent of the Party that is the country of origin of the resource or has acquired the resource in accordance with the CBD, unless otherwise determined by that Party. Countries of origin of genetic resources, according to the CBD, are countries that possess them "in *in situ* conditions", which are defined as "conditions where genetic resources exist within ecosystems and natural habitats, and, in the case of domesticated or cultivated species, the surroundings where they have developed their distinctive properties".[13] The Nagoya Protocol further states that benefits arising from the utilization of genetic resources shall be shared with the providing Party in a fair and equitable way on the basis of mutually agreed terms.[14] A potential problem in this regard is that for animal breeds that are the result of dispersed contributions and that owe their development to a range of actors and environments in several different countries, it will often be difficult to identify the country in which they "developed their distinctive properties."

The Nagoya Protocol also requires its Parties to

> *"take measures, as appropriate, with the aim of ensuring that traditional knowledge associated with genetic resources that is held by indigenous and local communities is accessed with prior and informed consent or approval and involvement of these indigenous and local communities, and that mutually agreed terms have been established."*[15]

They are also required to ensure that

> *"the benefits arising from the utilization of traditional knowledge associated with genetic resources are shared in a fair and equitable way with the communities holding such knowledge, upon mutually agreed terms."*[16]

Also with regard to traditional knowledge associated with genetic resources, the Nagoya Protocol states that

> *"Parties shall endeavour to support, as appropriate, the development by indigenous and local communities, including women within these communities, of: (a) Community protocols in relation to access to traditional knowledge associated with genetic resources and the fair and*

[11] "Genetic resources" means "genetic material of actual or potential value." "Genetic material" means "any material of plant, animal, microbial or other origin containing functional units of heredity." "Biotechnology" means "any technological application that uses biological systems, living organisms, or derivatives therefore, to make or modify products or processes for specific use" (CBD, Article 2).

[12] CBD, 2011, Article 2.

[13] CBD, Article 2.

[14] CBD, 2011, Article 5.1.

[15] CBD, 2011, Article 7.

[16] CBD, 2011, Article 5.5.

equitable sharing of benefits arising out of the utilization of such knowledge ..."[17]

The potential role of so-called biocultural community protocols in AnGR management is discussed in Part 4 Section D.

The key components of the Nagoya Protocol include the compliance measures: appropriate, effective and proportionate measures to provide that genetic resources utilized within a Party's jurisdiction are of good legal status, i.e. have been accessed with prior informed consent, and that mutually agreed terms have been established, as required by the relevant domestic ABS measures.[18] The rationale for these compliance measures is to discourage illegal access to, or acquisition of, genetic resources. To support compliance, countries have to monitor, and enhance the transparency of, the utilization of genetic resources and associated traditional knowledge, including designating one or more so-called checkpoints.[19] While the Nagoya Protocol's "user-country" measures may well have a deterrent effect in countries that implement and effectively enforce them, they may pose substantial administrative and logistical challenges in many countries. Similarly, Parties will need to consider the potential costs (transaction costs, administrative costs, etc.) of measures they are considering introducing in order to implement the Nagoya Protocol with respect to AnGR. The Nagoya Protocol does not distinguish between user and provider countries. All Parties will have to adopt user-country compliance measures.

2.3 Intellectual property rights

As discussed in the first SoW-AnGR,[20] rapid developments in the field of biotechnology have focused attention on the issue of intellectual property rights in relation to AnGR. Since 2007, the debate on these matters has continued in various international fora. While these debates continue, the World Trade Organization's (WTO) Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS Agreement) remains the main international legal framework in this field. While the TRIPS Agreement, under its Article 27, states that patents shall be available for any invention, whether product or process, in all fields of technology, it allows for some exemptions to patentability. Of particular relevance in the context of AnGR management is the following wording from paragraph 3(b) of Article 27:

"Members may also exclude from patentability ... plants and animals other than microorganisms, and essentially biological processes for the production of plants or animals other than non-biological and microbiological processes."

At the same time, the TRIPS Agreement does not prescribe a specific notion of invention and does not explicitly bind WTO Member States either to allow or to forbid the patentability of substances existing in nature. For further information on the question of the patentability of substances existing in nature, see WIPO (2011).

Article 27.3(b) states that a review of provisions on optional exceptions to patentability should take place four years after the entry into force of the WTO Agreement, i.e. in 1999. This review took place, but did not reach a definitive conclusion. After the Doha Declaration of 2001 (WTO, 2001), the discussion on the review of Article 27.3(b) was broadened to include the relationship between the TRIPS Agreement and the CBD, as well as the protection of traditional knowledge and folklore. Debate on this issue is still ongoing.

In addition to the developments in WTO fora, discussions on this topic are also taking place elsewhere. In 2000, members of the World Intellectual Property Organization (WIPO) established an Intergovernmental Committee on Intellectual Property and Genetic Resources, Traditional Knowledge and Folklore. In 2009, WIPO members agreed to develop an international legal instrument (or instruments) that would give genetic resources, traditional knowledge and traditional cultural expressions effective protection. This process is also ongoing. In particular, WIPO

[17] CBD, 2011, Article 12.3.
[18] CBD, 2011, Article 15.1.
[19] CBD, 2011, Article 17.1.
[20] See FAO, 2007a, Part 3 Section E Subsection 1.5 (pages 279–280) and Part 3 Section E Subsection 2.1 (pages 285–290).

members are considering whether, and to what extent, the intellectual property system should be used to ensure and track compliance with ABS systems in national laws established pursuant to the CBD, its Nagoya Protocol and the International Treaty.

One of the options under discussion is to develop mandatory disclosure requirements that would require patent applicants to show the source or origin of genetic resources, and also possibly evidence of prior informed consent and a benefit-sharing agreement. Another key issue is that of defensive protection of genetic resources, i.e. the implementation of measures aimed at preventing patents that do not fulfil the patentability requirements of novelty and inventiveness from being granted over genetic resources and associated traditional knowledge. Defensive protection measures could include, for example, the creation of databases on genetic resources and traditional knowledge to help patent examiners find relevant prior art and avoid the granting of erroneous patents. Over the years, WIPO has developed a number of tools in the area of intellectual property and genetic resources, including a database of Biodiversity-related Access and Benefit-sharing Agreements[21] and Intellectual Property Guidelines for Access to Genetic Resources and Equitable Sharing of the Benefits arising from their Utilization (WIPO, 2013).

Additional developments have taken place in the forum organized by WIPO's Standing Committee on the Law of Patents (SCP), established in 1998. The work of the Standing Committee led, in 2000, to the adoption of the Patent Law Treaty, which aims to harmonize certain formal aspects of the patent grant procedure. The scope of the Patent Law Treaty, however, does not cover substantive aspects of patent law. In order to harmonize the latter, the Standing Committee began, in 2001, to discuss a draft substantive patent law treaty. In 2006, the draft was put aside because no consensus had been reached on it. Although the draft treaty has been abandoned for the time being, the importance of conducting an international debate on substantive patent law has been recognized and the Standing Committee has been maintained. Currently, five topics related to substantive patent law are under debate within the Standing Committee, namely: exceptions and limitations to patent rights; technology transfer; quality of patents, including opposition systems; confidentiality of communications between patent advisors and their clients; and patents and health.

The first SoW-AnGR included a subsection on the role of patenting as an "emerging issue" in AnGR management.[22] Trends in the use of patents in the AnGR subsector were recently subject to a more in-depth analysis as the basis for the preparation of a WIPO patent landscape report (WIPO, 2014). Findings are summarized in Box 3F1.

Another aspect of the TRIPS Agreement that has some relevance for AnGR management is regulation of the use of geographical indications. Article 22 of the TRIPS Agreement defines geographical indications as "indications which identify a good as originating in the territory of a Member, or a region or locality in that territory, where a given quality, reputation or other characteristic of the good is essentially attributable to its geographical origin." Member countries are obliged to provide legal means by which the "use of any means in the designation or presentation of a good that indicates or suggests that the good in question originates in a geographical area other than the true place of origin in a manner which misleads the public as to the geographical origin of the good" can be prevented. Article 23 provides additional protection for geographical indications for wines and spirits.

Articles 22 and 23 have been subject to negotiations under the Doha Round.[23] A special session of the Council for TRIPS[24] has been negotiating the establishment of a multilateral register for wines and spirits, which would register geographical

[21] http://www.wipo.int/tk/en/databases/contracts/

[22] FAO, 2007a, Part 3 Section E Subsection 2.1 (pages 285–290).

[23] The Doha Round is the round of trade negotiations that began in 2001.

[24] http://www.wto.org/english/tratop_e/trips_e/gi1_docs_e.htm

PART **3**

Box 3F1

Findings of a patent landscape report on animal genetic resources

Patenting activity for animal genetic resources for food and agriculture (AnGR) has received little attention so far in policy discussions. A World Intellectual Property Organization (WIPO) patent landscape report prepared in collaboration with FAO establishes that patenting activity involving livestock occurs in the fields of biotechnology, pharmaceuticals, immunology and gene therapy, stem cells and transgenic animals. It shows that animals are important experimental models, sources of material for medical products and bioreactors for recombinant proteins. The report identifies six broad categories of AnGR-related technology development: artificial insemination; sex selection and control of oestrus; marker-assisted breeding; transgenic animals; animal cloning; xenotransplantation; and animal models. To assist in future policy deliberations on access to AnGR and benefit-sharing, a flexible and updatable indicator has been developed to monitor trends in patent activity in the AnGR subsector.

Key reproductive technologies in animal breeding, such as artificial insemination, embryo transfer, *in vitro* fertilization and superovulation, have a long history. The creation of a transgenic mouse using DNA microinjection in 1980 (the "oncomouse", see Patent US4736866A) marked the emergence of genetically engineered animals. This was followed by somatic cell nuclear transfer and animal cloning in the 1990s. Patenting activity in these areas focuses on methods rather than specific genetic sequences. In parallel, from the early 2000s onwards, phenotypic selection for breeding using Best Linear Unbiased Prediction (BLUP) approaches was increasingly complemented, and in some cases replaced, by DNA marker-assisted breeding and genomic selection indexes. The completion of genome mapping projects for pigs (2012), zebu cattle (2012) and water buffalo (2014) are likely to accelerate trends towards the use of genomic selection indexes.

Patenting activity involving AnGR increased markedly in the late 1990s, focusing on expressed sequence tags (ESTs) and single nucleotide polymorphisms (SNPs). SNPs are important in marker-assisted breeding for the identification of traits such as meat or milk quality. At the same time, patenting activity involving transgenic livestock also increased. However, activity involving AnGR declined sharply from 2001, caused by a combination of factors including an increasingly restrictive approach to the patentability of DNA sequences by patent offices and a lack of markets for food products from transgenic animals.

The majority of activity focuses on mainstream breeds and there is no substantive evidence of activity that might be considered to involve misappropriation or biopiracy of genetic resources and associated traditional knowledge in the patent data. Nevertheless, patent claims involving livestock are commonly constructed to include large groupings of animals (e.g. bovine, porcine or ruminant). Where granted and in force, such patents could affect the ability of livestock keepers to utilize AnGR or specific technologies in breeding. Furthermore, trends towards genetic selection on economic traits, such as milk or meat quality or disease resistance, reflected in patent documents could have negative implications for the conservation of the global livestock gene pool. Genome mapping projects and the rise of commercial genomic selection indexes suggest the convergence of genomic information with software and business methods that may be eligible for patent protection. Trends in activity arising from genome sequencing projects merit careful attention with regard to their implications (positive or negative) for AnGR management. Finally, research disclosed in patents on disease control and climate change technologies could have wider applicability to livestock keepers in developing countries, something that merits further research.

Provided by Eirini Kitsara, WIPO.
For further information, see WIPO, 2014.

indications for wines and spirits and provide notification of the registries for those Members using the system. Linked to the negotiations of the multilateral register, are discussions on the extension of the higher level of protection, as provided for in Article 23, beyond wines and spirits. Members remain deeply divided on this issue. Those in favour of expanding the register have argued that a higher level of protection for more goods is a better way to defend and market locally based products (e.g. WTO, 2005). Those in opposition have argued that the existing level of protection is adequate and that expanding protection would create unnecessary burdens that would disrupt legitimate marketing practices (Taubman *et al*., 2012). As part of the ongoing review pursuant to Article 24.2 of the TRIPS Agreement, negotiations on other matters related to geographical indications continue under the auspices of the Council for TRIPS. These include a stock-taking exercise of national practices in this field (WTO, 1998; 2010). Given the role of product marketing in the "valorization" of livestock breeds (see Part 3 Section D and Part 4 Section D), these developments are potentially relevant to AnGR management. However, their significance is difficult to assess.

The issue of patenting in the AnGR subsector has always been controversial. While some stakeholders argue that the possibility of obtaining a patent helps to stimulate innovation, others express a range of ethical and socio-economic concerns.[25] The trend towards greater use of the intellectual property rights system to incentivize and protect advances in breeding and associated technologies has been one of the factors motivating various civil society organizations to advocate the establishment of so-called livestock keepers' rights (see Part 3 Section A) and biocultural community protocols (see Part 4 Section D).

2.4 Regulation of international trade, including sanitary issues

The main international legal framework regulating trade livestock and livestock products is provided by the WTO's Agreement on Agriculture (adopted in 1994).[26] Trade in animals and animal products is greatly affected by sanitary rules, i.e. many countries' ability to trade is limited as a result of their having a poorer disease status than potential trading partners. This can have a knock-on effect on AnGR management. For example, access to breeding animals or genetic material may be constrained and restrictions on access to export markets may affect demand for livestock products and hence the profitability of using particular types of AnGR.

The WTO's Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) aims to ensure that trade restrictions are minimized by requiring that members ensure "that any sanitary or phytosanitary measure is applied only to the extent necessary to protect human, animal or plant life or health, is based on scientific principles and is not maintained without sufficient scientific evidence ..." (Article 2, paragraph 2). Measures that "conform to international standards, guidelines or recommendations" are "deemed to be necessary to protect human, animal or plant life or health, and presumed to be consistent with the relevant provisions [of the agreement]" (Article 3, paragraph 2). In the case of animals and animal products, the relevant international standards are those of the World Organisation for Animal Health (OIE)[27] and the Codex Alimentarius Commission.[28] Countries can implement more restrictive standards if there is scientific justification or if determined to be appropriate based on the risk assessment procedures set out in the agreement (Article 3, paragraph 3).

The legal framework for trade and sanitary matters that was in place in 2005/2006 remains largely unchanged in 2014. One issue that has become increasingly prominent in recent years is the question of private-sector standards, such as those set by supermarket chains. Standards of this type have the potential to affect demand for animal

[25] See FAO, 2007a, pages 285–89 for an overview of these issues.

[26] FAO, 2007a, Part 3 Section E Subsections 1.4 and 1.6 (pages 278–283).

[27] http://www.oie.int/

[28] http://www.codexalimentarius.org/

products and hence the use and development of AnGR. In 2011, the WTO's Committee on Sanitary and Phytosanitary Measures agreed to take some actions aimed at reducing the potential negative effects of private-sector standards on countries' abilities to trade internationally (WTO, 2011). Discussions on this topic have continued, but at the time of writing remain unresolved.

2.5 Conclusions

As far as legally binding instruments relevant to the management of AnGR are concerned, the most significant development of recent years has been the adoption and entry into force of the Nagoya Protocol. Implications for the AnGR subsector are not yet clear. Efforts to ensure appropriate provisions for the various subsectors of food and agriculture are ongoing, *inter alia* under the auspices of the CGRFA. Negotiations on various international legal frameworks that may directly or indirectly affect the management of AnGR, most notably on issues related to international trade and intellectual property rights, are also ongoing. The Global Plan of Action for Animal Genetic Resources notes the need to ensure that the various international instruments that affect countries' capacities to exchange, use and conserve AnGR, and to trade animal products, are mutually supportive. It calls for a review of such frameworks

> *"with a view to ensuring that [they] ... take into account the special importance of animal genetic resources for food and agriculture for food security, the distinctive features of these resources needing distinctive solutions, the importance of science and innovation, and the need to balance the goals and objectives of the various agreements, as well as the interests of regions, countries and stakeholders, including livestock keepers."*[29]

Whether or not AnGR-related concerns are successfully mainstreamed into negotiations related to the ongoing development of international legal frameworks, these frameworks will continue to influence the development of the livestock sector internationally and hence affect the use of AnGR. It is therefore important that stakeholders involved in AnGR management pay attention to developments in the international legal arena and have the capacity to follow them and interpret their implications for the subsector. There may be some need for capacity-development and awareness-raising in this field.

In terms of international policy, the major development since the time the first SoW-AnGR was prepared has been the adoption of the Global Plan of Action. Countries' ongoing commitment to the process has been demonstrated by developments such as the adoption of the Funding Strategy for the Global Plan of Action and the establishment of a mechanism for monitoring implementation, as well as by the large number of countries that reported on their implementation activities in 2012 and 2014. The Global Plan of Action was envisaged as a rolling plan, with an initial time horizon of ten years. The outputs of the second SoW-AnGR process will provide a basis for reviewing and potentially revising the Global Plan of Action (FAO, 2014b; 2015).

The adoption of the CBD's Strategic Plan for Biodiversity and the Aichi Targets, including Target 13 on the maintenance of genetic diversity, was another major development. Updated national biodiversity strategy and action plans, the main instruments for the implementation of the CBD at country level, are increasingly including references to AnGR and actions related to their management (see Subsection 4 for further discussion).

3 Regional frameworks

This subsection discusses the effects of legal and policy frameworks at regional level (i.e. applying to a group of countries) on the management of AnGR, focusing particularly on developments since the first SoW-AnGR was drafted in 2005/2006. The equivalent subsection in the first

[29] FAO, 2007b, Strategic Priority 21, Action 1.

SoW-AnGR focused largely on the legal and policy framework in place in the European Union (EU),[30] because of its comprehensive nature and many AnGR-relevant provisions. EU frameworks are, similarly, the main focus of this updated analysis (particularly given that the frameworks in most of the fields discussed in the first AnGR have been updated during the intervening period). Regional-level policy frameworks, and in particular regional-level legally binding instruments, in fields directly relevant to AnGR management are rare in other regions. The discussion of instruments outside the EU is therefore, inevitably, relatively brief in comparison. Initiatives at regional level not specifically related to legal and policy frameworks, particularly the activities of regional focal points for the management of AnGR, are discussed in Part 3 Section A.

3.1 The European Union

EU legislation relevant to AnGR management addresses a range of different topics, including conservation, zootechnics (animal breeding), animal health, trade in animals and animal products, organic agriculture, food and feed safety, the use of genetically modified organisms (GMOs) and access and benefit-sharing. The EU utilizes several different types of legal instrument, some of which are binding and some of which are not. Binding instruments fall into three main categories: regulations, directives and decisions. A regulation is a legislative act that must be applied in its entirety across the whole EU. A directive sets out goals that member countries must achieve, but leaves it up to countries to decide how they wish to achieve the these goals. A decision is binding on those (e.g. an EU country or an individual company) to whom it is addressed and is directly applicable (EU, 2014a).

[30] Member states: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom.

General frameworks addressing agriculture, rural development and biodiversity

The EU's Common Agricultural Policy (CAP) comprises a set of rules and mechanisms regulating the production, trade and processing of agricultural products in the EU. It has a major influence on the agricultural sector in EU member countries and has major implications for the management of all resources used in agriculture, including AnGR. The first SoW-AnGR emphasized the significance for AnGR management of the reforms to the CAP that had occurred over the preceding decade and a half, particularly the introduction of agri-environmental schemes, first under Council Regulation (EEC) No 2078/92 and then under Council Regulation (EC) No 1257/99. At the time the first SoW-AnGR was drafted, Council Regulation (EC) No 1698/2005, a new act providing a framework for support for rural development, financed by the European Agricultural Fund for Rural Development, had recently been passed. The objective of the fund, whose first funding period ended in 2013, is to improve the competitiveness of agriculture and forestry, the state of the environment and the countryside, and the quality of life and economic activity in rural areas (EU, 2012). On the basis of strategic guidelines (Council Decision 2006/144/EC), EU member countries developed national rural development strategy plans (RDP) for the 2007 to 2013 period. These plans constituted the reference framework for rural development programmes featuring measures grouped around four "axes": 1. improving the competitiveness of the agricultural and forestry sector; 2. improving the environment and the countryside; 3. quality of life in rural areas and diversification of the rural economy; and 4. "LEADER" (related to local development strategies involving public–private partnerships).

Council Regulation (EC) No 1698/2005 states specifically (Article 39) that, under Axis 2, agri-environment payments can be provided for the conservation of genetic resources in agriculture. The actions under the other axes do not directly target AnGR. However, they potentially influence demand for different types of AnGR via demand for

the various products and services that they provide. Measures that promote the diversification of the rural economy and the economic sustainability of rural livelihoods, particularly those of smaller-scale producers in harsh or remote production systems, have at least some potential to provide indirect support to the maintenance of diverse AnGR.

The background to the establishment of these instruments was the CAP reform of 2003, which involved the decoupling of farm support payments from production and the introduction of so-called single farm payments (Council Regulation (EC) No 1782/2003; Council Regulation (EC) No 73/2009). It was noted at the time that these developments, at least in theory, had the potential to reduce the profitability of keeping at-risk breeds and bring about a fall in their population sizes unless alternative economic incentives emerged (Canali and the Econogene Consortium, 2006). Concerns were also expressed about an increase in the minimum area eligible for single farm payments, because of the significant role played in breed conservation by part-time farmers and hobby breeders operating on small areas of land (RBST, 2009). Zjalic (2008) noted that the expected decline in the overall number of sheep and goats in the EU as a result of decoupling could prove to be a threat to some breeds, but also that agri-environmental schemes providing payments for raising at-risk breeds might become increasingly attractive as an alternative source of income. Such reflections about future trends are, however, inevitably rather speculative. A review undertaken in 2010, based on consultations with National Coordinators for the Management of Animal Genetic Resources from EU countries (Zjalic, 2010), suggested that the effects of the reforms on the status of at-risk breeds had generally not been large.

In 2010, the European Commission launched a public debate on the future of the CAP, which attracted 5 700 submissions from stakeholders, think tanks and research organizations, and the general public. The report summarizing the outcome of the process concluded there was considerable consensus among EU citizens that the objectives of agriculture in the EU should be "provision of a safe, healthy choice of food, at transparent and affordable prices; ensuring sustainable use of the land; activities that sustain rural communities and the countryside; and security of food supply (European Commission, 2010). The specific "directions to be followed" identified via the consultation process included efforts to "protect the environment and biodiversity, conserve the countryside, sustain the rural economy and preserve/create rural jobs, and mitigate climate change" (ibid.).

In 2011, the European Commission presented a set of legal proposals for the future of the CAP (EU, 2014b) and an "impact assessment" of various policy options (European Commission, 2011). In June 2013, political agreement on CAP reform was reached. In December of the same year, four basic regulations were adopted – Regulation (EU) No 1305/2013 on rural development, Regulation (EU) No 1306/2013 on "horizontal" issues such as funding and controls, Regulation (EU) No 1307/2013 on direct payments to farmers and Regulation (EU) No 1308/2013 on market measures – along with transitional rules for the year 2014. Under the regulation on rural development, "agri-environment-climate" support payments can be made "for the conservation and for the sustainable use and development of genetic resources in agriculture." Under the same regulation, the European Commission is also empowered to adopt delegated acts[31] related to "the conditions applicable to commitments to rear local breeds that are in danger of being lost to farming or to preserve plant genetic resources that are under threat of genetic erosion." In this regard, Commission Delegated Regulation (EU) No 807/2014, adopted in March 2014, sets out rules for determining whether a breed is "in danger of being lost to farming." In contrast

[31] The European Commission may be delegated "power to adopt non-legislative acts of general application to supplement or amend certain non-essential elements of the legislative act" (Article 290 of the Treaty on the Functioning of the European Union – available at http://tinyurl.com/pmkex58).

to previous arrangements, the new framework does not include a set of population thresholds. Member states are required to determine for themselves whether breeds fall into this category. The following conditions must be met:

"(a) the number of breeding females at national level concerned is stated;
(b) that number and the endangered status of the listed breeds is certified by a duly recognised relevant scientific body;
(c) a duly recognised relevant technical body registers and keeps up-to-date the herd or flock book for the breed;
(d) the bodies concerned possess the necessary skills and knowledge to identify animals of the breeds in danger."

The effects that the other aspects of the 2014 CAP reform will have on AnGR management are difficult to predict. Developments such as the provision of support for young people entering the agricultural sector and a range of measures to support the economic and social vitality of rural areas, along with the above-mentioned agri-environmental measures, are broadly compatible with efforts to support livestock-keeping livelihoods that involve the use of breeds that are at risk, or potentially at risk, of extinction (SAVE Foundation, 2013). With regard to the abolition of milk quotas, the country report from Poland notes that this is likely to have a significant effect on the utilization of AnGR, although precise outcomes are difficult to predict. The report notes that Poland has high potential to increase dairy production and that concentration of the sector might be very rapid and lead to substantial breed replacement.

In 2012, the European Commission launched the European Innovation Partnership "Agricultural Productivity and Sustainability" (EIP-AGRI) (European Commission, 2012a). European Innovation Partnerships are intended to "address weaknesses, bottlenecks and obstacles in the European research and innovation system that prevent or slow down good ideas being developed and brought to market" (European Commission, 2012b). The communication that launched EIP-AGRI heavily emphasized the important role of agricultural genetic resources, noting that "making use of European genetic diversity unlocks a vast potential for development." Roles are foreseen across most of the "areas of innovative actions" described in the document, which range from "increased agricultural productivity, output, and resource efficiency" to "biodiversity, ecosystem services, and soil functionality" and "innovative products and services for the integrated supply chain." A focus group on "genetic resources – cooperation models" has been established and held its first meeting in early 2014 (European Commission, 2014a).[32]

In the general field of biodiversity conservation and management, significant policy developments in recent years have included the adoption by the European Parliament (EU, 2007) of the 2006 Biodiversity Communication and Action Plan: "Halting the loss of biodiversity by 2010 – and beyond" (European Commission, 2006a; 2006b; 2006c). The plan included a set of objectives, targets and actions. Most relevant to AnGR were Objective 2: "To Conserve and Restore Biodiversity and Ecosystem Services in the Wider EU Countryside", which under the heading "Agricultural and rural development policy" included the target "Member States have optimised use of opportunities under agricultural, rural development and forest policy to benefit biodiversity 2007–2013" and the action "Strengthen measures to ensure conservation, and availability for use, of genetic diversity of crop varieties, livestock breeds and races, and of commercial tree species in the EU, and promote in particular their *in situ* conservation."

In 2011, the European Commission adopted the EU Biodiversity Strategy to 2020, which includes the headline target of "Halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, and restoring them in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss" (EU, 2011).

[32] Further information can be found on the European Commission website: http://tinyurl.com/opxf7qt (EIP-AGRI); http://tinyurl.com/pycgx8w (focus group on genetic resources).

Genetic resources for food and agriculture are targeted under several actions, including via references to facilitating "collaboration among farmers and foresters to achieve continuity of landscape features, protection of genetic resources and other cooperation mechanisms to protect biodiversity" (Action 9), encouraging "the uptake of agri-environmental measures to support genetic diversity in agriculture and explore the scope for developing a strategy for the conservation of genetic diversity" (Action 10) and regulating "access to genetic resources and the fair and equitable sharing of benefits arising from their use" (Action 20). In 2012, the European Parliament adopted a resolution[33] on the biodiversity strategy. Of particular relevance to AnGR management are paragraphs 71 and 72 of the resolution, which call for

> *"appropriate legislation and incentives for the maintenance and further development of diversity in farm genetic resources, e.g. locally adapted breeds and varieties"*

and stress

> *"the need for more effective cooperation at European level in the field of scientific and applied research regarding the diversity of animal and plant genetic resources in order to ensure their conservation, improve their ability to adapt to climate change, and promote their effective take-up in genetic improvement programmes."*

Animal genetic resources management

This subsection discusses instruments that specifically target the management of AnGR. These instruments fall roughly into two categories: those targeting animal breeding or "zootechnics" and those targeting the broader sustainable management of AnGR, with particular emphasis on breeds that are at risk of extinction.

EU zootechnical legislation addresses a range of issues related to animal breeding. The legal framework described in the first SoW-AnGR[34] was largely still in place at the time of writing (July 2014). Separate sets of legal instruments are in place for each of the main mammalian livestock species or species groups raised in the EU (bovine, porcine, ovine and caprine, and equine) addressing a range of different aspects of the breeding process and trade in breeding animals (recognition of breeding organizations, entering in herdbooks, pedigree certificates and acceptance for breeding). For "other breeding animals" a basic directive is in place, but no implementing measures providing rules for the various above-listed elements. Another set of instruments regulates the import of breeding animals and genetic material from outside the EU and a further Council Decision regulates the operation of INTERBULL as the official reference centre for pure-bred breeding animals of bovine species. The main objectives of this body of legislation are to promote public health and food safety (rules on identification and registration), ensure the quality of traded breeding stock (rules requiring uniform breeding methods) and promote equity among breeders (rules ensuring that all breeders and breeding organizations are subject to the same requirements).

At the time of writing, a review of these measures was underway with a view to their consolidation under a single regulation and directive, the aim being (*inter alia*) to address concerns about inconsistencies in the interpretation of the existing provisions by the authorities in different countries and hence potential obstacles to trade and the operation of the EU single market (European Commission, 2014b; 2014c). It is expected that this review will be completed by the end of 2015.

As described above, Council Regulation (EC) No 1698/2005 allowed for the provision of agri-environment payments for the conservation of genetic resources in agriculture, and similar provisions are now in place under Regulation (EU) No 1305/2013. These payments are the mainstays of support for *in situ* conservation measures in the EU. However, support for a range of activities related to the conservation and sustainable use of AnGR is also addressed within the framework of Council Regulation (EC) No 870/2004, which established a second Community Programme on

[33] P7_TA(2012)0146.

[34] FAO, 2007a, pages 295–296.

the "conservation, characterization, collection and utilization of genetic resources in agriculture." Actions that can potentially receive support under the programme include those related to establishing inventories of conservation measures and the exchange of scientific and technical information, as well as those more directly related to conservation (*in situ* and *ex situ*), characterization, etc. Seventeen co-funded actions under the programme commenced in 2007, with a maximum duration of four years (European Commission, 2013a).[35] Five of these projects targeted AnGR: Towards self-sustainable European Regional Cattle Breeds;[36] An Integrated Network of Decentralized Country Biodiversity and Genebank Databases;[37] Heritage Sheep;[38] European Livestock Breeds Ark and Rescue Net;[39] and A Global View of Livestock Biodiversity and Conservation.[40]

An independent expert evaluation of the Community Programme published in 2013 (European Commission, 2013b) noted a number of positive outcomes and recommended that the programme should be continued. It concluded that the programme had:

"a. stimulated considerable interest among various groups of stakeholders within the European Union and beyond;
b. promoted collaboration among diverse groups of stakeholders in different countries;
c. led to the establishment of useful links and partnerships across Europe;
d. advanced the understanding of some local practices and needs;
e. led to useful results and guidelines for the conservation of valuable genetic resources;
f. established well characterised and evaluated core collections and cryo-banks of various plant and animal species; and
g. improved the scientific knowledge on the nature, management and potential of genetic resources of some species of farm animals, crops and forest trees in Europe."

However, the assessment noted that the utilization component of the programme had not been addressed to the same extent as the other components. To address this gap, it recommended that "the primary objective of selected Actions be the delivery of appropriate utilisation of agricultural genetic resources in practice" and that "increased involvement of end-users and small and medium enterprises in the funded actions, to ensure the immediate transfer and implementation of project results." With regard to AnGR management specifically, the submission provided by the European Regional Focal Point on Animal Genetic Resources to the expert evaluation emphasized the opportunity that the programme provided to link "on-farm" conservation activities to research activities (ERFP, 2012). It also noted that applied research under the five AnGR-related co-funded actions had contributed enormously to the sustainable management of AnGR. The weak points of the programme were considered to be the limited amount of funding available overall and the lack of continuity associated with project-based activities (ibid.).

With the aim of implementing the recommendations of the evaluation of the second Community Programme, the European Parliament, in 2013, allocated 1.5 million euros for a "preparatory action on EU plant and animal genetic resources"[41] that would review the state of genetic resources-related activities in the EU and make practical recommendations for future improvements (European Commission, 2013c).

[35] See web site: http://ec.europa.eu/agriculture/genetic-resources/actions/index_en.htm
[36] See web site: http://ec.europa.eu/agriculture/genetic-resources/actions/f-012/index_en.htm
[37] See web site: http://ec.europa.eu/agriculture/genetic-resources/actions/f-020/index_en.htm
[38] See web site: http://ec.europa.eu/agriculture/genetic-resources/actions/f-040/index_en.htm
[39] See web site: http://ec.europa.eu/agriculture/genetic-resources/actions/f-066/index_en.htm
[40] See web site: http://ec.europa.eu/agriculture/genetic-resources/actions/f-067/index_en.htm
[41] See website: http://ec.europa.eu/agriculture/calls-for-tender/2013-271472_en.htm

The following themes were identified for inclusion in the review:

"improvement of the communication between Member States concerning best practice and the harmonisation of efforts in the conservation and sustainable use of genetic resources";
"enhancing networking among key stakeholders and end-users in view of exploring marketing (and other cooperation) opportunities, such as provided by quality schemes and short supply chains";
"improvement of the exchange of knowledge and research on genetic diversity in agricultural systems";
"adaptation of breeding methods and legislation to the need of conservation and sustainable use of genetic diversity";
"contribution to the successful implementation of rural development measures concerning genetic diversity in agriculture";
"explore bottlenecks and enabling conditions for the sustainable use of genetic resources in agriculture"; and
"reduction of the unnecessary administrative burden so as to provide better access to actions."

Access and benefit-sharing

Following the adoption of the Nagoya Protocol (see Subsection 2), the EU was faced with the task of establishing dedicated legislation that would enable it to proceed with ratification and implementation. A draft regulation was developed by the European Commission (European Commission, 2012c), based on an extensive impact assessment study covering all relevant economic sectors and involving broad stakeholder consultation (European Commission, 2012d). The draft regulation covered the elements of the Nagoya Protocol that required harmonization and were better addressed at EU level – namely user measures and compliance – leaving access requirements to be considered by the individual EU Member States.

The draft regulation, together with the proposal for the ratification of the Nagoya Protocol, was presented to the European Parliament and the Council of Ministers in October 2012. The submission of the draft regulation was followed by an intensive period of discussions and negotiations between the different EU institutions involved in the legislative process. Political compromise between the co-legislators – the Council and the European Parliament – on the text of a draft regulation was achieved at the end of 2013. The vote in the Plenary of the European Parliament took place in March 2014 and the Council of Ministers adopted the regulation the following month. Successful completion of the process enabled ratification of the Nagoya Protocol by the EU on 16 May 2014 and publication of Regulation (EU) No 511/2014 on 20 May. The remaining step at EU level was to develop and agree on implementing acts. An ABS Committee established by the European Commission completed this task in July 2015. The ratification of the Nagoya Protocol by individual Member States is proceeding in accordance with their internal procedures.

The regulation sets out rules governing compliance with the Nagoya Protocol's provisions on access and benefit-sharing for genetic resources and traditional knowledge associated with genetic resources. It is based on the principle that users of genetic resources should exercise "due diligence" in ascertaining that applicable rules on access and benefit-sharing have been and are followed (Article 4). The due diligence concept, which is elaborated in the EU timber regulation (Regulation (EU) No 995/2010), contains three elements: provision of information; risk assessment; and risk mitigation. The benefit-sharing requirements of the Nagoya Protocol are to be dealt with on the basis of "mutually agreed terms" between the provider and the user.

Regulation (EU) No 511/2014 also covers compliance measures, such as checkpoints (Article 7) and risk-based monitoring of users (Article 9), as well as the establishment of competent authorities and national focal points, and reporting and submission of information to the Access Benefit

Sharing Clearing House.[42] It requires Member States to establish penalties that are effective, proportionate and dissuasive. It also establishes important compliance-facilitation tools, such as EU-registered collections (Article 5) and recognized best practices (Article 8).

The influence that the Nagoya Protocol will have on the management of AnGR in the EU is difficult to predict. Effects will depend heavily on the access legislation adopted by individual Member States and other Parties to the Nagoya Protocol. However, it is possible that the new arrangements will help to promote gene banking and the development of AnGR held in the public domain.

Animal health

The first SoW-AnGR provided an overview of the EU framework for animal health – a large body of instruments addressing various individual species, health problems and livestock-sector activities – and noted a number of potential effects on AnGR and their management. Given that animal health problems can pose a direct threat to the survival of at-risk breed populations and can undermine the economic sustainability of livestock-keeping livelihoods, a well-regulated animal-health system is an important component of AnGR management in the broad sense. Potentially negative consequences include the effects of compulsory culling campaigns on at-risk breed populations and various restrictions and requirements that may constrain conservation activities or the keeping of certain breeds in their traditional production systems. The report noted both that some problems of this type had arisen at EU level and that some steps had been taken to address them (e.g. allowing for potential derogations for at-risk breeds in the event of a culling campaign and adjusting animal identification requirements to account for problems encountered in certain extensive production systems).

In 2008, the European Commission adopted a communication on an action plan for the implementation of a new animal health strategy for the EU for the six years to 2013 (European Commission, 2008). The strategy document, subtitled "Prevention is better than cure", noted the challenges posed by new and re-emerging diseases and by the increased volume of trade in animal products, both within the EU and with third countries. The strategy was based on four main pillars: "1. Prioritisation of EU intervention; 2. The EU animal health framework; 3. Prevention, surveillance and preparedness; and 4. Science, innovation and research" (European Commission, 2007).

With regard to regulation, the objective was to develop a "single clear regulatory framework" converging as far as possible with the standards and guidelines of the World Organisation for Animal Health (OIE)[43] and the Codex Alimentarius Commission.[44] After extensive consultations a proposal for a new regulation on animal health was published in 2013 (European Commission, 2013d), the intention being to streamline the large number of existing instruments in this field into a single law. In April 2014, the European Parliament adopted a legislative resolution containing a number of amendments to the draft act (EU, 2014c). These amendments featured a number of references to AnGR management, including statements that:

- competent authorities should consider effects on diversity and the need to conserve AnGR when deciding upon what actions to take in the event of a disease outbreak;
- the European Commission should take breed-level diversity into account when adopting delegated acts related to the approval of establishments[45] of various kinds; and
- breed should be included as a data item in traceability systems for genetic material.

[42] The Access and Benefit-sharing Clearing-House was established under Article 14 of the Nagoya Protocol.

[43] http://www.oie.int

[44] http://www.codexalimentarius.org/

[45] An "establishment" in this context refers to "any premises, structure, or any environment, in which animals or germinal products are kept, except for: (a) households keeping pet animals; (b) non-commercial aquaria keeping aquatic animals; (c) veterinary practices or clinics."

Organic products and other specialized food products

Supplying products to niche markets is recognized as a potential means of keeping breeds in profitable production and thereby reducing the likelihood that they will fall out of use and face the risk of extinction (see Part 4 Section D). Niche marketing can be facilitated by the existence of a legal framework that regulates the designation and labelling of particular classes of products that have characteristics that make them attractive to particular groups of consumers.

The first SoW-AnGR noted the existence of a number of EU quality schemes covering animal products, and briefly described the legal framework established during the 1990s to regulate the operation of these schemes.[46] A new framework was put in place in 2006: Council Regulation (EC) No 510/2006 on protected geographical indications (PDI) and protected designations of origin (PDO); and Council Regulation (EC) No 509/2006 on traditional specialties guaranteed (TSG). In the case of PDIs and PDOs, the rules stated that a name could not be registered if it conflicted "with the name of a plant variety or an animal breed and as a result is likely to mislead the consumer as to the true origin of the product." The regulation on TSGs, however, stated that the "name of a plant variety or breed of animal may form part of the name of a traditional speciality guaranteed, provided that it is not misleading as regards the nature of the product." Rules related to product specification (i.e. the description of the product for the purposes of its registration under one of the quality schemes) included no references to breed-related information. Many PDIs, PDOs and TGIs for animal products involve no requirement that the product comes from a specific breed.

2012 saw the adoption of a new unified instrument, Regulation (EU) No 1151/2012. The main innovative feature of this instrument is the establishment of a scheme for the use of "optional quality terms", the objective being "to facilitate the communication within the internal market of the value-adding characteristics or attributes of agricultural products by the producers thereof." The regulation establishes the term "mountain product" as an optional quality term and requires the European Commission to investigate the case for a new term "product of island farming". A report setting out the pros and cons of introducing this term was published late in 2013 (European Commission, 2013f). Conditions of use for the "mountain product" quality term are further elaborated under Commission Delegated Regulation (EU) No 665/2014. The European Commission has also investigated the possibility of establishing a labelling scheme for "local farming and direct sales" (European Commission, 2013f).

The EU legal framework for organic agriculture has also been revised since the time the first SoW-AnGR was drafted (2005/2006). The main instrument in the current framework is Council Regulation (EC) No 834/2007, which addresses both crop and livestock production. Detailed rules for the implementation of this regulation are set out in Commission Regulation (EC) No 889/2008. Under this new framework, provisions related to the choice of breeds for organic livestock production are similar to those previously in place,[47] i.e. account must be taken of animals' capacity to adapt to local conditions. Likewise, both the 1999 and the 2007 regulations refer to the use of well-adapted breeds being a fundamental element of organic disease-control strategies. The 2007 regulation also refers to the use of well-adapted breeds as a means of avoiding the use of welfare-unfriendly practices. The provisions of the 2007 regulation that address the use of "non-organic" animals for breeding purposes, allow some additional flexibility in the use of such animals in the case of breeds that are at risk of extinction.

On the policy front, the European Action Plan for Organic Food and Farming, launched by the European Commission in 2004 (European Commission 2004a; 2004b), was replaced in 2014 by the Action Plan for the Future of Organic Production in the

[46] See FAO, 2007a, pages 296–297.

[47] Regulation (EC) 1804/1999 (see FAO, 2007a, page 297 for further information).

European Union (European Commission, 2014d). The new plan aims to ensure, *inter alia*, that consumer trust and the integrity of organic production are maintained in the face of rising demand and changing societal expectations, while also avoiding overcomplicated rules that exclude small operators and maintaining the innovative role of the organic sector. It contains no specific references to the role of AnGR diversity in organic agriculture.

A legislative proposal for a new regulation (replacing that of 2007) was published by the European Commission in March 2014 (European Commission, 2014e; 2014f). The roles of well-adapted breeds are again highlighted and the above-mentioned provision related to the use of non-organic breeding animals from at-risk breeds is maintained (in other respects, the rules regarding the origin of breeding animals for use in organic agriculture become less flexible).

The precise implications of these developments for AnGR management remain unclear. While the growth of organic production probably contributes to some degree to increasing demand for locally adapted animals – and thus keeping relevant laws and policies updated is likely to be conducive to sustainable AnGR management – in many cases, organic production is based on "mainstream" breeds widely used in conventional agriculture. Effects on the use of AnGR at national level in some EU countries are discussed below in Subsection 4.4. Some criticism has been directed at the current EU framework on the grounds that allowing the widespread use of mainstream animals in organic agriculture creates welfare problems because of these animals' lack of adaptedness to more "natural" production environments (Compassion in World Farming, 2013; Eurogroup for Animals, 2013).

Animal welfare

The main EU legal instrument on the welfare of animals kept for farming purposes is Council Directive 98/58/EC. This directive includes rules on the use of breeding procedures and others related to the need to ensure that "on the basis of their genotype or phenotype" animals "can be kept without detrimental effect on their health and welfare." Specific instruments addressing the welfare of laying hens, calves, pigs and broiler chickens are also in place. The main developments since the time the first SoW-AnGR was drafted (2005/2006) have been the adoption of Council Directive 2007/43/EC on broiler welfare and Council Directive 2008/119/EC and Council Regulation (EC) No 1099/2009, updating, respectively, rules on calf welfare and welfare at the time of slaughter. The main policy instrument in this field is the EU Strategy for the Protection and Welfare of Animals 2012–2015 (European Commission, 2012e). The various new laws and policies do not include any provisions specifically related to the use of breeding technologies or to the circumstances in which particular genotypes can be raised. However, the broiler Directive does request a report on genetic parameters and their influence on broiler welfare.

The extent to which welfare-related instruments affect the management of AnGR is difficult to estimate. As production systems are adapted to meet welfare rules, demand for various types of AnGR is likely to change to some degree. More direct effects may potentially arise in connection with the use of breeds that have specific phenotypes that may affect their welfare. An interesting example of a cattle breed whose use has been the subject to legal challenges is the Belgian White Blue, which because of its double muscling phenotype has a high rate of caesarean sections (Lips *et al*., 2001). During the 1990s, the European Court of Justice ruled that under European zootechnical legislation (Directive 87/328/EEC) Sweden could not forbid, because of welfare concerns, the use of imported semen from this breed, on the grounds that "national authorities are not entitled to reject the use of semen of that breed … since the genetic peculiarities and defects of an animal may be defined only in the Member State in which the breed of cattle has been accepted for artificial insemination" (Case C-162/97).[48] In other

[48] Judgment of 19.11.1998 — Case C-162/97 Judgment of the Court (Fifth Chamber) 19 November 1998 (available at http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:61997CJ0162&from=EN).

words, as the Belgian authorities had approved the breed for artificial insemination, no restrictions on the use of its semen could be imposed by any EU member state.

Food and feed safety

In the field of food and feed safety, the main instruments noted in the first SoW-AnGR – Regulation (EC) No 178/2002 and Regulation (EC) No 882/2004 – continue to form the backbone of the EU legal framework. A new regulation on the traceability of food of animal origin, Regulation (EU) No 931/2011, has been put in place. These instruments do not include any provisions specifically related to breeding or AnGR management. Effective frameworks addressing these matters are, in general, likely to benefit livestock-keeping livelihoods by promoting animal health and consumer confidence in animal products and hence in some circumstances may indirectly benefit AnGR diversity. However, such legislation can potentially prove onerous for small-scale producers and may also create problems for the marketing of some speciality products (see Subsection 4 for further discussion).

3.2 Other regional frameworks

Many parts of the world have regional or subregional intergovernmental bodies that promote economic or political cooperation among their member countries. In some cases, these bodies have the authority to adopt legally binding instruments. Whether or not this is the case, they normally have some policies and strategies that aim to coordinate the actions of their member countries within particular areas of activity. Outside the EU, regional legal frameworks, where they exist, are relatively undeveloped and include few instruments specifically targeting the livestock sector, with the partial exception of animal health-related matters. It is beyond the scope of this report to review the legal and policy frameworks of all the world's regional and subregional bodies and their potential effects on AnGR management. However, a number of examples of livestock-related and AnGR-related instruments (mostly policy instruments) are discussed below.

Several of the subregional economic communities of Africa have developed policies that directly target AnGR management, as well as various provisions addressing the livestock sector in a broader sense. For example, in 2005, the Heads of State and Government of the Economic Community of West African States (ECOWAS)[49] adopted a regional agricultural policy referred to as ECOWAP (Decision A/Dec. 11/01/05). Livestock-related elements of the policy include plans to harmonize sanitary norms and standards and to establish a regional programme on transhumance. A decision on the use of "transhumance certificates" to regulate the cross-border movements of pastoralists had previously been adopted (Decision A/Dec. 5/10/98).[50] 2010 saw the publication of the Strategic Action Plan for the Development and Transformation of Livestock Sector in the ECOWAS Region (2011–2020) (ECOWAS Commission, 2010). The plan's objectives include:

> *"Improvement of the performance of local breeds through emphasis on the following: (i) Evaluation and harmonisation of the management of genetic resources; (ii) Facilitation of the development of regional centres of excellence and genetic value addition to local breeds as well as capacity building."*

The Regional Indicative Strategic Development Plan of the Southern African Development Community (SADC)[51] for the period 2005 to 2020 includes the "sustainable management and utilization of farm animal genetic resources" among its strategies for increasing production, productivity and profitability in the livestock sector (SADC, 2003). Other relevant elements of the plan include promoting diversification and intensification of crop and livestock systems and strengthening and

[49] Member states: Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo.

[50] See FAO 2007a, Box 65 (page 328).

[51] Member states: Angola, Botswana, Democratic Republic of the Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, United Republic of Tanzania, Zambia, Zimbabwe.

broadening early warning systems for livestock diseases. None of SADC's legally binding instruments target AnGR management specifically. However, the Protocol on Trade (1996) has an annex on sanitary and phyosanitary matters (approved in 2008). The organization has taken several initiatives of relevance to AnGR management in the region, including the Promotion of Regional Integration initiative, which operated between 2005 and 2009 with the aim of improving productivity and trade flows in the livestock sector, the Trans-boundary Animal Diseases Project and the Foot and Mouth Disease Programme.[52]

The African Union, as part of its efforts to foster agricultural development across the continent, has taken steps to promote the sustainable use and development of AnGR. For example, its framework for mainstreaming livestock into the Comprehensive Africa Agriculture Programme[53] calls for a number of actions targeting the characterization and conservation of AnGR, as well dissemination of information, technology transfer and harmonization of regulatory frameworks (AU-IBAR, 2010). The Strategic Plan 2014 to 2017 of the African Union – Interafrican Bureau for Animal Resources (AU-IBAR) addresses the implementation of the Global Plan of Action for Animal Genetic Resources in Africa (AU-IBAR, 2013).

As described in the first SoW-AnGR,[54] the African Union's predecessor, the Organization of African Unity, developed a model law on the protection of the rights of farmers and the regulation of access to biological resources, to assist countries in the development of national policies and legislation in this field (OAU, 2000). In the wake of the adoption of the Nagoya Protocol, the African Union Commission developed draft African Union Strategic Guidelines for the Coordinated Implementation of the Nagoya Protocol on Access and Benefit Sharing, which were adopted by the African Ministerial Conference on the Environment in March 2015 (Decision 15/3).

In Latin America, the Andean Community of Nations[55] has put in place a number of instruments relevant to AnGR management. For example, Decision 523 of 2002 approves the Regional Biodiversity Strategy for the Countries of the Tropical Andes. While this strategy does not include any provisions specifically addressing AnGR management, it includes a "line of action" on the conservation and sustainable use of native and locally adapted agrobiodiversity, which focuses, *inter alia*, on characterization, identifying means of stimulating the marketing and use of products and services to support *in situ* conservation, strengthening scientific and technical capacities, and addressing access and benefit-sharing issues. Decision 391 of 1996 establishes a common subregional regime for access to genetic resources. It targets all genetic resources, with no particular provisions for AnGR or for genetic resources for food and agriculture in general. Other relevant instruments in this subregion include Decision 328 on agricultural and animal health.

Elsewhere in the world, regional bodies have put in place few legal instruments or major policy instruments that target AnGR management or explicitly include it within broader fields of action such as livestock development or biodiversity conservation. One example of an instrument that acknowledges the significance of AnGR is the Cooperation Council of the Arab States of the Gulf's[56] General Regulations of Environment in the GCC States (1997), which states that responsibilities of agencies responsible for environmental protection and conservation should include issuing and implementing rules and regulations related to, *inter alia*, "conservation of biological resources of local domesticated animals and local plants of economic value and improving them."

[52] For further information see the SADC Livestock Production website (http://tinyurl.com/op3rupo)

[53] The Comprehensive Africa Agriculture Development Programme was endorsed by African Heads of State in 2004. For further information see the programme website: http://www.nepad-caadp.net/

[54] FAO, 2007a, Box 45 (page 292).

[55] Member states: Bolivia (Plurinational State of), Colombia, Ecuador, Peru.

[56] Member states: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates.

3.3 Conclusions

As recognized in the Global Plan of Action for Animal Genetic Resources, many aspects of AnGR management potentially benefit from coordination and cooperation at regional level. Regional collaboration does not necessarily depend on the existence of regional-level legal and policy frameworks. However, a lack of consistency and coordination at policy and legislative levels has the potential to inhibit both trade in genetic resources and non-commercial collaboration in conservation, research and so on. In this respect, a regional approach that facilitates harmonization may be useful. There may also be benefits in terms of cost effectiveness if countries are spared the need to develop their own frameworks from scratch. On the other hand, as with laws and policies at any level (e.g. national or global), regional frameworks have the potential to overburden stakeholders with costs and bureaucratic procedures or to fail because of a lack of capacity to implement them or because of poor design. Clearly, any plans to establish regional frameworks need to be well adapted to the needs and capacities of the respective regions. Experiences from the EU appear to indicate (see various examples above) that in some fields of activity legal and policy frameworks need to be overhauled quite frequently if they are to remain relevant – a point that may need to be borne in mind when considering the feasibility of regional approaches elsewhere. Another notable characteristic of developments in the EU are the wide-ranging stakeholder consultations that take place before any legal instruments are put in place.

Outside Europe, as was the case at the time of the first SoW-AnGR, regional policy and, particularly, legal instruments addressing AnGR management are few and far between. The topic appears not to have entered in any substantial way onto the agendas of many regional bodies. It is, of course, difficult without an in-depth analysis of circumstances in the respective regions to know what the potential benefits and costs of attempting to establish instruments of this kind might be.

Assessing the effects of existing frameworks is also difficult. In the EU, assessments of the impact of AnGR-related instruments have been published and indicate various positive outcomes. However, there is some concern about a lack of involvement of the "end-users" of genetic resources and a lack of focus on utilization relative to conservation. Little has been published on the effects of regional AnGR-related policies elsewhere in the world.

Changes since the time of the first SoW-AnGR have been quite substantial in Europe. Several areas of AnGR-relevant legislation have seen major revisions, often with the aim of consolidating and clarifying frameworks that had developed into elaborate sets of species- and topic-specific instruments. In many cases, the updated frameworks have been established only recently or are still in the process of development.[57] Their practical effects on AnGR management are therefore not yet evident. Outside Europe, the most prominent developments have been in policy rather than legal frameworks and mainly in Africa, both at continental (African Union) and at subregional levels.

List of legal instruments cited

Andean Community of Nations

Decision 328 Andean agricultural and livestock health (1992) (available at http://www.sice.oas.org/trade/junac/decisiones/Dec328e.asp).

Decision 391 Common regime on access to genetic resources (1996) (available at http://www.sice.oas.org/trade/junac/decisiones/dec391e.asp).

Decisión 523 Estrategia regional de biodiversidad para los países del trópico andino (2002) (available in Spanish at http://tinyurl.com/ppshlvb).

Cooperation Council for the Arab States of the Gulf

General Regulations of Environment in the GCC States, 1997 (available at http://tinyurl.com/q7fjny3).

[57] At the time of writing, July 2014.

Economic Community of West African States

Décision A/DEC. 5/10/98 relative à la réglementation de la transhumance entre les états membres del la CEDEAO. Vingt-et-unième session ordinaire de la Conférence des chefs d'état et de gouvernement. Abuja 30–31 Octobre 1998 (available in French at http://tinyurl.com/nsobh9e).

Decision A/DEC. 11/01/05 adopting an agricultural policy for the Economic Community of West African States (ECOWAP). Twenty-eighth session of the Authority of Heads of State and Government, Accra, 19th January 2005 (available at http://tinyurl.com/pz32kpy).

European Union

Commission Delegated Regulation (EU) No 665/2014 of 11 March 2014 supplementing Regulation (EU) No 1151/2012 of the European Parliament and of the Council with regard to conditions of use of the optional quality term 'mountain product' (available at http://tinyurl.com/o2kjac7).

Commission Delegated Regulation (EU) No 807/2014 of 11 March 2014 supplementing Regulation (EU) No 1305/2013 of the European Parliament and of the Council on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and introducing transitional provisions (available at http://tinyurl.com/nnbknfb).

Commission Regulation (EC) No 889/2008 of 5 September 2008 laying down detailed rules for the implementation of Council Regulation (EC) No 834/2007 on organic production and labelling of organic products with regard to organic production, labelling and control (available at http://tinyurl.com/b59rog).

Council Decision 2006/144/EC of 20 February 2006 on Community strategic guidelines for rural development (programming period 2007 to 2013) (available at http://tinyurl.com/nunb3v5).

Council Directive 87/328/EEC of 18 June 1987 on the acceptance for breeding purposes of pure-bred breeding animals of the bovine species (http://tinyurl.com/oclnhr2).

Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes (available at http://tinyurl.com/nel556k).

Council Directive 2007/43/EC of 28 June 2007 laying down minimum rules for the protection of chickens kept for meat production (available at http://tinyurl.com/mo4o444).

Council Directive 2008/119/EC of 18 December 2008 laying down minimum standards for the protection of calves (available at http://tinyurl.com/oaxgrqn).

Council Regulation (EEC) No 2078/92 of 30 June 1992 on agricultural production methods compatible with the requirements of the protection of the environment and the maintenance of the countryside (available at http://tinyurl.com/prfsuo9).

Council Regulation (EC) No 1257/99 of 17 May 1999 on support for rural development from the European Agricultural Guidance and Guarantee Fund (EAGGF) and amending and repealing certain Regulations (available at http://tinyurl.com/ntz6qow).

Council Regulation (EC) No 1782/2003 of 29 September 2003 establishing common rules for direct support schemes under the common agricultural policy and establishing certain support schemes for farmers and amending Regulations (EEC) No 2019/93, (EC) No 1452/2001, (EC) No 1453/2001, (EC) No 1454/2001, (EC) 1868/94, (EC) No 1251/1999, (EC) No 1254/1999, (EC) No 1673/2000, (EEC) No 2358/71 and (EC) No 2529/2001 (available at http://tinyurl.com/p8hovps).

Council Regulation (EC) No 870/2004 of 24 April 2004 establishing a Community programme on the conservation, characterisation, collection and utilization of genetic resources in agriculture and repealing Regulation (EC) No 1467/94 (available at http://tinyurl.com/pxxjay7).

Council Regulation (EC) No 1698/2005 of 20 September 2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) (available at http://tinyurl.com/al7gs2).

Council Regulation (EC) No 509/2006 of 20 March 2006 on agricultural products and

foodstuffs as traditional specialities guaranteed (available at http://tinyurl.com/o3rfwaf).

Council Regulation (EC) No 510/2006 of 20 March 2006 on the protection of geographical indications and designations of origin for agricultural products and foodstuffs (available at http://tinyurl.com/o6qkovr).

Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91 (available at http://tinyurl.com/4dcvy8).

Council Regulation (EC) No 73/2009 of 19 January 2009 establishing common rules for direct support schemes for farmers under the common agricultural policy and establishing certain support schemes for farmers, amending Regulations (EC) No 1290/2005, (EC) No 247/2006, (EC) No 378/2007 and repealing Regulation (EC) No 1782/2003 (available at http://tinyurl.com/nrtkyus).

Council Regulation (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing (available at http://tinyurl.com/q96hydm).

Regulation (EC) No 178/2002 of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety (available at http://tinyurl.com/np2pbzm).

Regulation (EC) No 882/2004 of 29 April 2004 on official controls performed to ensure the verification of compliance with feed and food law, animal health and animal welfare rules (available at http://tinyurl.com/p23uvu5).

Regulation (EU) No 995/2010 of 20 October 2010 laying down the obligations of operators who place timber and timber products on the market (available at http://tinyurl.com/c5lwg58).

Regulation (EU) No 931/2011 of 19 September 2011 on the traceability requirements set by Regulation (EC) No 178/2002 of the European Parliament and of the Council for food of animal origin (available at http://tinyurl.com/6o55jls).

Regulation (EU) No 1151/2012 of 21 November 2012 on quality schemes for agricultural products and foodstuffs (available at http://tinyurl.com/ojjz743).

Regulation (EU) No 1305/2013 of 17 December 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005 (available at http://tinyurl.com/qesmnxd).

Regulation (EU) No 1306/2013 of 17 December 2013 on the financing, management and monitoring of the common agricultural policy and repealing Council Regulations (EEC) No 352/78, (EC) No 165/94, (EC) No 2799/98, (EC) No 814/2000, (EC) No 1290/2005 and (EC) No 485/2008 (available at http://tinyurl.com/p28qeor).

Regulation (EU) No 1307/2013 of 17 December 2013 establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy and repealing Council Regulation (EC) No 637/2008 and Council Regulation (EC) No 73/2009 (available at http://tinyurl.com/qjz6j7v).

Regulation (EU) No 1308/2013 of 17 December 2013 establishing a common organisation of the markets in agricultural products and repealing Council Regulations (EEC) No 922/72, (EEC) No 234/79, (EC) No 1037/2001 and (EC) No 1234/2007 (available at http://tinyurl.com/p6o3enl).

Regulation (EU) No 511/2014 of 16 April 2014 on compliance measures for users from the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization in the Union (available at http://tinyurl.com/px94vur).

Southern African Development Community

Protocol on trade in the Southern African Development Community (1996) (available at http://tinyurl.com/pboj7eq).

Sanitary and phytosanitary (SPS) annex to the SADC Protocol on Trade approved by the SADC Committee of Ministers of Trade on 12 July 2008, Lusaka, Zambia (available at http://tinyurl.com/qeqnyhj).

4 National frameworks

4.1 Roles of national laws and policies in animal genetic resources management

"A range of policies and legal instruments have direct or indirect effects on the use, development and conservation of animal genetic resources. These instruments often pursue different objectives, such as economic development, environmental protection, animal health, food safety, consumer protection, intellectual property rights, genetic resources conservation, and access to and equitable sharing of benefits arising from the use of animal genetic resources." (FAO, 2007a)

As the quotation shows, the Global Plan of Action on Animal Genetic Resources[58] recognizes both the significant role of legal and policy frameworks in AnGR management, and the potentially complex nature of the effects involved. Laws and policies can serve as tools in AnGR management, but they also form part of the context within which AnGR management takes place. As discussed in Part 2 of this report, legal and policy frameworks are often among the factors shaping the development of a country's livestock sector.

There is no "blueprint" for an effective legal and policy framework for AnGR management. As well as having its own particular set of objectives, problems and opportunities, each country will have its own legal system and its own approach to the development and implementation of policy instruments. The Global Plan of Action does not attempt to prescribe solutions or even to provide a checklist of topics that need to be addressed. However, it does call on countries to

"periodically review existing national policies and regulatory frameworks, with a view to identifying any possible effects they may have on the use, development and conservation of animal genetic resources ..."

and to

"consider measures to address any effects identified in [the] reviews of policy and legal frameworks."[59]

Countries wishing to improve the effectiveness of their legal and policy frameworks as tools to promote the sustainable management of AnGR potentially have a number of different strategies at their disposal. For example, the Global Plan of Action notes that countries may wish to respond to any identified weaknesses in their existing provisions either via policy and legislative changes or by improving the implementation of existing measures.[60] With regard to the types of instruments required, the first SoW-AnGR tentatively concluded that, in some circumstances, attempting to develop elaborate legal frameworks may not be the best way forward. It noted the potential contribution of "sound policy decisions and strategies, complemented by a clear legal definition of the competences and duties of institutions, and a well-organized monitoring and evaluation system ..."[61] However, it also noted that some countries had reported the need to improve their legal frameworks in order to put their existing policies into operation. It also noted that some countries were increasingly relying on market mechanisms and private institutions to provide for various aspects of AnGR management and that in these circumstances close attention needed to be paid to the potential need for regulatory measures to ensure that public-goods aspects of AnGR management were adequately accounted for.

Whatever approach countries choose to take in terms of promoting or enabling effective AnGR management (i.e. whatever balance between legislation, policy measures and reliance on the market and private initiatives), it is likely that some aspects of livestock development (and other activities that affect livestock development) will be regulated by law and that

[58] FAO, 2007a, Rationale to Strategic Priority 20.

[59] FAO, 2007a, Strategic Priority 20, Actions 1 and 2.

[60] FAO, 2007a, Strategic Priority 20, Action 2.

[61] FAO, 2007a, page 333.

this will affect the management of AnGR. The field of animal health and sanitary protection – which the first SoW-AnGR concluded was the most heavily regulated aspect of the livestock management – is perhaps the most obvious example. Moreover, given increasing concerns about a number of public goods-related issues in the livestock sector (e.g. environmental protection and human public health), across ever wider areas of the world, it is possible that, in a number of countries, the range of livestock-sector activities subject to legal regulation may expand. Developments of this kind can present both challenges (e.g. additional regulatory burdens or restrictions on livestock keepers' activities) and opportunities (e.g. better protection from disease and environmental threat or potential new niche markets) for the management of AnGR. In some circumstances, it may be feasible to build "AnGR-friendly" provisions into legal instruments in these various fields. In others, it may be necessary to focus on policy measures that help livestock keepers and other managers of AnGR adapt to the circumstances created by the introduction of the new legislation.

4.2 Context, information sources and methodology

The broad range of potentially relevant legislation and policies, and the fact that the concrete effects of legislation and policies on AnGR management cannot necessarily be inferred simply from the wording of the respective instruments, have meant that it has been difficult to obtain a global overview of the state of national provisions in this field and their implications for AnGR. In 2003, FAO conducted a survey on the legal framework for AnGR management, in which questionnaires were sent to all National Coordinators for the Management of AnGR and the Chairs and Technical Secretaries of National Consultative Committees[62] on AnGR. Combined with information obtained from all the country reports[63] that had been submitted to FAO by September 2003 and from an extensive internet search, the results of the survey were used to prepare an FAO Legal Study entitled *The legal framework for the management of animal genetic resources* (FAO, 2006). The material assembled for this study was later combined with information obtained from additional country reports, from FAO's FAOLEX database[64] and via direct e-mail contact with National Coordinators to prepare a chapter on national legislation and policy for the first SoW-AnGR.[65] Both the legal study and the first SoW-AnGR stressed that the material presented should not be regarded as a comprehensive global inventory of relevant legal and policy instruments. The other main limitation of these studies was that, as noted above, an inventory of instruments does not necessarily provide a good indication of their effects on AnGR management – or of what needs to be done to supplement or improve them.

In 2013, as part of the preparation process for the second SoW-AnGR, FAO organized another global survey of national legal and policy frameworks (referred to below as the "legal survey"). All National Coordinators were invited to complete a questionnaire[66] in which they were asked to indicate the presence or absence of legal and policy instruments at national level in a number of fields directly or indirectly relevant to the management of AnGR, to describe these instruments, to indicate the effect they (or the absence of relevant laws and/or polices) were having on AnGR management, and to describe the country's needs with respect to the future development of its legal and policy framework. Forty-six fully completed questionnaires were

[62] These bodies were established for the preparation of country reports for the first SoW-AnGR process.

[63] Reports submitted as part of the first SoW-AnGR process (ftp://ftp.fao.org/docrep/fao/010/a1250e/annexes/CountryReports/CountryReports.pdf).

[64] http://faolex.fao.org/faolex/

[65] FAO 2007a, Part 3 Section E Subsection 4 (pages 307-333).

[66] http://www.fao.org/ag/againfo/programmes/documents/genetics/global/SoWAnGR_leg_policies_invitation_E.pdf

submitted.[67] This provided a smaller, but more in-depth, dataset than had been available for the previous studies. The objective of obtaining detailed information on how existing instruments affect AnGR management and on countries' future priorities was only partially met (answers were often worded in a very general way or referred to general improvements in AnGR management rather than specifically to improvements to legal and policy frameworks). The main country-report questionnaire for the second SoW-AnGR provided countries with additional opportunities to report on their legal and policy frameworks, particularly in the section on institutions and stakeholders (see Part 3 Section A) and the section on progress in implementing Strategic Priority Area 4 of the Global Plan of Action.

For the purposes of the legal survey, a "policy" was defined as follows:

> *"a set of planned actions adopted by government with the aim of meeting a specific objective or objectives – a policy may be approved by parliament, but is not as by intent or nature legally binding. Instruments of this type may be given a range of different names including 'strategy', 'programme' or 'plan'."*[68]

One of the objectives was to identify whether, how and to what extent formal instruments of this kind contribute to improving the management of AnGR relative to situations in which management actions (if any) are taken on a more ad hoc basis. The discussion that follows below focuses on formal policy instruments of this kind. It should, however, be recognized that "policy", in a broader sense, can include the unwritten "level of commitment" shown by a government to a given field of activity, whether or not it is targeted by a specific policy instrument. It may also refer to the "stance" or attitude of a government with respect to a particular question, influencing the type of action that is taken, but not part of a conscious and coherent effort to pursue a particular outcome. The legal survey did not address the effects of policies in these more informal senses. However, the country-report questionnaire provided countries with opportunities to comment on the state of policy implementation, the state of awareness of policy-makers and constraints (of any kind, including political) to the implementation of various AnGR management activities.

For the purpose of the survey, "legislation" was taken to include "both primary legislation (e.g. laws, acts)[69] and secondary legislation (e.g. regulations)[70]". Countries were also given the opportunity to report on "relevant court cases (especially in common law systems)[71] and on trends in customary law.[72]" Little or no information on the significance for AnGR management of customary law or legal precedent in common-law systems

[67] 17 OECD countries: Australia, Austria, Czech Republic, Finland, France, Germany, Hungary, Italy, Luxembourg, Netherlands, Norway, Republic of Korea, Slovenia, Spain, Sweden, Switzerland, United States of America. 29 non-OECD countries: Bhutan, Brazil, Bulgaria, Burundi, Costa Rica, Croatia, Cyprus, Democratic Republic of the Congo, Ecuador, Ethiopia, Ghana, Guatemala, Iraq, Jordan, Latvia, Malaysia, Mauritius, Montenegro, Namibia, Nepal, Serbia, Sri Lanka, Sudan, Suriname, Thailand, United Republic of Tanzania, Uruguay, Viet Nam, Zimbabwe.

[68] The phrase "planned actions" was used in recognition of the fact that the mere existence of a policy does not necessarily always translate into concrete activity.

[69] Primary legislation is normally enacted by a legislative body (e.g. parliament). [Foot note is part of the original quoted text.]

[70] Secondary or implementing legislation (regulations) is subsidiary to primary legislation; it provides more detail and is issued by an authority of the executive that has been specifically authorized in a parliamentary-level law to issue regulations on the respective matter. [Foot note is part of the original quoted text.]

[71] Common law, also known as case law or precedent, is law developed by judges through decisions of courts and similar tribunals. [Foot note is part of the original quoted text.]

[72] Customary law refers to the laws, practices and customs of indigenous and local communities which are an intrinsic and central part of the way of life of these communities. Customary laws are embedded in the culture and values of a community or society; they govern acceptable standards of behaviour and are actively enforced by members of the community (http://www.wipo.int/wipo_magazine/en/2010/04/article_0007.html). [Foot note is part of the original quoted text. Full reference = WIPO. 2010. What place for customary law in protecting traditional knowledge? *WIPO Magazine*, 4 (2010): 18–20.]

was submitted in the survey responses and the topics were not pursued further.

The discussion presented below is based largely on an analysis of the results of the legal survey, supplemented with material from the country reports. In the case of instruments specifically targeting the sustainable use, development and conservation of AnGR, examples drawn from FAO's FAOLEX database are also included. In a few cases, material from other sources is used to illustrate particular points that were not well covered in the survey responses. The discussion is divided into four main subsections:

- instruments specifically addressing AnGR management (characterization, surveying and monitoring, genetic improvement, conservation, etc., i.e. approximately the subject matter of the Global Plan of Action);
- instruments addressing various aspects of the marketing of livestock products (these instruments are not primarily concerned with AnGR management, but are highly relevant to efforts to promote sustainable use);
- instruments addressing animal health (again not specifically focused on AnGR, but a highly regulated field with substantial potential to affect AnGR management); and
- instruments addressing various general aspects of agricultural and rural development (not specifically focused on AnGR, but possibly including some AnGR-related provisions and possibly affecting AnGR management indirectly in various ways).

The discussion of each specific aspect of the legal and policy framework for AnGR management aims to provide an overview of the state of provision in the respective field (whether instruments are present, in development or non-existent), to present some examples of existing provisions, to draw attention to any gaps and weaknesses that countries report in existing frameworks and to summarize available information on countries' priorities for future developments. Where necessary, a short introduction to the topic and the main types of instrument that are likely to be relevant is included. In the case of instruments directly targeting the management of AnGR (Subsection 4.3) an attempt is made to present a quantitative analysis of the state of provision. It should be borne in mind that the figures presented are based purely on countries' responses to the legal survey and are therefore likely to be affected by differences in how the questionnaire was interpreted (e.g. in terms of precisely what kind of instrument qualifies for inclusion in which field of AnGR management). Moreover, it should also be recalled that, given the complexity of many aspects of AnGR management, the presence of an instrument addressing a given field does not necessarily indicate that there are no significant gaps in existing provisions.

Because of the relatively small number of survey responses received, the quantitative results presented below are not broken down by region as was done for the equivalent chapter in the first SoW-AnGR. However, to give an indication of differences between developed and developing countries, results for OECD (Organisation for Economic Co-operation and Development) and non-OECD countries are presented separately. The sample includes 17 OECD countries (50 percent of all OECD countries) and 29 non-OECD countries (20 percent of all non-OECD members of the CGRFA). Given that member countries of the EU are subject to regional-level legal and policy frameworks in many relevant fields (see Subsection 3 above), these countries are treated as a distinct subgroup in some of the textual descriptions. However, separate quantitative analyses are not presented for this group of countries.

The legal survey respondents were a self-selecting group that included approximately 35 percent of all the countries that submitted country reports.[73] The country-report questionnaire did not include detailed questions about legal policy frameworks. However, it required countries to provide a score (none, low, medium or high) for the state of their legal and policy frameworks for AnGR management (see Part 3

[73] Only one country (Australia) submitted a response to the legal survey but provided no country report.

Section A). Comparing the average scores of the survey respondents to those of the full set of countries that submitted country reports provided an opportunity to roughly evaluate how representative the subsample was with respect to the state of policies and legislation. As might have been expected, the survey respondents scored, on average, higher than did the full set of countries. In the case of OECD countries, the survey respondents scored on average 17 percent higher than the full sample for both legislation and policies.[74] The equivalent figures for non-OECD countries were 6 percent higher in the case of legislation and 15 percent higher in the case of policies.[75]

The choice of examples presented below, both in the main text and in boxes, is influenced to a large extent by the availability of information. However, the aim is to provide some geographical diversity, at least in terms of developing vs. developed countries. The focus is also, as far as possible, on instruments that include a substantial body of AnGR-focused provisions or have some clearly identifiable effect on AnGR management. It must, however, be emphasized that the examples presented are intended as illustrative instances of the kinds of instruments that countries have put in place. They are not necessarily typical of instruments in the respective field. They are also not intended as examples of "best practice", and the mention of an instrument is not intended to imply that it is superior to equivalent provisions in other countries.

[74] Out of a possible maximum score of 3, OECD legal survey respondents scored 2.69 on average for the state of their legislation (90 percent of the potential maximum) compared to an average score of 2.30 (77 percent) for all OECD countries in the full country report dataset. The equivalent figures for policies were, by coincidence, exactly the same.

[75] Out of a possible maximum score of 3, non-OECD legal survey respondents scored on average 1.31 (44 percent of the potential maximum) compared to 1.23 (41 percent) for all non-OECD countries in the full country report dataset. The equivalent scores for polices were 1.59 (53 percent) and 1.38 (46 percent).

4.3 Instruments targeting the management of animal genetic resources

Overall management of animal genetic resources

As awareness of the importance of AnGR has increased at policy level in recent years – particularly since the adoption of the Global Plan of Action in 2007 – a growing number of countries have recognized the need for a more coherent national approach to the management of their livestock biodiversity. In some cases, this was an explicit conclusion of the country report prepared for the first SoW-AnGR. For example, the country report of the United Kingdom states that "The creation of a National Action Plan, facilitated through the National Co-ordinator, for the conservation and utilisation of AnGR in the UK based on the recommendations in this Report is strongly recommended." The recommendation was followed up in 2006 with the publication of the *UK National Action Plan on Farm Animal Genetic Resources*.[76]

The Global Plan of Action itself recognizes the importance of adopting a "strategic planning approach to conservation and utilization strategies" that identifies priorities at (*inter alia*) national level.[77] In 2009, the CGRFA endorsed guidelines on the preparation of national strategies and action plans for AnGR (FAO, 2009e) and encouraged countries to make full use of them (FAO, 2009a). The guidelines emphasize the importance of obtaining government endorsement for national strategies and action plans, i.e. that these instruments should become formal national "policies" in the sense described above (Subsection 4.2) (although the guidelines also recognize that the most appropriate approach to obtaining governmental commitment will vary from country to country).

Twenty-six percent of the countries that submitted country reports indicated that they have government-endorsed national strategy and

[76] Available at http://tinyurl.com/or5t9ez

[77] FAO, 2007b, Paragraph 16.

action plans (NSAPs) in place. A further 4 percent reported that their NSAPS have been prepared, but are not yet government endorsed, and 24 percent reported that they are in the process of preparing NSAPs (see Figure 3F1).

As part of the legal survey, countries were asked about legislation and policy instruments targeting the "overall management of AnGR".[78] A large majority of responding OECD countries (76 percent) indicated that they have developed policies in this category. The figures for non-OECD countries were substantially lower (34 percent). However, a further 55 percent of non-OECD countries reported that they are in the process of developing policies of this type.[79] While many countries have chosen to develop AnGR-specific national strategies and action plans, some survey responses indicate that AnGR-related issues are addressed via national biodiversity strategies and action plans (i.e. instruments covering all types of biodiversity) (e.g. France),[80] via strategies for agricultural biodiversity as a whole (e.g. Italy)[81] or as part of a broad livestock-development policy or strategy (e.g. the United Republic of Tanzania).[82] The potential

[78] The intention was to obtain information on national strategies and action plans (which were specifically highlighted as an example in the footnote to the question) or equivalent policy instruments and on legal instruments of a similar broad scope.

[79] The equivalent figure for OECD countries is 6 percent, i.e. one additional country.

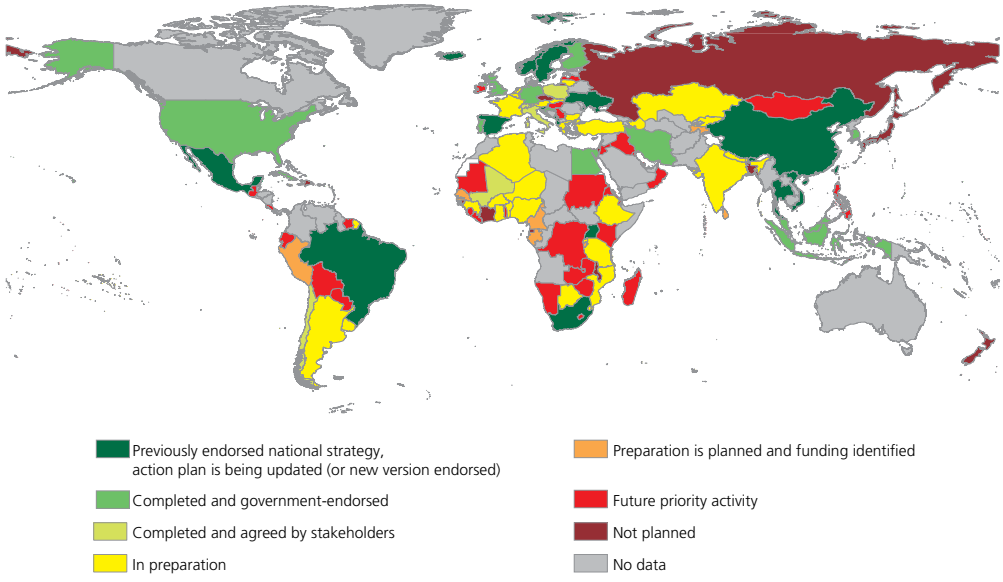
[80] National Biodiversity Strategy 2011–2020 (available in English at http://www.cbd.int/doc/world/fr/fr-nbsap-v2-en.pdf).

[81] Piano Nazionale sulla Biodiversità di Interesse Agricolo (available in Italian at http://www.reterurale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/1225).

[82] National Livestock Policy 2006 (available at http://tinyurl.com/oggwcag).

FIGURE 3F1

The status of national strategy and action plans for animal genetic resources



Source: Country Reports, 2014.

advantage of such an approach is that AnGR management may be better integrated into broader development strategies. The potential disadvantage is a lack of sufficiently detailed attention to AnGR and possibly a lack of sufficient "visibility" for AnGR-specific issues among policy-makers and the general public. The question of how AnGR management is addressed in legal and policy instruments addressing broader issues in rural development and environmental protection is discussed in more detail below (Subsection 4.6).

In cases where the survey responses highlight problems associated with the lack of an overarching national policy for AnGR management, the main concern is a lack of coordination among different policy initiatives. In the words of the response from Iraq, for example, AnGR-related work "is scattered and not organized." Similarly, the response from Bhutan states that

> *"since there are no overall policy directives, different agencies are promoting their own mandates. For example, Agency A promotes exotic high-yielding breed X in an area with traditional breed Y to increase production, while Agency B says breed Y has to be conserved ... [C]onservation and management of ... traditional breeds are less effective under such circumstances."*

Where legislation is concerned, 76 percent of OECD countries and 48 percent of non-OECD countries reported ed that they have legislation targeting "overall" management of AnGR (Figure 3F2).[83] Again, a substantial proportion of non-OECD countries reported that they have instruments under development. While it is possible to speculate that a single broad-scope instrument might help to promote a more cohesive approach, few if any survey responses mention any specific problems associated with the lack of an instrument of this kind. Evidence from the country reports suggests, on the other hand, that some countries regard the development of a more comprehensive legal instrument as an important priority. Hungary's country report, for example, makes several references to the objective of developing a new "Animal Breeding Act" that would address a wide range of different aspects of AnGR management.[84] Slovakia's country report, in describing the main constraints to improving the sustainable use and development of its AnGR, states that "the priority is to adopt legislation ... that will treat farm animal genetic resources comprehensively" – adding that this would require amendment of the existing Animal Breeding Act[85] and the introduction of relevant regulatory decrees.

Among the instruments described in the responses to the legal survey, one of the more comprehensive in its scope is Spain's Royal Decree 2129/2008,[86] which established the country's National Program for the Conservation, Improvement and Promotion of Livestock Breeds. A policy document, the Development Plan of the National Program for the Conservation, Development and Improvement of Livestock Breeds, followed in 2009.[87] The principles underlying the "joined-up"

[83] Some of the responses refer to a number of different instruments addressing different aspects of AnGR management rather than strictly to single instruments that aim to create a legal framework for multiple aspects of AnGR management.

[84] The country's current legal framework is based on the Law on Animal Breeding (1993/CXIV) (available in Hungarian at http://njt.hu/cgi_bin/njt_doc.cgi?docid=19614.243848).

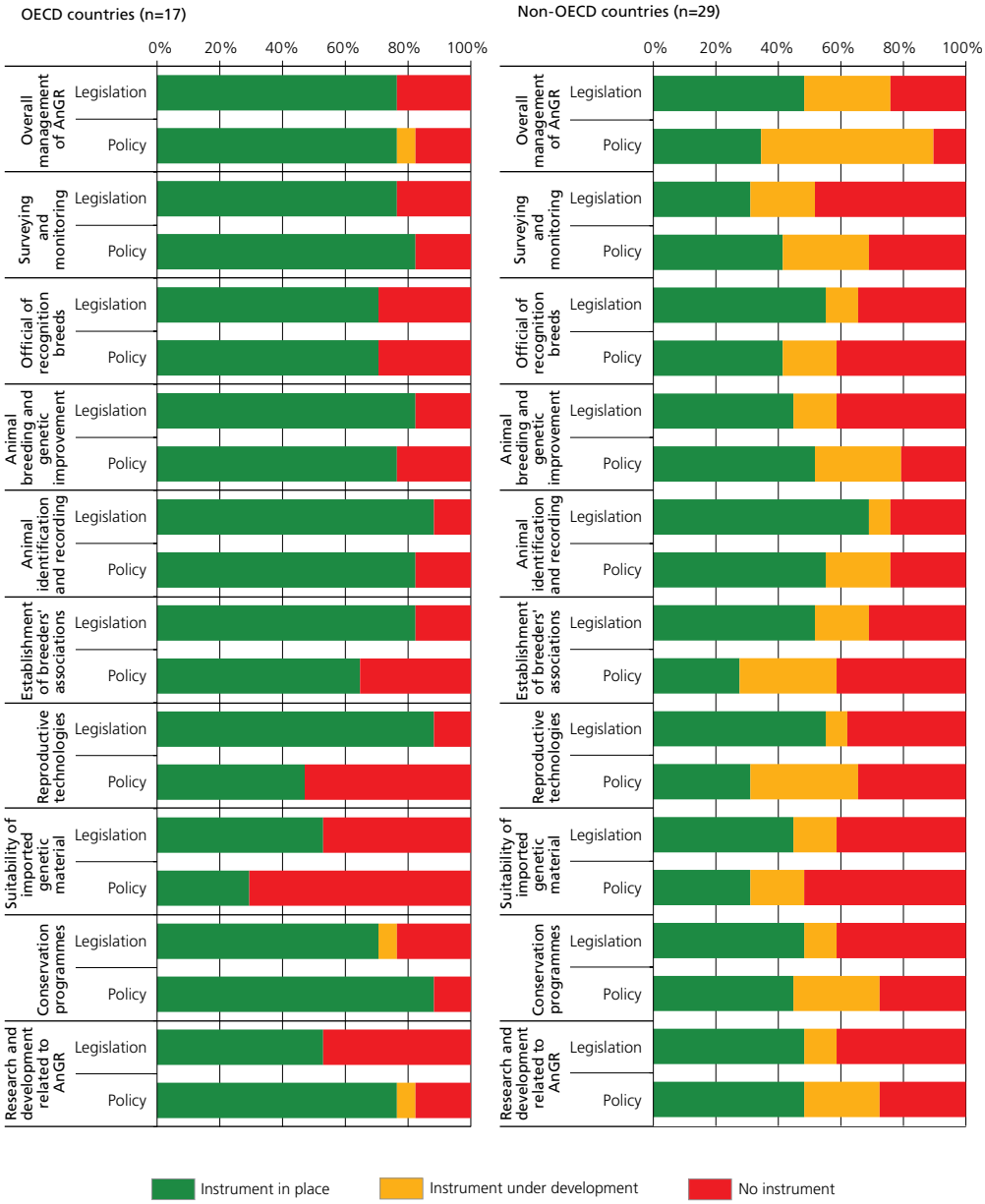
[85] ZÁKON z 13. mája 1998 o šľachtení a plemenitbe hospodárskych zvierat a o zmene a doplnení zákona č. 455/1991 Zb. o živnostenskom podnikaní (živnostenský zákon) v znení neskorších predpisov (available in Slovak at http://faolex.fao.org/docs/pdf/slo94705.pdf) amended by ZÁKON z 11. septembra 2009, ktorým sa mení a dopĺňa zákon č. 194/1998 Z. z. o šľachtení a plemenitbe hospodárskych zvierat a o zmene a doplnení zákona č. 455/1991 Zb. o živnostenskom podnikaní (živnostenský zákon) v znení neskorších predpisov v znení neskorších predpisov (available in Slovak at http://faolex.fao.org/docs/pdf/slo94706.pdf).

[86] Real Decreto 2129/2008, de 26 de diciembre, por el que se establece el Programa nacional de conservación, mejora y fomento de las razas ganaderas. Boletín oficial del Estado, Núm. 23 Martes 27 de enero de 2009 Sec. I. Pág. 9211 (available in Spanish at http://www.boe.es/boe/dias/2009/01/27/pdfs/BOE-A-2009-1312.pdf and in English at http://tinyurl.com/pwwdzw6).

[87] Plan de desarollo del Programa nacional de conservación mejora y fomento de las razas ganaderas (available in Spanish at http://tinyurl.com/osocu62).

FIGURE 3F2

State of development of legal and policy instruments



Source: Legal survey responses, 2013.

approach to national AnGR management taken in this decree are set out as follows in its preamble:

> *"While the need to characterize and conserve animal genetic resources has become a priority, this conservation must be linked to the selection of breeds that start from a better situation in terms of their census population size and productivity, and, in whatever case, to their sustainable use",*

which further states that it is the

> *"competency and responsibility of the public administration to implement effective regulation and planning of the [management of the country's] genetic heritage ..."*

Other reported instruments targeting multiple aspects of AnGR management include France's Law on Agricultural Orientation (2006)[88] and Germany's Animal Breeding Act (2006).[89] The survey responses did not include many examples of broad-scope legal instruments from outside Europe. However, a search of FAO's FAOLEX legal database[90] revealed a number of instruments, from various parts of the world, that target genetic improvement programmes but also include measures related to conservation (and to varying degrees other aspects of AnGR management). Examples (including additional examples from Europe) include Decree No. 2010-106 Regulating the Improvement of Domestic and Domesticated Animals in Madagascar,[91] Kyrgyzstan's Law on Pedigree Stockbreeding (2009),[92] Hungary's Decree No. 93 of (VII. 24.) concerning the Genetic Resources Conservation System of Protected Autochthonous Animal Species (2008),[93] Viet Nam's Decision No. 10/2008/QD-TTg approving the Strategy on Animal Breeding Development up to 2020 (2008)[94] (see Box 3F2) and Order No. 04/2004/L-CTN promulgating the Ordinance on Livestock Breeds (2004),[95] Poland's Act on Livestock Breeding (2007) (see Box 3F10),[96] Albania's Law on Livestock Breeding (2005) (see Box 3F3),[97] the Stock-breeding Law of the People's Republic of China (2005),[98] Uganda's Animal Breeding Act (2001),[99] Kazakhstan's Law No. 278-1 on Pedigree Stockbreeding (1998),[100] Uzbekistan's Law No. 165-I on Pedigree Stockbreeding (1995),[101] the Russian Federation's Federal Law No. 123-FZ on Pedigree Stockbreeding[102] and Ukraine's Law No. 3691-XII on Pedigree Stockbreeding (1993).[103] Another recent example is the Punjab Breeding Act of 2014 (Pakistan) (see Box 3F4).

A related category of legal instruments are those that address the establishment (or designation) of institutions responsible for overseeing or coordinating AnGR management at national

[88] Loi n° 2006-11 d'orientation agricole (available in French at http://faolex.fao.org/docs/texts/fra67797.doc).

[89] Tierzuchtgesetz. *Bundesgesetzblatt,* Part I, No. 64, 27 December 2006, pp. 3294–3315 (available in German with an English abstract at http://tinyurl.com/ogcuq4e).

[90] http://faolex.fao.org/faolex/

[91] Décret N°2010-106 du 2010/03/02 réglementant l'amélioration génétique des animaux domestiques et domestiqués à Madagascar (available in French at http://faolex.fao.org/docs/pdf/mad131582.pdf).

[92] Закон Кыргызской Республики о племенном деле в животноводстве Кыргызской Республики (available in Russian with an English abstract at http://tinyurl.com/o25spes).

[93] 93/2008. (VII. 24.) FVM rendeleta védett őshonos állatfajták genetikai fenntartásának rendjéről (available in Hungarian with an abstract in English at http://tinyurl.com/nelj9jl).

[94] *Công Báo* Nos. 75-76, 27 January 2008, pp. 26–33 (available in English at http://faolex.fao.org/docs/pdf/vie79311.pdf).

[95] *Công Báo* No. 16, 24 April 2004, pp. 20–30 (available in English at http://faolex.fao.org/docs/pdf/vie45179.pdf).

[96] Ustawa o organizacji hodowli i rozrodzie zwierząt gospodarskich (available in Polish with an English abstract at http://tinyurl.com/oqs6slp).

[97] Ligj Nr.9426, datë 6.10.2005 për mbarështimin e blegtorisë (available in Albanian with an English abstract at http://tinyurl.com/p7rossj).

[98] Available in English at http://faolex.fao.org/docs/texts/chn61879.doc

[99] Available in English at http://faolex.fao.org/docs/pdf/uga119210.pdf

[100] Закон Республики Казахстан от 09.07.1998 N 278-1 "О племенном животноводстве" (available in Russian with an English abstract at http://tinyurl.com/nbu5r4q).

[101] Закон Республики Узбекистан «О племенном животноводстве» 21 декабря 1995 г. N 165-I (available in Russian with an English abstract at http://tinyurl.com/pl2ajnq).

[102] Федеральный Закон Российской Федерации о племенном животноводстве (available in Russian with an English abstract at http://tinyurl.com/nd98uxb).

[103] Закон України про племінну справу у тваринництві (available in Ukrainian with an English abstract at http://tinyurl.com/nslbjh7).

Box 3F2

Viet Nam's legal framework for animal genetic resources management

Close to 70 percent of the Vietnamese population live in rural areas, and 80 percent of this group practise animal husbandry. In total, animal husbandry accounts for 18 to 25 percent of the country's agricultural gross domestic product. The current challenges facing animal husbandry in Viet Nam include unplanned, unsustainable growth in small-scale and sporadic production; low productivity, low quality and low production yields, resulting in uncompetitive products at high prices; lack of land zoned for agricultural purposes by the government; lack of investment; and lack of systematic organization of livestock services and management.

Legal instruments have been introduced in order to orient and develop goals for the livestock industry. These instruments facilitate specific plans for the provision of personnel, facilities, investment, zoning and general development, in order to combat the aforementioned challenges. The current strategy for the livestock sector encourages the development of commercial, industrial and commodity farms in which production and processing are better controlled. Food sanitation and security at national level are priorities.

The Ordinance on Livestock Breeds,[1] passed in April 2004 to take effect in July 2004, was originally drafted and approved with foreign, imported breeds in mind. The genetic improvement objectives addressed in this instrument are chiefly to create advantageous cross-breeds of exotic and indigenous breeds (Article 5.1) through characterization and selective research (Article 11), while conserving local breeds (Article 12). The first two objectives are manifested in a number of breeding programmes: for example, Sindhi crossed with local yellow cattle; and Landrace and Yorkshire crossed with local pig breeds. However, it was not until 2008 that more attention was paid to the objective of conserving indigenous breeds.

Decision No. 10/2008/QD-TTg[2] approving the Strategy on Animal Breeding Development up to 2020 was first drafted by the Ministry of Agriculture and Rural Development. A survey was sent to authorities in all 64 provinces, as well to as to livestock specialists and experts. Amendments were then made and passed at interdepartmental and interministerial conferences. The Decision was finally completed and presented to the government for approval.

Since its inception in 2008, the Decision has improved awareness of the role of livestock at national and local levels. Most provinces have put forth development plans for livestock production. Output of livestock products has increased by 25 to 30 percent thanks to higher breed productivity, better disease control and more environmentally sustainable practices.

Through the creation and implementation of this Decision, we have learned that in order for a legal instrument to be relevant to farmers' lives, strategy building must begin from real demands and needs. Goals and targets must have realistic timelines. Collaboration between stakeholders, government officials and NGOs is essential.

Areas that need improvement include more exhaustive and better-reinforced policies regarding the inclusion of indigenous breeds in breeding programmes. Awareness training for key stakeholders, especially policy-makers and governmental agencies, would help prevent near-sighted execution of relevant ordinances and potential oversights in regional policy-making. Collaboration and consultation with researchers and breed experts should also be instrumental in future policies.

Provided by Le Thi Thuy, National Coordinator for the Management of Animal Genetic Resources, Viet Nam.

[1] *Công Báo* No. 16, 24 April 2004, pp. 20–30 (available in English at http://faolex.fao.org/docs/pdf/vie45179.pdf).

[2] *Công Báo* Nos. 75-76, 27 January 2008, pp. 26–33 (available in English at http://faolex.fao.org/docs/pdf/vie79311.pdf).

Box 3F3
Albania's Law No. 9426 on Livestock Breeding

Albania is a country where the agricultural sector, and livestock production in particular, contributes significantly to the economy (18 percent of gross domestic product). The experience of the past 24 years of development under free-market conditions (1990 to 2014) has shown that the lack of an adequate legal framework is among the main factors constraining the effective management of biodiversity and that this has negative consequences for rural development.

The main legal instrument addressing animal genetic resources (AnGR) is Act No. 9426 of 20 January 2008 on Livestock Breeding,[1] which provides a framework for the conservation, evaluation and sustainable use of AnGR and of associated knowledge and technologies. In particular, it addresses methods and technologies for animal breeding and feeding, conservation and sustainable use of AnGR (including specific provisions for autochthonous/native/local breeds), criteria for the preparation and approval of breeding programmes, the provision of professional services related to livestock production, the establishment and administration of gene banks, the operation of breeders' associations and trade in breeding materials.

Although this law is considered an important step towards meeting international standards in the conservation and sustainable economic use of AnGR, its implementation is difficult because of a lack of human and infrastructural capacities. The objective for the medium term should be to complete the legislative framework for AnGR management in accordance with obligations deriving from the international conventions and agreements that Albania has ratified and to bring national legislation into line with international and European Union law. In particular, there is a need to elaborate the secondary legislation needed to implement *in situ* and *ex situ* conservation programmes, establish a national gene bank and a national agency for AnGR, and address property rights in light of the Nagoya Protocol on Access and Benefit-Sharing.

Provided by Kristaq Kume, National Coordinator for the Management of Animal Genetic Resources, Albania.

[1] Available in Albanian with an abstract in English at http://tinyurl.com/p9kaulb

level. Examples detected via search of FAOLEX include Poland's 2008 regulation[104] designating responsibility for the coordination of activities related to AnGR management and Argentina's Resolution No. 693/2004 Creating the National Advisory Commission for Genetic Resources for Food and Agriculture.[105] The legal basis for Turkey's institutional framework is described in Box 3F5. An interesting comment on the link between legal and institutional frameworks is provided in the country report from Cameroon, which states that

> *"the major impediment to implementation of [AnGR-related legislation] lies in the conflicts that arise due to their dispersal in different ministries, namely Livestock, Agriculture, Environment and Forestry. Harnessing these laws and attributing their implementation and monitoring to a single National Competent Authority will greatly improve the situation."*

Having considered a number of examples from countries that have chosen to develop broad-based instruments in this field, it is important to note that others have deliberately adopted a light touch with respect national legal and policy measures addressing AnGR management. In the United States of America, for example, breed development

[104] Rozporzadzenie w sprawie podmiotu upowaznionego do realizacji dzialan w zakresie ochrony zasobow genetycznych zwierzat gospodarskich. *Journal of Laws*, 2008 No. 108 Pos. 691 (available in Polish with an English abstract at http://faolex.fao.org/faolex).

[105] Resolución Nº 693/2004 – Créase la Comisión Nacional Asesora en Recursos Genéticos para la Alimentación y la Agricultura (CONARGEN) (available in Spanish at http://faolex.fao.org/docs/texts/arg121919.doc).

Box 3F4

The Punjab Livestock Breeding Act 2014 (Pakistan)

Pakistan has rich diversity of indigenous animal genetic resources (AnGR). Of the major livestock species, there are five breeds of buffaloes, 15 of cattle, 25 each of sheep and goats, 20 of camels and five of indigenous chickens. Documentation of breeds and production systems is weak. Attempts are being made to create awareness regarding the importance of AnGR and the need to improve their utilization.

Pakistan is home to world famous *Bos indicus* breeds of cattle, namely Sahiwal and Red Sindhi. Cross-breeding with exotic Holsteins and Jerseys is threatening these breeds. Establishing the Research Centre for Conservation of Sahiwal Cattle has helped to conserve the Sahiwal breed. Attempts to import Saanen and Boer goats can harm the locally adapted goat breeds. Prior to 2014, there was no legislation in place to stop unabated production (and import) of semen for artificial insemination. No certification/approval was required to produce semen locally. Semen from Sahiwal cattle and Nili-Ravi buffalo was produced in millions of doses without any attention to quality and genetic potential. It was felt that legislation was needed in order to improve the unique locally adapted breeds and to stop indiscriminate cross-breeding. A breeding policy, formulated in 2003 had not been adopted and legislation was needed to implement it. It took almost a decade, and a lot of consultation among different stakeholders, to reach the stage at which legislation could be drafted.

The Punjab Livestock Breeding Act 2014[1] was published on 29 May 2014. The objective of this act is to regulate livestock breeding services in the province of Punjab. It necessitates the formulation of an authority to regulate the provision of breeding services and to raise awareness regarding the need to conserve and improve the genetic potential of livestock breeds. It will encourage pedigree and performance recording and the development of herdbooks by breed societies. Semen production and distribution, artificial insemination services and the import of semen will operate under set regulations. Breed societies and promotional activities for the conservation of breeds will be supported. Awareness of the Punjab Livestock Breeding Act 2014 is likely to stimulate the creation of new breed societies. Other provinces are likely to follow the example of Punjab province, as they also have unique genetic resources to conserve and develop. If properly implemented, this will bring about a paradigm shift in the utilization of indigenous AnGR in the country. Periodic review of the implementation mechanism will be required, so that any adjustments needed to ensure the conservation and development of indigenous breeds can be made.

Provided by M. Sajjad Khan.

[1] Available at http://punjablaws.gov.pk/laws/2567.html

strategies are left in the hands of the private sector. Government involvement in AnGR management is focused largely on cryoconservation and assessing the status of genetic diversity (the country's response to the legal survey notes that the establishment of its National Animal Germplasm Program was enabled by legislation[106] passed in 1990). As another example, Australia's response to the legal survey reports no legislation within the category "overall management of AnGR." It notes that

> *"Australian Government policy on management of genetic resources is to create the enabling environment to allow both owners and users of animal genetic resources to establish breeding and conservation programs for their respective industries."*

The main mechanisms involved are reported to be

> *"industry-government partnerships [that] collaborate through R&D [(research and*

[106] Food, Agriculture, Conservation, and Trade Act of 1990. Provisions related to the National Genetic Resources Progam were amended by the Agriculture Act of 2014 (available at http://tinyurl.com/kpggybj).

Box 3F5

The legal basis for Turkey's animal genetic resources management programme

Turkey's National Consultative Committee on Conservation of Animal Genetic Resources and Animal Breed Registration Committee were established on the basis of its Regulation on the Conservation of Animal Genetic Resources and Regulation on Animal Breed Registration (both based on the Veterinary Services, Plant Health, Food and Feed Act of 2009).[1] The two Committees are charged, *inter alia*, with identifying objectives and drawing up policies related to the conservation, sustainable utilization and characterization of animal genetic resources and import and export of genetic material.

The primary legislation (the 2009 Act) addresses a wide range of topics spanning crop and animal agriculture and consumer protection, and is implemented by a large number of regulations in addition to those specifically related to animal genetic resources. The Act itself includes an article on "zootechnics", which in its detailed provisions focuses largely on the operation of herdbooks and the registration of breeding animals, but which also states that "The Ministry [of Food, Agriculture and Livestock] shall take measures to conserve animal genetic resources, and implement these measures or ensure that they are implemented."

2012 saw the introduction of a further legal instrument, the Regulation on Utilization and Export of Native Domestic Animal Genetic Resources[2] (also based on the 2009 Act), which regulates the use of animal genetic resources and includes a material transfer agreement for research-related purposes.

Sources: Government of Turkey, 2011; FAOLEX.

[1] Law on Veterinary Services, Plant Health, Food and Feed; Law No: 996; Adoption Date: 13/6/2010 (available in English at http://faolex.fao.org/docs/pdf/tur106155E.pdf). Similar provisions had been established under the Animal Improvement Act (No. 4631) of 2001 (available in Turkish at http://faolex.fao.org/docs/texts/tur24242.doc).

[2] Official Gazette of Turkey, No. 28418, 21 September 2012 (available in Turkish at http://www.resmigazete.gov.tr/eskiler/2012/09/20120921-3.htm).

development)] activities to determine future priorities for these industries and through these, the appropriate conservation, use and development of animal genetic resources."

With regard to the significance of legal measures relative to policy measures, it is interesting to note the following statement from Ireland's country report:

"Traditionally, laws were enacted in this area, but over the last 20 years policies developed by the sector have been the main drivers."

Integration of animal genetic resources management with other sectors of genetic resources for food and agriculture

As part of the legal survey, countries where asked whether they had any legal or policy instruments in place that specifically address the integration of AnGR management with the management of other genetic resources for food and agriculture. Such measures might, for example, aim to promote efficiency in the operation of genetic resources management programmes across sectors or to promote greater attention to ecological interactions between livestock and crop plants, forest trees, micro-organisms, aquatic species, etc.

Among OECD countries, in the case of both policies and legislation, 65 percent of respondents reported that they have instruments of this type in place. In the case of non-OECD countries, the figures were substantially lower (14 percent and 41 percent, respectively, for legislation and policy instruments). However, a number of countries reported that they have instruments under development (13 percent for legislation and 24 percent for policy instruments).

While the practical effects on AnGR management are not always clear, a number of countries provide examples of policies, strategies or institutions that, in one way or another, span several sectors of genetic resources. Austria, for example, describes several policy instruments, including the

Austrian Agri-Environmental Programme (ÖPUL) and Initiative Agriculture 2020,[107] that target all aspects of agriculture (including management of AnGR) in an integrated way, taking ecological and social factors into consideration. The aim – as described in the survey response – is to strengthen "a sustainable farm-based agriculture and forestry", within which sustainable management of AnGR is integrated. Other reported examples from Europe include Norway's National Strategic Plan of the Norwegian Genetic Resources Centre, which addresses livestock, crops and forest trees. The response from Germany notes that AnGR are considered in the country's National Agro-Biodiversity Strategy and National Rural Development Policy, and also mentions the importance of integrating the management of livestock with grassland management.

Reported examples from developing countries include Malaysia's National Strategies and Action Plans for Agricultural Biodiversity Conservation and Sustainable Utilization (strategies for plant, livestock, arthropod and microbial genetic resources published together in one document), which "strive for coordinated and holistic ways to identify, conserve and optimize the use of agricultural biodiversity in Malaysia".[108] The survey response from Brazil mentions that over the last decade the country's Ministry of Agriculture has been promoting integrated crop–livestock–forestry systems, which have reportedly contributed to reducing the amount of deforestation and greenhouse gas emissions associated with livestock production. It further notes that there is no specific legislation related to this activity, but that it has taken place within the framework of the country's Forestry Code,[109] which was revised in 2010.[110] Nepal (which is in the process of developing instruments in this field) highlights links to the management of pastures and forests:

> *"programs on conservation and promotion of farm animal genetic resources are tied up with the fodder, pasture and leasehold forestry programs …From the fiscal year 2013/14, the Government of Nepal has launched the forage pasture mission which also focuses [on] programs to conserve native animals as well as to increase the production and productivity of farm animals."*

Surveying and monitoring

As discussed in Part 4 Section A, establishing a national breed inventory and monitoring changes in the size and structure of breed populations are important elements of national AnGR management. Countries vary greatly in their capacities to implement surveying and monitoring activities (see Part 3 Section B) and in terms of their specific objectives for data collection. The tasks that need to be addressed by policy and legal frameworks in this field will thus vary from country to country. Nonetheless, given the need to assemble, store and report national-scale data in a consistent way over an extended period of time, some degree of leadership and coordination at national level is likely to be essential.

FAO's guidelines on *Surveying and monitoring of animal genetic resources* (FAO, 2011c) recommend that countries should review their requirements for data and information on AnGR and draw up strategies for meeting these requirements. The guidelines also note the importance of a "mandate" for national surveying and monitoring activities, i.e. that these activities should have "official status and backing from the relevant authorities." They further recommend that the key elements of such a mandate should include a definition of the objectives and scope of the activities (species and geographical

[107] http://www.lebensministerium.at/en/initiatives/Agriculture2020.html

[108] The quotation is taken from the preface of the document (which is available at http://www.fao.org/Ag/AGAInfo/programmes/documents/genetics/country_reports/Malaysia_NSAP_Oct2013.pdf).

[109] Lei n. 4.771, de 15 de setembro de 1965. Institui o novo Código Florestal (available in Portuguese at http://faolex.fao.org/docs/texts/bra12382.doc).

[110] Lei nº 12.651, de 25 de maio de 2012. Dispõe sobre a proteção da vegetação native (available in Portuguese at http://faolex.fao.org/docs/pdf/bra113357.pdf).

coverage, time frame), allocation of responsibilities to organizations and individuals (including responsibility for coordinating and overseeing the strategy), provisions related to stakeholder involvement, and provisions related to accessing and using the data collected.

Among responses to the legal survey, 76 percent of OECD countries reported that they have policy instruments in place in this field and 82 percent that they have legislation (Figure 3F2). The figures for non-OECD countries were 41 percent for policies and 31 percent for legislation. A substantial number non-OECD countries reported that they are in the process of developing legislation (21 percent) and/or policies (28 percent) in this field. Several other countries mentioned that they regard the development of legislation and/or policies in this field as an important objective.

Survey responses from a number of European countries (e.g. Austria and the Netherlands) note that national implementation of EU regulations on animal registration facilitate the monitoring of breed population sizes. The usual pattern in EU countries is for monitoring programmes to be based on the involvement of breed societies. The societies keep track of demographic trends in their respective breeds and provide data to a central authority that operates a database of some kind. The legal and policy frameworks for such programmes vary from country to country, but in all EU countries they are underpinned by legislation on animal registration and on the operation of breed societies. Some countries have legislation in place that explicitly allocates the task of operating a monitoring programme to a particular national body. In other cases, monitoring programmes have been established or strengthened through policy measures without recourse to specific legislation. While most survey responses from EU member countries do not mention any future needs in terms of improving legal or policy frameworks in this field, there are some indications that further strengthening is required. For example, Germany mentions the need to establish a specific regulation on monitoring. The country report from Slovakia lists a lack of "legislation concerning the responsibility of individual institutions" as one of the main obstacles to the implementation of surveying and monitoring programmes. Among countries from other parts of Europe, the survey response from Norway notes the need to establish monitoring systems for species that currently lack adequate recording systems at breed level, but states that this needs to be addressed more at policy than at legislative level.

Survey responses from developing countries provide little detailed information on the nature of their existing or planned legislation and policies in this field, on the impacts of existing measures or on steps that need to be taken to improve them. However, several countries note the practical difficulties involved in implementing their existing instruments. One objective mentioned by several countries (e.g. Brazil, Costa Rica and Sri Lanka) is to have breed-level data collection included in national livestock censuses. A search of the FAOLEX database did not reveal many examples of legal instruments from non-OECD countries that specifically address surveying and monitoring. Where instruments are in place, the main objective appears to be the establishment of institutional responsibilities. For example, China's above-mentioned Stock-breeding Law of 2005 allocates responsibility "for organizing the investigation of livestock and poultry genetic resources, releasing national reports about the status of livestock and poultry genetic resources and publishing the list of livestock and poultry genetic resources approved by the State Council" to the stockbreeding and veterinary administrative department of the State Council. Cameroon's Decree No. 2012/382 of 2012 on the organization of the Ministry of Livestock, Fisheries and Animal Industries[111] charges the Insemination and Animal Genetic Resources Service with inventory of AnGR and the identification of breeds that are at risk of extinction.

[111] Décret nº 2012/382 du 14 septembre 2012 portant organisation du Ministère de l'Elevage, des Pêches et des Industries Animales (available in French at http://faolex.fao.org/docs/pdf/cmr126963.pdf).

Official recognition of breeds

Given that the breed is generally the main unit of management in national AnGR management programmes, many countries are likely to see the need for some kind of procedure (formal or informal) whereby a livestock population can be officially recognized as a breed by the national authorities, if only for matters such as international reporting on the state of AnGR diversity. Countries may also wish to establish procedures for the allocation of breeds to categories such as "native", "locally adapted" and "exotic." While formal mechanisms and strict criteria are not necessarily required, if recognition as a breed (or as belonging to a particular category of breed) affects how a livestock population is treated under national laws and policies (e.g. eligibility for support payments under conservation schemes), clear legal definitions of the criteria and processes involved may be important.

Seventy-one percent of the OECD countries that responded to the legal survey reported that they have legislation in place addressing the question of the official recognition of breeds (Figure 3F2). The same proportion reported that they have policies. The figures for non-OECD countries were 55 percent and 41 percent, respectively. It should, however, be noted that the reported legal instruments are quite diverse in terms of how prescriptive they are and the extent to which they grant a role to the national authorities. For example, the response from Australia refers to the country's Competition and Consumer Act (2010)[112] rather than to any AnGR-specific legislation and notes that the recognition of breeds is the responsibility of breed societies.

Several survey responses from European countries indicate that clearly defined criteria and/or procedures for the recognition of breeds are set out in laws or regulations. The response from Slovenia, for example, notes that a new breed or line can be recognized by the minister competent for animal husbandry on the basis of advice from the country's Animal Husbandry Council. Detailed rules on the criteria and procedures for the recognition of breeds (along with specific rules for the recognition of breeds as "indigenous" or "traditional") are set out in the Regulation on Conservation of Farm Animal Genetic Resources (2011).[113] Bulgaria, in its survey response, notes that the country's Law on the Protection of New Plant Varieties and Animal Breeds of 1998 (as amended in 2010)[114] includes a list of autochthonous breeds and breeds developed in Bulgaria that are considered the property of the state, as well as provisions related to the recognition of other breeds (whether newly developed or brought in from outside the country) by the State Breed Commission. In this particular case, the law creates the basis for a *sui generis* intellectual property rights (IPR) system for livestock breeds: a breeder who has "created or discovered and developed" a breed can be issued with an "animal breed certificate" valid for 30 years. Another example is provided in the response from Latvia, which notes that its Agricultural Data Centre established a commission for approval of breeds in accordance with Cabinet Regulation No. 475 (21.06.2011) Approval and Registration of Farm Animal Breeds.[115] The commission includes representatives from the country's Agricultural Data Centre and from scientific and educational institutions. The approval process takes into account the "number of female and male animals, characteristic traits, productivity and genetic structure of [the] population." Some countries, in contrast, have adopted a more flexible approach based on ongoing advice to government from officially recognized expert bodies. For example, the United Kingdom's National Action Plan on Farm Animal

[112] Available at http://www.comlaw.gov.au/Details/C2011C00003/Download

[113] Pravilnik o ohranjanju biotske raznovrstnosti v živinoreji (Regulation on Conservation of Farm Animal Genetic Resources) (available in Slovenian at http://tinyurl.com/nm8l28a and in English http://tinyurl.com/ntyb4qw)

[114] Закон за закрила на новите сортове растения и породи животни (available in Bulgarian at http://tinyurl.com/pxlo9uh – the original act from 1998 is available in English at http://tinyurl.com/qb2pr6t).

[115] Lauksaimniecības dzīvnieku šķirnes apstiprināšanas un reģistrācijas kārtība (available in Latvian at http://likumi.lv/doc.php?id=232283).

Box 3F6

Official recognition of livestock breeds in Brazil

In Brazil, official recognition of livestock breeds is regulated by Law No. 4.716/1965,[1] Decree No. 58.984/1966[2] and Technical Guidance SNAP 47/1987.[3] The procedure requires the respective breeders' association (at this point in the process regarded as a "promotional association") to submit an application to the Ministry of Agriculture. The application is then assessed by Ministry technicians and experts recruited on an ad hoc basis, taking into consideration, *inter alia*, the uniqueness of the animals, the proposed descriptors and whether or not the breed has already been registered under another name. If the conclusion is that the candidate population qualifies as a separate breed, the Ministry of Agriculture will recognize it and will allow the association to start issuing registration documents for the animals – including pedigrees, and so on. Copies of these documents have to be sent to the Ministry of Agriculture so that they can be checked.

Every time a new breed is recognized, there is an increase in the number of herds and breeders, and consequently in the number of animals. Recently, two locally adapted cattle breeds have been recognized by the Ministry of Agriculture: the Curraleiro Pe-Duro and the Criollo Lageano. In the case of the Criollo Lageano, there were only two herds remaining before the recognition of the breed in 2008. Since then, the number of herds has increased to 27. There are still many locally adapted breeds that have not been recognized by the Ministry of Agriculture. One of them, the Pantaneiro cattle breed, has just (late 2013) started the process, with the creation of a promotional breeders' association.

Source: Adapted from Brazil's response to the 2013 legal survey.

[1] Lei No 4.716, de 29 de junho de 1965. Dispõe sôbre a organização, funcionamento e execução dos registros genealógicos de animais domésticos no País (available in Portuguese at http://tinyurl.com/oqfwrt5).

[2] Decreto Nº 58.984, de 3 de agosto de 1966. Aprova o Regulamento da Lei número 4.716, de 29.6.65, que dispõe sôbre o registro genealógico de animais domésticos no País.

[3] Portaria Nº 47, de 15 de outubro de 1987.

Genetic Resources (2006) recommended that this role be given to the country's National Standing Committee on Farm Animal Genetic Resources.[116] This body later developed a set of definitions[117] for use in the country's breed inventory and guidance on the evidence needed to prove that a breed should be included in the inventory.[118]

Some countries report that legal frameworks for breed recognition are still in the process of being developed. Montenegro's survey response, for example, notes that the country's Law on Livestock Farming (2010)[119] lays down rules for the recognition of new breeds and lines of domestic animals developed in Montenegro "in accordance with the scientific methods", but also notes that secondary legislation laying down more detailed conditions and procedures needs to be developed. It further notes that developing a regulation for the recognition of already-known autochthonous breeds is an important objective with respect to the genetic assessment and conservation of these breeds.

Non-European countries that report legal instruments in this field include Brazil, where the recognition of a breed goes hand in hand with the recognition of a breeders' association (see Box 3F6) and Viet Nam. In the latter country, the Ordinance on Livestock Breeds (2004)[120] sets out rules under which "new livestock breeds shall be recognized and put on the lists of livestock breeds permitted for production and business promulgated by [the relevant ministry]." The procedure involves determining "the difference, stability, uniformity of yield, quality [and] disease resistance of new breeds", as well as any potential "harmful effects." The registration process in Indonesia is described in Box 3F7.

[116] Currently the Farm Animal Genetic Resources Committee (web site: http://www.defra.gov.uk/fangr/).

[117] *Definition of a breed for the purpose of the UK National Inventory* (available at http://www.defra.gov.uk/fangr/2011/03/17/national-inventory/).

[118] *Eligibility of a UK breed for inclusion in the UK National Breed Inventory* (available at http://tinyurl.com/o57cvrk).

[119] Закон о сточарству (available in Montenegrin at http://tinyurl.com/ozn4jas).

[120] Ordinance on Livestock Breeds (No. 16/2004/PL-UBTVQH11) (available in English at http://tinyurl.com/o8b8lqs).

Box 3F7
Registration of livestock breeds in Indonesia

Indonesia is home to many diverse plant, animal and microbial genetic resources. Not all have been managed properly or characterized to identify their valuable traits. There is great potential to enhance the use of the country's animal genetic resources in the production of meat, milk and eggs as sources of protein for human consumption. To protect these valuable resources, the Government of Indonesia, through the Minister of Agriculture, released Decree No. 19/Permentan/OT.140/2/2008 on the registration of livestock breeds. To operationalize the decree, a commission has been set up to evaluate proposals for breed registration submitted by the local governments in the breeds' home areas. The commission consists of around 20 people, including scientists from national research institutes and universities, as well as officials from the General Livestock Services. Each proposal consists of:

1. a justification for the proposed registration;
2. a description of the breed's specific traits;
3. a description of the breed's geographical distribution; and
4. information on the superiority of the breed's traits.

The operationalization of the commission was initiated in 2010 through several meetings. As of March 2013, the commission had registered the following 27 breeds: Aceh cattle (Aceh); Alabio duck (South Kalimantan); Bali cattle (Bali); Batur sheep (Central Java); Gaga chicken (South Sulawesi); Garut sheep (West Java); Gembrong goat (Bali); Kaligesing goat (Central Java); Kisar sheep (Maluku); Kokok-balenggek chicken (West Sumatera); Lakor buffalo (Maluku); Madura cattle (East Java); Magelang duck (Central Java); Moa buffalo (Maluku); Palu sheep (Central Sulawesi); Pampangan buffalo (South Sumatera); Pegagan duck (South Sumatera); Pelung chicken (West Java); Pesisir cattle (West Sumatera); Pitalah duck (West Sumatera); Rambon goat (Central Java); Sentul chicken (West Java); Sumbawa buffalo (West Nusa Tenggara); Sumbawa cattle (West Nusa Tenggara); Sumbawa horse (West Nusa Tenggara); Tegal duck (Central Java); and Wonosobo sheep (Central Java). Each registration is established via a ministerial decree.

After the release of a ministerial decree for the registration of a breed, the local government releases local regulations related to the management of the breed. The rules specify that the local government should take care of the breed by:

1. allocating budget for maintaining the breed;
2. maintaining the breed's diversity;
3. improving income generation from the breed; and
4. involving many farmers in conservation activities.

Provided by Bess Tiesnamurti.

The survey responses provide relatively little information on the effects that legislation (or lack of legislation) in this field has on AnGR management. Neither do they provide much information on countries' future needs in terms of developing legislation or policies in this field. Some responses note positive effects. Cyprus, for example, comments that legislation has "major implications for PDO [protected designation of origin] applications for specific products." The descriptions of arrangements in Brazil and Indonesia presented in Boxes 3F6 and 3F7 provide further examples of how sustainable AnGR management has benefited from the process of breed recognition.

Some countries mention that a lack of legislation on breed recognition creates problems or report that the introduction of legislation is a future priority. For example, the response from Bhutan mentions that its lack of legislation in this field hampers the conservation and sustainable use of its traditional breeds. Likewise, Nepal's response notes that official recognition of breeds would help in promoting conservation and sustainable use activities. Other responses,

however, state that the absence of legislation has little effect. For example, the United States of America (as noted above, a country that relies largely on the private sector to manage its AnGR) reports that it has no legislation or policies in this field, but that this has "no negative impact on animal genetic resources management." Mauritius (a country with a small number of breeds and that, to date, has given little emphasis[121] to *in situ* conservation or policies promoting sustainable use of locally adapted breeds) notes that, although it has no legislation in place, all stakeholders accept the breed inventory used by the government in, for example, its National Biodiversity Strategic and Action Plan.[122]

Genetic improvement programmes

Genetic improvement programmes can have major implications for the livelihoods of individual livestock keepers and breeders, for the profits of commercial organizations and for national objectives such as food security and the maintenance of diverse portfolios of AnGR. However, they are complex undertakings (see Part 4 Section C), and establishing and sustaining effective breeding programmes has proven to be a challenge in many countries (see Part 3 Section C). The roles of different stakeholder groups, including those of public-sector bodies, in the planning and implementation of genetic improvement programmes (or the extent to which their participation is regarded as an objective) varies greatly from country to county (see Part 3 Section C). Along with major differences between countries in terms of technical and organizational capacity to implement the various elements of breeding programmes, this means that the challenges involved in establishing appropriate legal and policy frameworks for genetic improvement programmes are very diverse.

Policies supporting or influencing the objectives of breeding programmes – or promoting changes in breed utilization (e.g. substitution of one breed by another) – are discussed in Part 3 Section C, based on the material provided in the country reports. The emphasis below in this subsection is therefore on legal frameworks.

Eighty-two percent of the OECD countries that responded to the legal survey indicated that they have legislation addressing animal breeding and genetic improvement in place (Figure 3F2). Slightly fewer (76 percent) indicated that they have policies in place. Among non-OECD respondents, the equivalent figures were 45 and 52 percent, respectively, with a further 14 percent reporting that they have legislation in preparation and 28 percent that they have policies in preparation.

One factor that facilitates the establishment of breeding programmes is the existence of a national animal identification system. Because of the multiple benefits that can be obtained from having such a scheme, compulsory animal identification systems are widespread in developed countries. Eighty-eight percent of OECD countries that responded to the legal survey reported that they have legislation in place in the field of "animal identification and recording" (Figure 3F2). The figure rises to 100 percent if countries reporting animal identification laws related to animal health (see Subsection 4.5 below) are included. There is also growing interest in the establishment of animal identification schemes in developing countries. Sixty-nine percent of non-OECD survey respondents indicated that they have legislation related to animal identification in place and a further 7 percent that they are developing legislation. The main motivation for the development of animal identification systems is to improve animal health and the traceability of animal products (see Subsections 4.4 and 4.5 for further discussion). However, once systems exist they can also serve other purposes such as the identification of animals for breeding purposes.

In many countries, particularly in the developed regions of the world, the main stakeholders involved in implementing breeding programmes are breeders' associations. These associations are usually non-governmental bodies

[121] According to its country report.

[122] Available in English at https://www.cbd.int/doc/world/mu/mu-nbsap-01-en.pdf

operated by their members. National authorities may, however, choose to introduce legal and policy measures to promote the establishment of such organizations or to regulate their operation, with the aim of promoting the sustainable development of national AnGR, as well as improving rural livelihoods, food security, etc. Defined standards and procedures for the various elements of breeding programmes can also help ensure effective implementation and create conditions in which breeding animals can be traded with confidence.

As discussed above in Subsection 3, EU member countries are obliged to comply with EU-level legal instruments related to animal identification, the recognition of breeders' associations, the keeping of herdbooks, the contents of pedigree certificates, performance testing and genetic evaluation and the acceptance of animals for breeding. Countries vary in the extent to which they go beyond establishing the basic EU-prescribed legal framework and seek more actively to influence the objectives and implementation of breeding programmes. For example, the survey response from the Netherlands states that genetic improvement is completely in the hands of the private sector and that the only remaining involvement of the government in breeding is through pre-competitive public–private research programmes and other specific research projects. The response from Germany mentions that its Animal Breeding Act (see above) regulates the process of recognizing breeding programmes and makes performance recording and the estimation of breeding values mandatory, but contains no rules directly addressing breeding goals. It notes that in the case of breeds that are at risk of extinction, conservation breeding programmes that do not involve performance evaluation are permitted. It further notes that, if necessary, breeders' associations can be required to cooperate in the implementation of conservation measures (although this is reported not to have happened to date).

Slovenia, in its country report, mentions that in order (*inter alia*) to ensure the maintenance of genetic diversity and the overall progress of the livestock sector, it has established a "basic common breeding programme" for all livestock species, the implementation of which – by breeding organizations in collaboration with research institutions – is financed by the government. Rules related to the establishment and implementation of the common programme are set out in the country's Livestock Breeding Act.[123] The implementation of this programme, and of other approved breeding programmes, forms the basis of Slovenia's conservation programme – in accordance with the requirements of its Regulation on Conservation of Farm Animal Genetic Resources (see above). Further information on legislation related to conservation breeding programmes is provided below in the subsection on conservation.

Among countries elsewhere in the world, instruments addressing the establishment or operation of breeders' associations are the most commonly reported type of legislation related to breeding programmes. Fifty-two percent of non-OECD respondents to the legal survey indicated that they have legislation of this type in place. Costa Rica's response, for example, mentions its Executive Decree No. 19400 (1989),[124] which transfers responsibility for the management of genealogical registers to breeders' associations and prescribes minimum standards for the operation of these associations. Zimbabwe's response mentions the Zimbabwe Herd Book, a registering body for breeders' associations that was established by act of parliament in 1981.[125] Namibia mentions its Livestock Improvement Act (1977), which – as well as containing provisions related to the recognition of breeders' associations – grants exclusive rights to the Namibian Stud Book Association to

[123] Zakon o Živinoreji (ZŽiv) (available in Slovenian at http://tinyurl.com/o6o4pbw and in English at http://tinyurl.com/n2thv8c). In the English version, the programme is referred to as the "Joint basic breed programme".

[124] Traspasa Registro Genealógico de Ganado a Asociación de Productores y Criadores de Ganado N° 19400-MAG (available in Spanish at http://www.mag.go.cr/legislacion/1990/de-19400.pdf).

[125] Registration of Pedigree Farm Livestock Act, Act 21/1981 (available at http://faolex.fao.org/docs/pdf/zim60476.pdf).

issue pedigree certificates. Responses from several countries (e.g. Ghana, Sri Lanka, Suriname and the United Republic of Tanzania) indicate that they are in the process of developing legislation in this field.

Few of the survey responses provide any information on legal instruments related to the establishment of breeding programmes by the public sector. Viet Nam's Ordinance on Livestock Breeds (2004)[126] sets out basic objectives for state policies on livestock breeding, which include ensuring "the development of livestock breeds along the direction of industrialization and modernization on the basis of livestock breed development strategy, planning and plans", supporting "organizations and individuals tasked to multiply or raise purebred livestock breeds, prototypal, grandparental and nucleus breed stocks" and encouraging "organizations and individuals to produce and use new livestock breeds." The above-mentioned Namibian Livestock Improvement Act allows for the establishment "by the Minister"[127] of schemes to evaluate and certificate the performance of particular kinds and breeds of animals with the object of improving their genetic production potential. The Livestock Act of Bhutan (2001)[128] is described in Box 3F8.

Several of the AnGR-related laws listed above in the subsection on "general instruments" include provisions related to the role of the state in coordinating and/or implementing genetic improvement programmes, the operation of state-run breeding establishments and/or the provision of breeding services by the public sector. Madagascar's Decree N°2010-106,[129] for example, establishes the country's National Council for Genetic Improvement, which is allocated the task (*inter alia*) of developing national genetic improvement programmes. The "genetic improvement service" of the Livestock Ministry is charged with coordinating and monitoring the implementation of the council's recommendations. Regional "Breed Offices" are given the task of supporting and overseeing the operation of herd books by livestock-keepers' associations. As another example, Kyrgyzstan's Law on Pedigree Livestock Breeding[130] includes provisions related to the organization of a state herd book and to the supply of state support to breeding organizations. It assigns a role in coordinating the activities of breeding organizations to an "Authorized State Body for Pedigree Stockbreeding" and also includes provisions related to the operation of state breeding farms.

In so far as they provide any information on the effects that legislation related to breeding programmes is having on AnGR management, the survey responses generally indicate that the reported instruments are having a positive effect. France, for example (referring to both legal and policy measures), states that

> *"the collective organization of the measures allows different organizations to carry out their missions ... [in] animal breeding, management of genetic diversity and the sustainable conservation of genetic resources."*

Likewise, the response from Austria states that

> *"the regulations guarantee that a breeders' organisation is competent and works according to approved good practice methods."*

The responses from countries where there is no legislation in place generally provide little detailed information on their future priorities. The country report from Rwanda, however, notes that the main weakness of the national legal framework is the lack of an "animal breeding law" that would (*inter alia*)[131] regulate

[126] *Công Báo* No. 16, 24 April 2004, pp. 20–30 (available in English at http://faolex.fao.org/docs/pdf/vie45179.pdf).

[127] The Minister of Agriculture, Water and Rural Development.

[128] Available in English at http://faolex.fao.org/docs/pdf/vie45179.pdf

[129] Décret N°2010-106 du 2010/03/02 réglementant l'amélioration génétique des animaux domestiques et domestiqués à Madagascar (available in French at http://faolex.fao.org/docs/pdf/mad131582.pdf).

[130] Закон Кыргызской Республики о племенном деле в животноводстве Кыргызской Республики (available in Russian with an English abstract at http://tinyurl.com/o25spes).

[131] The other objective mentioned is to regulate the entry of new genetic material into the country.

"who is entitled to collect and sell semen and from what animals, who can do inseminations and [under] what ... minimum standards/requirements, pedigree registration[,] ... the recognition of breed associations and their herd books, the right to issue pedigree certificates and ... [the implementation of] performance testing and genetic evaluation".

Few countries report specific gaps in their existing provisions (although some note that implementation needs to be strengthened) or any problems caused by existing instruments. One exception is provided in the United Kingdom's country report, which lists "zootechnical legislation requirements being unachievable for numerically small breeds" among the obstacles to enhancing AnGR conservation measures. As is the case in several other areas of AnGR management, the survey response from the United States of America notes that the absence of legislation on breeding programmes (other than on animal identification) does not cause any problems with regard to AnGR management.

Reproductive biotechnologies

Legal and policy frameworks related to the use of reproductive technologies such as artificial insemination and embryo transfer have the potential to affect both breeding and conservation programmes. More broadly, they may influence the types of AnGR used by livestock keepers (e.g. if programmes only provide genetic material from certain breeds) and hence potentially affect both livestock-keeping livelihoods and the diversity of national livestock populations. The extent to which these technologies are in use in livestock production at country level is discussed in Part 3 Section E.

Relevant policies in this field can include instruments that aim to promote the use of reproductive technologies via the provision of subsidized services or via extension activities. In the case of legal instruments, the main objectives are generally to ensure the quality of the germplasm used in sanitary and genetic terms. Provisions typically relate to the licensing and inspection of artificial insemination centres and other facilities, quality controls on donor animals, and inspection and certification of imported or exported materials. Bhutan's Livestock Act of 2001 (see Box 3F8) can

Box 3F8

The legal and policy framework for breeding programmes in Bhutan

The legal and policy framework for animal breeding in Bhutan is based on the Livestock Act of Bhutan (2001)[1] and the Livestock Breeding Policy of 2007.

According to Chapter III of the Livestock Act, which addresses "designated farms", the Ministry of Agriculture may establish its own farms for genetic improvement and conservation and may also "help private farms in breeding." The Act also includes rules related to the supply of breeding animals to farms and the use of artificial insemination and embryo transfer.

The Breeding Policy sets out strategies for the development of breeding programmes and practices for large ruminants and – in less detail – for the country's other main livestock species. In the case of cattle, separate strategies are in place for peri-urban areas (based on cross-breeding) and for remote rural areas (based on promotion of the locally adapted Siri cattle and Mithun crosses, and – in the longer term – establishment of community-based breeding programmes). All the species- or breed-level strategies are based on a situational analysis of the current state of breeding practices and knowledge. Despite the systematic approach, the Bhutan's response to the 2013 legal survey reports that breeding policies for species other than cattle remain unclear and that this has contributed to an increase in the use of exotic breeds and cross-breeds and a decline in the populations of locally adapted breeds. In the case of cattle, Bhutan's country report states that the existing policy will favour effective management of locally adapted multipurpose cattle, but that little has yet been done in terms of the implementation of measures to improve their performance.

Sources: Country report of Bhutan; Bhutan's response to the 2013 legal survey.

[1] Available in English at http://www.nab.gov.bt/assets/uploads/docs/acts/2014/Livestock_Act_2001_Eng.pdf

Box 3F9

The legal framework for the use of reproductive biotechnologies in Brazil

Companies that produce, collect, process or market the semen and embryos of cattle, buffaloes, goats, sheep, horses, pigs or poultry in Brazil must be registered with the Ministry of Agriculture. Such companies are responsible for sending information on the animals from which material is collected, as well as on the number of semen samples or embryos collected, to the Inspection Division of Animal Genetic Material. The regulatory basis for the use of animal genetic material in Brazil is Law No. 6.446/1977,[1] which provides for the mandatory inspection and surveillance of semen used for artificial insemination. This law is regulated by Decree No. 187/1991,[2] which defines the role of the Ministry of Agriculture in the registration of sires, as well as in the registration of industrial and commercial companies and in the surveillance of genetic material imported or exported via airports, ports and border stations.

Any owner sending an animal as a donor to an artificial insemination centre must present performance certification indicating that the genetic material from the animal will be able to improve the production records of the respective breed.

Source: Adapted from Brazil's response to the 2013 legal survey.

[1] Lei nº 6.446, de 5 de outubro de 1977. Dispõe sobre a inspeção e a fiscalização obrigatórias do sêmen destinado à inseminação artificial em animais domésticos, e dá outras providências (available in Portuguese at http://tinyurl.com/q7rxo82).

[2] Decreto No. 187 de 9 de agosto de 1991. Regulamenta a Lei nº 6.446, de 5 de outubro de 1977, que dispõe sobre a inspeção e fiscalização obrigatórias do sêmem destinado à inseminação artificial em animais domésticos (available in Portuguese at https://www.planalto.gov.br/ccivil_03/decreto/1990-1994/D0187.htm).

serve as an example: this law contains a subchapter on artificial insemination and embryo transfer, which provides for the establishment of artificial insemination units (laboratories and housing facilities for donor animals) according to prescribed standards, forbids the use of semen from unlicensed premises, requires that donors of semen or embryos be certificated for genetic merit and disease status, requires that consignments of semen and embryos entering the country have a valid import licence and provides for inspection of artificial insemination units and laboratories used for semen processing and embryo storage. Further provisions are included in the country's Livestock Rules and Regulations of 2008 and the Livestock Breeding Policy of 2007. Brazil's legal framework in this field is described in Box 3F9.

A large majority (88 percent) of the OECD countries that responded to the legal survey indicated that they have legislation in place related to the use of reproductive biotechnologies (Figure 3F2). The figure for policies was lower (47 percent). This may be because developed countries where the service provision is largely in the hands of the private sector do not feel the need for policies in this field. In the case of non-OECD countries, the figures were 55 percent for legislation and 31 percent for policies.

Survey responses from countries that have legislation in place generally indicate that it serves its purpose of promoting the safe and efficient use of reproductive biotechnologies. A problem is, however, noted in the country report from Cyprus, which states that legal constraints affecting the use of fresh semen create difficulties for the use of artificial insemination in locally adapted ruminant breeds. The survey responses also mention few specific gaps in existing legislation. The response from Burundi notes the need to expand the species coverage of its legislation, while the responses from both Austria and Spain note the potential need to develop legislation to regulate the use of cloning. The only response that mentions any provisions specifically addressing potential problems that legal restrictions on the use of reproductive technologies might cause in AnGR management is that from Spain, which states that in the case of Royal Decree 841/2011[132] exemptions to the requirements

[132] Real Decreto 841/2011, de 17 de junio, por el que se establecen las condiciones básicas de recogida, almacenamiento, distribución y comercialización de material genético de las especies bovina, ovina, caprina y porcina, y de los équidos (available in Spanish at http://www.boe.es/boe/dias/2011/07/14/pdfs/BOE-A-2011-12107.pdf).

of the law are possible in the case of breeds that are at risk of extinction or difficult to manage, or for the establishment of a gene bank. It further states that future requirements include a system for determining with more precision the situations in which exemptions from sanitary rules should be allowed. With regard to problems caused by the absence of legislation, Malawi's country report notes that the

> *"lack of a breeding protocol and regulation has led to use of non-evaluated bulls for AI [(artificial insemination)] and potential inbreeding due to few bulls being used."*

Conservation

As the state of conservation programmes and policies is discussed in Part 3 Section D, the focus in this subsection is on legal instruments. Legislation in the field of AnGR conservation may address a range of different issues, including institutional responsibilities for implementing or coordinating national conservation programmes, the establishment of conservation facilities such as gene banks, the provision of support payments to the keepers of at-risk breeds, and the definition of the responsibilities of particular stakeholder groups such as breeders' associations.

Among the respondents to the legal survey, 71 percent of OECD countries reported that they have legislation in place targeting AnGR conservation and 88 percent that they have policies (Figure 3F2). The figures for non-OECD countries were 48 percent for legislation and 44 percent for policies. Countries were also asked specifically about measures targeting *in vivo* conservation and cryoconservation (Figure 3F3).[133] In the case of OECD countries, in both the legal and the policy categories, more respondents reported that their instruments target cryoconservation than *in vivo* conservation (71 percent vs. 65 percent for legislation and 76 percent vs. 65 percent for polices). In contrast, among non-OECD countries, more respondents reported instruments targeting *in vivo* conservation than cryoconservation (41 percent vs. 31 percent for both legislation and policies). However, a substantial proportion of non-OECD countries (34 percent) reported that they have a policy instrument under development in this category, suggesting a growing interest in cryoconservation in developing countries.

As noted above in the subsection on instruments targeting the general management of AnGR, a number of countries have legal instruments in place that assign responsibility for implementing conservation programmes to specific bodies as part of their overall mandates to implement or support national AnGR management programmes. A few other countries report legislation related specifically to the establishment of gene banks. One example is the Kenya Animal Genetic Resources Centre Order (2011),[134] which, *inter alia*, establishes the centre as a state corporation, defines its functions and the composition and competencies of its governing board, and establishes arrangements related to its funding.[135]

At a more fundamental level, legislation may serve to establish the implementation of (and/or provision of support to) AnGR conservation activities as one of the responsibilities of the national government. For example, France's Agricultural Orientation Law (2006)[136] states that the government is authorized to take (by ordinance) the measures necessary to conserve of AnGR diversity, making specific efforts to conserve local breeds, particularly

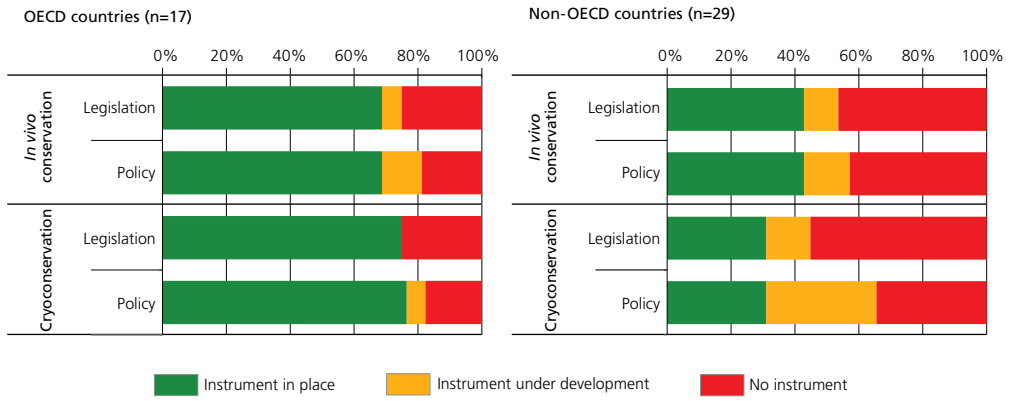
[133] Answering these subquestions was optional. Countries that reported instruments targeting conservation were asked to indicate whether these include measures specifically related to the two categories of conservation. In fact, almost all countries provided answers to both the subquestions. The few gaps that remained could be filled based on the assumption that if no conservation instruments were reported there could be no provisions targeting the individual categories of conservation. It was thus possible to calculate figures base on the full dataset of 46 countries.

[134] Available in English at http://faolex.fao.org/docs/pdf/ken106282.pdf (the order is mentioned in Kenya's country report in connection with the country's plans to establish an *in vitro* gene bank).

[135] The above-mentioned legislation establishing the National Animal Germplasm Program in the United States of America is another example.

[136] Loi n° 2006-11 du 5 janvier 2006 d'orientation agricole (available in French at http://tinyurl.com/ppfcl5n).

FIGURE 3F3
Types of conservation targeted by legal and policy instruments



Source: Legal survey responses, 2013

those from mountain areas. The same country's Rural and Sea Fishing Code[137] states that the state shall ensure the conservation of AnGR diversity in collaboration with all relevant stakeholders. As another example, Viet Nam's Ordinance on Livestock Breeds (2004)[138] prescribes that the state

> *"shall invest in and render support for the collection and conservation of precious and rare livestock gene sources; build establishments for keeping precious and rare livestock gene sources; and preserve precious and rare livestock gene sources in localities."*

The extent to which the activities of bodies mandated to manage national conservation programmes are prescribed in legal instruments varies greatly from country to country. Slovenia's above-mentioned Regulation on Conservation of Farm Animal Genetic Resources, for example, includes quite detailed provisions related both to the elements of the national conservation programme and to associated activities such as the official recognition of breeds (see above). The conservation programmes prescribed in this regulation are based on breeding programmes certified in accordance with the legislation described above in the subsection on genetic improvement, but also include risk-status monitoring and conservation-related research, education, training and public-awareness raising, as well as proposals for *ex situ in vivo* conservation measures and for activities related to the ethnological, cultural, historical and environmental roles of the respective breeds.

As noted above, in a number of countries, legislation addressing the operation of breeding programmes includes explicit references to conservation or the need to maintain genetic diversity. Spain's Royal Decree 2129/2008, for example, classifies "[breed] improvement programmes" either as "selection programmes" or as "conservation programmes." A conservation programme is defined as an

> *"improvement programme which has as its objective the maintenance of genetic diversity to guarantee the conservation of*

[137] Code rural et de la pêche maritime. Article D653-9 Créé par Décret n°2006-1662 du 21 décembre 2006 - art. 3 JORF 23 décembre 2006 (available in French at http://tinyurl.com/ppfcl5n).

[138] Available at http://faolex.fao.org/docs/pdf/vie45179.pdf

a breed, cross-bred population,[139] *bloodline or variety and to prevent its extinction or to increase its population."*

Improvement programmes of whatever category have to be submitted to the competent authority as part of the process through which the respective breeders' association acquires official recognition. The obligations of breeders' associations under the decree include implementing the officially approved improvement programme (whether "conservation" or "selection") for their respective breed. If a conservation programme has been approved, participation "in the form that the competent authorities stipulate" is obligatory for all livestock breeders who belong to the respective breeders' association. The contents of a conservation programme (i.e. the elements that have to be included in the plans submitted for approval by the competent authority) are listed in an annex to the decree. The decree further states that the decision as to whether or not a conservation programme is required is to be based on the "degree of development, population size, zootechnical value and productive capacity" of the breed.

As noted above in Subsection 3, EU legislation includes provisions related to support payments for the keepers of breeds considered to be at risk of extinction. Several survey responses from EU member countries mention conservation programmes that include payments made in accordance with this legislation. Examples include the Austrian Agri-Environmental Programme 2007–2013,[140] which allowed for payments to be made to the keepers of 31 "acknowledged endangered breeds" provided that they were members of the respective breeding organization, followed the breeding programme for the breed and – if the breed was classified as "highly endangered" – followed the mating recommendations drawn up by the breeding organization.

The survey responses do not generally provide detailed information on how the reported legal and policy instruments contribute to the implementation of concrete conservation activities. In some cases, countries report that conservation activities underpinned by legislation have been associated with improvements in the status of at-risk breeds. Taking Austria again as an example, the country's survey response notes that since its Agri-Environmental Programme was established in 1995,[141] the populations of all at-risk breeds in the country have grown significantly and none have been lost. It should, of course, be borne in mind that, while appropriate legal frameworks may contribute to such successes they are also likely to depend on a wide range of other factors, including the availability of resources, capacity to plan and implement appropriate activities and "political will" to support them on the part of the national authorities and other stakeholders. The relative significance of legal and other factors – and chains of cause and effect among them – are difficult to identify and are likely to vary from country to country.

In some cases, the existence of legislation may help promote the provision of financial resources for conservation: some legal instruments (e.g. China's Stock-breeding Law of 2005[142] and Montenegro's Law on Livestock Farming – 2010)[143] make specific references to the inclusion of AnGR-related funding in state budgets. Alternatively, a lack of funding may inhibit the development of legislation. For example, the survey response from Latvia notes that developing laws and regulations that allocate institutional responsibilities for implementing conservation programmes is an important objective, but that this has not been done because regular funding to support the work has not been secured.

The survey responses generally do not report any specific problems associated with current legal or policy frameworks or any specific gaps

[139] "encaste" in the original Spanish.

[140] For details of AnGR conservation measures implemented under this scheme, see the Austrian Programme for the Conservation of Acknowledged Endangered Breeds (available in English at http://tinyurl.com/nkl9bdt).

[141] The predecessor of the programme mentioned in the preceding paragraph.

[142] Available in English at http://faolex.fao.org/docs/texts/chn61879.doc

[143] Закон о сточарству (available in Montenegrin at http://tinyurl.com/ozn4jas).

Box 3F10

The legal basis for animal genetic resources conservation in Poland

Poland's Animal Breeding Law of 20 August 1997,[1] brought in after the introduction of the market economy into the country, set out provisions for fundamental changes in the organization of breeding and reproduction in farm animals. The law enabled the transfer of responsibilities over animal breeding from the state (the Central Animal Breeding Office) to breeders' organizations, and created the legal and institutional conditions for this change.

The 1997 law did not contain any provisions specifically targeting the conservation of animal genetic resources (AnGR); the only reference appeared in Article 1, which indicated that the scope of the law encompassed the regulation of issues related to animal breeding and the management of AnGR.

The designation of Poland's National Focal Point for Animal Genetic Resources, and particularly the process of preparing the country report for the first report on *The State of the World's Animal Genetic Resources*, contributed to awareness raising and to an informed discussion on the further development of animal breeding legislation. The National Focal Point played an active role in this development and lobbied for the inclusion of an acknowledgment of the state's obligation to conserve AnGR in the legislation.

Amendments introduced to the 1997 law in 2004 included, for the first time, an article setting out provisions for the conservation of breeds, varieties and lines of farm animals threatened with extinction due to small or decreasing population size (Article 21a). This was a major development that was fundamental to the establishment of a legal and institutional framework for AnGR conservation. The article also included provision for an implementing act, through which the Minister of Agriculture would identify an entity to be given responsibility for implementing and coordinating conservation programmes and for the collection and storage of biological material for cryoconservation. While efforts to conserve native breeds had been underway in Poland since the 1980s, the amended law established a legal basis for comprehensive conservation activities and resulted in the coordination of these activities being entrusted to the National Research Institute of Animal Production.

In 2007, the further development and transformation of animal breeding and reproduction in Poland, including implementation of European Union legislation, led to the adoption of a new Animal Breeding Law.[2] Provisions for the conservation of endangered breeds were further enhanced (Article 28). The law sets out the elements of conservation programmes and defines the responsibilities of the entity entrusted by the Minister of Agriculture with coordination of conservation activities. The law coheres with the Rural Development Programme (currently 2014–2020, earlier phases 2004–2006 and 2007–2013), which provides support to farmers who keep endangered local breeds.

Issues for consideration in the further development of the legal framework for conservation include formal recognition of the National Bank of Animal Genetic Resources Biological Material and amendments to the list of species eligible for inclusion in conservation programmes.

Provided by Elżbieta Martyniuk, National Coordinator for the Management of Animal Genetic Resources, Poland.

[1] Dz.U. 1997 Nr 123 poz. 774 Ustawa z dnia 20 sierpnia 1997 r. o organizacji hodowli i rozrodzie zwierząt gospodarskich (available in Polish at http://isap.sejm.gov.pl/DetailsServlet?id=WDU19971230774).

[2] Dz.U.07.133.921 Ustawa z dnia 29 czerwca 2007 r. o organizacji hodowli i rozrodzie zwierząt gospodarskich (available in Polish at http://faolex.fao.org/docs/pdf/pol87292.pdf).

or weaknesses in them. Some responses do, however, indicate problems associated with the absence of legislation. The response from Bhutan, for example, states that the

> *"lack of legislation on conservation programs hampers execution of conservation, especially* in-situ *conservation. The Biodiversity Act of Bhutan 2001 needs to be updated and AnGR conservation and management [needs to be] ... included."*

Similarly, the country report from Italy mentions that the country's ability to make appropriate plans for AnGR conservation is constrained by the lack of a national law, although the problem is partially mitigated by the existence of several regional laws.[144]

Importation of genetic material

As discussed in Section C of Part 1, there are considerable international flows of AnGR. While it is generally accepted that enabling livestock keepers and breeders to access a wide range of genetic material, whether from inside or outside their home countries, is an important objective, countries may for various reasons wish to control the flow of genetic resources across their borders.

The most common reason for placing legal restrictions on the import of genetic material is to prevent the entry of transboundary animal diseases. Controls of this type, which have to comply with international regulations related to trade barriers (see Subsection 2), are discussed below in Subsection 4.5. Countries may also choose to put in place rules related to the characteristics of the genetic material itself. Rules of this type potentially relate to the genetic quality of specific consignments of genetic material (e.g. requiring that it comes from animals that have been subject to genetic evaluation) or to categories of genetic material (e.g. to the breed from which it comes). It has sometimes been proposed that countries should require compulsory assessments of potential impacts on AnGR diversity, livelihoods and the environment before allowing a new breed to be imported. Counter arguments are that such measures can constitute a barrier to trade and that ensuring that breeders and livestock keepers are sufficiently well informed to make appropriate decisions about the type of animals they wish to use is a more appropriate approach (for discussion see Tvedt *et al*., 2007; Pilling, 2007).

The legal survey requested countries to report on instruments aimed at ensuring the suitability of imported genetic material for use in local production environments. Among reporting OECD countries, 52 percent stated that they have legislation of this type in place. The equivalent figure for non-OECD countries was 45 percent (Figure 3F2). In the case of policies, the figures were 29 percent and 31 percent, respectively.

There appears to have been some diversity in how this question was interpreted. Where the responses provide details, they generally refer to legislation targeting the quality of imported genetic material, rather than measures specifically related to matching imported material to production systems in the importing country. As discussed above in Subsection 3, imports of genetic material into EU member countries from "third countries" (i.e. non-member countries) have to comply with rules set out in the relevant EU directive.[145] A number of responses from European countries refer to this requirement (although, as indicated by the above-cited figures for OECD countries, not all EU respondents considered that their instruments fall into the category targeted by this question).

The responses from developing countries, where they provide details, also for the most part refer to general legislation targeting the quality of imported genetic material. The response from Brazil, for example, states that imported material must be accompanied by a pedigree record of at

[144] For example: Legge regionale 14 ottobre 2008, n. 26 Tutela delle risorse genetiche autoctone vegetali ed animali di interesse agrario. B.U. Regione Basilicata N. 50 del 16 ottobre 2008 (available in Italian at http://tinyurl.com/q28dn8e).

[145] Council Directive 94/28/EC of 23 June 1994 laying down the principles relating to the zootechnical and genealogical conditions applicable to imports from third countries of animals, their semen, ova and embryos, and amending Directive 77/504/EEC on pure-bred breeding animals of the bovine species (available at http://tinyurl.com/o8fq6kr).

least three generations and by performance certification attesting to the potential of the material to improve the production levels of the respective breed. Likewise, the survey response from Ecuador notes that, in order to guarantee the development of the national livestock sector, the introduction of animals of low zootechnical quality for the purpose of breeding is prohibited, even in the case of international donations, and that import documents for breeding animals or other genetic material must include pedigrees. Namibia's response notes that the relevant instrument in this field is the above-mentioned Livestock Improvement Act of 1977. This law requires that anyone wishing to import animals, semen, ova or eggs into Namibia must obtain written permission from the Registrar of Livestock Improvement. If a breeders' society exists for the respective breed, the application must be lodged with the society, which will then make a recommendation to the Livestock Improvement Board.

None of the survey responses describe any instruments requiring compulsory impact assessments prior to the introduction of new breeds. However, South Africa's country report notes that its Animal Improvement Policy (2006)[146] calls for the implementation of "biological impact studies" before new breeds are imported so that their potential impact on locally adapted AnGR can be assessed (see Part 1 Section C). A few survey responses express some concern about the absence of such measures. The response from Cyprus, for example, notes that the

> *"import of exotic genetic material that cannot cope with [the] local production environment, results in financial losses for the farmers and, sometimes, [leads] to genetic dilution of local animal genetic resources"*

and the need for

> *"tighter control, policies and infrastructure to allow for genetic assessment before introduction of genetic material for the purpose of animal husbandry."*

[146] Animal Improvement Policy for South Africa. Notice 165 of 2007. *Government Gazette*, No. 30459 (16 November 2007): 41–66.

Some survey responses advocate an approach based on awareness-raising rather than on legal measures. The response from the Czech Republic, for example, states that future needs include carrying out an assessment of the suitability of imported material from different breeds and publishing its results "to improve the general awareness on this issue and facilitate farmers' decisions."

Animal genetic resources-related research

A lack of sufficient information about the characteristics of AnGR, particularly the characteristics of locally adapted breeds, is often noted as a constraint to their effective management (FAO, 2007), as is a lack of appropriate tools for their characterization, conservation, use and development. Strengthening AnGR-related research is therefore an important objective. Relevant legal instruments include those that prescribe the inclusion of AnGR-related research in national research activities and/or establish the institutional framework for such research activities (e.g. establishing research organizations or prescribing their mandates). Research activities may also be affected by legislation in fields such as animal welfare, sanitary protection and ABS.

While several survey responses note that research on AnGR is neglected, a number of relevant legal and policy instruments are reported. Most OECD respondents (76 percent) indicated that they have relevant policies in place (Figure 3F2). Fewer (53 percent) reported legislation. The equivalent figures for non-OECD countries were 48 percent for both policies and legislation. Among legal instruments, reported examples include Slovenia's Regulation on the Conservation of Farm Animal Genetic Resources (2011),[147] under which the activities to be covered by the country's Programme for Conservation of Farm Animal Genetic Resources include "research, education, training, and raising public awareness and promotion in the field of conservation of livestock biodiversity." Under the

[147] Pravilnik o ohranjanju biotske raznovrstnosti v živinoreji (Regulation on Conservation of Farm Animal Genetic Resources) (available in Slovenian at http://tinyurl.com/nm8l28a and in English at http://tinyurl.com/ntyb4qw).

same instrument, the organization "appointed as a public-service gene-bank for animal husbandry" is charged with research into the zootechnical and molecular characteristics of indigenous breeds. Most of the reported legal instruments in this category do not include such detailed AnGR-specific provisions, but outcomes in terms of promoting research on the topic are generally reported to be positive. The precise mechanisms involved are not always clear. However, the response from Latvia (which reports "no specific regulations regarding research related to AnGR") links the need for legislation to the need for regular funding for AnGR-related research.

Reported national policies that target AnGR-related research include the Renewable Natural Resources Research Policy of Bhutan (2011),[148] whose section on veterinary and livestock health includes the objective of enhancing "sustainable livestock production and health through participatory selective breeding, identification of promising indigenous animals and animal products"; Costa Rica's State Policy for the Food and Agriculture Sector and Rural Development,[149] which includes a strategy for improving the infrastructure for research into genetic improvement (focusing particularly on the creation of gene banks and the establishment of public–private partnerships for the management of genetic resources); and Malaysia's National Strategies and Action Plans on Agricultural Biodiversity Conservation and Sustainable Utilization,[150] which include a subsection on "monitoring and research" of AnGR. The survey response from Germany notes that "research on conservation and sustainable use of AnGR is part of the research agenda of public research conducted by the Ministry of Agriculture and other institutions." It also notes that a number of research programmes not specifically focused on AnGR (e.g. on organic farming and various aspects of biodiversity management) can, in principle, include projects in this field. The response from Spain, likewise, notes that several National Research Plans implemented by the National Institute for Agricultural and Food Research and Technology (INIA)[151] have included activities related to AnGR.

Transgenic animals and the use of transgenic products

Given the number of genetically modified crop varieties available for use in agriculture and the various controversies that surround their use, many countries have put in place regulatory frameworks of one kind or another addressing the use of genetically modified organisms (GMOs) in agriculture and the use of products derived from GMOs. These frameworks generally establish mechanisms via which specific GMOs or products derived from GMOs can be assessed and (if deemed appropriate) certified for use (see Box 3F11 for an example), prohibit or restrict the use of particular categories of GMOs or GMO-derived products and/or set out rules aimed at ensuring the safe use of GMOs. To date, the most prominent GMO-related issue in the livestock sector has been the use of GMOs in animal feed. Any future moves to expand the use of transgenic animals in agriculture and food production will inevitably bring regulatory issues to the fore.

As part of the legal survey, countries were asked to report on legislation related to the use of transgenic livestock and whether current legal frameworks have any effect on AnGR and their management. A majority of responding OECD countries (76 percent) reported that they have relevant legislation in place, while 47 percent reported policies. The equivalent figures for non-OECD countries were 41 percent and 27 percent respectively.

The survey responses do not highlight many AnGR-specific issues. Some countries report that they are in the process of developing legislation related to the use of GMOs in general. Some responses note that current frameworks do not specifically address livestock. However, no specific problems related to gaps in existing legislation are mentioned. Some countries report that they

[148] Available in English at http://tinyurl.com/pq7za53

[149] Política de Estado para el Sector Agroalimentario y el Desarrollo Rural Costarricense 2010–2021 (available in Spanish at http://www.mag.go.cr/bibliotecavirtual/a00289.pdf).

[150] Available in English at http://tinyurl.com/owjbqr7

[151] http://www.inia.es/IniaPortal/verPresentacion.action

Box 3F11

The regulatory framework for the use of genetically modified organisms in Australia

All dealings with genetically modified (GM) organisms in Australia are regulated by the Gene Technology Regulator under the Gene Technology Act 2000. The Regulator will only grant a licence for the commercial release of a GM crop if it has been assessed as safe for human health and the environment. Every potential licensee must provide the Regulator with an application, which is subject to public consultation and a transparent risk assessment process, involving a comprehensive risk assessment and risk management plan. The principals underpinning the risk assessment process are based on international standards originally developed by bodies such as the World Health Organization, the Codex Alimentarius Commission and the Organisation for Economic Cooperation and Development.

Similarly, GM foods are not approved for sale unless they have been assessed as safe for human consumption, and those foods that are approved must be labelled to allow consumers to make an informed choice. GM foods are only approved for sale once assessed as safe by Food Standards Australia New Zealand (FSANZ). To enable consumers to make informed choices GM foods are required to be labelled in accordance with the Australia New Zealand Food Standards Code, administered by FSANZ. The exemptions to the GM labelling requirements relate to food products that do not contain GM material of any type and are therefore indistinguishable from conventionally produced foods, including animals fed on GM feed.

There are no GM animals or animal products currently approved for commercial release in Australia.

Source: Australia's response to the 2013 legal survey.

have established institutional responsibilities for dealing with the regulation of the use of GMOs in the livestock sector. Costa Rica, for example, notes that the National Animal Health Service has been assigned the task of developing and implementing provisions related to the use, release or commercialization of genetically modified animals – or their products or subproducts – that could present any kind of risk to the environment or to human or animal health.[152] Countries report varying levels of legal restriction on the use of GMOs. The survey response from Austria, for example, states that

> *"the use of genetically modified animals and their products is forbidden in agricultural production in Austria. Imported products containing GMO may be used for feedstuff but must be labelled accordingly."*[153]

With regard to the effects of these measures, the response notes that

> *"organic farming plays an important role in Austrian agriculture. To further protect the organic sector, use of GMOs in agriculture is not desirable."*

The response from Norway notes that the country's legal prohibition of the use of GMOs in all food and feed creates problems with regard to the sourcing of feed products, particularly soybeans. However, there is no indication that this has any particular effect on the management of AnGR.

Access and benefit-sharing

International developments in the field of access and benefit-sharing are described above in Subsection 2. As part of the legal survey, countries were asked about the state of ABS-related legislation and policies at national level and about whether existing or planned instruments include any specific provisions related to AnGR or genetic resources for food and agriculture in general. Previous assessments of use and exchange practices in the AnGR sector (e.g. FAO, 2009c) have generally concluded that few ABS-related prob-

[152] Ley N° 8.495. Ley general del Servicio Nacional de Salud Animal. *La Gaceta* N° 93, 16 de mayo de 2006 (available in Spanish at http://faolex.fao.org/docs/pdf/cos78033.pdf).

[153] Verordnung der Bundesministerin für Gesundheit und Frauen über die Kennzeichnung von Erzeugnissen, die aus gentechnisch veränderten Organismen bestehen oder solche enthalten (Gentechnik-Kennzeichnungsverordnung) Bundesgesetzblatt Nr. BGBl. II Nr. 5/2006 (available in German at http://tinyurl.com/pf6ec8e).

lems have arisen, either in terms of potential users being unable to access AnGR or in terms of AnGR being acquired without adequate consent being obtained from the providers or without appropriate sharing of benefits. However, they also suggest that some stakeholders have concerns about potential future developments: on the one hand that additional regulations may inhibit or add to the transaction costs of exchanging AnGR and on the other that greater interest in utilizing locally adapted AnGR outside their areas of origin (e.g. as part of climate change adaptation efforts) may lead to inequitable exploitation of these resources.

The survey responses largely reflect the low profile of ABS issues in the AnGR subsector. The proportion of countries reporting that they have ABS-related legislation currently in place was low: 18 percent in OECD countries and 28 percent in non-OECD countries. The figures for policies were 35 percent and 28 percent, respectively. A number of countries, however, reported that national ABS-related instruments are being introduced or updated in order to enable them to meet their commitments under the Nagoya Protocol. In the case of OECD countries, of all the topics covered in the survey, ABS was the one for which the largest number of respondents reported that instruments are "in development": 47 percent in the case of legislation and 29 percent in the case of policies. The equivalent figures for non-OECD countries were substantially lower (particularly in the case of legislation) at 10 percent and 21 percent, respectively. Fifty-nine percent of OECD respondents and 31 percent of non-OECD respondents reported that their existing or planned instruments feature at least some provisions specifically targeting AnGR (including exemptions, or potential exemptions, for AnGR from general ABS rules). However, few responses highlight any concrete AnGR-related ABS issues that need, or have needed, to be addressed at legislative or policy level. A few note the need to develop measures addressing access to genetic material for research purposes or for storage in gene banks (and subsequent extraction of the material for use). Again, however, no specific problems (current or foreseen) are described.

Some survey responses indicate that AnGR are included under ABS-related provisions set out in general instruments on biodiversity. Domesticated animals are, for example, explicitly included within the scope of the Biodiversity Act of Bhutan (2003)[154] and hence within the scope of the ABS-related rules set out in this law. In this case, the provisions allow for the possibility of exemptions for AnGR (and plant genetic resources for food and agriculture) under "special rules and regulations or conditions" where the competent authority deems appropriate.

Reported legal instruments that include provisions specifically related to the export of AnGR include Montenegro's above-mentioned Law on Livestock Farming (2010),[155] which states that

> *"indigenous and endangered indigenous breeds can be exported only if exports do not threaten their numerical strength and their protection, based on authorization from the Ministry."*

Similarly, Viet Nam's Ordinance on Livestock Breeds (2004)[156] states that "international exchange of precious and rare livestock gene sources" requires permission from the Ministry of Agriculture. Another example is provided in Turkey's country report: a regulation adopted in 2012 – the Regulation on Utilization and Export of Native Domestic Animal Genetic Resources[157] (see also Box 3F5) – prohibits the export of AnGR without permission from the Ministry of Food, Agriculture and Livestock. It also requires foreign researchers to obtain permission to use AnGR for research purposes in Turkey and Turkish researchers to obtain permission to use AnGR for research abroad. Export of at-risk AnGR for commercial purposes is forbidden and requests for genetic material from gene banks are not to be accepted

[154] Available in English at http://www.icimod.org/resource/2216

[155] Закон о сточарству (available in Montenegrin at http://tinyurl.com/ozn4jas).

[156] *Công Báo* No. 16, 24 April 2004, pp. 20–30 (available in English at http://faolex.fao.org/docs/pdf/vie45179.pdf).

[157] *Official Gazette of Turkey*, No. 28418, 21 September 2012 (available in Turkish at http://tinyurl.com/naaagwp).

if stocks are limited. Export is prohibited unless the prescribed application procedures are followed and a material transfer agreement prepared.

China's Stock-Breeding Law (2005)[158] includes the following specific reference to benefit-sharing arrangements:

> *"Where any livestock or poultry genetic resource included in the protection list is to be exported from China or is to be researched and utilized within China in cooperation with any foreign institution or individual, the applicant shall file an application with the stockbreeding and veterinary administrative department of the provincial people's government and shall simultaneously put forward a plan on sharing the benefits with the state."*

No survey responses or country reports describe any specific effects that provisions of this kind have had, to date, on the use and exchange of AnGR.

Patenting

International developments with regard to legal frameworks addressing intellectual property rights in the field of AnGR management are discussed above in Subsection 2. National-level measures were addressed as part of the legal survey. Countries were asked to provide information on their patent laws, particularly whether they include any provisions specifically related to AnGR or to living organisms in general. Because the questions were clearly interpreted differently by different countries, it is difficult to provide an overview of the findings in quantitative terms. However – whatever the legal framework in the respective country – the survey responses generally suggest that patent law has had little impact on AnGR management. No specific concerns are raised about existing frameworks. However, some responses note the need for adaptation or clarification of existing provisions or called for a more homogeneous approach globally.

The responses from several EU member countries refer to the exclusion of "animal varieties" from patentability under the EU directive on the legal protection of biological inventions.[159] Similar exclusions are reported in the responses from a few other countries (e.g. Malaysia and Switzerland). Little information is provided on the effects of these exclusions. In the case of Switzerland, the effects of the existing framework are described as follows:

> *"Respect is given to safety of breeds and genetic diversity, privilege of farmers and breeders is respected, benefit sharing is respected, fundamental research can be done."*

The response from Austria notes that a change in the law "would have powerful effects on the management of Animal Genetic Resources in EU/Austria" and the need for "decisions in the EU about the legality of future patenting praxis." The response from Bulgaria mentions that under the country's *sui generis* system for livestock breeds (see above), autochthonous breeds are excluded from "authorship claims", which it is stated "can be harmful for the conservation and development of the breed."

4.4 Instruments related to marketing

In most production systems, the management of AnGR is influenced – at least to some degree – by the need to produce goods or services that can be sold at a profit. If a breed's products are difficult to market, it will often become less popular with livestock keepers and, in extreme cases, may fall completely out of use and become extinct. While the basic driving forces of markets for livestock products are consumer demands and competition among producers, they are also generally regulated, at least to some extent, by legislation and may be influenced by public policies. The main objectives of these instruments are normally to protect the interests of consumers and/or to promote the development of a flourishing livestock

[158] Available in English at http://faolex.fao.org/docs/texts/chn61879.doc

[159] Directive 98/44/EC of the European Parliament and of the Council of 6 July 1998 on the legal protection of biotechnological inventions (available at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31998L0044).

sector (or the economy more broadly). However, because they may differentially affect the profitability of different types of livestock production, they have the potential to influence the types of AnGR that are kept by livestock keepers.

Consumer protection

Most if not all countries have some kind of legislation in place that aims to protect consumers by prohibiting the sale of dangerous or defective goods, goods marketed under misleading descriptions and so on. While legislation of this type has no obvious differential effects on the marketing of products from different types of AnGR, it may underpin more specific regulations or initiatives that do have such effects.

Where animal products are concerned, one of the most significant aspects of consumer protection is food safety. While effective regulation in this field is, clearly, extremely important from the perspective of public health and in terms of consumer confidence in livestock products, food safety laws can create challenges for the producers of certain types of food (including traditional products such as cheeses made from raw milk) or for producers that operate in conditions that make it difficult to comply fully with the relevant rules (e.g. some small-scale livestock keepers). The possibility that effects of this kind might create problems for the marketing of products from at-risk breeds was acknowledged in the first SoW-AnGR. However, there was little to indicate that this was a widespread issue. A small number of responses to the legal survey mention problems of this kind. The response from the Czech Republic, for example, states that

> *"the impact appears to be in some respect negative. Compliance with legal measures brings a number of inspections [and] additional administrative burden. It requires technical measures which might be capital intensive. For that reason some farms retreat from keeping animals and ... [AnGR diversity] decreases."*

Likewise, the response from Norway notes that

> *"due to high hygienic standards requiring expensive production equipments, these regulations challenge the profit for small-scale entities."*

Product traceability

An issue closely related to consumer protection is that of the traceability of food products of animal origin through all stages of production, processing and distribution, i.e. from the birth of the animal to the sale of the product to the consumer. As noted above in Subsection 4.3, traceability is one of the multiple benefits potentially associated with an effective animal identification system. Traceability is important from the perspective of improving food safety. It can also help to increase consumers' confidence in claims made about the origin of products as part of marketing campaigns. It can, however, create substantial transaction costs. A compulsory traceability system normally requires legal backing to ensure compliance.

Traceability systems and related legal frameworks are widespread in developed countries. EU regulations, for example, are noted above in Subsection 3. There is also increasing interest in establishing traceability systems in developing countries. Examples of relevant legislation reported in the responses to the legal survey include the United Republic of Tanzania's Act on Animal Identification and Traceability (2010),[160] Ecuador's Ministerial Accord establishing the Animal Identification and Traceability System (2011),[161] Namibia's Animal Identification Regulations (2009)[162] and Uruguay's Resolution on the Animal Identification and Registration System (2011).[163]

[160] Available in English at http://tinyurl.com/oum2t2h

[161] Acuerdo N° 41 – Crea el Sistema de Identificación y Trazabilidad Animal (SITA) (available in Spanish at http://faolex.fao.org/docs/pdf/ecu120083.pdf).

[162] Animal Identification Regulations (GN No. 29 of 2009) *Government Gazette of the Republic of Namibia,* No. 4217 of 5 March 2009 (available in English at http://faolex.fao.org/docs/pdf/nam126791.pdf).

[163] Resolución N° 11/011 – Sistema de Identificación y Registro Animal (SIRA) (available in Spanish at http://faolex.fao.org/docs/pdf/uru110739.pdf).

The survey responses do not highlight any particular problems with regard to the effectiveness of existing legislation as a basis for establishing effective traceability systems. However, the response from the United Republic of Tanzania notes that the country's system is new and that more efforts are needed to ensure that it functions properly and is sustainable over the longer term. The indirect effects that the existence of a traceability system has on AnGR management are likely to vary from country to country depending on how it affects market access and demand for various kinds of animal product. The livestock sector in general is likely to benefit from greater consumer confidence and possible opportunities to enter new markets. The survey response from Slovenia, for example, notes that traceability increases buyers' awareness of the origin of food products and increases demand for food from local sources. On the negative side, the response from the Czech Republic notes that, as in the case of food-safety regulations, complying with traceability legislation can sometimes be a burden for small-scale producers.

Marketing schemes – mainstream and niche products

Several countries indicate in their survey responses that they have policy measures in place supporting marketing schemes for livestock products. In some cases, these measures have been established on the basis of specific legislation. Some of these policies and laws target mainstream livestock products. Others focus on (or include provisions related to) the marketing of niche products, i.e. products with specific characteristics that appeal to a particular subset of consumers. A few survey responses note that "general" laws or policies on marketing do not adequately address the marketing of products from a diverse range of AnGR, either because of a lack of provisions specifically addressing this area or because the types of products promoted tend to come from a narrow range of "mainstream" breeds. The response from Nepal, for example, notes that a

> *"lack of clear policy for the marketing of animal products specially from the native breeds and of niche products hinders the conservation of animal genetic resources".*

The response from Luxembourg notes that

> *"animal products are ... [promoted] under the national meat quality labels (beef, pork, direct farm sales, etc.) or private initiatives. Mostly, conventional intensive beef breeds and pig hybrids are valued under these labels."*

Reported examples of marketing laws that address the promotion of niche products include Slovenia's Act on the Promotion of Agricultural and Food Products (2011).[164] Marketing activities within the framework of this law reportedly contribute to increasing product diversity and awareness of "autochthonous and other breeds of AnGR", which in turn helps to keep the breeds in use.

There are a number of specific niche markets that are recognized as having at least some potential as outlets for the sale of products from breeds that are not competitive in mainstream markets. These include the market for organic products, the market for products sold under protected designations of origin (or similar labels that indicate the geographical source of a product or the methods used in its production) and the market for products produced under labels that indicate high standards of animal welfare. The legal survey specifically asked countries to report on laws or policies related to markets of this type. Responses are discussed in the following paragraphs.

Organic production. In the case of organic production, all the responding OECD countries and more than 60 percent of responding non-OECD countries reported that they have legislation in place. The sample of countries that responded to the survey appears to be a little more advanced in this respect than the world as a whole. UNEP (2013) reports that 86 countries

[164] Zakon o promociji kmetijskih in živilskih proizvodov (available in Slovenian at http://tinyurl.com/o4d7lcd).

have legislation on organic agriculture in place, while another 26 countries are in the process of drafting legislation.

A legal framework for organic production normally consists of a set of standards that producers have to follow in order to be permitted to describe their products as organic, arrangements for the certification of organic products and rules related to the use of logos and labels indicating that products are organic. By increasing consumer confidence in organic products and providing protection against fraudulent competition, an effective legal framework increases the likelihood that producers who follow organic standards will be able to make a profit and continue operating. If organic products are produced for export, they normally have to be certified by a certification body that is recognized by the relevant authorities in the importing country (UNEP, 2013). In addition to legislative measures, countries may choose to introduce various kinds of policy measure to encourage or support the development of organic production (support payments, provision of information to producers and consumers, etc.).

Organic standards for livestock production typically include some reference to the types of breed that are appropriate for use in organic systems. The Codex Alimentarius Commission's Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods (FAO/WHO, 2007), for example, state that

> *"the choice of breeds, strains and breeding methods shall be consistent with the principles of organic farming, taking into account in particular:*
> *a) their adaptation to the local conditions;*
> *b) their vitality and resistance to disease;*
> *c) the absence of specific diseases or health problems associated with some breeds and strains (porcine stress syndrome, spontaneous abortion etc.)."*

As noted above in Subsection 3, the EU regulation on organic production refers to the need to choose breeds that are appropriate to the production conditions. Examples at national level include Canada's General Principles and Management Standards,[165] which serve as organic standards within the framework of the Organic Products Regulations (2009)[166] and state that

> *"the operator shall ... select breeds and types of livestock that are suitable for site-specific conditions within the local environment and production system and that are resistant to prevalent diseases and parasites ..."*

While rules related to the use of well-adapted animals in organic production clearly have some potential to influence AnGR management, in many cases the breeds used in organic production are the same as those used in conventional production in the same geographical area (FAO, 2007a). A further point to note is that a well-developed legal framework will not, in and of itself, create a thriving organic sector if consumers have little interest in organic products or are unable to pay the higher prices usually associated with them. Any potential benefits in terms of promoting the sustainable use of AnGR are likely to depend on a number of factors in addition to legal and policy frameworks.

Among respondents to the legal survey, several European countries indicated that the presence of a legal framework for organic livestock production has some positive effect on the maintenance of breeds that might otherwise be at risk of abandonment. The response from Austria, for example, notes that

> *"one of the major principles of organic livestock farming is to use animal breeds that are adapted to climatic and other local conditions. The organic farming sector in Austria contributes to diversity of farm animals by following [this] principle and by supporting the use of rare animal breeds."*

Other examples of countries reporting positive effects include Croatia, the Czech Republic and Germany. Some countries, however, report that

[165] Organic Production Systems General Principles and Management Standards. CAN/CGSB-32.310-2006 (available at http://tinyurl.com/nubfg9m).

[166] Available at http://laws-lois.justice.gc.ca/PDF/SOR-2009-176.pdf

effects of this kind are limited (e.g. Cyprus and Norway).

Most survey responses from developing countries, even if they indicate that some legal or policy measures are in place, do not mention any particular effects on AnGR management. An exception is the response from Thailand, which notes that its provisions in this field help to promote the conservation of AnGR. The Thai Agricultural Standard for Organic Agriculture (2005) states that

> *"the choice of breeds, strains and breeding technique shall be consistent with the principles of organic agriculture taking into account in particular: their adaptability to the local conditions; the capacity of vitality and resistance to diseases by selection of breeds which are resistant to diseases such as tick-borne disease, etc."*[167]

On the policy side, the response from Nepal notes that its Agriculture Policy of 2004 and Poultry Policy of 2011 include provisions related to the marketing of organic products and that some guidelines have also been formulated for the promotion of organic products. While several other developing countries indicate that strengthening the organic sector is regarded as an important objective, little information is provided on the specific legal and policy measures required or on potential effects on the management of AnGR.

Geographical indications. As in the case of organic labelling schemes, the objective of geographical indications and similar designations is to prevent false claims about product origin and thereby ensure that the consumer is not deceived and that genuine producers of the sought-after products can take advantage of price premiums. The significance of niche markets in efforts to promote the sustainable use and conservation of AnGR is discussed in Part 3 Section D and Part 4 Section D. The following discussion focuses on legal and policy instruments.

As described above in the Subsection 3, several geographical indication schemes have been established under EU legislation. Many EU member countries mention this in their survey responses. The responses suggest that the extent to which the schemes have contributed to keeping potentially threatened breeds in use varies considerably from country to country. However, in most countries such schemes are clearly regarded as valuable, or potentially valuable, tools for promoting sustainable use and conservation. Some responses mention national schemes (e.g. France's Label rouge)[168] in addition to the EU-level schemes. No particular weakness in existing provisions are highlighted in the survey responses, but several note that the link to specific breeds is usually indirect, i.e. breeds usually benefit because they are associated with the location or production system associated with the indication rather than because their use is mandatory for inclusion in the scheme. Some countries, however, have gone a step further and established breed-specific labelling schemes. Examples of legislation addressing schemes of this type include Spain's Royal Decree 505/2013 Regulating the Use of the Logo "Autochthonous Breed" in Products of Animal Origin (2013),[169] under which breeders' associations for officially recognized autochthonous breeds are able to establish specifications for the use of the logo for their respective breeds. The specifications (minimum contents for which are set out in an annex to the decree) have to be submitted to the competent authorities for approval.

Provisions related to geographical indications are reported by some non-EU European countries,

[167] Thai Agricultural Standard TAS 9000-2005. Organic Agriculture Part 2: Organic Livestock. National Bureau of Agricultural Commodity and Food Standards Ministry of Agriculture and Cooperatives (available in English at http://www.acfs.go.th/standard/download/eng/Organic_Agriculture2.pdf).

[168] Code rural et de la pêche maritime. Article L641-1 (available in French at http://tinyurl.com/o4l5yep).

[169] Real Decreto 505/2013, de 28 de junio, por el que se regula el uso del logotipo «raza autóctona» en los productos de origen animal (available in Spanish at http://www.boe.es/boe/dias/2013/07/24/pdfs/BOE-A-2013-8048.pdf).

such as Montenegro[170] and Serbia,[171] but appear to be uncommon in other regions of the world. One exception is Brazil,[172] where products that have a distinct reputation associated with their place of origin and unique qualities associated with local production conditions or know-how can be assigned a registration of geographical indication. Brazil's survey response indicates that by the end of 2013 geographical indications had been granted to two types of cheese (Canatra and Serro) and one type of beef (Pampa Gaúcho).

In some circumstances, a label for a class of products sourced from a particular geographical area and/or produced using specific methods can be established under trademark law. The survey response from Nepal, for example, mentions labels established for pashminas and for carpets made from the wool of native sheep breeds.

Animal welfare-related labelling. If consumers are willing to pay premium prices for animal products derived from high-welfare production systems, it may be necessary to regulate product labelling in order to ensure that they are provided with accurate information that allows them to make informed choices about their purchases. For example, EU legislation includes provisions related to the labelling of eggs as "free range."[173] Potential effects on the management of AnGR arise because the type of animals suitable for keeping in different types of production system may vary (e.g. more "robust" animals for outdoor production systems). Legislation that facilitates the marketing of products from higher-welfare (often higher-cost) production systems may help to keep breeds of this type in use. Most instruments in this category reported in the responses to the legal survey focus on organic production rather than on other high-welfare production methods. Several responses recognize that there is some potential for at-risk breeds to benefit from the existence of marketing schemes for high-welfare products, but no specific cases are highlighted. Likewise, few specific gaps in existing legislation are mentioned, although the response from Germany notes the possibility that EU-level legislation regulating the use of voluntary animal welfare labels might be required in the future.

Few responses from developing countries report any legislation in this field or mention it as a priority for the future. Interest appears to be higher in countries that target export markets. Brazil's survey response, for example, while stating that there is no legislation in this field, mentions its Permanent Technical Committee on Animal Welfare, created in 2008, whose duties include legislative alignment of domestic standards with the scientific criteria established by international agreements to which the country is a signatory, as well as preparing and stimulating the Brazilian agricultural sector to comply with the requirements of its export markets. The response from Namibia mentions the Farm Assured Namibian Meat Scheme,[174] which combines animal welfare standards with rules on environmental protection, animal identification and traceability and various other aspects of animal husbandry and record keeping.

4.5 Instruments related to animal health and welfare

The first SoW-AnGR concluded that animal health was the most highly regulated aspect of livestock management globally. Most, if not all, countries have put in place legislation that aims to control

[170] Ukaz o proglašenju Zakona o oznakama porijekla, geografskim oznakama i oznakama garantovano tradicionalnih specijaliteta poljoprivrednih i prehrambenih proizvoda / Law on Designations of Origin, Geographical Indications and Indications of Traditional Specialities Guaranteed for Agricultural and Food Products. *Official Gazette of Montenegro,* No. 18/11 (available in English at http://www.wipo.int/wipolex/en/text.jsp?file_id=287272 and in the original at http://www.wipo.int/wipolex/en/text.jsp?file_id=249273).

[171] Law on Indications of Geographical Origin. *Official Gazette of the Republic of Serbia*, No. 18/2010 (available in English at http://www.wipo.int/wipolex/en/text.jsp?file_id=186618).

[172] Instrução Normativa Nº 25/2013 Estabelece as condições para o Registro das Indicações Geográficas (available in Portuguese at http://revistas.inpi.gov.br/pdf/PATENTES2230.pdf).

[173] Commission Regulation (EC) No 589/2008 of 23 June 2008 laying down detailed rules for implementing Council Regulation (EC) No 1234/2007 as regards marketing standards for eggs (available at http://tinyurl.com/66ewtgq).

[174] http://www.nammic.com.na/jdownloads/Manuals/fanmeatmanual.pdf

the spread of livestock diseases within national borders and to prevent the introduction of diseases from outside. Many countries have also established policies or programmes of various kinds that aim to improve the health of their livestock populations. In addition to provisions related to the establishment of relevant institutions (veterinary services and so on), legal frameworks in this field can include provisions that place various kinds of restriction on the activities of livestock keepers and other stakeholders (prohibiting practices that contribute to the spread of diseases) and may also make compulsory certain activities that contribute to disease control (e.g. slaughter and safe disposal of infected animals).

The impacts that policies and legislation in the animal-health field have on AnGR and their management are generally indirect. Control of animal health problems helps to support livestock-keeping livelihoods, to protect animal populations (including at-risk breeds) from the effects of disease epidemics and to facilitate the exchange of breeding animals and genetic material both at national level and internationally. Effective policy and legal instruments that promote animal health can therefore contribute in many ways to the sustainable management of AnGR. Having noted these benefits, it has to be acknowledged that it in some circumstances an improved animal-health situation may facilitate the replacement of locally adapted breeds by disease-susceptible exotic breeds, with potentially negative consequences for diversity. Clearly, this does not mean that animal health-related policies and legislation should be neglected in order to help keep resistant breeds in use. It may, however, be a factor to bear in mind when assessing the effects of livestock-sector policies on AnGR management (see Part 2).

Another potentially problematic effect of animal health-related legislation is that it may prescribe the compulsory culling of animal populations affected by (or that have come into contact with) particular infectious diseases. Culling campaigns against disease such as foot-and-mouth disease, classical swine fever and African swine fever have led to the extinction of an (apparently) small number of breeds and substantially reduced the population sizes of several others (for further discussion of this threat, see Part 1 Section F). Less dramatically, legal requirements or restrictions imposed in order to improve disease control may make it difficult or costly to continue keeping livestock in certain production systems, with potentially negative consequences for the associated AnGR. A further set of potential problems relate to restrictions on access to breeding material. Such problems are most likely to arise because of sanitary controls on imports, but may also occur because of rules related to the movement of animals within the country or to the use of genetic material in the form of semen, embryos, etc. (potentially including material cryoconserved at an earlier time when sanitary rules were less strict).

As part of the legal survey, countries were asked to report on a range of animal health-related laws and policies, including those related to animal identification, the import and export of animals and breeding material, the movement of livestock within the country, the use of reproductive biotechnologies[175] and the control of epidemics through culling.

As discussed above (Subsection 4.3), animal identification systems serve a number of purposes and can contribute in several ways to the management of AnGR. The main initial motivation is often to improve disease control, but systems developed for this purpose can serve other objectives such as facilitating genetic improvement programmes and programmes for monitoring of population trends. Several survey responses note the multiple benefits that can be obtained from having legislation on animal identification in place. All OECD respondents to the survey reported that they have legislation related to animal identification in place, as did more than 50 percent of non-OECD countries, with a further 10 percent reporting that they are

[175] The focus in this subsection is on sanitary issues in the use of reproductive biotechnologies. Other issues related to the use of these technologies are discussed above in Subsection 4.3.

developing legislation in this field. Effects on AnGR diversity are generally regarded either as neutral or as positive, the latter because the systems help to reduce the threat posed by epidemics.

The survey responses do not highlight any particular AnGR-related problems associated with animal identification laws. It is, nonetheless, interesting to note that some issues have arisen in the past. The first SoW-AnGR, for example, noted that some amendments to EU legislation on animal identification had to be introduced to account for the difficulty of attaching ear tags to animals kept in certain extensive production systems within the required time limits after birth.[176] More recently, the survival of certain types of semi-feral pony in the United Kingdom was reportedly threatened by the high costs of compulsory "horse passport" identification documents and microchipping. Derogations, allowable under the relevant EU regulation,[177] were incorporated into national legislation to address the problem.[178]

Many survey responses note that national legislation prescribes compulsory culling in certain circumstances and that this poses a potential threat to AnGR. While some countries' legislation allows for possible derogations to protect at-risk breed populations (reported examples include Finland and Germany), the survey results suggest that provisions of this kind are not widespread. Several countries note the need to review legislation in this field.

A few survey responses mention problems, or potential problems, arising because of sanitary restrictions on the import of breeding animals or genetic material. Brazil's response, for example, notes that for many years Brazilian breeders of various zebu cattle breeds were unable to import semen or embryos from India. Spain's response notes that legislation of this kind might hamper the exchange of genetic material and that in the case of transboundary breeds at risk of extinction, simplified mechanisms that facilitate the implementation of conservation programmes need to be developed.

With regard to animal movements at country level, the survey response from Brazil notes that when a disease outbreak occurs, restrictions on the movement of breeding animals across state boundaries cause some problems for breeders, but also notes that these restrictions are accepted because breeders recognize the benefits in terms of disease control. The response from Norway reports that

> *"movement of live AnGR within Norway is highly regulated and restricted by law, especially [in the case of] sheep and goats. This makes sustainable breeding a big challenge since it is almost impossible to get 'new' breeding animals to the herd."*

It further notes that

> *"exemptions based on [the needs of] national AnGR should be accepted within this legislation."*

Another problem is mentioned in the response from Latvia, which notes that restrictions on marketing imposed in order to control diseases can have a significant effect on livestock keepers' incomes.

A small number of survey responses indicate that legislation related to the use of reproductive technologies and frozen genetic material can have implications for cryoconservation programmes. The response from Spain, for example, reports that specific provisions for at-risk breeds are included in its Royal Decree 841/2011 Establishing Basic Conditions for Collection, Distribution and Marketing of Genetic Material from Bovine, Ovine, Caprine and Equine Species.[179]

[176] For example, Commission Decision 2004/764/EC of 22 October 2004 concerning an extension of the maximum period laid down for the application of eartags to certain bovine animals kept in nature reserves in the Netherlands (available at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32004D0764). See FAO, 2007a, page 300 for further discussion of regulations of this type.

[177] Commission Regulation (EC) No 504/2008 of 6 June 2008 implementing Council Directives 90/426/EEC and 90/427/EEC as regards methods for the identification of equidae (available at http://tinyurl.com/qgnyzjn).

[178] For example: The Equine Identification (Wales) Regulations 2009 (available at http://www.legislation.gov.uk/wsi/2009/2470/made).

[179] Real Decreto 841/2011, de 17 de junio, por el que se establecen las condiciones básicas de recogida, almacenamiento, distribución y comercialización de material genético de las especies bovina, ovina, caprina y porcina, y de los équidos (available in Spanish at http://www.boe.es/boe/dias/2011/07/14/pdfs/BOE-A-2011-12107.pdf).

The legal survey also sought information on instruments related to animal welfare (instruments related specifically to labelling are discussed above in Subsection 4.4). Potential effects of such instruments on AnGR management might arise, for example, because of rules affecting the use of particular reproductive technologies. Indirect effects might arise if production systems have to be adapted in order to account for welfare rules and this in turn leads to changes in the types of AnGR kept. It is also possible that activities (e.g. sports) that create demand for particular types of animal might be banned or restricted under welfare legislation.

The survey responses suggest that while many countries have animal welfare legislation and policies in place, impacts on AnGR management are limited (or at least unrecognized). Some responses note that because locally adapted breeds tend to be associated with extensive systems – often regarded as high-welfare systems – the keepers of these breeds may be less likely than the keepers of other breeds to be affected by any financially burdensome welfare-related rules that might be introduced.

4.6 General instruments related to agriculture, land use, rural development and natural-resources management

The final section of the legal survey was devoted to legislation and policies that address "agriculture, land use and natural resources management", i.e. that address the overall management of the production systems, ecosystems and environments within which AnGR are used and developed. The topics covered included very broad fields of action such as agricultural and livestock development, the use of natural resources, environmental protection and management of biodiversity (including wild biodiversity), as well as some more specific topics such as the management of natural and human-induced disasters.[180] In this context, influences on AnGR and their management may be direct or indirect. One the one hand, a law or policy may have an impact because of specific provisions related to AnGR; in other words AnGR may (to some degree) have been "mainstreamed" within the respective field. On the other, a policy or law that does not include a specific reference to AnGR may have an inadvertent effect (positive or negative) on AnGR (e.g. by promoting or constraining the operation of different types of livestock production that tend to use different types of AnGR).

The various topics addressed in this part of the survey (and below in this subsection) are closely inter-related. The "architecture" of legal and policy frameworks addressing them (e.g. whether topics are addressed separately or under broad all-encompassing instruments) inevitably varies from country to country. The absence of a specific instrument does not necessarily mean the topic is being neglected. For some categories, it is therefore not particularly informative to present quantitative figures for the proportion of countries having instruments in place. The survey questionnaire was, however, arranged topic by topic (proceeding roughly from the broader to the narrower), with the aim of eliciting as much information as possible. The description presented below is structured in a similar way.

Agriculture and rural development

The management of AnGR is closely entwined with the management of a range of other natural resources and with many aspects of agricultural and rural development. These resource-use and developmental issues are likely to be major themes of interest for national governments and therefore targeted by legal and policy measures of one kind or another. Growing concerns about the harmful effects that agriculture can have on the environment and growing awareness of the importance of ecosystem services used in agriculture and produced in agricultural systems have contributed to a growing interest in a more integrated approach to these issues at policy level.

As described above in Subsection 3, measures that address interactions between agriculture

[180] For a discussion on policy and legal instruments in the latter field, see Part 1 Section F (Threats to AnGR).

and the environment are a significant feature of policies and legislation at EU-level. All EU member countries developed national rural development strategy plans for the 2007 to 2013 period. Most of the policies of this type reported in the survey responses were from European countries (including both members and non-members of the EU). Examples include the New Hungary Rural Development Programme,[181] which included an action on "Preservation of native and endangered farm animal genetic resources through breeding" under which livestock keepers who raise a "protected native or endangered farm animal breed" and adhere to rules regarding herd book registrations and the mating plans prescribed in the respective breeding programme are eligible to receive support payments in line with the rules set out in the relevant EU legislation.[182]

In some circumstances, the recognition of AnGR issues in a broad rural development programme may provide a framework for the development of a national strategy and action plan specifically for AnGR. For example, Montenegro's Action Plan for the Conservation of Genetic Resources in Agriculture[183] (published in 2008) was foreseen in the country's Agriculture and Rural Development Strategy (2006).[184]

The extent to which agri-environmental schemes affect the management of AnGR indirectly by influencing trends in livestock-sector development is not easy to assess. However, the inclusion of measures aimed at supporting livelihoods in more remote and "marginal" areas, the diversification of the rural economy and the use of grazing livestock to provide various ecosystem services implies some potential for positive outcomes in terms of promoting the use of more diverse livestock populations. An example of an indirect effect of this kind is provided in the survey response from Luxembourg, which states that although the country's rural development programmes are "not particularly aimed at conserving farm animal genetic resources", they include measures aimed at protecting forest soils against compaction, including support for the use of horses for work in the forests – a task for which the rare Ardennes horse is reportedly well suited.

Legal instruments in this field reported in survey responses from non-European countries tend to be less focused on the multiple functions of agriculture and its multiple impacts on ecosystem function. They generally do not include specific provisions related to the sustainable use or conservation of AnGR. The focus is often on the sustainable use of specific natural resources that underpin agriculture (water, soil, etc.), access to these resources, land-use planning and/or establishing the institutional framework for the management and development of the agricultural sector. Reported examples include Uruguay's Law on Land Management and Sustainable Development (2008)[185] and Sri Lanka's Agrarian Development Act (2000).[186] Ecuador's Organic Law on Food Sovereignty[187] explicitly refers to the multiple social and environmental considerations that have to be accounted for in land use and to the importance of maintaining ecological functions. It also refers explicitly to the conservation of agrobiodiversity, although the focus is largely on plants. Any effects on AnGR management reported

[181] New Hungary Rural Development Programme NHRDP Version 9, amended according to EC comments Ares (2012)796680_02072012 – February 2013 (available in English at www.mvh.gov.hu/MVHPortal/files/1039501_NHRDP_version_9pdf).

[182] Council Regulation 1974/2006/EC, of 15 December 2006 laying down detailed rules for the application of Council Regulation (EC) No 1698/2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) (available at http://faolex.fao.org/docs/pdf/eur68184.pdf).

[183] Akcioni plan očuvanja genetičkih resursa u poljoprivredi (2009–2013) (available in Montenegrin at http://tinyurl.com/pwe2j8q).

[184] Montenegro's agriculture and European Union. Agriculture and rural development strategy. Final report of the EU funded project (available in English at http://tinyurl.com/oljz327).

[185] Ley N° 18.308 Ordenamiento territorial y desarrollo sostenible (available in Spanish at http://www.parlamento.gub.uy/leyes/AccesoTextoLey.asp?Ley=18308&Anchor).

[186] Agrarian Development Act, No. 46 of 2000 (available in English at http://faolex.fao.org/docs/pdf/srl43285.pdf).

[187] Ley Orgánica del Régimen de la Soberanía Alimentaria 2009 (available in Spanish at http://www.soberaniaalimentaria.gob.ec/?page_id=132#sthash.MC9aPFkS.dpuf).

in the survey responses are indirect: sustainable management of AnGR can only occur in sustainable production systems. For example, the response from Burundi mentions (*inter alia*) laws on the management of soil[188] and water[189] and notes that "land and water are key issues in the management of genetic resources."

Among reported policy instruments, Costa Rica's State Policy for the Food and Agriculture Sector and Rural Development 2010–2020[190] includes (in addition to the above-mentioned provisions on AnGR-related research – see Subsection 4.3) a section on agrobiodiversity, which – interestingly from the perspective of this chapter – calls for an exhaustive analysis of the country's legislation on genetic resources and intellectual property and the establishment of a national plan for its application. It also calls for efforts to strengthen the conservation and use of plant and animal genetic resources, emphasizing collaborative and interdisciplinary approaches within the frameworks of national programmes for the two subsectors and the respective global plans of action. A section on climate change adaptation emphasizes the importance of *in situ* and *ex situ* conservation of crop, livestock and fish genetic resources.

Livestock sector development

The legal survey also asked countries about instruments specifically focusing on the overall development of the livestock sector. These would typically be national livestock-development strategies or plans, or legal instruments of similar scope. Few of the survey responses indicate that broad livestock-sector policies include any provisions related to promoting the sustainable use, development or conservation of AnGR. The picture provided by the country reports is, however, rather more positive. Sixty-five percent of countries report that they have livestock development strategies or plans that address AnGR management and a further 12 percent that the topic will be addressed in a forthcoming plan. The region with the highest proportion of countries (83 percent) reporting such policies is Africa. In many cases, little information is provided on the content or state of implementation of these policies. It cannot be assumed that all are having a positive effect on AnGR management. Nonetheless, a number of the policy documents referred to in the reports include substantial provisions related to the sustainable use, development and conservation of AnGR and of locally adapted breeds in particular.

Kenya's National Livestock Policy (2008)[191] includes a section on AnGR that contains plans, *inter alia*, for the implementation of demographic surveys of AnGR, the development of guidelines on appropriate matching of breeds and production environments, the strengthening of various aspects of the organizational infrastructure for breeding programmes (e.g. animal registration and recording schemes, breeders' associations and the delivery of breeding services, such as artificial insemination) and the establishment of breeding programmes for locally adapted breeds (see Box 3F12 for further information). As another example, India's National Livestock Policy (2013)[192] sets out breeding policies for all the main species of (mammalian) livestock present in the country, with varying degrees of emphasis given to the development of locally adapted breeds. Other elements of the policy include promoting the use of reproductive biotechnologies and the implementation of conservation measures including the provision of support to migratory pastoralist communities that manage breeds of "buffaloes, sheep, goats, yaks, etc."

Several countries report that although policies exist their implementation is weak or that general

[188] Décret du 26 novembre 1958 sur la conservation et utilisation des sols (available in French at http://faolex.fao.org/docs/pdf/bur39375.pdf).

[189] Loi n°1/02 du 26 mars 2012 portant code de l'eau au Burundi (available in French at http://faolex.fao.org/docs/pdf/bur129952.pdf).

[190] Política de Estado para el Sector Agroalimentario y el Desarrollo Rural Costarricense 2010–2021 (available in Spanish at http://www.mag.go.cr/bibliotecavirtual/a00289.pdf).

[191] Available at http://tinyurl.com/obuqbuq

[192] Available at http://dahd.nic.in/dahd/WriteReadData/NLP%202013%20Final11.pdf

Box 3F12

Animal genetic resources management in Kenya's National Livestock Policy

The Kenya National Livestock Policy (2008) was formulated with an aim of addressing the challenges facing the livestock subsector in the fields of breeding, nutrition and feeding, disease control, value addition and marketing, and research and extension. Specific objectives include establishing appropriate management systems for the sustainable development of the livestock industry, effectively improving and conserving available animal genetic resources (AnGR), achieving effective control of animal diseases and pests, ensuring the safety of foods of animal origin and focusing research efforts in the livestock subsector on resolving current and emerging problems.

With regard to the management of AnGR, the policy addresses, or intends to address, characterization, inventory and documentation, and sustainable use and conservation of indigenous AnGR. Specific achievements attributable to the National Livestock Policy include:

1. the establishment, through a legal notice, of the Kenya Animal Genetic Resources Centre, which is tasked with establishment, under the guidance of the National Animal Genetic Resources Advisory Committee, of a gene bank that will take custody of tissues, DNA, semen and embryos from all important livestock and emerging livestock species in Kenya – the material will be conserved for posterity and made available for research and breeding as deemed appropriate;
2. conversion of livestock farms and sheep and goat stations into conservation farms for breeds that are considered vulnerable, especially those threatened by cross-breeding and natural disasters;
3. collection of livestock data as part of the 2009 human population census, which provided livestock populations by species – an agriculture census is planned for 2015, and if it takes place, will provide information about the AnGR in Kenya;
4. regulation of all breeding-service providers and the establishment of farmer groups, cooperatives and other community-based structures to provide artificial insemination services;
5. increasing financial support from the government for livestock registration and performance recording;
6. allocation of additional funds by the government for the commercialization of indigenous chickens and for upgrading the Rabbit Multiplication Centre; and
7. establishment of a livestock insurance scheme.

Implementation has enhanced awareness among the public and among government officials regarding the need to manage AnGR sustainably. Pastoralists have become more involved in conservation efforts for breeds such as the Red Maasai sheep. This came about when some of them realized that if they cross-breed all their flocks they lose them all whenever there is the severe drought, while the Red Maasai animals survive. The policy is also intended to contribute to the development of breeding programmes for indigenous AnGR.

The policy was developed with the participation of key livestock sector stakeholders. Their views were gathered via workshops arranged in various parts of the country and later via a national forum. The draft policy was presented to the Cabinet and finally passed by the Kenyan Parliament.

Provided by Cleopas Okore, National Coordinator for the Management of Animal Genetic Resources, Kenya.

provisions related to AnGR management need to be elaborated in more detail. South Africa mentions that both its National Livestock Development Strategy and its Animal Improvement Policy (2006)[193] promote the sustainable use of AnGR and are linked to the country's Animal Improvement Act (1998).[194] Both policies were reportedly undergoing revision in parallel to the second SoW-AnGR reporting process, with the aim of ensuring consistency among the instruments and their relevance under changing circumstances, "including climate change and climate smart animal agriculture."

As far as indirect effects on AnGR management are concerned, there are indications in the responses to the legal survey that livestock development policies can have both positive and negative effects on diversity. The response from Mauritius, for example, notes that the country's livestock policy aims to increase its

> *"self-sufficiency in certain commodities ... through the provision of imported animals with better production potential as well as infrastructure and equipment."*

The consequence of this for AnGR is that

> *"exotic animals with higher production potential are being favoured at the expense of local animals and their crosses."*

The response from Suriname, however, notes the existence of breeding, livestock-management and livestock-extension policies that target small-scale farmers in low external input production systems, and that within these policies "local genetics are sometimes the choice."

Management of biodiversity

The next topic explored in the legal survey was legislation and policies addressing the management of biodiversity (i.e. biodiversity as a whole rather than agricultural biodiversity or AnGR in particular). From the AnGR management perspective, the main questions of interest with regard to these instruments are:

- whether they include any provisions directly related to promoting the conservation and sustainable use of AnGR;
- whether they include any provisions that may indirectly affect AnGR management (e.g. by restricting the use of grazing animals in protected areas); and
- whether they include any provisions that affect access to AnGR or the sharing of benefits derived from their use (this issue is discussed above – see Subsection 4.3).

National policies on biodiversity are very widespread (Figure 3F4). As of April 2014, National Biodiversity Strategies and Action Plans (NBSAPs) (the principal instruments for implementing the CBD at national level) had been developed by 179 countries.[195] To assess the extent to which these plans address the management of AnGR, the 174 NBSAP documents available on the CBD website in April 2014 were searched using relevant keywords. Based on the results of this search and the information provided in the country reports, the plans could be roughly grouped into the following three categories: no mention of AnGR (18 percent); AnGR explicitly included in the scope of the plan, but no AnGR-focused activities mentioned (13 percent); and AnGR-focused actions mentioned (69 percent). The practical impact of these AnGR-related provisions is difficult to assess, but is not necessarily very large. For example, Austria's response to the legal survey states that "the Austrian National Biodiversity Strategy has little impact on the management of animal genetic resources."

The survey responses indicate that legislation targeting the management of biodiversity is also widespread. More than 80 percent of OECD countries and almost 70 percent of non-OECD countries reported that they have legislation in place (Figure 3F2). Several responses indicate that the conservation of AnGR is explicitly included within the scope of

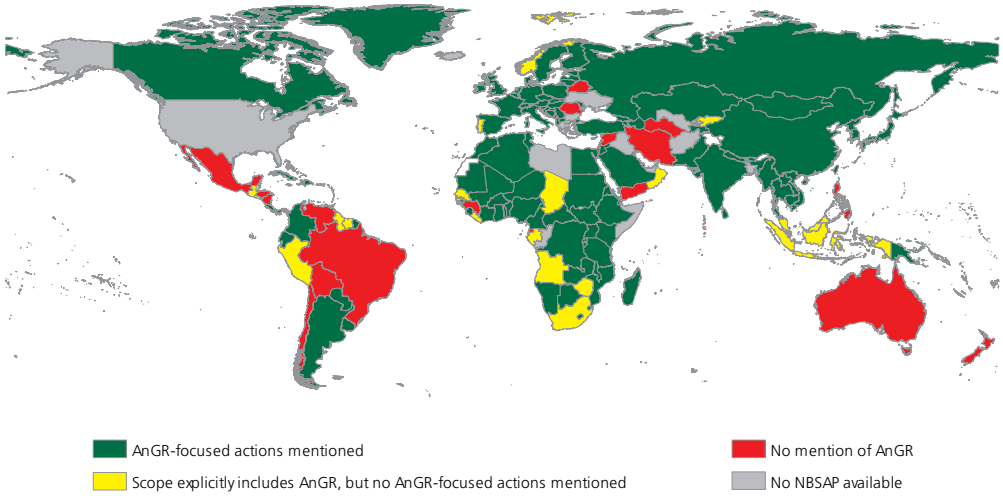
[193] Animal Improvement Policy for South Africa. Notice 165 of 2007. *Government Gazette,* No. 30459 (16 November 2007: 41–66) (available at http://www.gov.za/documents/animal-improvement-policy-south-africa).

[194] Animal Improvement Act 62 of 1998 (available at http://faolex.fao.org/docs/pdf/saf17623.pdf).

[195] http://www.cbd.int/nbsap/

FIGURE 3F4

Inclusion of animal genetic resources issues in national biodiversity strategies and action plans



Note: Analysis based on national biodiversity strategies and action plans (NBSAPs) available on the website of the Convention on Biological Diversity (www.cbd.int/nbsap) (accessed in April 2014).

national biodiversity legislation. For example, the Biodiversity Act of Bhutan (2003)[196] states that

> *"This Act shall apply to all the genetic and biochemical resources including wild, domesticated and cultivated species of flora and fauna, both* in-situ *and* ex-situ *conditions found within the territory of [the] Kingdom of Bhutan."*

Norway's Nature Diversity Act (2009)[197] states that "The genetic diversity of domesticated species shall be managed in such a way that it helps to secure the future resource base" and further that "The King may make regulations regarding special conservation measures for domesticated species ..." Other reported examples in which AnGR are explicitly mentioned as targets for conservation measures are the biodiversity laws of Viet Nam (2008)[198] and Costa Rica (1999).[199]

The survey responses provide little information on practical effects that instruments of this type have on AnGR management. Likewise, little information is provided on any priority requirements in terms of developing new instruments or improving existing ones. A few of the reported legal instruments include provisions allowing for restrictions to be imposed on the use of grazing animals in circumstances where they are regarded as a potential threat to biodiversity. None of the

[196] The Biodiversity Act of Bhutan, Water Sheep Year 2003 (available in English at http://tinyurl.com/oo6ovrm).

[197] Act of 19 June 2009 No. 100 Relating to the Management of Biological, Geological and Landscape Diversity (Nature Diversity Act) (available in English at http://www.regjeringen.no/en/doc/laws/Acts/nature-diversity-act.html?id=570549).

[198] Luật số 20/2008/QH12 của Quốc hội: LUẬT ĐA DẠNG SINH HỌC (Law No. 20/2008/QH12. Biodiversity Law) (available in Vietnamese at http://tinyurl.com/pn947rv and in English at http://tinyurl.com/newysn5).

[199] Ley de Biodiversidad (available in Spanish at http://tinyurl.com/obvn7cz).

survey responses indicated that such instruments have caused any problems for AnGR management (see, however, Box 1F3 in Part 1 Section F).

Environmental protection and planning

Another field of legislation and policy that can affect the development of livestock production systems and hence indirectly affect the management of AnGR is environmental protection. As described above, instruments focusing on biodiversity were treated as a separate category in the legal survey. The category "environmental protection" was therefore intended to catch instruments related to other environmental issues such as the pollution of land, air and water. While a large majority of responding countries reported that they have legislation and policies relating to environmental protection in place, few mentioned any impacts on AnGR management. However, there were some exceptions. The survey response from France, for example, notes that its National Plan on Climate Change Adaptation[200] and its legislation on water management have affected the availability of animal feed (e.g. in some areas a reduction in the availability of forage maize and an increase in the proportion of grass in the diet). These changes, in turn, are reported to affect AnGR management, as they may favour the use of breeds that make good use of grass-based diets. Similarly, France's "Écoantibio" plan (National Action Plan for the Reduction of Risks of Antibiotic Resistance in Veterinary Medicine)[201] is reported to have led breeders to pay greater attention to "rusticity" and disease resistance.

Rules related to the establishment of livestock farms and holdings – another category of instrument addressed in the legal survey – can target a range of concerns including environmental, animal health and animal welfare-related matters. Where regulations are in place, farmers and livestock keepers typically have to register their holdings and comply with certain minimum standards. The survey responses indicate that legislation of this type is widespread. Some mention that regulations can constrain the establishment, operation or expansion of livestock holdings. However, no examples of significant effects on AnGR management are reported. Several responses note that small-scale holdings where locally adapted breeds tend to be kept are less strictly regulated than larger holdings. The country report from Norway notes that the

> *"production of pork and poultry has since 1975 been legally regulated by a concession act. This act aims to avoid the development of industrial-type animal production in the most concentrate-intensive production systems. The accepted upper limit of herd sizes [was] ... increased in 1992, 1995, 2003 and 2013."*

Rangeland management

Another area in which environmental concerns interact with livestock development is rangeland management. Access to grazing land is vital to many livestock-keeping livelihoods – and by extension to the maintenance of many breeds. This is one of the few fields of action in which the results of the legal survey suggest that legislation is more prevalent in non-OECD than in OECD countries. This is probably because land-ownership systems other than straightforward private ownership (under which management and access is largely a matter for the individual owner) are more widespread in non-OECD countries.

While livestock-keeping communities often have – or used to have – traditional mechanisms for regulating access to grazing land, in recent decades (in some cases over a longer period) legislation has come to play an increasing role in rangeland management. Several examples of national legislation in this field were discussed in the first SoW-AnGR.[202] Because they directly

[200] Plan national d'adaptation de la France aux effets du changement climatique 2011 – 2015 (available in French at http://tinyurl.com/o28vmx7).

[201] Plan national de reduction des risques d'antibiorésistance en médecine vétérinaire (available in French at http://tinyurl.com/q3crwm4 and in English at http://tinyurl.com/pvnwwjs).

[202] FAO 2007a, pages 310–311.

affect access to productive resources, laws and policies in this field are potentially more controversial than some of the other types of legislation discussed in this section. While stated objectives, such as promoting the sustainable use of grazing land, typically appear to favour the sustainable use of AnGR, detailed provisions – or details of implementation – may or may not favour the continuation of livestock-keeping livelihoods and practices that support the maintenance of locally adapted breeds.

In so far as the legal survey responses provide any information on the consequences of legislation in this field for AnGR management, they note positive outcomes. The responses from several European countries (e.g. France, Hungary and Latvia) note that increased interest, at policy level, in the protection of permanent meadows and other grassland habitats has created opportunities for keeping locally adapted breeds in use.

It should, however, be noted that some criticism has been levelled at existing legislation in this field. Hesse and Thebaud (2006), for example, argue that while the pastoral laws adopted in several West African countries during the 1990s and early 2000s include a number of positive features, their complicated bureaucratic mechanisms, and sectoral approaches that artificially divide local livelihood systems, have the potential to disempower pastoralist communities and undermine their grazing-based livelihood strategies. Legal frameworks and policies in West Africa have, nonetheless, been described as "more favourable" to pastoralism than those in East Africa, which reportedly tend to favour sedentarization (Inter-Résaux, 2012). The African Union's Policy Framework for Pastoralism in Africa (African Union, 2013) notes positive trends in pro-pastoral policies and legislation in Africa, but recognizes that major challenges remain. Appropriate legislation – accompanied by institutional and operational measures – is recognized as an essential component of efforts to improve pastoral policies. Specifically, it is recognized that there is a need to secure

"access to rangelands for pastoralists through supportive land tenure policies and legislation, and further development of regional policies to enable regional movements and livestock trade" (ibid.).

Stakeholder participation

A further issue addressed in the legal survey was the question of stakeholder participation. Countries were also asked to provide information on legal and policy frameworks promoting the participation of livestock keepers in decision-making related to livestock-sector development. Instruments of this type are reported to be widespread. In some cases, the survey responses indicate that even though there is no legislation or formal policy in place, frequent consultations with a range of stakeholders take place. The effects on AnGR management are generally reported to be positive, although as discussed in Part 3 Section A, many countries acknowledge that much remains to be done to improve stakeholder participation in this field.

The legislation reported in this category includes general instruments related to the participation of citizens in the development of national laws and policies (e.g. Slovenia's Resolution on Legislative Regulation of 2009),[203] instruments related to the organization of research and development programmes (e.g. Australia's Primary Industries and Energy Research and Development Act of 1989),[204] instruments addressing the development of the agricultural sector (e.g. Spain's Royal Decree 822/2010)[205] and instruments specifically focusing on livestock breeding (e.g. Bulgaria's Animal Breeding Law of 2000, as amended in 2010).[206]

[203] Resolucija o normativni dejavnosti (ReNDej) (available in Slovenian at http://tinyurl.com/oyfsuyr).

[204] Available at http://www.comlaw.gov.au/Series/C2004A03948

[205] Real Decreto 822/2010, de 25 de junio, por el que se aprueba el Reglamento de desarrollo de la Ley 10/2009, de 20 de octubre, de creación de órganos consultivos del Estado en el ámbito agroalimentario y de determinación de las bases de representación de las organizaciones profesionales agrarias (available in Spanish at http://tinyurl.com/pdy97x7).

[206] Закон за животновъдството в сила от 09/09/2000 г. (available in Bulgarian at http://tinyurl.com/qejpg4a).

Several survey responses describe institutional frameworks for the participation of livestock keepers and other stakeholders in decision-making processes without providing details of the legal and policy instruments (if any) that underpin them. A number of responses from countries where there are no instruments in place report the need to strengthen participation, although not necessarily through the development of a formal instrument. The general topic of stakeholder participation is discussed in more detail in Part 3 Section A.

In this context, it is important to note that the link between legal and policy frameworks and stakeholder participation is often a two-way relationship: not only may laws and policies help to promote participation, but appropriate stakeholder participation may help to create more appropriate laws and policies and facilitate their implementation. For example, the country report from Botswana, commenting on AnGR-related laws, notes that

"farmers feel that they are more recipients of these laws, as they are seldom consulted ... [or enabled to have an] input in the law-making process."

5 Changes since 2005

Because of differences in the approaches to data collection and the number of countries that participated, it is not possible to compare the figures presented above directly to those presented in the equivalent chapter of the first SoW-AnGR. It is also not possible, based on the survey results, to provide a detailed analysis of how many countries have developed legal and policy instruments in specific fields during the period between 2005 and 2013. Indicators of change include the substantial proportion of countries (particularly non-OECD countries) that report that they are in the process of developing legal or policy instruments and (less quantifiably) the numerous post-2005 instruments presented as examples above.

In response to a question in the country-report questionnaire about the development of legal and policy frameworks since the adoption of the Global Plan of Action, 20 percent of countries reported that progress had been made in this field (in addition to 23 percent that stated that they already had comprehensive legislation and policies in place before 2007) (Table 3F3). In addition, as part of the assessment of institutions and stakeholders (see Part 3 Section A), countries were asked to score (none, low, medium or high) the current state of their legal and policy frameworks and the state of implementation of these frameworks. For the first SoW-AnGR, countries were assigned scores based on the information provided in their country reports.[207] Clearly, the two sets of scores are not directly comparable. As well as being affected by differences in methodology, the differences between the two sets of scores may reflect changes in countries' objectives and "ambitions" over the years. While these caveats should be borne in mind, the findings appear to indicate positive developments overall. Out of 110 countries that were included in both scoring exercises, far more increased their scores (between 45 percent and 48 percent depending on the category) than decreased their scores (between 13 percent and 16 percent) between 2005 and 2013.[208]

While it appears that progress has been made, the country reports indicate that a large proportion of countries still consider their legal and policy frameworks – and the state of implementation of these frameworks – to be inadequate. There is some indication that mainstreaming of AnGR into wider legal and policy frameworks (e.g. livestock-sector development strategies and national biodiversity strategies and action plans)

[207] FAO, 2007a, Table 58 (pages 207–213). In this case, scores were allocated jointly for laws and policies.

[208] For state of legislation: 45 percent with an increased score vs. 16 percent with a decrease. For state of policies: 46 percent with an increased score vs. 13 percent with a decrease. For implementation of legislation: 48 percent with an increased score vs. 15 percent with a decrease. For implementation of policies: 48 percent with an increased score vs. 14 percent with a decrease.

TABLE 3F3
Progress in the development of legal and policy frameworks

Region	Number of country reports	Comprehensive framework before GPA adoption	Progress since GPA adoption	No progress since GPA adoption
	%			
Africa	40	10	18	72
Asia	20	10	40	50
Europe and the Caucasus	35	54	26	20
Latin America and the Caribbean	18	11	6	83
Near and Middle East	7	0	14	86
North America	1	100	0	0
Southwest Pacific	7	14	0	86
World	**128**	**23**	**20**	**57**

Note: GPA = Global Plan of Action for Animal Genetic Resources.
Source: Country reports, 2014

has become more widespread, but the practical consequences of this are as yet unclear. The number of national strategies and action plans for AnGR developed in recent years also indicates that additional attention is being paid to AnGR management at policy level. However, the implementation of most of these instruments is still at an early stage.

Interest in the development of AnGR-related legal measures is apparently widespread. However, the question raised in the first SoW-AnGR about whether elaborate legal frameworks are always necessary or appropriate remains to be resolved. It is not clear, based on the country reports and responses to the legal survey, that all countries have adequately assessed the impact of their current legislation (or lack of legislation) on AnGR management or developed a clear vision of their future needs in this field. Where this is the case, the Global Plan of Action's recommendation regarding the need to conduct "periodic reviews" of legal and policy frameworks to identify effects on AnGR management – and, if necessary, steps that can be taken to improve the situation – remains relevant.

6 Gaps and needs

The results of the legal survey give an indication (based on a limited sample of countries) of which areas of AnGR management are well covered by laws and policies and which are not. However, the extent to which specific gaps in this coverage represent significant constraints to AnGR management on a global scale is difficult to estimate. Priorities for improving national legal and policy frameworks have to be developed at country level based on careful assessments of national needs and circumstances. Some country reports suggest that weaknesses in policy- and law-making processes constitute a bottleneck that inhibits progress towards better AnGR management. Perhaps the most significant of these weaknesses is a lack of stakeholder participation, but a lack of expertise in the formulation of legal instruments is also an issue for some countries.

The country reports note a number of different factors that contribute to problems in the implementation of policy and legal frameworks. These include a lack of human and financial resources, logistical problems, lack of coordination between

different departments, excessive bureaucracy, lack of awareness on the part of stakeholders, lack of clarity in the formulation of legal and policy texts, and lack of harmony between the procedures envisaged in such texts and the administrative arrangements through which they are meant to be implemented. Addressing some of these constraints may be relatively straightforward given the necessary political will, but others may be difficult to overcome, at least in the short to medium term. A realistic assessment of what is feasible and what policy and legal tools are appropriate in national circumstances is likely to be important. The process of developing, or where relevant reviewing and updating, national strategies and action plans for AnGR (FAO, 2009e) may provide countries with the opportunity to assess the state of their existing policy and legal frameworks, in consultation with a range of stakeholders, and identify any changes that may be required.

References

African Union. 2013. *Policy framework for pastoralism in Africa securing, protecting and improving the lives, livelihoods and rights of pastoralist communities*. Addis Ababa (available at http://tinyurl.com/phmxofn).

AU-IBAR. 2010. *Framework for mainstreaming livestock in the CAADP pillars*. Nairobi, African Union – Interafrican Bureau for Animal Resources (available at http://www.nepad-caadp.net/pdf/Action%20plan%20for%20development%20of%20livestock.pdf).

AU-IBAR. 2013. *Strategic Plan 2014–2017.* Nairobi, African Union – Interafrican Bureau of Animal Resources (available at http://www.au-ibar.org/component/jdownloads/finish/77/1931).

Canali, G. & the Econogene Consortium. 2006. Common agricultural policy reform and its effects on sheep and goat market and rare breeds conservation. *Small Ruminant Research*, 62: 207–213.

Country reports. 2014. The reports can be accessed at http://www.fao.org/3/a-i4787e/i4787e03.htm.

CBD. 2002. *Bonn Guidelines on Access to Genetic Resources and Fair and Equitable Sharing of the Benefits Arising out of their Utilization*. Montreal, Canada, Convention on Biological Diversity (available at https://www.cbd.int/doc/publications/cbd-bonn-gdls-en.pdf).

CBD. 2011. *Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity*. Text and annex. Montreal, Canada, Convention on Biological Diversity (available at https://www.cbd.int/abs/doc/protocol/nagoya-protocol-en.pdf).

Compassion in World Farming. 2013. *Contribution to the consultation on the review of the EU policy on organic agriculture* (available at http://ec.europa.eu/agriculture/consultations/organic/contributions/1-ciwf_en.pdf).

ECOWAS Commission. 2010. *Strategic Action Plan for the Development and Transformation of Livestock Sector in the ECOWAS Region (2011-2020).* Abuja (available at http://tinyurl.com/ps77fft).

ERFP. 2102. *Questionnaire for the consultation of stakeholders on the community programme on genetic resources in agriculture – Council Regulation (EC) No 870/2004. Response from the European Regional Focal Point for Animal Genetic Resources* (available at http://tinyurl.com/ojqt2ga).

EU. 2007. *European Parliament resolution of 22 May 2007 on halting the loss of biodiversity by 2010* (available at http://tinyurl.com/ppqcafd).

EU. 2011. *The EU Biodiversity Strategy to 2020*. Brussels (available at http://tinyurl.com/plpojgs).

EU. 2012. *European Agricultural Fund for Rural Development (EAFRD).* European Union website (available at http://tinyurl.com/6ft3kel) (accessed 12 June 2014).

EU. 2014a. *Regulations, directives and other acts*. European Union website (available at http://europa.eu/eu-law/decision-making/legal-acts/index_en.htm) (accessed 11 June 2014).

EU. 2014b. *Legal proposals for the CAP after 2013.* European Union website (available at http://ec.europa.eu/agriculture/cap-post-2013/legal-proposals/index_en.htm) (accessed 17 June, 2014).

EU. 2014c. *European Parliament legislative resolution of 15 April 2014 on the proposal for a regulation of the European Parliament and of the Council on Animal Health (COM(2013)0260 – C7-0124/2013 – 2013/0136(COD)) (Ordinary legislative procedure: first reading*). Strasbourg, France (available at http://tinyurl.com/nf27ghe).

Eurogroup for Animals. 2013. *Contribution to the consultation on the review of the EU policy on organic agriculture* (available at http://tinyurl.com/nety8c7).

European Commission. 2004a. *Action Plan for the Future of Organic Production in the European Union*. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels (available at http://tinyurl.com/puom5aa).

European Commission. 2004b. *European Action Plan for Organic Food and Farming.* Commission Staff Working Document. Annex to the Communication from the Commission. Brussels (available at http://tinyurl.com/nnvb24w).

European Commission. 2006a. *Halting the loss of biodiversity by 2010 – and beyond – Sustaining ecosystem services for human well-being.* Communication from the Commission. Brussels (available at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52006DC0216I).

European Commission. 2006b. *Sustaining ecosystem services for human well-being. {COM(2006)216 final. Impact assessment.* Annex to the Communication from the Commission – Halting the loss of biodiversity by 2010 – and beyond. Commission Staff Working Document. Brussels (available at http://tinyurl.com/ogedqfz).

European Commission. 2006c. *Technical annex.* Annexes to the Communication from the Commission – Halting the loss of biodiversity by 2010 – and beyond – Sustaining ecosystem services for human well-being. Commission Staff Working Document. Brussels (available at http://tinyurl.com/qgqt2j8).

European Commission. 2007. *A new animal health strategy for the European Union (2007-2013) where "Prevention is better than cure"*. Brussels (available at http://tinyurl.com/5z5d25).

European Commission. 2008. *Action plan for the implementation of the EU Animal Health Strategy*. Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions. Brussels (available at http://tinyurl.com/66c799).

European Commission. 2010. *The Common Agricultural Policy 2013. Your ideas matter. The Common Agricultural Policy 2013. Public debate. Summary report.* Brussels (available at http://tinyurl.com/q6qlyxe).

European Commission. 2011. *Impact assessment. Common Agricultural Policy towards 2020*. Commission Staff Working Paper. Brussels (available at http://tinyurl.com/pl9lu4g).

European Commission. 2012a. *Communication from the Commission to the European Parliament, the Council and the European Economic and Social Committee on the European Innovation Partnership 'Agricultural Productivity and Sustainability'*. COM/2012/079 final. Brussels (available at http://tinyurl.com/qykwl7j)

European Commission. 2012b. *Innovation Partnerships: new proposals on raw materials, agriculture and healthy ageing to boost European competitiveness.* European Commission press release IP/12/196 29/02/2012. Brussels (available at http://tinyurl.com/o4hgoqf).

European Commission. 2012c. *Proposal for a regulation of the European Parliament and of the Council on access to genetic resources and the fair and equitable sharing of benefits arising from their utilization in the Union*. Brussels (available at http://tinyurl.com/org8ene).

European Commission. 2012d. *Impact assessment accompanying the document Proposal for a regulation of the European Parliament and of the Council on access to genetic resources and the fair and equitable sharing of benefits arising from their utilization in the Union /* SWD/2012/0292 final */.* Commission Staff Working Document. Brussels (available at http://tinyurl.com/pfwtlv5).

European Commission. 2012e. *Communication from the Commission to the European Parliament, the Council and the European Economic and Social*

Committee on the European Union Strategy for the Protection and Welfare of Animals 2012-2015. Brussels (available at http://tinyurl.com/p9yth3a).

European Commission. 2013a. *Preserving genetic resources in agriculture. Achievements of the 17 projects of the Community Programme 2006-2011*. Brussels (available at http://tinyurl.com/npb2y4s).

European Commission. 2013b. *Independent Expert Evaluation of Council Regulation (EC) No. 870/2004 Conservation, Characterisation, Collection and Utilisation of Genetic Resources in Agriculture*. Annex to Commission Staff Working Document Accompanying the document Report from the Commission to the European Parliament, the Council and the Economic and Social Committee Agricultural Genetic Resources – from conservation to sustainable use. Brussels (available at http://tinyurl.com/ndnz3xe).

European Commission. 2013c. *Call for tenders N°AGRI-2013-EVAL-07. Preparatory action – EU plant and animal genetic resources in agriculture. Tender specifications*. Brussels (available at http://tinyurl.com/qbw4sbe).

European Commission. 2013d. *Proposal for a regulation of the European Parliament and of the Council on animal health.* Brussels (available at http://tinyurl.com/potm3nw).

European Commission. 2013e. *Report from the Commission to the European Parliament and the Council on the case for an optional quality term 'product of island farming'*. Brussels (http://tinyurl.com/q3um3nj).

European Commission. 2013f. *Report from the Commission to the European Parliament and the Council on the case for a local farming and direct sales labelling scheme*. Brussels (available at http://tinyurl.com/ngqtfb6).

European Commission. 2014a. *EIP-AGRI Focus Group 4: Genetic Resources – Cooperation Models Report of the first meeting 6-7 February 2014, Rome, Italy*. Brussels (available at http://tinyurl.com/oz4w9mh).

European Commission. 2014b. *Proposal for a regulation of the European Parliament and of the Council on the zootechnical and genealogical conditions for trade in and imports into the Union of breeding animals and their germinal products*. Brussels (http://tinyurl.com/q2xesqu).

European Commission. 2014c. *Proposal for a directive of the European Parliament and of the Council amending Directives 89/608/EEC, 90/425/EEC and 91/496/EEC as regards references to zootechnical legislation*. Brussels (available at http://tinyurl.com/oddfow5).

European Commission. 2014d. *Action Plan for the Future of Organic Production in the European Union*. Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions. Brussels (available at http://tinyurl.com/puom5aa).

European Commission. 2014e. *Proposal for a regulation of the European Parliament and of the Council on organic production and labelling of organic products, amending Regulation (EU) No XXX/XXX of the European Parliament and of the Council [Official controls Regulation] and repealing Council Regulation (EC) No 834/2007*. Brussels (http://tinyurl.com/oas99k6).

European Commission. 2014f. *Annexes to the proposal for a regulation of the European Parliament and of the Council on organic production and labelling of organic products, amending Regulation (EU) No XXX/XXX of the European Parliament and of the Council [Official controls Regulation] and repealing Council Regulation (EC) No 834/2007. COM(2014) 180 final. Annexes 1 to 5.* Brussels (available at http://tinyurl.com/pfhhmux).

FAO. 2004. *Report of the Tenth Regular Session of the Commission on Genetic Resources for Food and Agriculture, Rome, Italy, 8–12 November 2004*. CGRFA-10/2004/REP. Rome (available at ftp://ftp.fao.org/docrep/fao/meeting/014/j3951e.pdf).

FAO. 2006. *The legal framework for the management of animal genetic resources*, by A. Ingrassia, D. Manzella & E. Martynuik for the Development Law Service FAO Legal Office. FAO Legislative Study 89. Rome (available at http://www.fao.org/ag/magazine/LegalStudy89.pdf).

FAO. 2007a. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2007b. *Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration.* Rome (available at http://www.fao.org/docrep/010/a1404e/a1404e00.htm).

FAO. 2007c. *Draft strategic priorities for action for the sustainable use, development and conservation of animal genetic resources for food and agriculture*. Working Document. Commission on Genetic Resources for Food and Agriculture, Eleventh Regular Session, Rome, 11-15 June 2007. CGRFA-11/07/6. Rome (available at ftp://ftp.fao.org/docrep/fao/meeting/014/j9572e.pdf).

FAO. 2007d. *Report of the Conference of FAO. Thirty-fourth Session, Rome, 17–24 November 2007*. C 2007/REP. Rome (available at ftp://ftp.fao.org/docrep/fao/meeting/012/k0669e01.pdf).

FAO. 2009a. *Report of the Twelfth Regular Session of the Commission on Genetic Resources for Food and Agriculture, Rome, 19-23 October 2009*. CGRFA-12/09/REPORT. Rome (available at ftp://ftp.fao.org/docrep/fao/meeting/017/k6536e.pdf).

FAO. 2009b. *Funding Strategy for the implementation of the Global Plan of Action for Animal Genetic Resources*. Rome (available at http://www.fao.org/docrep/012/i1674e/i1674e00.pdf).

FAO. 2009c. *The use and exchange of animal genetic resources for food and agriculture*. CGRFA Background Study Paper No. 43. Rome (available at ftp://ftp.fao.org/docrep/fao/meeting/017/ak222e.pdf).

FAO. 2009d. *Report of the Conference of FAO Thirty-sixth Session, Rome 18–23 November, 2009*. C 2009/REP. Rome (available at http://www.fao.org/docrep/meeting/019/k6302e.pdf).

FAO. 2009e. *Preparation of national strategies and action plans for animal genetic resources*. FAO Animal Production and Health Guidelines. No. 2. Rome (available at http://www.fao.org/docrep/012/i0770e/i0770e00.htm).

FAO. 2011a. *Joint Work Plan with the Convention on Biological Diversity*. Information Document. Commission on Genetic Resources for Food and Agriculture, Thirteenth Regular Session Rome, 18–22 July 2011. CGFRFA-13/11/Inf.11. Rome (available at http://www.fao.org/docrep/meeting/023/mb707e.pdf).

FAO. 2011b. *Report of the Thirteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture Rome, Italy, 18 – 22 July 2011*. CGRFA-13/11/Report. Rome (available at http://www.fao.org/docrep/meeting/024/mc192e.pdf).

FAO. 2011c. *Surveying and monitoring of animal genetic resources*. Animal Production and Health Guidelines. No. 7. Rome (available at http://www.fao.org/docrep/014/ba0055e/ba0055e00.htm).

FAO. 2012. *Report of the First Session of the Ad Hoc Technical Working Group on Access and Benefit-Sharing for Genetic Resources for Food and Agriculture, Longyearbyen (Svalbard), Norway, 11–13 September 2012*. CGRFA/WG-ABS-1/12/Report. Rome (available at http://www.fao.org/docrep/meeting/026/me840e.pdf).

FAO. 2013a. *Report of the Fourteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture Rome, Italy, 15–19 April 2013*. CGRFA-14/13/Report. Rome (available at http://www.fao.org/docrep/meeting/028/mg538e.pdf).

FAO. 2013b. *Targets and indicators for animal genetic resources for food and agriculture*. Working Document. Fourteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture Rome, Italy, 15–19 April 2013. CGRFA-14/13/4.2. Rome (available at http://www.fao.org/docrep/meeting/027/mf582e.pdf).

FAO. 2014a. *Synthesis progress report on the implementation of the Global Plan of Action for Animal Genetic Resources – 2014*. Information Document. Fifteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture, Rome, 19–23 January, 2015. CGRFA-15/15/Inf.18. Rome (available at http://www.fao.org/3/a-mm278e.pdf).

FAO. 2014b. *Implementation and updating of the Global Plan of Action for Animal Genetic Resources*. Working Document. Fifteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture, Rome, 19–23 January 2015. CGRFA-15/15/11. Rome (available at http://www.fao.org/3/a-mm522e.pdf).

FAO. 2015. *Report of the Fifteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture, Rome, 19 – 23 January 2015*. CGRFA-15/15/Report. Rome (available at http://www.fao.org/3/a-mm660e.pdf).

FAO/WHO. 2007. *Organically produced foods.* Third edition. Rome, Geneva (available at ftp://ftp.fao.org/docrep/fao/010/a1385e/a1385e00.pdf).

Government of Turkey. 2011. *Domestic animal genetic resources in Turkey*. Ankara, Republic of Turkey, Ministry of Food, Agriculture and Livestock, General Directorate of Agricultural Research and Policy (available at http://tinyurl.com/pypnwtn).

Hesse, C. & Thebaud, B. 2006. Will pastoral legislation disempower pastoralists in the Sahel? Indigenous Affairs, 1/06: 14–23 (available at http://tinyurl.com/om658ef).

Inter-Résaux. 2012. *Pastoralism in sub-Saharan Africa: know its advantages, understand its challenges, act for its sustainability*. Food Sovereignty Brief No. 5, May 2012. Inter-Résaux Développement Rural/SOS Faim (available at http://tinyurl.com/qgbjrrx).

Legal survey responses. 2013. Responses to a questionnaire survey conducted by FAO (available at http://www.fao.org/3/a-i4787e/i4787e02.htm).

Lips, D., De Tavernier, J., Decuypere, E. & Van Outryve, J. 2001. Ethical objections to caesareans: implications on the future of the Belgian White Blue. In *Preprints of EurSafe. "Food Safety, Food Quality and Food Ethics" The Third Congress of the European Society for Agricultural and Food Ethics, 35 October 2001 Florence, Italy*, pp. 291–294. Milan, Italy, University of Milan (available at http://tinyurl.com/ojqtwj9).

OAU. 2000. *African Model Legislation for the Protection of the Rights of Local Communities, Farmers and Breeders, and for the Regulation of Access to Biological Resources*. Addis Ababa, Organization of African Unity (available at http://www.wipo.int/wipolex/en/text.jsp?file_id=252153).

Pilling, D. 2007. Genetic impact assessments – summary of a debate. *Animal Genetic Resources Information*, 41: 101–107 (available at ftp://ftp.fao.org/docrep/fao/010/a1206t/a1206t00.pdf),

RBST. 2009. *Consultation on the implementation of the CAP Health Check reforms relating to the Single Farm Payment Scheme and other direct payments. Response of the RBST*. Warwickshire, UK, Rare Breeds Survival Trust (available at http://tinyurl.com/pozoy2w).

SADC. 2003. *Southern African Development Community. Regional Indicative Strategic Development Plan*. Gaborone (available at http://tinyurl.com/nt5b4bb).

SAVE Foundation. 2013. Agrobiodiversity within the CAP: a chance for rural and social development. *SAVE eNews*, 4/2013: 1–2.

Taubman, A., Wager, H. & Watal, J. 2012. *A handbook on the WTO TRIPS Agreement*. Cambridge UK, Cambridge University Press.

Tvedt, M.V., Hiemstra, S.J., Drucker, A.G., Louwaars, N. & Oldenbroek, K. 2007. *Legal aspects of exchange, use and conservation of animal genetic resources*. FNI Report 1/2007. Lysaker, Norway, Fridtjof Nansen Institute (available at http://www.fni.no/doc&pdf/fni-r0107.pdf).

UNEP. 2013. *Green economy and trade. Trends, challenges and opportunities*. Nairobi, United Nations Environment Programme (available at http://tinyurl.com/c3xnhbt).

WIPO. 2011. *Patent-related flexibilities in the multilateral legal framework and their legislative implementation at the national and regional levels – PART II. Committee on Development and Intellectual Property (CDIP) Seventh Session Geneva, May 2 to 6, 2011*. Geneva, Switzerland, World Intellectual Property Organization (available http://tinyurl.com/py5yvhe).

WIPO. 2013. *Draft intellectual property guidelines for access to genetic resources and equitable sharing of the benefits arising from their utilization*. Consultation Draft, February 4, 2013. Geneva, Switzerland, World Intellectual Property Organization (available at http://tinyurl.com/nl9rb4v).

WIPO. 2014. *Patent landscape report on animal genetic resources*, by P. Oldham, S. Hall & C. Barnes. Geneva, Switzerland, World Intellectual Property Organization (available at http://www.wipo.int/edocs/pubdocs/en/wipo_pub_947_3.pdf).

WTO. 1998. *Review under Article 24.2 of the application of the provisions of the section of the TRIPS Agreement on Geographical Indications. Checklist of questions*. Council for Trade-Related Aspects of Intellectual Property Rights. IP/C/13. Geneva, Switzerland, World Trade Organization (available at http://www.wto.org/english/tratop_e/trips_e/ta_docs_e/5_3_ipc13_e.pdf).

WTO. 2001. *Declaration on the TRIPS Agreement and Public Health*. Ministerial Conference, Fourth Session, Doha, 9–14 November 2001. Geneva (available at http://tinyurl.com/qgj9arj).

WTO. 2005. *Geographical indications. Communication from the European Communities.* General Council, Trade Negotiations Committee, Council for Trade-Related Aspects of Intellectual Property Rights, Special Session. WT/GC/W/547 TN/C/W/26 TN/IP/W/11. Geneva, Switzerland, World Trade Organization (available at http://tinyurl.com/ox5h8sc).

WTO. 2010. *Annual report of the Council for TRIPS.* IP/C/56. Geneva, Switzerland, World Trade Organization (available at http://tinyurl.com/p52e2ug).

WTO. 2011. *Actions regarding SPS-related private standards. Decision of the Committee.* G/SPS/55. Committee on Sanitary and Phytosanitary Standards. Geneva, Switzerland, World Trade Organization (available at http://docsonline.wto.org/imrd/directdoc.asp?DDFDocuments/t/G/SPS/55.doc).

Zjalic, M. 2008. *Farm animal production systems and threats to biodiversity in Europe*. Paper presented at the Globaldiv Summer School, 8–12 September 2008, Piacenza, Italy. GlobalDiv (available at http://www.globaldiv.eu/SummerSchool/docs/Zjalic/ZjalicHandout.pdf).

Zjalic, M. 2010. *Technical report on review of impact of changes in CAP on farm animal biodiversity in the European Union*. GlobalDiv WP 4. Rome, European Federation of Animal Science (available at http://tinyurl.com/maaodgj).

Part 4

THE STATE OF THE ART

Introduction

This part of the report provides an overview of the state of the art in methodologies, tools and techniques for the management of animal genetic resources for food and agriculture (AnGR). There is no well-defined set of methodologies encompass by the phrase "management of AnGR". However, it can be taken to encompasses all technical, policy and logistical operations involved in understanding and documenting AnGR (inventory, characterization, surveying and monitoring); using and developing AnGR; conserving AnGR; and ensuring fair and equitable access to AnGR and sharing of benefits from their utilization.

The sections contained in this part of the report – addressing, in turn, surveying, monitoring and characterization, molecular tools, breeding programmes, conservation and economic evaluation – are each intended to serve as updates of the equivalent sections in the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture*, published in 20007. They therefore focus in particular on developments over the last decade or so. Each section ends with an assessment of gaps in current knowledge and proposes priorities for future research.

Section A

Characterization, inventory and monitoring

1 Introduction

The Global Plan of Action for Animal Genetic Resources (FAO, 2007a) notes that:

> *"Understanding the diversity, distribution, basic characteristics, comparative performance and the current status of each country's animal genetic resources is essential for their efficient and sustainable use, development and conservation. Complete national inventories, supported by periodic monitoring of trends and associated risks, are a basic requirement for the effective management of animal genetic resources. Without such information, some breed populations and unique characteristics they contain may decline significantly, or be lost, before their value is recognized and measures taken to conserve them."*[1]

The Convention on Biological Diversity calls on countries to identify and monitor their biodiversity, including agricultural biodiversity. It recognizes that these activities are fundamental to the conservation and sustainable use of genetic resources. It also calls for the identification and monitoring of factors that threaten or are likely to threaten biodiversity.[2]

Knowledge of animal genetic resources (AnGR) is fundamental to their sustainable use, development and conservation. As defined in the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007b),

> *"characterization of animal genetic resources encompasses all activities associated with the identification, quantitative and qualitative description, and documentation of breed populations and the natural habitats and production systems to which they are or are not adapted".*[3]

The objective of characterization is to increase knowledge of AnGR and their present, and potential future uses, in a wide variety of environments (FAO, 1984; Rege, 1992). Characterization activities should contribute to objective and reliable prediction of animal performance in defined environments, so as to allow a comparison of the potential performance of different types of AnGR within the various production systems found in a country or region.

The term "surveying" is typically used in the context of national efforts to obtain data on the size of breed[4] populations. However, there is no clear cut distinction between surveying and characterization. A "survey" may collect a range of different types of AnGR-related data, while characterization, broadly defined, includes the task of obtaining data

[1] FAO, 2007a, Paragraph 23, Introduction to Strategic Priority Area 1.

[2] Article 7 of the Convention on Biological Diversity (available at http://www.cbd.int/convention/articles.shtml?a=cbd-07).

[3] FAO, 2007b, page 347.

[4] FAO (1999) defines breed as follows: "either a subspecific group of domestic livestock with definable and identifiable external characteristics that enable it to be separated by visual appraisal from other similarly defined groups within the same species or a group for which geographical and/or cultural separation from phenotypically similar groups has led to acceptance of its separate identity." This broad definition is a reflection of the difficulties involved in strictly defining the term "breed". For further discussion of the breed concept, see FAO, 2007b, pages 339–340.

on population sizes. A survey that provides, for the first time, sufficient data to estimate the size of a national breed population is often referred to as a "baseline survey" (FAO, 2011a). At national level, surveying and characterization comprise the identification and description of the respective country's AnGR, including their population sizes and structures, geographical distributions and production environments, as well as threats to their survival. Monitoring is the process of documenting how the sizes and structures of breed populations – along with their geographical distributions and production environments and the threats that they face – change over time. Characterization is typically differentiated into two categories: phenotypic characterization and molecular characterization (see Box 4A1).

In addition to data collection, the process of characterization, surveying and monitoring also includes the systematic documentation of the information gathered, so as to allow easy access by stakeholders involved in the management of AnGR. Monitoring of breed populations is a prerequisite for the operation of the early warning and response systems for AnGR (FAO, 2008) called for in the Global Plan of Action (see Box 4A2).[5]

The first SoW-AnGR presented an overview of the significance of characterization, surveying and monitoring in AnGR management and the main activities involved. The material presented below updates this overview, drawing on guideline publications prepared by FAO during the intervening years (FAO, 2011a; 2011b; 2012a) and focusing particularly on recent developments.

Box 4A1
Phenotypic and molecular characterization

The term "phenotypic characterization of animal genetic resources" generally refers to the process of identifying distinct breed populations and describing their external and production characteristics within given production environments – along with description of these production environments. The process involves desk work in terms of gathering existing data, as well as field work recording information (descriptions, photos and trait measurements) for a group of representative animals. The term "production environment", in this context, refers not only to the "natural" environment (climate, terrain, etc.), but also to management practices and the uses to which the animals are put. Broadly defined, it can also be taken to include social and economic factors such as market orientation, marketing opportunities and gender issues. Recording the geographical distribution of breed populations is considered to be an integral part of phenotypic characterization.

Complementary procedures used to unravel the genetic basis of phenotypes, their patterns of inheritance from one generation to the next, within-breed genetic structure and levels of variability, and relationships between breeds are referred to as "molecular characterization" (or alternatively as "molecular genetic characterization" or simply "genetic characterization"). In this case, inferences are drawn from a representative sample of animals that have been subject to a genotyping procedure.

In essence, phenotypic and molecular characterization of animal genetic resource are used to measure and describe genetic diversity in these resources as a basis for understanding them and utilizing them sustainably.

2 Characterization as the basis for decision-making

Decision-making related to the management of AnGR requires reliable data. Figure 4A1 illustrates the basic decision-making steps involved in identifying a strategy for managing a breed population. Breeds are grouped into categories according to their risk of extinction (the orange rectangles in the figure) and this defines the types of actions taken to manage them. The octagons

[5] FAO, 2007a, Strategic Priority 1: "Inventory and characterize animal genetic resources, monitor trends and risks associated with them, and establish country-based early-warning and response systems."

Box 4A2
Elements of a country-based early warning and response system

It has been recommended (FAO, 2008) that a country-based early warning system for animal genetic resources should include the following elements:

1. a facilitating policy and legal framework (specific requirements will depend on needs and circumstances of the respective country);
2. institutional arrangements (allocation of responsibility for coordinating the system, establishment of relevant advisory groups, stakeholder networks, etc.)
3. a monitoring system (arrangements for keeping track of breeds' risk statuses as they change over time);
4. a risk-status classification system (criteria that can be used to allocate breeds to risk-status categories);
5. data and information management systems (including a national animal genetic resources database);
6. a priority-setting mechanism (a system for determining which breeds should be prioritized for conservation if resources are limited);
7. Breed recovery teams and breed recovery plans (arrangements for the implementation of conservation measures, including plans to protect breeds from acute threats such as disease epidemics);
8. Regional and global collaboration (cooperation, for example, in the organization of conservation programmes for transboundary breeds or in the establishment of regional gene banks); and
9. National, regional and global reporting and communication.

Note: Further information on monitoring and conservation measures can be found in the relevant FAO guidelines (FAO, 2011a; 2012b; 2013).

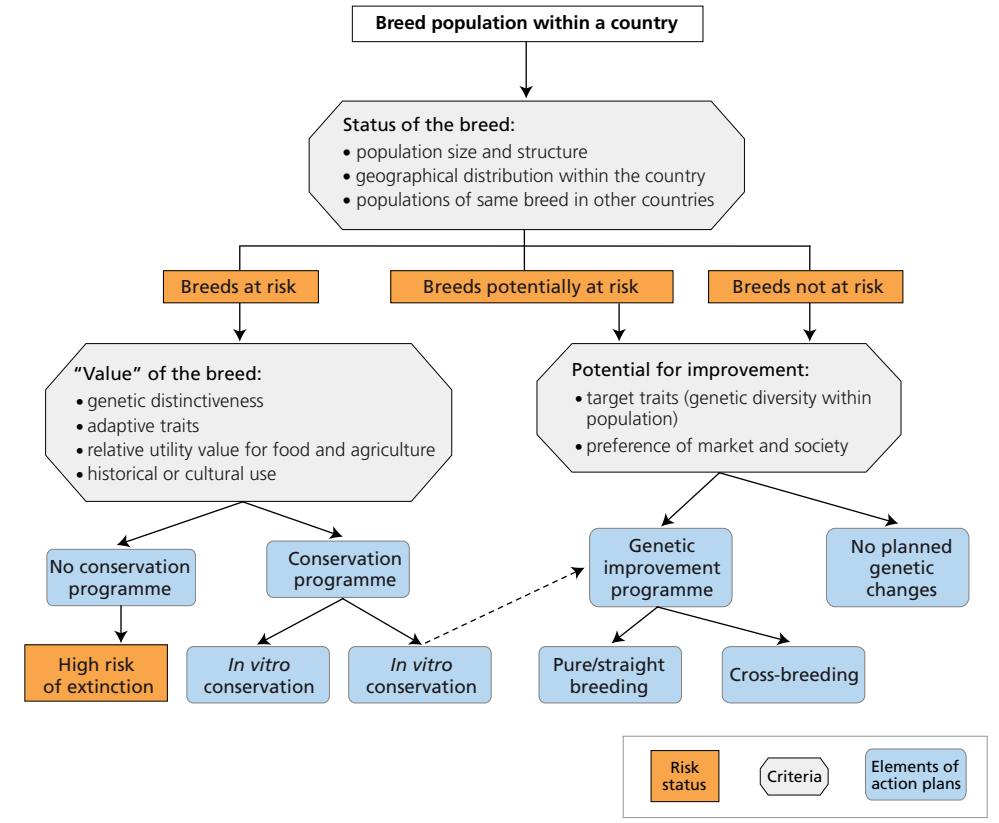
in the figure list criteria considered when assigning breeds to risk categories and when determining the course of action to take. Characterization provides the information necessary to evaluate a breed with respect to the various criteria upon which the categorization and management decisions are made.

Breed surveys will provide the bulk of the information needed to establish a breed's risk status. An effective baseline survey at national level will establish a reliable estimate of the size, structure and geographical distribution of the breed's population and regular monitoring will record how these change over time. If the breed is present in more than one country (i.e. a transboundary breed), national surveys in all countries where it is present will be needed in order to obtain an accurate estimate of its global population size (a breed's international distribution and global risk status may be factors to consider in decision-making at national level, but knowledge of these factors should clearly not be regarded as a prerequisite for action).

Analysis of data from molecular characterization studies allows inferences to be drawn not only on the present genetic structure of a breed population, but also on the breed's history (see Part 1 Section A). Molecular characterization can also be used to refine knowledge about transboundary populations by contributing to the identification of breeds that have different names but show little differentiation at the genetic level (see Part 4 Section B).

The relative utility value of a breed for food and agriculture will depend on a combination of factors and can be assessed on the basis of the results of phenotypic characterization studies that record performance, adaptability and product quality, along with descriptions of the production environments in which the animals are kept. Phenotypic characterization will also provide an indication of the breed's genetic distinctiveness, as unique traits can be expected to have a significant genetic basis. Molecular characterization can confirm this differentiation with respect to functional genes and extend it to "neutral" areas of the genome that are not subject to the forces of selection. A combination of phenotypic character ization (including information on production

FIGURE 4A1
Management of breed populations – flow chart of decisions



Source: FAO, 2007b.

environments) and molecular characterization will indicate a breed's adaptive traits and provide some indication of the biological basis for the observed characteristics. Studies will ideally also note any particular historical or cultural significance of the breeds targeted.

Molecular characterization can help in the evaluation of a breed's potential for genetic improvement. For simply inherited traits controlled by a single locus or a few well-defined loci, molecular analyses can determine whether a given breed carries the most favourable allele(s) and at what frequency. The situation is more complicated for quantitative traits, because such traits are influenced by many genes – and few of these genes have been identified. However, genetic variation is essential for genetic improvement, and molecular characterization can be used to obtain a general assessment of a breed's genetic variability. An approach of this kind relies on the assumption that overall genetic variation (which includes variation for neutral loci that do not influence traits) is proportional to the variation for trait-influencing loci.

As noted above, description of the production environment is an essential element of phenotypic characterization. It can allow inferences

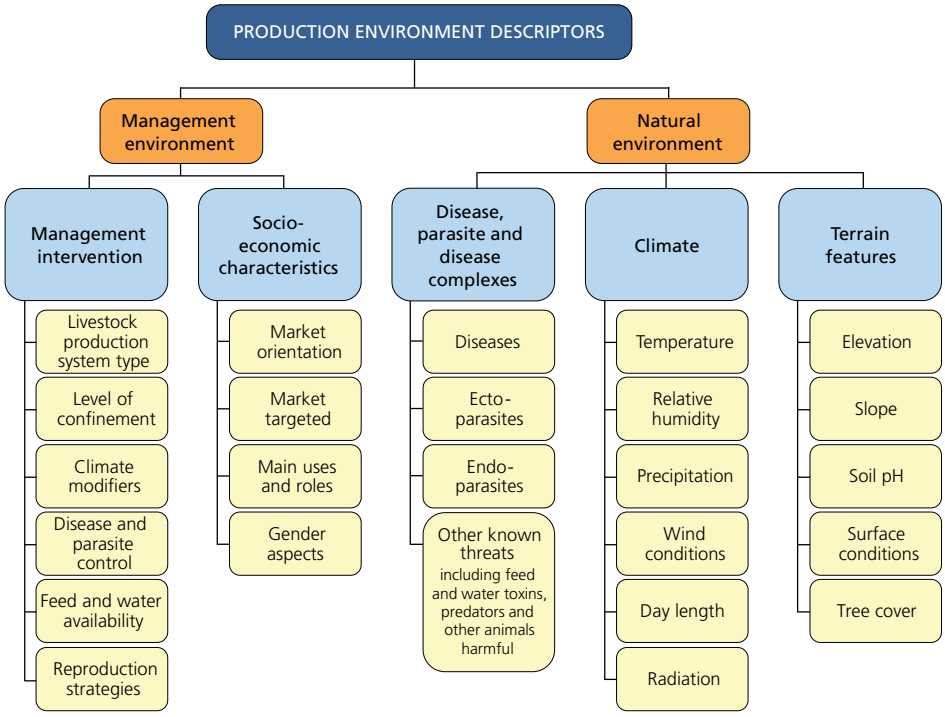
to be drawn regarding a breed's potential for improvement, particularly whether or not its genetic potential is being constrained by the environment (natural conditions or management capacity). Describing the production environment in which a breed has been raised for many years can also serve as an indirect means of characterizing its adaptive traits, based on the assumption that, over the years, the breed will have become adapted to the conditions in which it is kept. A description of the production environment in the broad sense may include an assessment of marketing opportunities and current and potential future demand for products or services provided by breeds and thereby provide information that can be used in planning their future management.

Knowledge of the production environments in which performance measurements are taken is, clearly, also essential if they are to be interpreted appropriately. A set of standard production environment descriptors has been developed for use in the Domestic Animal Diversity Information System (DAD-IS) (FAO, 2012a; FAO/WAAP, 2008). The main elements of the framework are shown in Figure 4A2.

3 Tools for characterization, surveying and monitoring

Since the first SoW-AnGR was prepared, FAO has developed and distributed technical guidelines on

FIGURE 4A2
Descriptor system for production environments



Source: FAO/WAAP, 2008.

surveying and monitoring (FAO, 2011a), phenotypic characterization (FAO, 2012a) and molecular characterization (FAO, 2011b). These guidelines describe in detail the tools recommended for use in the respective fields. They also describe some of the major developments that have occurred in the field of characterization in recent years.

The guidelines on surveying and monitoring provide advice on how to draw up a strategy for meeting national needs for data and information on AnGR. They also offer practical advice on how to plan and implement an AnGR survey – covering the whole process from planning the survey to disseminating the outputs and taking the first steps in translating results into action. A range of surveying methods are presented and advice is offered on how they can be combined and integrated within an effective strategy that addresses both the task of acquiring a baseline of data on AnGR and the subsequent task of monitoring changes over time. Box 4A3 provides brief descriptions of various methods or tools that can be used for surveying and monitoring.

When planning a survey or a surveying strategy, the appropriate choice of tools will depend on the specific objectives and on the circumstance in which the data will be collected (state of capacity to implement surveying activities, characteristics of the communities targeted, challenge posed by the rural landscape, availability of funding, etc.). Table 4A1 provides an overview of the suitability of different tools as methods for answering some of the basic questions that AnGR surveys attempt to address.

The guidelines on phenotypic characterization (FAO, 2012b) offer advice on how to conduct a well-targeted and cost-effective phenotypic characterization study and provide an overview of the concepts and approaches that underpin phenotypic characterization. They also provide practical guidance on planning and implementing field work, data management and data analysis. Generic data collection formats for phenotypic characterization of major livestock species, as well as a framework for recording data on breeds' production environments are also included.

To summarize briefly, phenotypic characterization encompasses the following activities (FAO, 2012b):

1. describing the geographical distribution of the targeted breeds and if possible the size and structure of their populations;
2. assessing the breeds' phenotypic characteristics, including physical features and appearance, economic traits (e.g. growth, reproduction and product yield/quality) and some measures (e.g. range) of variation in these traits – the focus is generally on productive and adaptive attributes;
3. obtaining images of typical adult males and females, as well as of herds or flocks in their typical production environments;
4. gathering information on the breeds' origin and development;
5. describing any known functional and genetic relationships with other breeds within or outside the respective country;
6. describing the biophysical and management environment(s) in which the breeds are kept;
7. documenting the breeds' responses to environmental stressors such as disease and parasite challenge, climatic extremes and poor feed quality, along with any other special characteristics related to adaptation; and
8. cataloguing any relevant indigenous knowledge (including gender-specific knowledge) related to the breeds and their management.

Many of these tasks can be accomplished through desk work or by consulting breeders or other stakeholders. The clearest exceptions are items 2 and 3, which require recording of data on a representative sample of live animals directly in their production environments.

The guidelines on molecular characterization (FAO, 2011b) include a short overview of progress in molecular characterization of AnGR over the preceding two decades and prospects for the future. They also provide practical advice for researchers wishing to undertake a molecular characterization study. The guidelines emphasize the importance of obtaining high-quality and representative biological samples that yield

Box 4A3
Surveying and monitoring methods – a toolbox

Mapping expeditions: The term "mapping expedition" is used to describe a set of journeys undertaken (with limited contact with local livestock-keeping communities) for the purpose of obtaining rudimentary information on the animal genetic resources (AnGR) within a given geographical area. A mapping expedition can be used to map the approximate distribution of particular breeds and species, and may serve to frame subsequent surveys that will use other methods. However, the lack of contact with livestock keepers will result in very little acquisition of knowledge on production systems, livestock-keeping communities or the uses of AnGR. Geographic information system (GIS) tools and knowledge of the links between landscape types and livestock production systems may help to focus the mapping expedition.

Breed search tours: A "breed search tour" aims to fill gaps in breed inventories and identify breeds to be targeted by more detailed characterization studies. It involves an expedition to a part of the country where the livestock population has not been thoroughly studied and where it is suspected that undocumented breeds may be present. Planning a survey of this type may involve studying sources of historical information about the livestock populations in the targeted area. A breed search tour can be a low-cost activity that takes up relatively little time. However, it is possible that no undocumented breeds will be found.

Transects: In some locations it may be possible to estimate the numbers and types of animals present by using transect methods similar to those that have been developed for surveying wildlife. The approach involves drawing transects, *a priori*, across the area targeted by the survey and then travelling along them. The animals observed along the transect are counted and complex statistical methods are then used to estimate the numbers of animals in the area as a whole.

Aerial surveys: Aerial surveys can be thought of as airborne mapping expeditions or transects. They are appropriate only for use in sparsely populated and open landscapes and can be relatively expensive because of the need for costly equipment and highly skilled personnel. Despite these limitations, poor accessibility, the unpredictable movements of pastoralists' herds and security uncertainties may justify the use of aerial surveys as a means of estimating the size and structure of livestock populations and their spatial and seasonal distributions. In some areas, such surveys may be the only realistic option for achieving systematic coverage and obtaining the data needed for comprehensive statistical analysis. The main weakness of aerial surveys is a lack of contact with local livestock keepers and with the animals themselves. However, they may provide a starting point for further surveying activities that provide more information on livestock-keeping communities and the causes behind the outcomes observed from the air.

Household surveys: A household survey involves collecting data from a random sample of households chosen from among all households meeting a specific set of criteria referred to as the "sampling frame". The larger the sample as a fraction of the whole, the more accurate the survey will be as an estimator of the target group. Information is obtained via interviews, normally held face to face with household members. The interviews are commonly based on a questionnaire.

Rapid appraisal: The term "rapid appraisal" can be used to describe data collection activities that involve interaction with livestock keepers and/or other knowledgeable stakeholders, but are not based on formal sample-based surveys. Rapid appraisals are multidisciplinary in nature and normally require visits to the communities targeted. Triangulation – the use of several sources in order to validate the data obtained – is a key characteristic. A range of rapid-appraisal tools are available and they can be selected and combined to meet the objectives of particular surveys or surveying strategies. Group interviews and exercises can serve as an alternative, or as a complement, to interviews with individual livestock-keeping householders or other informants.

(Cont.)

Box 4A3 *(Cont.)*
Surveying and monitoring methods – a toolbox

Key informants: Key informants are individuals who are targeted because of their particular knowledge about some aspect of the location or production system targeted by the survey or because they have broad knowledge that can be drawn upon as an alternative or complement to conducting a survey of individual livestock keepers. Advantages of using key informants include the potential for obtaining a lot of information from a limited number of interviews and the potential for obtaining detailed information within the key informants' areas of expertise. Disadvantages of using key informants include the possibility that the key informants are insufficiently well-informed about the situation on the ground and the risk that the knowledge and opinions of the livestock keepers themselves, particularly marginalized groups, may be overlooked.

Obtaining information from breed societies: Breed societies, where they exist, can be considered a specific category of key informant. They are particularly useful for monitoring population size and structure and hence for identifying when breeds come to be at risk of extinction. Breed societies can be asked to report at regular intervals on the numbers of breeding males and females that are registered in their herd/flock books or (where possible) to provide details of animal pedigrees. Obtaining data from breed societies is a rapid and relatively easy means to keep track of population trends. Breed societies will also be knowledgeable about breeds' geographical distributions, morphology, performance, uses, production environments, marketing and so on.

Censuses: In a technical sense, a census is a household survey of wide scope and in which all qualifying households are interviewed. Most countries implement national agricultural censuses once every ten years; they may also implement more specific livestock censuses. In some countries, national censuses are based on sampling rather than on complete enumeration of the target populations.

Note: Detailed descriptions of the methods and their advantages and disadvantages can be found in FAO (2011a).

standardized data that can be integrated into analyses on an international scale.

With respect to biological samples, the guidelines suggest the collection of samples from at least 40 animals from across the geographic range of the breed. Blood has traditionally been the most frequently sampled material, but tissue and hair are gaining in popularity. Equipment has been developed for sampling ear tissues during the process of tagging animals for identification purposes. This approach efficiently combines animal identification with sample collection and links the identification number of the animal to the container in which the tissue sample is captured and stored. The material in the sampling tubes can also be cryopreserved and stored in a gene bank for possible use in population regeneration through cloning via somatic cell nuclear transfer (FAO, 2012b).

Ideally, for maximum efficiency, phenotypic and molecular genetic characterization activities will be combined, so that body measurements and other relevant traits can be recorded from the same animals from which biological samples are taken. Recording geographic coordinates for each animal from which samples and measurements are taken facilitates the description of their production environments, as the coordinates can be linked to other georeferenced datasets. A simple method for the collection of phenotypic data based on images is described in Box 4A4.

A variety of biotechnological tools are available for assaying the DNA collected during molecular characterization. Lists of the standard International Society for Animal Genetics–FAO Advisory Group panels of microsatellite markers for nine common livestock species are included in the guidelines on molecular genetic characterization

TABLE 4A1

Usefulness of different surveying and monitoring tools to address different survey questions

Surverying and monitoring tools	Mapping expedition	Breed search tour	Transect[1]	Aerial survey	Rapid appraisal	Household survey	Census
Identification and characterization							
Is Breed A present in the survey area and listed in the relevant breed inventory?	*****	*****	*****	*	***	*****	****
What are the characteristic identifiers of Breed A?	**	***	***	*	****	*****	*
Is Breed A part of a common gene pool that extends beyond national borders?	**	***	*	*	*****	*****	**
How many animals of Breed A are there?	*	**	****	**	**	*****	****
What is the geographical distribution of Breed A?	*****	***	***	**	***	*****	*****
What role does the breed play within the production environment in which it is kept?	*	***	*	*	****	*****	**
Is Breed A associated with a particular socio-economic or cultural group?	*	****	*	*	***	*****	***
Does Breed A have any important adaptations or unique traits?	*	**	*	*	*****	*****	*
What are the threats to Breed A?	*	**	**	*	*****	*****	*
Monitoring							
Is Breed A increasing or decreasing in numbers?	*	*	****	**	****	***	****
Is a recognized threat to Breed A increasing of deceasing?	*	*	**	*	*****	***	**

Note: The number of asterisks represents the usefulness of the tool: * = of little use; ***** = very useful.
[1] Assuming this approach is feasible in the respective production environment.
Source: FAO, 2011a.

(FAO, 2011b). These panels are, however, limited to the characterization of neutral genetic variability.

4 Information systems

The information gathered through characterization, surveying and monitoring activities is not useful unless a system is in place to ensure it is organized and made easily available to stakeholders. An information system normally includes data, hardware and software for the organization, analysis and storage of these data, and facilities for communication. Information systems can be manual or automated and may or may not be publicly accessible. The most widely used systems are those that are publicly available on the internet.

The roster of public-domain electronic AnGR information systems that are globally accessible and contain data from more than one country has remained largely unchanged since the time the first SoW-AnGR was prepared. Two of these systems – the Domestic Animal Diversity Information System (DAD-IS)[6] and the European Farm Animal Biodiversity Information System (EFABIS)[7]

[6] http://fao.org/DAD-IS
[7] http://efabis.tzv.fal.de/

Box 4A4

A digital enumeration method for collecting phenotypic data for genome association

Genomic science aimed at finding important adaptive genetic variations requires consistent data across animal populations. The ADAPTMap* Digital Phenotype Collection Method is a new method for obtaining consistent phenotypic data by digital enumeration of categorical and continuous values. It is an easy to use, low-cost procedure that involves the collection of data on health status indicators (anaemia status, age and weight), body measurements, shapes and coat colour and pattern via digital images, using mobile technology.

The method calls for six photos: four for body measurements and two for health indicators. The animal walks directly into the photo set and has to make only two right one-quarter turns to allow the first four photos (Shots 1 to 4) to be taken. The camera is positioned at the eye level of the animal at a distance of 3 m. The two health indicator photos are close-ups of the teeth (tooth age) (Shot 5) and eye (FAMACHA score**) (Shot 6).

Novel calibration signs designed to affirm size and colour are made of sturdy, light-weight metal and dry-erase pens are used to record sample data captured by the images. A field photo sampling kit (see photo) includes everything needed except the camera.

Twelve sampling teams have employed the method in 12 countries, sampling roughly 2 000 goats and collecting over 12 000 images. An ADAPTMap Quick Start Guide was developed and proved valuable in enabling the sampling teams to set up the equipment and take the photos properly. Samplers generally had little difficulty applying the method; however, the FAMACHA and tooth shots were challenging.

Shot 1: Rear

Shot 2: Naked Goat

Shot 3: Sign

Shot 4: Front

Shot 5: Teeth

Shot 6: FAMACHA

(Cont.)

Box 4A4 *(Cont.)*

A digital enumeration method for collecting phenotypic data for genome association

The method is designed to provide consistent phenotypic measurements that can be used in conjunction with DNA sampling to inform genomics research, guide animal selection for breeding programmes and facilitate animal genetic conservation decisions. It will enable countries to take advantage of state-of-the-art science and support them in identifying priority breeds for conservation. The data may be used in research, surveillance efforts to detect emerging animal health issues or as a tool for on-farm herd record keeping management and animal health care.

Simplification of the collection protocol is being explored. The associated digital phenotyping software under development could be integrated into other livestock software applications.

*ADAPTMap is an international project for characterization of goats on a global level that employs landscape genomics to study adaptation to local environments (see www.goatadaptmap.org for more information).
**FAMACHA score is based on the colour of the inner eyelid and is used as indicator of the animal's level of anaemia.
Provided by Jennifer Woodward-Greene, Jason K. Kinser, Heather J. Huson, Tad S. Sonstegard, Johann (Hans) Sölkner, Iosif I. Vaisman and Curtis P. Van Tassell. The work is funded by USAID Feed the Fututre, the USDA and FAO

(previously EAAP–AGDB) – are part of a linked network of information systems (EFABISnet)[8]. Countries are able to set up their own national information systems ("nodes") linked to EFABIS. Seventeen countries[9] (as of October 2014) operate national nodes that regularly exchange data with EFABIS, which in turn exchanges data with DAD-IS. The national nodes can be accessed via the web. In most cases the data are provided in English and the respective local language. In addition to the core data structure that is common to all the systems in the region, countries can add data structures that reflect their specific needs. Data pertaining to these national specificities are not synchronized with EFABIS. Similarly, EFABIS, is tailored to the specific requirements of the European region (e.g. it includes a register of cryobank material) and data pertaining to these specificities are not transferred to DAD-IS. The number of national breed populations for which some information is available in DAD-IS has increased by about 6 percent (from 14 017 in 2006 to 14 896 in 2014) and the proportion of breeds for which population data are recorded has increased from 42 to 59 percent (see Part 1 Section B for further information).

The Domestic Animal Genetic Resources Information System (DAGRIS),[10] managed by the International Livestock Research Institute (ILRI), is based on a database of research information obtained from published and grey literature (DAGRIS, 2007). At the time the first SoW-AnGR was prepared, DAGRIS comprised a single central database. However, dispersed national units have now been established for some countries through an initiative known as "Country DAGRIS" (DAGRIS, 2013). Oklahoma State University's Breeds of Livestock[11] information system (Oklahoma State University, 2005) provides brief summaries of breed origins, characteristics and uses. Although this resource is maintained, little new information has been added in recent years. Brazil, Canada and the United States of America are collaborating in the development of Animal-GRIN (the Animal Genetic Resources Information Network)[12] as a common platform for the management of AnGR-related data.[13] Wikipedia, the online

[8] http://efabis.net

[9] Austria, Bulgaria, Cyprus, Estonia, Finland, Greece, Hungary, Iceland, Ireland, Italy, Netherlands, Poland, Republic of Moldova, Slovenia, Slovakia, Switzerland, United Kingdom.

[10] http://dagris.ilri.cgiar.org/

[11] http://www.ansi.okstate.edu/breeds/

[12] http://nrrc.ars.usda.gov/A-GRIN/main_webpage/ars?record_source=US

[13] http://nrrc.ars.usda.gov/A-GRIN/database_collaboration_page#

Box 4A5

Biogeoinformatics for the management of animal genetic resources

The management of animal genetic resources requires data on population and evolutionary genetics and on animal husbandry practices, but also on the socio-economic and environmental conditions in the locations where animals are bred. The integration of these different types of information by means of geographical coordinates and geographic information systems (GIS) will facilitate the development of monitoring systems able to identify at-risk breeds and thereby support conservation prioritization. Supported by expert-based decision-making approaches, web-based platforms developed on the basis of expertise in biology, GIS and computer science are able to simultaneously assess animal demographics and the sustainability of breeding activities in areas of interest.

In parallel, and in conjunction with molecular genetic data, the use of geographical coordinates enables the use of livestock landscape genomics to seek regions of the genome influencing the ability of animals to cope with environmental variations. The approach can be used to identify key traits involved in parasite resistance, to support efforts to conserve the adaptive potential of locally adapted breeds and even to increase adaptability in industrial breeds. Specific software developed at the interface of geographic, biological and computer sciences can be used to identify regions of the genome that may be under natural selection and involved in evolutionary processes such as local adaptation.

Biogeoinformatics has a crucial role to play in the characterization of animal genetic resources. It will not be possible to extract new knowledge from the data tsunami brought about by the advent of high-throughput molecular tools, new sources of high-resolution environmental data and new sources of socio-economic information unless efficient and easy-to-use computing tools are developed. If the discipline is to fulfil its potential in the coming decades, the livestock community will need to ensure that recording of geographical coordinates for any sampled animals is treated as a standard practice and thus that links can be made to information available in georeferenced databases.

Provided by Stéphane Joost, Solange Duruz and Sylvie Stucki.

encyclopedia,[14] has descriptive entries for many individual livestock breeds. Breeds are, clearly, not the main focus of this resource and the information available is not standardized.

Information systems for AnGR are developed and administered as global public goods and have limited ability to attract investment from the private sector or major funding agencies. This explains the very limited amount of information that they contain relative to what would potentially be possible – and would be necessary for them to achieve their stated purposes effectively.

[14] http://en.wikipedia.org/wiki/Main_Page

5 Changes since 2005

Developments in telecommunication technologies, expansion of their range of usage and decreases in their costs are creating greater potential for the use of these technologies in surveying and monitoring. However, adoption of these technologies for this purpose has been very limited. Increasing numbers of countries are exploiting telecommunication technologies to establish or enhance animal identification and traceability systems (FAO, 2015). However, in most cases these systems do not gather data on the breeds to which animals belong.

Advances in global positioning technologies and geographic information systems have created opportunities for more accurate and detailed

descriptions of breeds' production environments. Box 4A5 discusses some recent developments in this field. Various publicly available databases provide access to georeferenced data on the climate and other environmental measures such as soil type and vegetation. If the geographical coordinates of breed distributions have been recorded, they can be linked to these datasets as part of efforts to characterize breeds' production environments. Global positioning technologies and geographic information systems, along with advances in molecular genetic characterization have also facilitated the use of "landscape genomics" in the study of adaptation at molecular level.

Developments in the field of molecular genetic analysis since the time the first SoW-AnGR was prepared have been nothing short of revolutionary (details are provided in Part 4 Section B). Genome sequencing has become much more rapid and much less costly. Reference genome sequences have been established for all the major livestock species and several minor ones. The genomes of several thousand individual animals, most commonly cattle, have been sequenced. The single nucleotide polymorphisms (SNPs) identified through sequencing have become the basis for high-throughput genotyping assays with which tens of thousands of markers can be screened simultaneously. One shortcoming, however, is that development of these technologies for livestock has been driven by the commercial market. As a result, the tools have been created for, and are more applicable to, the species and breeds that are most common in industrialized countries (i.e. a limited number of international transboundary breeds).

As far as phenotypic characterization is concerned, genomic and other technological advances have increased opportunities and demands for so-called advanced characterization. Such studies involve relatively complex data-gathering activities, particularly repeated measurements over a period of time (e.g. weights of young animals to characterize growth rate), and often target novel traits related to the cost and efficiency of production rather than to the quantity of output produced. The scientific community has recently realized that a lack of phenotypic information, rather than genomic information, has now become the limiting factor in the study of biological systems and processes. "Phenomics" – the study of phenotypes from a systematic perspective – has thus recently emerged as an important discipline. Phenomics involves the collection of data on multiple phenotypes, including "traditional" traits and biological indicator traits measured in an automated manner. Integration of phenomics concepts into phenotypic characterization, although not yet widely done, is likely to become more common in the future, especially as more effort is made to characterize breeds for complex phenotypes such as heat resistance and other forms of adaptation.

Characterization of rumen microbes is an emerging research topic that may assist in the reduction of greenhouse gas emissions (Box 4A6).

6 Conclusions and research priorities

Adequate surveying, monitoring and characterization of AnGR are prerequisites for successful management of these resources and for informed decision-making in national livestock development. A strategic and coherent approach is needed and all activities should be undertaken in close cooperation with livestock keepers and other stakeholders. There is still particular need to develop innovative methods and tools that take advantage of the potential of telecommunication networks (e.g. cellular phones and mobile internet) for use in surveying and monitoring. The political will to undertake surveying and monitoring at breed level is also essential. Most national livestock censuses and animal identification systems do not record information about breeds.

In many countries, comprehensive breed definitions that unambiguously distinguish different populations are often lacking. Also often lacking are descriptions of the production environments

Box 4A6

Rumen microbes: small but significant

Rumen microbes play a central role in the nutrition, health and greenhouse gas emissions of ruminant animals. However, we do not know whether the rumen microbial community is the same in all ruminants, and how much host species, diet and geography influence the microbial community. The Global Rumen Census Project (www.globalrumencensus.org.nz) was established to address this knowledge gap and aims to characterize the composition and diversity of rumen microbial communities. In total, 742 samples from a range of ruminants, and other mammals with similar digestive systems, were provided by collaborators from 58 research institutions in 33 countries (www.globalrumencensus.org.nz/samples). The samples encompassed a wide variety of species and breeds, including taurine cattle (Charolais, Cika, Hereford, Highland, Holstein, Icelandic, Korean Native, White Park, etc.), zebu cattle (Muturu, N'Dama, Nelore, White Fulani, etc.), goats (Creole, Red Sokoto, Saanen, etc.), deer, water buffalo (Murrah, Nili-Ravi, etc.), to name but a few. Samples from non-farmed ruminants were also included. The sampled animals were from a range of different production systems (small and large-scale commercial operations, research farms and the wild) and locations (temperate, tropical, high-altitude locations, etc.) and consumed a wide variety of diets, comprising many different forages and concentrate combinations of greatly differing quality.

As part of the Global Rumen Census Project, DNA was extracted from the samples, and bacterial, archaeal, protozoal and fungal marker genes were sequenced using a standardized pipeline. The dataset comprises 5 million bacterial, 1 million archaeal, 1 million protozoal and 15 000 fungal sequencing reads. Analysis of these data will allow the identification of factors that influence which taxa are present in the rumen and allow the following questions to be addressed:

- How much variation is there in rumen microbial communities?
- What is the extent of diversity in each microbial group?
- What novel groups are present?
- Is there a core microbial community?

Interrogation of sample (meta-)data will allow the identification of factors that influence which taxa are present in the rumen.

Many of the rumen microbes have not been adequately characterized, often due to a lack of available representative cultures. A second project with collaborators from 14 countries, the Hungate1000 (www.hungate1000.org.nz), aims to generate a reference set of rumen microbial genome sequences from cultivated rumen bacteria and archaea, together with representatives of rumen anaerobic fungi and ciliate protozoa. Data from the Global Rumen Census are being used to inform the selection of candidates for isolation and genome sequencing. The Hungate1000 project currently has genome sequencing in progress for more than 280 microbial cultures (http://www.hungate1000.org.nz/genomes.html). Results will be used to initiate genome-based research aimed at understanding rumen function, feed conversion efficiency, methanogenesis and plant cell wall degradation in order to find a balance between food production and greenhouse gas emissions. Results from both projects will aid the analysis of future rumen microbiome studies.

Both projects are funded by the New Zealand Government in support of the Livestock Research Group of the Global Research Alliance on Agricultural Greenhouse Gases (http://www.globalresearchalliance.org) to support international efforts to develop methane mitigation and rumen adaptation technologies.

Provided by Gemma Henderson, Peter H. Janssen, Adrian Cookson, Sinead Leahy and Bill Kelly.

in which breeds are kept and in which they achieve given levels of performance. FAO is cooperating with several countries to collect such information, but recording has yet to be implemented on a wide scale.

With regard to research priorities, the first SoW-AnGR noted that growing interest in issues such as animal welfare, distinctive product qualities, human–health effects, the environmental impacts of livestock production and the efficiency of resource utilization meant that there was a need for characterization studies to target traits relevant to these concerns. Specific priorities identified included research into the robustness of different breeds, as measured by the extent of genotype–environment interactions, and into the genetic basis of robustness and disease resistance, including infection mechanisms and host–pathogen interactions. These priorities remain relevant. More generally, there is a need to improve understanding of the contributions that different types of livestock make to the economy and to rural development, including not only the supply of marketed products, but also the provision of regulating, habitat and cultural ecosystem services (see Part 1 Section D and Part 4 Section E for further discussion of ecosystem services). Studies that investigate the links between the characteristics of specific breeds and the supply of niche products and ecosystem services may also be significant in the planning of conservation measures, given that functions of this kind are increasingly being regarded as potential means of keeping at-risk breeds in use (see Part 3 Section D and Part 4 Section D).

Lack of phenotypic data has always been a constraint in developing countries, but advances in genomics and interest in new traits have meant that phenotyping has now become the main limiting factor in characterization in both developing and developed countries. Methods for measuring phenotypic characteristics associated with health, fitness, adaptability and the provision of ecosystem services need to be improved.

There is a need to develop cheap and efficient tools for monitoring AnGR populations, including monitoring of their geographic distributions. It is possible that in the era of the internet and crowd sourcing it may be possible to develop more participatory approaches to the collection of AnGR-related data. This would require forms of organization that differ from those used in conventional top-down surveying and monitoring programmes. Investigating the feasibility of using such approaches would be likely to require input from the social sciences.

Ideally, decision-making in AnGR management would be based on comprehensive information. However, given that immediate action is required, there is a need to develop tools and methods that make effective use of the information that is presently available.

Existing AnGR information systems have relatively little functionality beyond simple searches by country or breed. There is a need to create user-friendly tools that allow stakeholders to access the data they require and conduct customized analyses. However, information systems are only as good as the information they contain. Insertion of missing data and regular updating and correction of existing data are essential. This process would be facilitated by the development of specific software applications that reduce the work associated with data input. Georeferencing of AnGR-related data needs to be expanded and made routine, so as to allow these data to be linked to georeferenced geophysical and agro-ecological data and to provide more precise information about the current and past geographic distributions of specific AnGR. Finally, given that no single information system can gather and store all relevant data, the interconnectivity and interoperability of information systems and databases need to be further developed.

References

DAGRIS. 2007. *Domestic Animal Genetic Resources Information System (DAGRIS)*, edited by S. Kemp, Y. Mamo, B. Asrat & T. Dessie. Addis Ababa, International Livestock Research Institute (available at http://dagris.ilri.cgiar.org).

PART **4**

DAGRIS. 2013. *Domestic Animal Genetic Resources Information System (DAGRIS)*, edited by O. Mwai, Y. Mamo & T. Dessie. Addis Ababa International Livestock Research Institute.

FAO. 1984. *Animal genetic resource conservation by management, databanks and training*. Animal Production and Health Paper No. 44/1. Rome (available at http://www.fao.org/docrep/010/ah808e/ah808e00.htm).

FAO. 1999. *The Global Strategy for the Management of Farm Animal Genetic Resources. Executive brief*. Rome (available at http://dad.fao.org/cgi-bin/getblob.cgi?sid=-1).

FAO. 2007a. *Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration*. Rome (available at ftp://ftp.fao.org/docrep/fao/010/a1404e/a1404e00.pdf).

FAO. 2007b. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2008. *Development of country-based early warning and response systems for animal genetic resources.* Fifth Session of the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture, Rome 28–30 January 2009. CGRFA/WG-AnGR-5/09/4. Rome (available at http://www.fao.org/docrep/meeting/021/K3812e.pdf).

FAO. 2011a. *Surveying and monitoring of animal genetic resources*. FAO Animal Production and Health Guidelines. No. 7. Rome (available at www.fao.org/docrep/014/ba0055e/ba0055e00.pdf).

FAO. 2011b. *Molecular genetic characterization of animal genetic resources*. Animal Production and Health Guidelines. No. 9. Rome (available at http://www.fao.org/docrep/014/i2413e/i2413e00.pdf).

FAO. 2012a. *Phenotypic characterization of animal genetic resources*. Animal Production and Health Guidelines. No. 11. Rome (available at www.fao.org/docrep/015/i2686e/i2686e00.pdf).

FAO. 2012b. *Cryoconservation of animal genetic resources*. FAO Animal Production and Health Guidelines. No. 12. Rome (available at http://www.fao.org/docrep/016/i3017e/i3017e00.htm).

FAO. 2013. In vivo *conservation of animal genetic resources.* FAO Animal Production and Health Guidelines. No. 14. Rome (available at http://www.fao.org/docrep/018/i3327e/i3327e00.htm).

FAO/WAAP. 2008. *Report of the FAO/WAAP Workshop on Production Environment Descriptors for Animal Genetic Resources, held in Capralola, Italy, 6–8 May 2008*, edited by D. Pilling, B. Rischkowsky & B. Scherf. Rome (available at http://dad.fao.org/cgi-bin/getblob.cgi?sid=-1,593).

Oklahoma State University. 2005. *Breeds of livestock*. Stillwater, Oklahoma, USA. Department of Animal Science, Oklahoma State University (available at http://www.ansi.okstate.edu/breeds/).

Rege, J.E.O. 1992. Background to ILCA's animal genetic resources characterization project, objectives and agenda for the research planning workshop. *In* J.E.O. Rege & M.E. Lipner, eds. *Animal genetic resources: their characterization, conservation and utilization. Research planning workshop, ILCA, Addis Ababa, Ethiopia, 19-21 February, 1992*, pp. 55–59. Addis Ababa. International Livestock Centre for Africa.

Section B

Molecular tools for exploring genetic diversity

1 Introduction

Recent advances in the field of genomic technology have constituted a major innovation in livestock production. The increasing availability of molecular tools is deeply affecting the ways in which livestock species are studied and managed. This section provides an overview of recent developments related to molecular tools and their use, focusing particularly on the period since the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007) was prepared.

The first SoW-AnGR noted that the main roles of molecular technologies in the characterization of AnGR include:

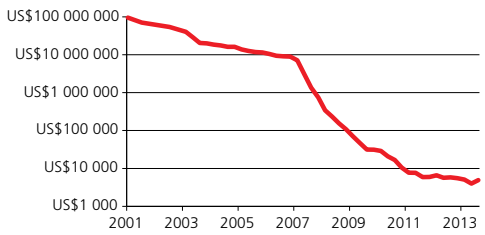
- assessing functional and neutral genetic variability within and between populations, including investigation of their history (domestication, expansion or reduction of the population size, migrations, introgression episodes, etc.);
- assessing the current state of a population in terms of risks related to inbreeding and genetic drift, using estimators such as effective population size; and
- genetic characterization of traits (e.g. physical appearance, productivity, disease resistance and other adaptability traits) specific to given populations.

The report highlighted the following three ongoing developments in molecular biology as being particularly relevant to AnGR management:

- the establishment of whole genome sequences for various livestock species;
- the development of technologies for measuring polymorphisms at loci spread across the entire genome; and
- the development of technologies for measuring gene transcription and expression on a large scale.

Since the first SoW-AnGR was prepared, the list of species whose genomes have been sequenced has continued to grow. It now includes chicken (2004), sheep (2010), cattle (2009), horse (2009), pig (2012), rabbit (2009), turkey (2009) and goat (2013). The costs of genotyping and sequencing have declined sharply during this period (Figure 4B1). High-density SNP arrays, allowing the simultaneous assay of several tens of thousands to several hundreds of thousands of SNPs, are available for use in livestock species at a cost of US$100 or less if a relatively large number of individuals are sequenced. Genomes

FIGURE 4B1
Change in cost per genome sequenced in humans



Note: Costs expressed on a logarithmic scale.
Source: Based on data from National Human Genome Research Institute (http://www.genome.gov/pages/der/sequencing_costs_jul2014.xlsx; accessed January 2015).

Box 4B1
From DNA to phenotype

The genome of livestock species is organized in pairs of chromosomes, each inherited from one of the parents and chemically made up of large molecules of DNA (deoxyribonucleic acid). Each gene in an individual, therefore, has two copies, known as alleles, one on each chromosome of a pair (with the exception of non-paired sex chromosomes). Chromosomes comprise genes and intergenic regions. The former encode proteins and other products. The latter, which represent the majority of the genome, are believed to play various regulatory roles (The ENCODE Project Consortium, 2012). Genes typically consist of coding sequences (exons) separated by introns and accompanied by regulatory elements. Like intergenic regions, introns carry no protein-coding information, but sometimes play a role in the regulation of gene expression.

Nucleic acids are strands of smaller molecules called nucleotides. DNA has four types of nucleotide (adenine, cytosine, guanine and thymine). The instruction encoded in a gene depends on the sequence in which these nucleotides are ordered. This sequence information is put into action in two steps. The first is the transcription (copy) of genetic information into another type of nucleic acid, RNA (ribonucleic acid). Both exons and introns are transcribed into a primary messenger RNA molecule. In the second step, these molecules (transcripts) are edited and eventually translated into proteins (particular three-nucleotide sequences correspond to particular amino acids, the molecules that constitute a protein). Gene expression is highly tissue-specific and time-dependent. Not all genes are translated into proteins; some express their function as non-coding RNA molecules that play important roles in protein synthesis (transfer RNA and ribosomal RNA) and various regulatory processes (microRNA and long non-coding RNA, two types of regulatory RNA that differ in terms of the number of nucleotides they consist of – approximately 20 and more than 200 nucleotides, respectively).

Phenotypic differences between individuals, populations and species are a consequence both of environmental effects (including epigenetic mechanisms – see Box 4B5) and of variations in DNA sequences. These variations may be caused by point mutations leading to the substitution of single nucleotides (single nucleotide polymorphisms – SNPs), insertions, deletions, duplications, copy number variations or inversions of DNA fragments. If SNPs are in exons, different alleles may lead either to the same amino acid (synonymous SNPs) or to a different amino acid (non-synonymous SNPs) being included in the resulting protein. DNA variations can be classified as "functional" or "neutral". In the case of functional variation, changes in the sequence of nucleotides in the DNA molecule induce changes in the phenotypic function of the organism. In the case of neutral variation, a change in the DNA sequence does not give rise to any change in function.

Because genes or SNPs that lie near each other on a chromosome (i.e. are physically "linked" to each other) tend be inherited together, a neutral variant can be associated with a functional one. In addition, this interdependence between linked genes means that the various combinations of their alleles are not distributed randomly (a phenomenon termed "linkage disequilibrium"). Linkage and linkage disequilibrium allow the use of one site of polymorphism as a "genetic marker" for polymorphism in a nearby region.

can be sequenced for less than US$3 000 each with moderate coverage (e.g. "eight-fold" coverage – meaning that, on average, each position in the genome is sequenced eight times). Sequencing smaller fractions of genomes (restriction site associated DNA sequencing – RAD-Seq) can be used directly in the characterization of individual animals (this is termed "genotyping by sequencing") (De Donato *et al.*, 2013). Similarly, the development of tools capable of assaying a high density of transcripts and even direct transcriptome sequencing (also known as "RNA-seq" – short for RNA sequencing), has increased capacity to study gene expression and hence to unravel

the complex physiological regulation of target traits (D'Alessandro and Zola, 2012).

2 Developments in the use of DNA markers

Progress in sequencing techniques and the opportunities offered by the development of high-density marker arrays have considerably improved the availability of DNA information over the last ten years, both in terms of the number of markers identified and in terms of the cost of genotyping.

Until recently, microsatellites remained one of the most popular types of marker in genetic characterization studies (Lenstra *et al.*, 2012), used for example in projects such as "GlobalDiv", which ran from 2007 to 2010 and combined microsatellite datasets from various diversity studies from different parts of the world (Ajmone-Marsan *et al.*, 2010). Microsatellite data continue to be used, especially in developing countries (e.g. Abdullah *et al.*, 2012; Azam *et al.*, 2012) and in the context of conservation and priority setting at regional level (e.g. Medugorac *et al.*, 2011; Ginja *et al.*, 2013). However, they are increasingly being superseded by the use of SNP marker arrays. With the advent of next-generation sequencing, mitogenomics (analysis of the whole mitochondrial genome rather than a limited fragment of mitochondrial DNA) can be routinely used in livestock species, including less intensively studied species such as goats (Doro *et al.*, 2014) and horses (Achilli *et al.*, 2012). The recent generation of whole genome reference sequences for many livestock species has allowed "population genetics" to become "population genomics". Population genomics uses large sets of SNPs to study specific variations across the genome and determine how they have been shaped by the history (e.g. changes in population size, selection, and cross-breeding) of livestock populations. SNPs can be assigned to various classes (neutral vs. genic, intron vs. exon or synonymous vs. non-synonymous), which provides opportunities for more detailed analysis of diversity. The past decade has also witnessed a revolution in sequencing technologies that has led to the development of various platforms for DNA and RNA sequencing, known collectively as next-generation sequencing technologies (see Metzker, 2010 and Davey *et al.,* 2011 for reviews). These tools can rapidly (in a few days or weeks) provide sequence data in the form of short reads (sequenced DNA fragments between 100 and 400 base pairs long on average) that collectively cover the whole genome of a sample (or the transcriptome of a particular organ) several times. Identifying SNPs from this type of data is relatively easy, provided that a reference sequence has been established (Nielsen *et al.*, 2011), which is the case for most livestock species. Methods have also been developed for SNP discovery in newly sequenced species (Norman *et al.*, 2013) and these approaches may prove useful for less common livestock species.

High-density SNP panels are now widely used for genome-wide association studies (GWAS), genomic prediction and population genomic analyses. However, the preliminary phase, i.e. SNP discovery or SNP selection from databases, is critical. If data have not been obtained randomly, standard estimators of population genetic parameters should be applied with caution. Non-random selection may occur if SNP sets are derived for use on a given set of breeds but later used on other breeds or if SNP sets are filtered to meet certain criteria (e.g. a minimum allele frequency).

Many current tools are affected by both these factors, as they have been developed primarily using widely used international transboundary breeds and with the use of SNP-filtering criteria. Such protocols bias the distribution of allelic frequencies relative to what would be expected in a random sample. The resulting inaccuracy in estimation of genetic parameters is known as "ascertainment bias". Bias caused by problems of this kind is probably present in most commercial and ready-to-use medium- and high-density SNP panels currently available for use in livestock species. Unbiased estimates of the absolute genetic diversity (i.e. the nucleotide diversity) of a population can, in theory, be

Box 4B2
Glossary: genetic markers

Genetic marker: a DNA sequence variation that is informative with respect to a specific location (locus) on a particular chromosome.

Microsatellites: segments of DNA characterized by a variable number of copies (typically 5 to 50) of sequence motifs of around two to five bases (referred to as a repeat unit). At any one locus (site in the genome), there are usually several different "alleles" in a population, each allele identifiable by the number of repeat units detected via polymerase chain reaction (PCR). Many microsatellites have a large degree of polymorphism. In many species, they were the first standard marker technology used to characterize diversity. However, due to their comparatively infrequent presence across the genome, inconsistent reproducibility across laboratories and genotyping platforms, and higher genotyping cost per locus, microsatellites are being replaced by other technologies.

Single-nucleotide polymorphism (SNP): a DNA sequence variation that results from a change in the nucleotide at a single location in the genome. SNPs usually have only two alleles. They may represent either neutral or functional genetic diversity and generally occur throughout the genome. In most species, SNPs occur, on average, once in every 100 to 300 positions in the DNA sequence. For most major livestock species, commercial arrays are available that allow substantial numbers of SNPs (from a few hundreds to over a million) to be genotyped in a single reaction at a low cost per marker. SNP arrays are now routinely used as more informative alternatives to microsatellite panels in genetic diversity studies.

Markers of sex-specific inheritance: certain parts of the genome have sex-specific inheritance. Mitochondrial DNA is passed from the mother to the offspring. The Y-chromosome in mammals is inherited from father to son, while the W-chromosome in birds is inherited from mother to daughter. This class of markers can include both SNPs and other sequence variations and has been instrumental in identifying wild ancestors, localizing domestication centres and reconstructing colonization and trading routes.

Sequence variation: with the emergence of whole-genome sequencing, the entire variation present in the DNA sequence is now available as a potential source of marker information. This variation comprises SNPs and insertions and deletions (InDels) (loss or gain of one or more nucleotides relative to the species reference sequence), duplications, copy number variations (CNVs) (variation in the number of copies of sections of the DNA) or inversions of DNA fragments. Sequencing can be performed on a whole genome basis or only for specific parts of the genome (e.g. the exome or genome fractions used for genotyping by sequencing). Whole-genome sequences will be the ultimate source of genetic diversity information, as they harbour the motifs responsible for genetic differences between breeds. However, efficient management, use and storage of this information will require, in addition to sequencing capacities, substantial development of resources in bioinformatics (methods, tools and hardware).

obtained only via whole genome sequencing. Statistical approaches that explicitly account for the methods used in SNP discovery and sample preparation have been developed for use when undertaking various kinds of population genetics analyses with SNPs (Nielsen *et al.,* 2011; Kofler *et al.,* 2011). Large-scale projects have also started to harvest genome-wide information for use in characterizing livestock populations at national or international scale, including studies on cattle (Gauthier *et al.,* 2010), sheep (Kijas *et al.*, 2012), horses (McCue *et al.* 2012; Orlando *et al.,* 2013), pigs (Groenen *et al.,* 2010), chickens (Weigend *et al.,* 2015) and goats (Dong *et al.,* 2013).

It is important to note that although cost per SNP is low relative to microsatellites (and decreases with the number of SNPs analysed) the costs of high-density assays – currently (2015)

US$50 to US$200 and depending heavily on the number of arrays purchased – are nonetheless prohibitive for many applications. Costs continue to decline, however, and financially realistic options are likely to eventually become available for most situations. This being said, even if lower cost genotyping assays become available, the bioinformatic infrastructure in most developing countries will still require further development. Both the sheer amount of raw data and the complexity of analytical models are several orders of magnitude larger than those associated with microsatellite-based analyses. This is true for work with SNP array data, but even more so for work with sequence data.

Further studies are in the process of identifying millions of SNPs and haplotypes (specific allelic combinations for a given set of loci) and also other sequence variants such as insertion–deletion polymorphisms (InDels) and copy number variants (CNV) (see Box 4B2 for explanations of these terms). Novel sequencing technologies are continuously evolving, accompanied by a drop in cost per sequenced genome (see Figure 4B1). Allele frequency differences and diversity measures derived from them can be obtained inexpensively by sequencing pooled DNA from multiple individuals from a population (e.g. Qanbari *et al*., 2012). Sooner or later, sequence-based approaches will become the standard methodology for generating data for use in livestock diversity studies.

Marker information will become even more useful when linked to biological background information available in specialized databases. Information about marked genes and their functions is available in the Ensembl database[1] (among others) for many livestock species. Information on quantitative trait loci (QTL) is collected in the AnimalQTL database[2] and genomic pathway information is available through KEGG.[3] In human genetics, the Encode project[4] is systematically annotating functional elements in the genome, and similar initiatives are emerging in other species, including livestock (Andersson *et al.*, 2015). On this basis it can, for example, be judged whether observed between-breed diversity in a given genomic region is purely neutral and has been generated by genetic drift or is of functional relevance and may have been caused by selection. Making systematic use of such information will allow a shift from a purely statistical assessment of genetic diversity to a more informative functional approach.

3 Characterization of within-population diversity

Classical estimators of genetic variability (heterozygosity, F-statistics, etc.) are still commonly used. However, some are not adapted for use with biallelic markers (e.g. number of alleles per locus, which is invariably equal to two for biallelic markers). As the use of SNPs has become more common, so has the use of individual and population genomic indicators of diversity and similarity, such as coancestry and inbreeding (Meuwissen and Goddard, 2001; Keller *et al.*, 2011; Saura *et al.*, 2013; Curik *et al.*, 2014). Some of these indicators make it possible to test whether inbreeding effects are more or less important in specific genomic locations, or whether inbreeding comes from a more or less distant common ancestor (e.g. Ferenčaković *et al*., 2013). Estimators of genetic variability can also be used in conservation decision-making as a means of optimizing the choice of breeding animals so as to minimize the loss of genetic variability (Oldenbroek, 2007).

In parallel, several methods of estimating present and past effective population sizes have been developed or improved, based either on the correlation between allele frequencies (linkage disequilibrium) or on runs of homozygosity (Sved, 1971; Hill, 1981; Hayes *et al.*, 2003; Waples, 2006; Li and Durbin, 2011; Hillestad *et al.*, 2014). These approaches have been increasingly applied in livestock, including cattle (de Roos *et al.*, 2008;

[1] http://www.ensembl.org
[2] http://www.animalgenome.org/cgi-bin/QTLdb/index
[3] http://www.genome.jp/kegg
[4] http://www.genome.gov/encode

Flury *et al.*, 2010), sheep (Kijas *et al.*, 2012), pigs (Uimari and Tapio, 2011), chickens (Qanbari *et al.*, 2010) and horses (Corbin *et al.*, 2010). It should be noted, however, that the widely used approach suggested by Sved (1971) has some methodological shortcomings (Sved, 2008) and is especially sensitive to non-random samples of SNPs (Corbin *et al.*, 2012; Ober *et al.*, 2013).

At the time the first SoW-AnGR was prepared, it was generally considered that because of the limited number of markers available it was more efficient to use genealogical information than molecular information in conservation decision-making (Fernandez *et al.*, 2005). This appears no longer to be the case. Commercial SNP arrays are now affordable and provide estimates of genetic relationships that account for the random segregation and recombination of chromosomes that occur during inheritance from parents to offspring. Because marker-based information provides better estimates of genetic relationships than pedigree data, inclusion of genomic data is likely to increase the efficiency of conservation schemes (Hasler *et al.*, 2011; Toro *et al.*, 2014).

4 Characterization of between-population diversity

Relationships between populations have long been assessed through the estimation of genetic distances, which are often used to construct phylogenetic trees to visually infer genetic relationships. However, a major drawback of reconstructing phylogenetic trees is that the evolution of lineages is assumed to be non-reticulate, i.e. it is assumed that while lineages may diverge, they never result from crosses between lineages. There is therefore a tendency for these methods to be replaced by alternative graphical networks or other approaches such as Bayesian clustering methods or multivariate analysis (Bertorelle *et al.*, 2004). One of the most popular model-based Bayesian approaches in current use is the model-based clustering method developed by Pritchard *et al.* (2000) (STRUCTURE software), although alternatives are available (e.g. Alexander *et al.*, 2009). The approach uses Monte Carlo Markov chain simulation to assign individuals to a chosen number of clusters (populations), inferring genetic origins without *a priori* knowledge or assumptions. This is a particularly important consideration in livestock populations, where unsuspected admixture may have occurred. The approach is, however, not without limits. For example, inferred clusters may not always be ancestral, but rather related to highly inbred populations ("inbreeding bias") or to populations over-represented in the dataset ("sampling bias") (Lenstra *et al.*, 2012). Multivariate analysis approaches are interesting alternatives to model-based approaches, as they are generally assumption-free methods and are specifically designed for summarizing large and complex datasets into a small number of synthetic variables (Jombart *et al.*, 2010). These various approaches are usually applied to microsatellite or SNP marker information. They have been extensively used in livestock studies, either independently or (because of the complementary information they may provide) in parallel (Muchadeyi *et al.*, 2007; Leroy *et al.*, 2009; Gautier *et al.*, 2010; Kijas *et al.*, 2012). Methods have been developed over the last few years that use dense haplotype data to unravel fine-scale population structure (Lawson *et al.*, 2012) or apply advanced admixture analysis in order to infer the presence and historical timing of admixture events among human populations (Patterson *et al.*, 2012; Pickrell and Pritchard, 2012; Hellenthal *et al.*, 2014).

Recently, a growing number of methods for combining genomic information with information from other sources, often related to the environments where animals are raised, have been developed (Pariset *et al.*, 2012). Landscape genomics is an approach that aims to use various methods (e.g. estimation of molecular distance, Bayesian and multivariate analyses) to identify environmental factors that shape genetic variability. For example, a study on Vietnamese goats showed that social organization and husbandry practices were as important as geographical distance in shaping genetic structure (Berthouly *et al.*, 2009). The increasing density of markers genotyped may also allow these approaches to be used to identify chromosomal

regions and genes likely to be subject to positive selection linked to the environment. Finally, knowledge of the history of livestock populations has greatly increased in the last ten years, based on the development of new methods and the increasing availability of large sets of markers (see Part 1 Section A). For instance, a recent study on horse breeds (Wallner *et al.*, 2013) showed that the diversity of the paternally inherited Y-chromosome was very low in comparison to that of maternally inherited mitochondrial DNA haplotypes, a finding consistent with the disproportionate use of a limited number of popular stallions over recent centuries. Genome-wide panels of markers also make it possible to discriminate areas of the genome whose variation has increased or decreased though history in relation to specific gene function.

5 Molecular tools for targeting functional variation

Recent advances in genomics have clearly improved our capacity to characterize functional variation in livestock species. Detection and mapping of QTLs, i.e. markers physically linked to a genomic variant that underlies variation in a quantitative trait, have benefited from increased genome coverage, as well as from the development of new methodologies. In particular, the use of sequence data may allow causative polymorphism to be targeted directly instead of via QTLs. The molecular background of various breed-specific traits has been the subject of numerous investigations (Table 4B1) (see also Box 4B3). The molecular analysis of adaptive variation has also improved knowledge of the possible adverse effects of selection on the health and productivity of animals. For example:

- Several gene variants are pathogenic or confer sterility in homozygous animals. For instance, myostatin deficiency caused by mutations in the MSTN (myostatin) gene hinders the delivery of calves (Bellinge *et al.*, 2005).
- Gene variants exhibiting clear antagonism between milk yield and fertility (increasing the former while decreasing the latter) have been identified in cattle (Kadri *et al.*, 2014).
- The use of only a few top sires promotes inbreeding and thus increased homozygosity. This effect, which inevitably increases the proportion of offspring that have recessive genetic defects, can be assessed using neutral genetic markers (Lenstra *et al.*, 2012). Several pathogenic mutations in livestock species, most of which are recessive, have been identified. They surpass in number the gene variants known to be involved in economic traits (Nicholas *et al.*, 2012).
- Significant deficiency or complete absence of individuals homozygous for a given haplotype may indicate the presence of a recessive genetic defect causing early embryonic mortality. This concept has been successfully used in the identification of possible causes of reduced fertility in various cattle populations (Fritz *et al*., 2013).

International consortia have provided large amounts of data on SNPs and other variants. For example, the "1 000 bull genomes project" (Daetwyler *et al.*, 2014) identified 28.3 million variants, related, *inter alia*, to coat colour, embryonic loss and production traits. However, it is still difficult to obtain genome sequences for a large number of animals at an affordable price. Methods have therefore been developed that can be used to "impute" or infer the genotypes of individual animals for which information is sparse (e.g. obtained using low- or medium-density SNP chips) from information on a subset of individuals that have been sequenced (e.g. those studied in the above-mentioned 1 000 bull genomes project) (Jansen *et al.*, 2013).

Although the study of animal genetic diversity has typically concentrated on direct differences in genomes, the impact of genetic diversity on the expression of genes may be relevant, especially as interest grows in functional genetic diversity relative to neutral genetic diversity. Since the mid-1990s, the widespread use of DNA microarrays and serial analysis of gene expression (SAGE), both of which provide a snapshot of actively expressed

Box 4B3

How genetic tools helped to solve the mystery of the origin of the Booroola gene

Exceptionally high litter size in an Australian Merino flock kept at the Booroola Estate in Cooma, New South Wales, attracted the attention of scientists from the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO). Initial analysis of ewes' pedigrees and performance records led to a hypothesis regarding the segregation of a major gene affecting this trait and increasing litter size in carriers. This hypothesis was first substantiated by analysis of litter-size segregation in families (Piper and Bindon, 1982). The origin of the high-fecundity gene in the low-prolific Merino population, however, remained a mystery until Professor Helen Newton Turner found evidence that ancestors of the Booroola flock could have had some admixture of Indian Bengal sheep brought to Australia from Calcutta in the 1790s (Turner, 1983). The hypothetical major gene increasing litter size was named Fecundity Booroola (*FecB*).

The first genetic markers linked to the *FecB* locus were discovered by a New Zealand team led by Professor Grant Montgomery (Montgomery, 1993). Further research led to the conclusion that the Booroola gene is located on the sixth chromosome. The first molecular test, devised to enable the introgression of the *FecB* mutation into the Romney breed, was based on the polymorphism of three microsatellite sequences (Lord *et al.*, 1998).

The real breakthrough with respect to the physiological basis for increased fecundity happened in 2001, when teams from AgResearch (New Zealand), INRA (France) and Edinburgh University (United Kingdom) independently discovered that carriers of the Booroola gene have a mutation in the bone morphogenetic protein receptor IB gene (*BMPR-IB*). The Booroola gene (*FecB*) is a dominant autosomal gene with an additive effect on ovulation rate.

Garole sheep of Bengal

Photo credit: Kanhaiya M. Chavan.

The discovery of the mutation and the development of the molecular test enabled the identification of the mutation in the Garole sheep of Bengal, a breed that is well known for its large litter sizes – thus supporting Professor Turner's theory. At present, the *BMPR-IB* mutation has been found in a number of breeds that have high fecundity. The list includes Javanese Thin Tail sheep (Davis, 2009) and some Chinese breeds such as the Huyang, Small Tail Han (STH), Cele, Duolang and Chinese Merino (Hua and Yang, 2009). It seems that the original mutation took place in Mongolian Fat Tail sheep and was introgressed into Chinese breeds and later into the Indian Garole and Javanese breeds as a result of the movement of people and animals along the Silk Road.

So the mystery was solved thanks to the persistence of scientists and development of technology. Over time, the *FecB* mutation has been introgressed into about 40 breeds, all around the world (Walkden-Brown *et al.*, 2008).

Provided by Elżbieta Martyniuk.

genes and transcripts in a biological sample, has facilitated high-throughput molecular studies of the transcriptome. Microarray experiments provide a cost-effective means of studying the transcriptome, and the bioinformatic and statistical analyses (referred to as "analysis pipelines")

TABLE 4B1

Examples of non-disease phenotypes specific to one or more livestock breeds

Species/breed(s)	Phenotype	Gene or locus	Reference
Cattle			
French	Dairy traits	Several candidate genes	Flori *et al.*, 2009
Several	Dairy and beef traits	Several candidate genes	Rothammer *et al.*, 2013
Danish Red	High milk yield, low fertility	Deletion removing *RNASEH2*#	Kadri *et al.*, 2014
Several	Milk protein content	*ABCG2*+	Braunschweig, 2010
Several	Muscular hypertrophy	*MSTN*#* (different mutations)	Nicholas and Hobbs, 2012; O'Rourke *et al.*, 2013
Holstein	Stature	*PLAG1-CHCHD7* intergenic	Karim *et al.*, 2011
Dexter	Short stature	*ACAN*#	Cavanagh *et al.*, 2007
Dutch Belted Galloway Swiss Brown	Belted pattern	*HES1* (candidate gene)	Drogemuller *et al.*, 2010
Sheep			
Several	Litter size	*GDF9*# (*FecG*, different mutations)	Vage *et al.*, 2013
Several	Litter size	*BMP15*# (*FecX*, different mutations)	Nicholas and Hobbs, 2012
Several	Litter size	*BMPR1B* (Booroola, *FecB*)	Davis *et al.*, 2006
Lacaune	Litter size	B4GALNT2 (*FecL*)	Drouilhet *et al.*, 2013
Texel and others	Muscular hypertrophy	*MSTN* (= *GDF8*)	Clop *et al.*, 2006
Dorset	Muscular hypertrophy	*CLPG**	Braunschweig, 2010
Pig			
European	Muscle growth	*IGF2*	Braunschweig, 2010
Horse			
Quarter	Type I muscle fibres	*MSTN*	Petersen *et al.*, 2013
Several	Endurance	*GYS1*#	McCoy *et al.*, 2014
Chicken			
Several	Naked neck	*BMP12*	Mou *et al.*, 2011
Several	Frizzle feather	*KRT75*	Ng *et al.*, 2012
Several	Silky feather	*PDSS2*	Feng *et al.*, 2014
Several	Comb shape	*MNR2*	Imsland *et al.*, 2012

Note: Several mutations may already have played a role in more general adaptation to domestication (see Part 1, Section A, Table 1A2).
causative gene variant is pathogenic or confers sterility if homozygous; * recent gene mutation; + ATP-binding cassette, sub-family G (WHITE), member 2.
Sources: Braunschweig, 2010; Nicholas and Hobbs, 2012.

used to transform raw microarray data into interpretable results are now well established (Ritchie *et al.*, 2015). Since the time the first SoW-AnGR was prepared, the development of high-throughput sequencing in the field of transcriptomic analysis (RNA sequencing or RNA-seq) has led to radical changes (Mortazavi *et al.*, 2008), primarily because RNA-seq approaches do not necessarily require prior knowledge of a genome sequence or annotation (identification of locations and functions of coding regions within a genome) and can therefore be used even in poorly characterized organisms. In addition, it enables a wide range of novel applications, including detection

of weakly expressed genes and alternative splicing isoforms (variations in the proteins translated from the same gene) (Wang *et al.*, 2008; Pan *et al.*, 2008), variable assembly of transcripts (Trapnell *et al.*, 2010; Guttman *et al.*, 2010; Robertson *et al.*, 2010; Grabherr *et al.*, 2011; Schulz *et al.*, 2012) and allele-specific expression (Skelly *et al.*, 2011).

Recent comparisons have indicated good overall agreement among results obtained using microarrays, quantitative PCR (polymerase chain reaction) and RNA-seq across different sequencing platforms (Zhao *et al.*, 2014; Trapnell *et al.*, 2013; Nookaew *et al.* 2012; Liu *et al.*, 2011). However, although microarrays and RNA-seq are both used to characterize transcriptional activity, the experimental, bioinformatic and analytical steps associated with the two differ considerably (Oshlack *et al.*, 2010). In particular, RNA-seq experiments generate much more data than alternative transcriptomic approaches and require more sophisticated analyses and therefore greater technical capacity in bioinformatics and biostatistics (e.g. Langmead and Salzberg, 2012; Grabherr *et al.*, 2011; Oshlack and Wakefield, 2009; Zhou *et al.*, 2014). The analytical processes of transcriptomics constitute a major area of research in bioinformatics and statistics.

In recent years, studies using RNA-seq to examine genetic variation in gene expression have been undertaken in cattle (Li *et al.*, 2011), chickens (Endale Ahanda *et al.*, 2014; Davis *et al.*, 2015) and pigs (Corominas *et al.* 2013; Fischer *et al.*, 2015). The objectives of these studies have included the identification of candidate genes influencing phenotypic differences and the study of differences in gene expression associated with specific SNPs.

6 The role of bioinformatics

The successful use of high-throughput technologies in the study of genetic diversity is largely contingent on the availability of support and expertise in bioinformatics and statistics. Increasingly large and complex datasets need to be understood, organized, quantified, and analysed. Developing and applying the methods and software tools needed to do this requires appropriate computing resources (including sufficient computational power and memory to store and manipulate large data files) and programming skills. For example, genome sequencing and RNA-seq studies often require the services of a dedicated bioinformatics team to pre-process the data, including raw-data quality control and sequence alignment or assembly, in addition to biostatisticians for eventual data analysis. Bioinformatic support is often also an integral part of the development, maintenance and interrogation of biological databases.

An increasing number of well-documented and open-access bioinformatics and statistical tools are available online. For example, the Bioconductor project[5] is an open-source open-development software project that develops and provides widespread access to a diverse set of well-documented statistical and graphical analysis tools (written in the R programming language) for high-throughput genomic data. In addition, an increasing number of free and publicly accessible resources (e.g. the Galaxy project,[6] an open web-based platform) are available to facilitate bioinformatic analyses without the need for extensive programming knowledge.

It is highly desirable that when researchers gather large-scale genomic data for a given project they make them freely available to other researchers once the initial analyses have been completed. Increasingly, scientific journals and research-funding organizations request that data underlying publications or generated in publicly funded projects be deposited in open repositories. This kind of open-source policy will generate a large quantity and variety of reference data, across species and breeds, that can be used for increasingly comprehensive and informative diversity studies.

[5] http://master.bioconductor.org
[6] http://galaxyproject.org

7 Conclusions and research priorities

The world of genetics has been revolutionized over the last decade with the advent of massive parallel sequencing and high-throughput genotyping technologies. Other technologies and opportunities are on the way (see Box 4B4). These developments have opened many opportunities to utilize molecular techniques in the management of AnGR. However, while these technologies facilitate the sequencing of complete genomes or the genotyping of high-density SNP panels at moderate cost, they have not completely replaced traditional molecular markers such as microsatellites, mainly because of their still relatively high costs and the additional skills needed to analyse the enormous amount of data they produce. Low-cost alternatives, such as low-density SNP panels, that allow genetic variants scattered across the genome to be queried and can feasibly be used in small and medium-sized laboratories are in development, but remain to be implemented in practice.

Understanding of genetic diversity needs to be improved, even in the most widely used livestock species. For example, comprehensive assessments of genetic diversity using molecular genetic markers need to be extended to locally adapted breeds, particularly those with small population sizes. The value of the large quantities of data that currently exist in fragmented form needs to be maximized (e.g. by undertaking meta-analyses and by making as much data as possible publicly available for use by breeders, researchers and policy-makers). Improvements in sequencing and genotyping technologies have already provided standards that can be used as references for further genotyping and sequencing studies. Reference genomes, biological background information and population genotypic data are still not available for some species, but sequencing efforts currently underway in laboratories around the world will soon fill these gaps. For most populations and production systems, taking full advantage of the opportunities that advances in genomics have created for the study of genetic diversity will also require new and additional phenotypic data.

Understanding of the genetic basis of adaptive traits also needs to be improved. Potential approaches include the use of new technologies, such as genome sequencing and geographic

Box 4B4
What are the promises of the post-genomic era?

Over the last twenty years, the use of molecular tools has acquired paramount importance in animal breeding through the development of genetic tests, as well as the implementation of genomic selection in a growing number of species. The role of molecular tools is expected to continue expanding. Potential developments include:

- increased use of whole-genome sequencing for genomic selection, identification of new functional variants (allowing selection on new traits) and analysis of genetic diversity;
- the use of epigenetics (see Box 4B5) in the study of environment × genome interactions to provide insight into complex traits, especially those related to development;
- the use of meta-genomic studies that consider the gut microbiome to enable the optimization of the rumen microbial ecosystem for better feed-conversion efficiency; and
- combining genomics with other advanced biotechnologies, such as *in vitro* embryo transfer (selecting breeding candidates at the embryo stage) and genetic engineering (introducing genes of interest into the genome or even directly editing the genome through novel technologies such the CRISPR/Cas system), which may bring about major changes in the way animals are raised and selected.

Some of these developments would, clearly, raise social and ethical concerns that would need to be addressed before putting them into practice.

Sources: Gonzalez-Recio, 2012; Hayes *et al.*, 2013.

Box 4B5

The reality and promises of epigenetics for animal production

The term "epigenetics" refers to mechanisms that cause variation of gene activity and are based not on variation in the nucleotide sequence but on chemical modifications of DNA and chromatin, for instance, affecting the degree of chromatin compaction or the accessibility of regulatory sequences to transcription factors.

Epigenetic processes occur during cell, tissue and organismal differentiation processes such as gametogenesis, embryo genome activation, X-chromosome inactivation and genomic imprinting (the differential expression of certain genes depending on which parent they come from). Epigenetic modifications driven by environmental factors, such as diet, stress and disease, form a molecular memory (transient or permanent) that adapts the organism and programmes signalling and metabolic pathways appropriate for particular conditions. Epigenetic marks are meiotically and mitotically inherited and the epigenome represents an additional level in genotype–phenotype mapping.

As epigenetic variation explains part of the so-called missing heritability (i.e. the part of genetic variation not explained by individual genes), there may be interest in using epigenetics in livestock breeding, for instance through genomic imprinting and metabolic programming (stimulation of early development to influence later physiological outcome). Particularly in cross-breeding schemes, imprinting offers new opportunities to establish dam and sire lines with enhanced production performances and maternal abilities and to produce cross-breeds according to market requirements. The interaction between genetic (breed) and environmental factors such as diets and management practices is key to the use of epigenetics in animal breeding. Extensive knowledge of epigenetic mechanisms and gene regulation will, in future, offer new opportunities in livestock breeding in relation to environment–genome–epigenome interactions.

Provided by Klaus Wimmers.

information systems, in combination with new data-capture methods (e.g. remote sensing, image analysis and mid-infrared technology) and analytical approaches (e.g. landscape genetics approach), to facilitate the identification of signatures of natural selection reflecting local adaptation to diseases and other environmental conditions. This is of particular importance in the light of climate change. There is a need to develop methods for integrating molecular information into conservation and breeding programmes, and these methods need to be adapted to different environmental, agricultural and socio-economic circumstances. Tackling this task will be a challenge and will require substantial additional data (on genotypes, phenotypes and production environments). Greater international collaboration in data collection, analysis and interpretation will be essential.

References

Abdullah, M.A., Martojo, H., Noor, R.R., & Solihin, D.D. 2012. Genetic characterization of the Aceh cattle using phenotypic, mitochondrial DNA of D-loop region and microsatellite DNA analyses. *Reproduction of Domestic Animals*, 47 (Suppl 1): 15–17.

Achilli, A., Olivieri, A., Soares, P., Lancioni, H., Hooshiar, K.B., Perego, U.A., Nergadze, S.G., Carossa, V., Santagostino M., Capomaccio, S., Felicetti, M., Al-Achkar, W., Penedo, M.C.T., Verini-Supplizi, A., Houshmand, M., Woodward, S.R., Semino, O., Silvestrelli, M., Giolotto, E., Pereira, L., Bandelt, H.J. & Torroni, A. 2012. Mitochondrial genomes from modern horses reveal the major haplogroups that underwent domestication. *Proceedings of the National Academy of Sciences*, 109: 2449–2454.

Ajmone-Marsan, P. & GLOBALDIV Consortium. 2010. A global view of livestock biodiversity and conservation-GLOBALDIV. *Animal Genetics,* 41: 1–5

Alexander, D.H., Novembre, J. & Lange, K. 2009. Fast model-based estimation of ancestry in unrelated individuals. *Genome Research*, 19: 1655–1664.

Andersson, L., Archibald, A.L., Bottema, C.D., Brauning, R., Burgess, S.C., Burt, D.W., Casas, E., Cheng, H.H., Clarke, L., Couldrey, C., Dalrymple, B.P., Elsik, C.G., Foissac, S., Giuffra, E., Groenen, M.A., Hayes, B.J., Huang, L.S., Khatib, H., Kijas, J.W., Kim, H., Lunney, J.K., McCarthy, F.M., McEwan, J.C., Moore, S., Nanduri, B., Notredame, C., Palti, Y., Plastow, G.S., Reecy, J.M., Rohrer, G.A., Sarropoulou, E., Schmidt, C.J., Silverstein, J., Tellam, R.L., Tixier-Boichard, M., Tosser-Klopp, G., Tuggle, C.K., Vilkki, J., White, S.N., Zhao, S., Zhou, H. & The FAANG Consortium. 2015. Coordinated international action to accelerate genome-to-phenome with FAANG, the Functional Annotation of Animal Genomes project. *Genome Biology*, 16: 57.

Azam, A., Babar, M.E., Firyal, S., Anjum, A.A., Akhtar, N., Asif, M. & Hussain, T. 2012. DNA typing of Pakistani cattle breeds Tharparkar and Red Sindhi by microsatellite markers. *Molecular Biology Reports,* 39: 845–849.

Bellinge, R.H.S., Liberles, D.A., Iaschi, S.P.A., O'Brien, P.A. & Tay, G.K. 2005. *Myostatin* and its implications on animal breeding: a review. *Animal Genetics*, 36: 1–6.

Berthouly, C., Do Ngoc, D., Thévenon, S., Bouchel, D., Nhu Van, T., Danes, C., Grosbois, V., Hoang Thanh, H., Vu Chi, C. & Maillard, J.-C. 2009. How does farmer connectivity influence livestock genetic structure? A case-study in a Vietnamese goat population. *Molecular Ecology*, 18: 3980–3991.

Bertorelle, G., Bruford, M., Chemini, C., Cristiano, V. & Hauffe, H.C. 2004. New, flexible Bayesian approaches to revolutionize conservation genetics. *Conservation Biology*, 18: 1–2.

Braunschweig, M.H. 2010. Mutations in the bovine ABCG2 and the ovine MSTN gene added to the few quantitative trait nucleotides identified in farm animals: A mini-review. *Journal of Applied Genetics*, 51: 289–297.

Cavanagh, J.A., Tammen, I., Windsor, P.A., Bateman, J.F., Savarirayan, R., Nicholas, F.W. & Raadsma, H.W. 2007. Bulldog dwarfism in Dexter cattle is caused by mutations in ACAN. *Mammalian Genome*, 18: 808–814.

Clop, A., Marcq, F., Takeda, H., Pirottin, D., Tordoir, X., Bibe, B., Bouix, J., Caiment, F., Elsen, J.M., Eychenne, F., Larzul, C., Laville, E., Meish, F., Milenkovic, D., Tobin, J., Charlier, C. & Georges, M. 2006. A mutation creating a potential illegitimate microRNA target site in the myostatin gene affects muscularity in sheep. *Nature Genetics*, 38: 813–818.

Corbin, L.J., Blott, S.C., Swinburne, J.E., Vaudin, M., Bishop, S.C. & Woolliams, J.A. 2010. Linkage disequilibrium and historical effective population size in the Thoroughbred horse. *Animal Genetics*, 41: 8–15.

Corbin, L.J., Liu, A.Y., Bishop, S.C. & Woolliams, J.A. 2012. Estimation of historical effective population size using linkage disequilibria with marker data. *Journal of Animal Breeding and Genetics*, 129: 257–270.

Corominas, J., Ramayo-Caldas, Y., Puig-Oliveras, A., Estellé, J., Castello, A., Alves, E., Pena, R.N., Ballester, M. & Folch, J.M. 2013. Analysis of porcine adipose tissue transcriptome reveals differences in *de novo* fatty acid synthesis in pigs with divergent muscle fatty acid composition. *BMC Genetics*, 14: 843.

Curik, I., Ferenčaković, M. & Sölkner, J. 2014 Inbreeding and runs of homozygosity: a possible solution to an old problem. *Livestock Science*, 168: 26–34.

D'Alessandro, A. & Zola, L. 2012. Meat science: From proteomics to integrated omics towards system biology. *Journal of Proteomics*, 78: 558–577.

Daetwyler, H.D., Capitan, A., Pausch, H., Stothard, P., van Binsbergen, R., Brøndum, R.F., Liao, X., Grohs, C., Jung, S., Baur, A., Esquerré, D., Gollnick, N., Legrain, S., Laurent, P., Djari, A., Rossignol, M.N., Klopp, C., Rocha, D., Fritz, S., Eggen, A., Bowman, P., Coote, D., Chamberlain, A., VanTassel, C.P., Hulsegge, I., Goddard, M., Guldbrandtsen, B., Lund, M.S., Veerkamp, R., Boichard, D., Fries, R. & Hayes, B.J. 2014. Whole genome sequencing of 234 bulls facilitates mapping of monogenic and complex traits in cattle. *Nature Genetics*, 46: 858–865.

Davey, J.W., Hohenlohe, P.A., Etter, P.D., Boone, J.Q. & Catchen, J.M. 2011. Genome-wide genetic marker discovery and genotyping using next generation sequencing. *Nature Reviews Genetics*, 12: 499–510.

Davis, G.H. 2009. The Booroola gene: origin, distribution, use and management of the Fec B mutation. *In* S.W. Walkden-Brown, J.H.J. van der Werf, C. Nimbkar & V.S. Gupta, eds. *Use of the FecB (Booroola) gene in sheep-breeding programs. Proceedings of the Helen Newton Turner Memorial International Workshop held in Pune, Maharashtra, India, 10–12* November *2008*. ACIAR Proceedings No. 133. Canberra, Australian Centre for International Agricultural Research (available at http://aciar.gov.au/files/node/11617/ACIAR_PR133(online).pdf).

Davis, G.H., Balakrishnan, L., Ross, I.K., Wilson, T., Galloway, S.M., Lumsden, B.M., Hanrahan, J.P., Mullen, M., Mao, X.Z., Wang, G.L., Zhao, Z.S., Robinson, J.J., Mavrogenis, A.P., Papachristoforou, C., Peter, C., Baumung, R., Cardyn, P., Boujenane, I., Cockett, N.E., Eythorsdottir, E., Arranz, J.J. & Notter, D.R. 2006. Investigation of the booroola (*FecB*) and inverdale (*FecX(I)*) mutations in 21 prolific breeds and strains of sheep sampled in 13 countries. *Animal Reproduction Science*, 92: 87–96.

Davis, R.V., Lamont, S.J., Rothschild, M.F., Persia, M.E., Ashwell, C.M. & Schmidt, C.J. 2015. Transcriptome analysis of post-hatch breast muscle in legacy and modern broiler chickens reveals enrichment of several regulators of myogenic growth. *PLoS ONE*, 10: e0122525.

De Donato, M., Peters, S.O., Mitchell, S.E., Hussain, T. & Imumorin, I.G. 2013. Genotyping-by-sequencing (GBS): a novel, efficient and cost-effective genotyping method for cattle using next-generation sequencing. *PLoS ONE,* 8: e62137.

De Roos, A.P.W., Hayes, B.J., Spelman, R.J. & Goddard, M.E. 2008. Linkage disequilibrium and persistence of phase in Holstein–Friesian, Jersey and Angus cattle. *Genetics*, 179: 1503–1512.

Dong, Y., Xie, M., Jiang, Y., Xiao, N., Du, X., Zhang, W., Tosser-Klopp, G., Wang, J., Yang, S., Liang, J., Chen, W., Chen, X.J., Zeng, P., Hou, Y., Bian, C., Pan, S., Li, Y., Liu, X., Wang, W., Servin, B., Sayre, B., Zhu, B., Sweeney, D., Moore, R., Nie, W., Shen, Y., Zhao, R., Zhang, G., Li, J., Faraut, T., Womack, J., Zhang, Y., Kijas, J., Cockett, N., Xu, X., Zhao, S., Wang, J. & Wang, W. 2013. Sequencing and automated whole genome optical mapping of the genome of the domestic goat (*Capra hircus*). *Nature Biotechnology*, 31: 135–141.

Doro, M.G., Piras, D., Leoni, G.G., Casu, G., Vaccargiu, S., Parracciani, D., Naitana, S., Pirastu, M. & Novelletto, A. 2014. Phylogeny and patterns of diversity of goat mtDNA haplogroup reveals by resequencing complete mitogenomes. *PLoS ONE*, 9: e95969.

Drogemuller, C., Demmel, S., Engensteiner, M., Rieder, S. & Leeb, T. 2010. A shared 336 kb haplotype associated with the belt pattern in three divergent cattle breeds. *Animal Genetics,* 41: 304–307.

Drouilhet, L., Mansanet, C., Sarry, J., Tabet, K., Bardou, P., Woloszyn, F., Lluch, J., Harichaux, G., Viguie, C., Monniaux, D., Bodin, L., Mulsant, P. & Fabre, S. 2013. The highly prolific phenotype of Lacaune sheep is associated with an ectopic expression of the B4GALNT2 gene within the ovary. *PLoS Genetics*, 9: e1003809.

The ENCODE Project Consortium. 2012. An integrated encyclopedia of DNA elements in the human genome. *Nature,* 489: 57–74.

Endale Ahanda, M-L., Zerjal, T., Dhorne-Pollet, S., Rau A., Cooksey, A. & Giuffra, E. 2014. Impact of the genetic background on the composition of the chicken plasma miRNome in response to a stress. *PLoS ONE*, 9: e114598.

FAO. 2007. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2011. *Molecular genetic characterization of animal genetic resources.* FAO Animal Production and Health Guidelines. No. 9. Rome (available at http://www.fao.org/docrep/014/i2413e/i2413e00.htm).

Feng, C., Gao, Y., Dorshorst, B., Song, C., Gu, X., Li, Q., Li, J., Liu, T., Rubin, C.J., Zhao, Y.,Wang, Y., Fei, J., Li, H., Chen, K., Qu, H., Shu, D., Ashwell, C., Da, Y., Andersson, L., Hu, X. & Li, N. 2014. A cis-regulatory mutation of PDSS2 causes silky-feather in chickens. *PLoS Genetics*, 10: e1004576.

Ferenčaković, M., Sölkner, J. & Curik, I. 2013. Estimating autozygosity from high-throughput information: effects of SNP density and genotyping errors. *Genetics Selection Evolution*, 45: 42.

Fernandez, J., Villanueva, B., Pong-Wong, R. & Toro, M.A. 2005. Efficiency of the use of pedigree and molecular marker information in conservation programs. *Genetics*, 170: 1313–1321.

Fischer, D., Laiho, A., Gyenesei, A. & Sironen, A. 2015. Identification of reproduction related gene polymorphisms using whole transcriptome sequencing in the large white pig population. *Genes Genomes Genetics*, 5: [Epub ahead of print].

Flori, L., Fritz, S., Jaffrezic, F., Boussaha, M., Gut, I., Heath, S., Foulley, J.L. & Gautier, M. 2009. The genome response to artificial selection: A case study in dairy cattle. *PLoS ONE*, 4: e6595.

Flury, C., Tapio, M., Sonstegard, T., Drogemuller, C., Leeb, T., Simianer, H., Hanotte, O. & Rieder, S. 2010. Effective population size of an indigenous Swiss cattle breed estimated from linkage disequilibrium. *Journal of Animal Breeding and Genetics,* 127: 339–347.

Fritz, S., Capitan, A., Djari, A., Rodriguez, S.C., Barbat, A., Baur, A., Grohs, C., Weiss, B., Boussaha, M., Esquerre, D., Klopp, C., Rocha, D. & Boichard, D. 2013. Detection of haplotypes associated with prenatal death in dairy cattle and identification of deleterious mutations in GART, SHBG and SLC37A2. *PLoS ONE,* 8: e65550.

Gautier, M., Laloë, D. & Moazami-Goudarzi, K. 2010. Insights into the genetic history of French cattle from dense SNP data on 47 worldwide breeds. *PLoS ONE*, 5(9): e13038.

Ginja, C., Gama, L.T., Cortes, O., Delgado, J.V., Dunner, S., García, D., Landi, V., Martin-Burriel, I., Martinez-Martinez, A., Penedo, M.C.T., Rodellar, C., Zaragoza, P., Canon, J. & Biobovis Consortium. 2013. Analysis of conservation priorities of Iberoamerican cattle based on autosomal microsatellite markers. *Genetics Selection Evolution*, 45: 35.

Gonzalez-Recio, O. 2012 Epigenetics: a new challenge in the post-genomic era of livestock. *Frontiers in Genetics*, 2: 106.

Grabherr, M.G., Haas, B.J., Yassour, M., Levin, J.Z., Thompson, D.A., Amit, I., Adiconis, X., Fan, L., Raychowdhury, R., Zeng, Q., Chen, Z., Mauceli, E., Hacohen, N., Gnirke, A., Rhind, N., di Palma, F., Birren, B.W., Nusbaum, C., Lindblad-Toh, K., Friedman, N. & Regev, A. 2011. Full-length transcriptome assembly from RNA-seq data without a reference genome. *Nature Biotechnology*, 29: 644–652.

Groenen, M.A., Archibald, A.L., Uenishi, H., Tuggle, C.K., Takeuchi, Y., Rothschild, M.F., Rogel-Gaillard, C., Park, C., Milan, D., Megens, H.J., Li, S., Larkin, D.M., Kim, H., Frantz, L.A., Caccamo, M., Ahn, H., Aken, B.L., Anselmo, A., Anthon, C., Auvil, L., Badaoui, B., Beattie, C.W., Bendixen, C., Berman, D., Blecha, F., Blomberg, J., Bolund, L., Bosse, M., Botti, S. *et al.* 2012. Analysis of pig genomes provide insight into porcine demography and evolution. *Nature*, 491: 393–398.

Guttman, M., Garber, M., Levin, J.Z., Donaghey, J., Robinson, J., Adiconis, X., Fan, L., Koziol, M.J., Gnirke, A., Nusbaum, C., Rinn, J.L., Lander, E.S. & Regev, A. 2010. *Ab initio* reconstruction of cell type-specific transcriptomes in mouse reveals the conserved multi-exonic structure of lincRNAs. *Nature Biotechnology,* 28: 503–10.

Hasler, H., Flury, C., Menet, S., Haase, B., Leeb, T., Simianer, H., Poncet, P.A. & Rieder, S. 2011. Genetic diversity in an indigenous horse breed: implications for mating strategies and the control of future inbreeding. *Journal of Animal Breeding and Genetics,*128: 394–406.

Hayes, B.J., Lewin, H.A. & Goddard, M.E. 2013. The future of livestock breeding: genomic selection for efficiency, reduced emissions intensity, and adaptation. *Trends in Genetics*, 29: 206–14.

Hayes, B.J., Visscher, P.M., McPartlan, H.C. & Goddard, M.E. 2003. Novel multilocus measure of linkage disequilibrium to estimate past effective population size. *Genome Research*, 13: 635–643.

Hellenthal, G., Busby, G.B., Band, G., Wilson, J.F., Capelli, C., Falush, D. & Myers, S. 2014. A genetic atlas of human admixture history. *Science*, 343: 747–751.

Hill, W.G. 1981 Estimation of effective population size from data on linkage disequilibrium. *Genetics Research*, 38: 209–216.

Hillestad, B., Woolliams, J.A., Meuwissen, T., Våge, D.I. & Klemetsdal, G. 2014. Estimating rate of inbreeding and effective population size using genomic data in Norwegian Red Cattle. In *Proceedings, 10th World Congress of Genetics Applied to Livestock Production, Vancouver, BC, Canada, August 17–27, 2014* (available at http://tinyurl.com/ngeyujq).

Hua, G-H. & Yandg, L-G. 2009. A review of research progress of *FecB* gene in Chinese breeds of sheep. *Animal Reproduction Science*, 116, 1–9.

Imsland, F., Feng, C., Boije, H., Bed'hom, B., Fillon, V., Dorshorst, B., Rubin, C.J., Liu, R., Gao, Y., Gu, X., Wang, Y., Gourichon, D., Zody, M.C., Zecchin, W., Vieaud, A., Tixier-Boichard, M., Hu, X., Hallböök, F., Li, N. & Andersson, L. 2012. The rose-comb mutation in chickens constitutes a structural rearrangement causing both altered comb morphology and defective sperm motility. *PLoS Genetics,* 8: e1002775.

Jansen, S., Aigner, B., Pausch, H., Wysocki, M., Eck, S., Benet-Pagès, A., Graf, E., Wieland, T., Strom, T.M., Meitinger, T. & Fries, R. 2013. Assessment of the genomic variation in a cattle population by re-sequencing of key animals at low to medium coverage. *BMC Genomics*, 14: 446.

Jombart, T., Devillard, S. & Balloux, F. 2010. Discriminant analysis of principal components: a new method for the analysis of genetically structured populations. *BMC Genetics*, 11: 94.

Kadri, N.K., Sahana, G., Charlier, C., Iso-Touru, T., Guldbrandtsen, B., Karim, L., Nielsen, U.S., Panitz, F., Aamand, G.P., Schulman, N., Georges, M., Vikki, J., Lund, M.S. & Druet, T. 2014. A 660-kb deletion with antagonistic effects on fertility and milk production segregates at high frequency in Nordic Red cattle: Additional evidence for the common occurrence of balancing selection in livestock. *PLoS Genetics*, 10: e1004049.

Karim, L., Takeda, H., Lin, L., Druet, T., Arias, J.A., Baurain, D., Cambisano, N., Davis, S.R., Farnir, F., Grisart, B., Harris, B.L., Keehan, M.D., Littlejohn, M.D., Spelman, R.J., Georges, M. & Coppieters, W. 2011. Variants modulating the expression of a chromosome domain encompassing PLAG1 influence bovine stature. *Nature Genetics*, 43: 405–413.

Keller, M.C., Visscher, P.M. & Goddard, M.E. 2011. Quantification of inbreeding due to distant ancestors and its detection using dense single nucleotide polymorphism data. *Genetics*, 189: 237–249.

Kijas, J.W., Lenstra, J.A., Hayes, B., Boitard, S., Porto Neto, L.R., San Cristobal, M., Servin, B., McCulloch, R., Whan, V., Gietzen, K., Paiva, S., Barendse, W., Ciani, E., Raadsma, H., McEwan, J., Dalrymple, B. & International Sheep Genomics Consortium Members. 2012. Genome-wide analysis of the world's sheep breeds reveals high levels of historic mixture and strong recent selection. *PLoS Biology*, 10: e1001258.

Kofler, R., Orozco-terWengel, P., De Maio, N., Pandey, R.V., Nolte, V., Futschik, A., Kosiol, C. & Schlötterer, C. 2011. PoPoolation: a toolbox for population genetic analysis of next generation sequencing data from pooled individuals. *PLoS ONE,* 6: e15925

Langmead, B. & Salzberg, S.L. 2012. Fast gapped-read alignment with Bowtie 2. *Nature Methods*, 9: 357–359.

Lawson, D.J., Hellenthal, G., Myers, S. & Falush, D. 2012. Inference of population structure using dense haplotype data. *PLoS Genetics*, 8:e1002453.

Lenstra, J.A., Groeneveld, L.F., Eding, H., Kantanen, J., Williams, J.L., Taberlet, P., Nicolazzi, E.L., Sölkner, J., Simianer, H., Ciani, E., Garcia, J.F., Bruford, M.W., Ajmone-Marsan, P. & Weigend, S. 2012. Molecular tools and analytical approaches for the characterization of farm animal diversity. *Animal Genetics*, 43: 483–502.

Leroy, G., Callèle L., Verrier E., Mériaux J.C., Ricard, A. & Rognon, X. 2009. Genetic of a large set of horse breeds raised in France assessed by microsatellite polymorphism. *Genetics Selection Evolution*, 41, 5.

Li, H. & Durbin, R. 2011. Inference of human population history from individual whole-genome sequences. *Nature*, 475: 493–496.

Li, R., Rinaldi, M. & Capuco, A. 2011. Characterization of the abomasal transcriptome for mechanisms of resistance to gastrointestinal nematodes in cattle. *Veterinary Research*, 42: 114.

Liu, S., Lin, L., Jiang, P., Wang, D. & Xing, Y. 2011. A comparison of RNA-Seq and high-density exon array for detecting differential gene expression between closely related species. *Nucleic Acids Research*, 39: 578–588.

Lord, E.A., Davis, G.H., Dodds, K.G., Henry, H.M., Lumsden, J.M. & Montgomery, G.W. 1998. Identification of Booroola carriers using microsatellite markers. In *Proceedings of the 6th World Congress on Genetics Applied to Livestock Production, Armidale, Australia, Volume 27*, pp. 19–22.

McCoy, A.M., Schaefer, R., Petersen, J.L., Morrell, P.L., Slamka, M.A., Mickelson, J.R., Valberg, S.J. & McCue, M.E. 2014. Evidence of positive selection for a glycogen synthase (GYS1) mutation in domestic horse populations. *Journal of Heredity*, 105: 163–172.

Medugorac, I., Veit-Kensch, C.E., Ramljak, J., Brka, M., Marković, B., Stojanovic, S., Bytyqi, H., Kochoski, L., Kume, K., Grünenfelder, H.P., Bennewitz, J. & Förster, M. 2011. Conservation priorities of genetic diversity in domesticated meta-populations: a study in taurine cattle breeds. *Ecology and Evolution,* 1: 408–420.

Metzker, M.L. 2010. Sequencing technologies – the next generation. *Nature Reviews Genetics,* 11: 31–46.

Meuwissen, T.H.E. & Goddard, M.E. 2001. Prediction of identity by descent probabilities from marker-haplotypes. *Genetics Selection Evolution*, 33: 605–634.

Montgomery, G.W., Crawford, A.M., Penty, J.M., Dodds, K.G., Ede, A.J., Henry, H.M., Pierson, C.A., Lord, E.A., Galloway, S.A., Schmack, A.E., Sise, J.A., Swarbick, P.A., Hanrahan, V., Buchanan, F.C. & Hill, D.F. 1993. The ovine Booroola fecundity gene (*FecB*) is linked to markers from a region of human chromosome 4q. *Nature Genetics*, 4: 410–414.

Mou, C., Pitel, F., Gourichon, D., Vignoles, F., Tzika, A., Tato, P., Yu, L., Burt, D.W., Bed'hom, B., Tixier-Boichard, M., Painter, K.J. & Headon, D.J. 2011. Cryptic patterning of avian skin confers a developmental facility for loss of neck feathering. *PLoS Biology*, 9: e1001028.

Mortazavi, A., Williams, B.A., McCue, K., Schaeffer, L. & Wold, B. 2008. Mapping and quantifying mammalian transcriptomes by RNA-seq. *Nature Methods*, 5: 621–628.

Muchadeyi, F.C., Eding, H., Wollny, C.B.A., Groeneveld, E., Makuza, S.M., Shamseldin, R., Simianer, H. & Weigend, S. 2007. Absence of population substructuring in the Zimbabwe chicken ecotypes inferred using microsatellite analysis. *Animal Genetics*, 38: 332–339.

Ng, C.S., Wu, P., Foley, J., Foley, A., McDonald, M.L., Juan, W.T., Huang, C.J., Lai, Y.T., Lo, W.S., Chen, C.F., Leal, S.M., Zhang, H., Widelitz, R.B., Patel, P.I., Li, W.H. & Chuong, C.M. 2012. The chicken frizzle feather is due to an alpha-keratin (KRT75) mutation that causes a defective rachis. *PLoS Genetics*, 8: e1002748.

Nicholas, F.W. & Hobbs, M. 2012. Mutation discovery for mendelian traits in non-laboratory animals: a review of achievements up to 2012. *Animal Genetics,* 45: 157–170.

Nielsen, R., Paul, J.S., Albrechtsen, A. & Song, Y.S. 2011. Genotype and SNP calling from next generation sequencing data. *Nature Reviews Genetics*, 12: 433–451.

Nookaew, I., Papini, M., Pornputtpong, N., Scalcinati, G., Fagerberg, L., Uhlén, M. & Nielsen, J. 2012. A comprehensive comparison of RNA-Seq-based transcriptome analysis from reads to differential gene expression and cross-comparison with microarrays: a case study in *Saccharomyces cerevisiae*. *Nucleic Acids Research*, 40: 10084–10097.

Norman, A.J., Street, N.R. & Spong, G. 2013. *De novo* SNP discovery in the Scandinavian brown bear (*Ursus arctos*). *PLoS ONE*, 8:e81012.

Ober, U., Malinowski, A., Schlather, M. & Simianer, H. 2013. The expected linkage disequilibrium in a finite population revisited. *arXiv*:1304.4856v2 [q-bio.PE].

Oldenbroek, K. 2007. *Utilisation and conservation of farm animal genetic resources*. Wageningen, the Netherlands, Wageningen Academic Publishers.

Orlando, L., Ginolhac, A., Zhang, G., Froese, D., Albrechtsen, A., Stiller, M., Schubert, M., Cappellini, E., Petersen, B., Moltke, I., Johnson, P.L.F., Fumagalli, M., Vilstrup, J.T., Raghavan, M., Korneliussen, T., Malaspinas, A.-S., Vogt, J., Szklarczyk, D., Kelstrup, C.D., Vinther, J., Dolocan, A., Stenderup, J., Velazquez, A.M.V., Cahill, J., Rasmussen, M., Wang, X. *et al.* 2013. Recalibrating Equus evolution using the genome sequence of an early Middle Pleistocene horse. *Nature*, 499: 74–78.

O'Rourke, B.A., Greenwood, P.L., Arthur, P.F. & Goddard, M.E. 2013. Inferring the recent ancestry of myostatin alleles affecting muscle mass in cattle. *Animal Genetics,* 44: 86–90.

Oshlack, A., Robinson, M.D. & Young, M.D. 2010. From RNA-seq reads to differential expression results. *Genome Biology*, 11: 220.

Oshlack, A. & Wakefield, M.J. 2009. Transcript length bias in RNA-seq data confounds systems biology. *Biology Direct*, 4: 14.

Pan, Q., Shai, O., Lee, L.J., Frey, B.J. & Blencowe, B.J. 2008. Deep surveying of alternative splicing complexity in the human transcriptome by high-throughput sequencing. *Nature Genetics*, 40: 1413–1415.

Patterson, N.J., Moorjani, P., Luo, Y., Mallick, S., Rohland, N., Zhan, Y., Genschorek, T., Webster, T. & Reich, T. 2012. Ancient admixture in human history. *Genetics*, 192: 1065–1093.

Pariset, L., Joost, S., Gargani, M. & Valentini, A. 2012. Landscape genomics in livestock. *In* M. Çalişkan, ed. *Analysis of genetic variation in animals*, pp. 189–216. Rijeka, Croatia, INTECH.

Petersen, J.L., Mickelson, J.R., Rendahl, A.K., Valberg, S.J., Andersson, L.S., Axelsson, J., Bailey, E., Bannasch, D., Binns, M.M., Borges, A.S., Brama P., da Câmara Machado, A., Capomaccio, S., Cappelli, K., Cothran, E.G., Distl, O., Fox-Clipsham, L., Graves, K.T., Guérin, G., Haase, B., Hasegawa, T., Hemmann, K., Hill, E.W., Leeb T., Lindgren, G., Lohi, H., Lopes, M.S., McGivney, B.A., Mikko, S., Orr, N., Penedo, M.C., Piercy, R.J., Raekallio, M., Rieder, S., Røed, K.H., Swinburne, J., Tozaki, T., Vaudin, M., Wade, C.M. & McCue, M.E. 2013. Genome-wide analysis reveals selection for important traits in domestic horse breeds. *PLoS Genetics*, 9: e1003211.

Pickrell, J.K. & Pritchard, J.K. 2012. Inference of population splits and mixtures from genome-wide allele frequency data. *PLoS Genetics*, 8: e1002967.

Piper, L.R. & Bindon, B.M. 1982. Genetic segregation for fecundity in Booroola merino sheep. *In* Burton & W.C. Smith, eds. *Proceedings of the 1st World Congress on Sheep and Beef Cattle Breeding, 1980. Volume 1*, pp. 395–400. Palmerston North, New Zealand, Dunmore Press.

Pritchard, J.K., Stephens, M. & Donnelly, P. 2000. Inference of population structure using multilocus genotype data. *Genetics*, 155: 945–59.

Qanbari, S., Hansen, M., Weigend, S., Preisinger, R. & Simianer, H. 2010. Linkage disequilibrium reveals different demographic history in egg laying chickens. *BMC Genetics*, 11:103.

Qanbari, S., Strom, T.M., Haberer, G., Weigend, S., Gheyas, A.A., Turner, F., Burt, D.W., Preisinger, R., Gianola, D. & Simianer, H. 2012. A high resolution genome-wide scan for significant selective sweeps: An application to pooled sequence data in laying chickens. *PLoS ONE* 7: e49525.

Ritchie, M.E., Phipson, B., Wu, D., Law, C.W., Shi, W. & Smyth, G.K. 2015. Limma powers differential expression analyses for RNA-sequencing and microarray studies. *Nucleic Acids Research*, *doi:*10.1093/nar/gkv007.

Robertson, G., Schein, J., Chiu, R., Corbett, R., Field, M., Jackman, S.D., Mungall, K., Lee, S., Okada, H.M., Qian, J.Q., Griffith, M., Raymond, A., Thiessen, N., Cezard, T., Butterfield, Y.S., Newsome, R., Chan, S.K., She, R., Varhol, R., Kamoh, B., Prabhu, A-L., Tam, A., Zhao, Y., Moore, R.A., Hirst, M., Marra, M.A., Jones, S.J., Hoodless, P.A. & Birol, I. 2010. *De novo* assembly and analysis of RNA-seq data. *Nature Methods*, 7: 909–912.

Rothammer, S., Seichter, D., Forster, M. & Medugorac, I. 2013. A genome-wide scan for signatures of differential artificial selection in ten cattle breeds. *BMC Genomics,* 14: 908-2164-14-908.

Saura, M., Fernández, A., Rodríguez, M.C., Toro, M.A., Barragán, C., Fernández, A.I. & Villanueva, B. 2013. Genome-wide estimates of coancestry and inbreeding in a closed herd of ancient Iberian pigs. *PLoS ONE*, 8(10): e78314.

Schulz, M.H., Zerbino, D.R., Vingron, M. & Birney, E. 2012. Oases: robust *de novo* RNA-seq assembly across the dynamic range of expression levels. *Bioinformatics*, 28: 1086–1092.

Skelly, D.A., Johansson, M., Madeoy, J., Wakefield, J. & Akey, J.M. 2011. A powerful and flexible statistical framework for testing hypotheses of allele-specific gene expression from RNA-seq data. *Genome Research*, 21: 1728–1737.

Sved, J.A. 1971. Linkage disequilibrium and homozygosity of chromosome segments in finite populations. *Theoretical Population Biology,* 2: 125–141.

Sved, J.A. 2008. Linkage disequilibrium and its expectation in human populations. *Twin Research and Human Genetics,* 12: 35–43.

Toro, M., Villanueva, B. & Fernandez, J. 2014. Genomics applied to management strategies in conservation programmes. *Livestock Science*, 166: 48–53.

Trapnell, C., Hendrickson, D.G., Sauvageau, M., Goff, L., Rinn, J.L. & Pachter, L. 2013. Differential analysis of gene regulation at transcript resolution with RNA-seq. *Nature Biotechnology*, 31: 46–53.

Trapnell, C., Williams, BA., Pertea, G., Mortazavi, A., Kwan, G., van Baren, M.J., Salzberg, S.L., Wold, B.J. & Pachter, L. 2010. Transcript assembly and quantification by RNA-seq reveals unannotated transcripts and isoform switching during cell differentiation. *Nature Biotechnology*, 28: 511–515.

Turner, H.N. 1983. Origins of the CSIRO Booroola. *International Journal of Sheep and Wool Science*, 31(1): 10–13.

Uimari, P. & Tapio, M. 2011. Extent of linkage disequilibrium and effective population size in Finnish Landrace and Finnish Yorkshire pig breeds. *Journal of Animal Science*, 89: 609–614.

Vage, D.I., Husdal, M., Kent, M.P., Klemetsdal, G. & Boman, I.A. 2013. A missense mutation in growth differentiation factor 9 (GDF9) is strongly associated with litter size in sheep. *BMC Genetics,* 14: 1-2156-14-1.

Walkden-Brown, S.W., van der Werf, J.H.J., Nimbkar, C. & Gupta, V.S. (eds.). 2008. *Use of the* FecB *(Booroola) gene in sheep-breeding programs. Proceedings of the Helen Newton Turner Memorial International Workshop held in Pune, Maharashtra, India, 10–12 November 2008*. ACIAR Proceedings No. 133. Canberra, Australian Centre for International Agricultural Research (available at http://aciar.gov.au/files/node/11617/ACIAR_PR133(online).pdf).

Wallner, B., Vogl, C., Shukla, P., Burgstaller, J.P., Druml, T. & Brem, G. 2013. Identification of genetic variation on the horse Y chromosome and the tracing of male founder lineages in modern breeds. *PLoS ONE*, 8: e60015.

Wang, E.T., Sandberg, R., Luo, S., Khrebtukova, I., Zhang, L., Mayr, C., Kingsmore, S.F., Schroth, G.P. & Burge, C.B. 2008. Alternative isoform regulation in human tissue transcriptomes. *Nature*, 456: 470–476.

Waples, R. 2006 A bias correction for estimates of effective population size based on linkage disequilibrium at unlinked gene loci. *Conservation Genetics*, 7: 167–184.

Weigend, S., Janssen-Tapken, U., Erbe, M., Ober, U., Weigend, A., Preisinger, R. & Simianer, H. 2015. Potentials of biodiversity in chickens. *Züchtungskunde,* 86: 25–41.

Zhao, S., Fung-Leung, W.P., Bittner, A., Ngo, K. & Liu, X. 2014. Comparison of RNA-Seq and microarray in transcriptome profiling of activated T Cells. *PLoS ONE,* 9: e78644.

Zhou, X., Lindsay H. & Robinson, M.D. 2014. Robustly detecting differential expression in RNA sequencing data using observation weights. *Nucleic Acids Research*, 42: e91.

Section C

Breeding strategies and programmes

1 Introduction

This section serves as an update of the overview of the state of the art in genetic improvement methods presented in the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007a).[1] The importance of appropriate breeding strategies and programmes is highlighted throughout the Global Plan of Action for Animal Genetic Resources (FAO, 2007b), particularly in Strategic Priority Area 2, Sustainable Use and Development. The material presented in the first SoW-AnGR included an overview of the "context for genetic improvement", which described both the factors influencing the objectives of breeding programmes (market demands, wider societal concerns about the nature and impacts of livestock production, the need to provide animals suitable for a diverse range of production environments, growing recognition of the importance of maintaining genetic diversity in livestock populations, etc.) and the latest scientific and technological developments in the field. This was followed by a description of the various activities or "elements" that make up a breeding programme and then by a review of the current state of breeding programmes by production system (high input vs. low input) and by species. Much of this material remains relevant. While the livestock sector is continuously evolving (see Part 2), the challenges that breeding programmes have to contend with remain broadly similar to those that existed at the time the first SoW-AnGR was prepared (2005/2006). Similarly, the basic constituent elements of a typical breeding programme have not changed.

This update largely follows the same structure as that described above for the first SoW-AnGR. Emphasis is given to recent developments, but each subsection aims to provide sufficient background information (where relevant, a short recapitulation of the material presented in the first report) to make it comprehensible, in standalone form, to the non-specialist reader. High-input systems are again treated separately from low-input systems. These terms can be defined in various ways, but for the purposes of this section, "high-input systems" is used to refer to systems in which external inputs such as supplementary feeds, veterinary medicines and advanced breeding and reproductive technologies are relatively easily obtainable and widely used (precise levels of use will depend on the particular circumstances) and "low-input systems" to systems where the use of such technologies is more limited, often because of factors such as inaccessibility, unaffordability, lack of relevant knowledge or lack of organizational capacity. Departures from the structure of the first SoW-AnGR include separate subsections on sheep and goat breeding in high-input systems and the addition of a subsection on rabbit breeding in high-input systems. The issue of breeding in the context of conservation programmes is addressed in Part 4 Section D. As indicated above, the broad context for breeding programmes (trends in the livestock sector) is addressed in Part 2.

[1] FAO, 2007a, Part 4 Section D (pages 381–427).

PART **4**

2 Scientific and technological advances

2.1 Quantitative genetics

Since the time the first SoW-AnGR was prepared (2005/2006), there have been few technological advances in the field of quantitative genetics. The standard method for estimating breeding values and ranking animals according to their genetic merit continues to be traditional BLUP (best linear unbiased prediction). This method uses phenotypic information on animals and their relatives to predict the genetic potential of each animal. Existing tools for controlling inbreeding in herds and populations (e.g. Meuwissen, 1997) have become more widely utilized. From a given set of selection candidates, these tools allow the selection of a group of parents in which the genetic merit is maximized while a measure of genetic variation (e.g. the average coefficient of coancestry) is constrained.

Many breeding organizations, particularly in the dairy cattle, pig and chicken industries, have long been using mate selection software to minimize the effects of inbreeding in their breeding populations (Weigel and Lin, 2000). Over recent years, the various algorithms have been made more efficient (e.g. Kinghorn, 2011) and their value in the control of genetic defects has been recognized (Van Eenennaam and Kinghorn, 2014). Not surprisingly given the increasing use of genomic information in breeding programmes (see Subsection 2.3 and Subsection 4), software for managing inbreeding in the context of increasingly available genomic data has also been developed (e.g. Schierenbeck *et al.*, 2011).

2.2 Molecular genetics

Knowledge of the biology of traits is being enhanced by the availability of an ever increasing amount of genetic information, much of it unavailable only a few years ago. Genotypes can now be obtained much faster and at a lower

Box 4C1

Reduction of genetic variability and its consequences in cattle breeds

Intensive selection may reduce the genetic diversity of livestock populations even if the number of animals remains high. A study of Holstein, Jersey and Angus cattle (very widely used international transboundary cattle breeds) undertaken by de Roos *et al.* (2008) used single nucleotide polymorphism (SNP) markers to investigate linkage disequilibrium (non-random association between alleles). Information on linkage disequilibrium can be used to trace the evolution of effective population size (N_e) over past generations. Several historical episodes of reduction in N_e were identified, including one 10 000 generations ago – corresponding to the time of cattle domestication – during which N_e fell to a few thousands. Another reduction occurred over recent generations, during which time effective population sizes fell to close to 100 as a result of the introduction of new breeding techniques.

Low N_e does not yet seem to have affected the selection potential of widely used transboundary breeds. However, other effects – related to the spread of inherited disorders or to a reduction in fitness associated with inbreeding depression – have been observed. A recent study estimated that in Holstein and Jersey cattle a 1 percent increase in inbreeding, as indicated by pedigree or genomic information, was associated with a decrease of 0.4-0.6 percent of the phenotypic mean for milk, fat and protein yields and an increase of 0.02-0.05 percent for calving intervals. Inbreeding depression can be managed either by minimizing overall inbreeding within the breeding scheme or by targeting specific regions of the genome associated with inbreeding depression.

Based on de Roos *et al.* (2008) and Pryce *et al.* (2014).
See also Part 1 Section F Table 1F1.

cost than they could just five years ago. A simple biological sample (usually blood, hair, tissue or semen) from an individual animal can be used to determine its entire DNA sequence. Of particular interest are the areas where the sequence differs, at a single point, from that of the common reference sequence for the respective species. Such differences are referred to as single nucleotide polymorphisms (SNPs). Combined with enhanced computational capacity, these developments mean that researchers can analyse the genome for more complex traits than ever previously thought possible. It is likely that genotyping costs will continue to decline and that computational capacity will continue to improve – and that therefore the use of these tools will become ever more widespread in the coming years (see Part 4 Section B).

2.3 Gene-based selection

As knowledge of molecular genetics and trait biology has improved, it has been possible to improve breeding programmes through the use of various types of gene-based selection. Most traits of economic importance in livestock are so-called quantitative traits, the phenotypes of which are the result of the combined small effects of many genes. In some instances, however, individual genes can have substantial effects. Molecular genetics can be used to detect the presence of these genes and this information can be used in concert with phenotypic information from animals and their relatives in a process generally referred to as marker-assisted selection (MAS), where "marker" refers to a polymorphic locus either directly responsible for the genetic differences observed or "linked" to the causative locus by being situated nearby on the same chromosome. Most commonly, MAS is applied using linked loci rather than the causative gene, although some accuracy is lost by doing this.

At the time the first SoW-AnGR was prepared (2005/2006), several countries had incorporated MAS into their national breeding programmes for dairy cattle (e.g. Liu *et al.*, 2004; Boichard *et al.*, 2006) and other species. The application of MAS was judged to be profitable in dairy cattle even with only moderate linkage between the marker and the causative gene. However, for species lacking the complex system of artificial insemination (AI) and progeny testing that is in place for dairy cattle, MAS was considered to be a profitable strategy only in the case of highly informative markers located very close to the causative loci (Boichard *et al.*, 2006).

In recent years, the availability of genomic information has greatly increased and continues to accumulate at a rapid pace. Cost-efficient DNA sequencing methods have facilitated the development of assays that can provide genotypes for tens to hundreds of thousands of SNPs for only a few tens or hundreds of dollars per animal. Thus, nearly all genes with effects on phenotypic traits can be marked by a SNP. It has become possible to apply genome-wide approaches that are more comprehensive than simple MAS based on a few markers.

Researchers have established ways of incorporating information on the genetic make-up of individual animals into breeding programmes for complex traits influenced by many genes, a process known as genome-enabled selection. There are two general approaches to this: genome-enhanced BLUP (Garrick, 2007; VanRaden, 2007; Zhang *et al.,* 2007) and SNP-effect models.

Whereas genetic evaluations based on traditional BLUP utilize average relationships based on animals' pedigrees, genome-enhanced BLUP utilizes the actual genomic relationship between the animals. For example, with traditional BLUP, two animals with the same sire are assumed to have exactly one-quarter of their genes in common. In reality, this proportion is not a fixed quantity, but rather ranges from zero to one-half. Genome-enhanced BLUP allows this proportion to be estimated more precisely. The approach can be extended – via a method known as single-step genome-enhanced BLUP – to incorporate phenotypes from individuals that are not genotyped (Aguilar *et al.,* 2010; Christensen and Lund, 2010).

PART **4**

Simple genome-enhanced BLUP is based on the assumption that all regions of the genome have an equal influence on the phenotype being evaluated. Although this assumption facilitates the statistical analysis and generally yields satisfactory results, our knowledge of biology tells us that this assumption is not strictly true; only certain genes have actual physiological effects on a given trait. Computational methods such as Bayesian regression allow differential weighting of specific genomic regions that have a particularly large statistical association with the trait of interest, in other words where findings are consistent with the presence of a quantitative trait locus (QTL) affecting the trait.

In SNP effect models, effects on phenotype are simultaneously estimated for all genotyped SNPs in a so-called "training population" for which full phenotypic information is available (Erbe *et al.*, 2010). The output is referred to as a "SNP-key" and can be used to predict the breeding value of animals that are genotyped, but for which no phenotypic data have been recorded. Such predicted breeding values are obtained by summing the estimated effects at each genotyped SNP. To incorporate information from individuals that have not been genotyped, the resulting genomic prediction is "blended" with an estimate of breeding value derived using traditional BLUP. This blended estimate is used as the final genetic index value for each animal.

Another distinction to note is that between high- and low-density genotyping. High-density genotyping involves analysing 50 000 to 1 million SNPs. Low-density genotyping only analyses a few hundred to a few thousand SNPs. The cost of high-density genotyping is more than twice that of low-density genotyping. Costs can be reduced via a process known as "imputation", in which high-density genotyping is conducted only in a base population of animals that have many descendants (usually AI sires) and the information obtained is then used to develop a system for inferring or deducing the missing information for animals that have been subject only to low-density genotyping. The correlation between low-density and high-density genotyping has been shown to be approximately 0.95 (Hickey *et al.,* 2012).

If genomic information is used alone (i.e. is based exclusively on historical phenotypic data), the genetic improvement resulting from selection may not exceed that achieved using traditional BLUP with phenotypes for selection candidates (Dekkers, 2007; Muir, 2007). Moreover, because of the effects of selection and recombination, the accuracy of genomic estimated breeding values (GEBVs) decreases as the number of generations from the training population increases. All available phenotypic and genomic information should be incorporated into GEBVs to ensure that they are as accurate as possible.

Studies have attempted to predict GEBVs for one breed based on the phenotypes of a training population belonging to another breed. The value of this approach has been found to be small or non-existent (Hayes *et al.*, 2009a; Erbe *et al.*, 2012). In numerically small breeds that have adequate phenotyping, multibreed genomic selection may, in future, prove to be an interesting option (Hozé *et al.*, 2014), especially for breeds with a shared genetic history. However, in developing countries, a lack of routinely recorded reference populations is likely to be a significant barrier for the foreseeable future (see Subsection 5.3). Development of genome-enabled selection strategies that can alleviate the constraints imposed by low population sizes and limited phenotypic data is therefore a priority.

Genome-enabled selection can be expected to improve the accuracy of EBVs, particularly for young animals for which phenotypic data are not available (Meuwissen *et al.,* 2001). Increasing EBV accuracy proportionally increases the expected rate of genetic gain. Having more accurate EBVs at a younger age allows selection decisions to be made earlier, which reduces the generation interval and increases genetic gain per unit of time.

In general, genome-enabled selection is beneficial because it can be used to increase the accuracy of the EBVs of animals without direct phenotypic measurements. This general rule applies not

only with respect to young animals, but also to sex-limited traits, traits that are difficult or impossible to measure in the live animal, traits measured at the end of an animal's productive life and as yet undetermined traits that are not currently measured but may become important in the future. In the latter instance, data collected in the future could be used to obtain EBVs for animals that are no longer living but from which cryopreserved semen or other germplasm is available. Genetic material from these animals could thus potentially be used to enhance the trait in the *in vivo* population.

Genome-enabled selection has been implemented in some animal breeding programmes, including programmes for pigs and dairy cattle. In pigs, generation intervals are already low, and hence the greatest effect of genome-enabled selection is on the accuracy of selection for traits that are difficult to measure or measured late in life, such as disease resistance (difficult to define and measure systematically), feed efficiency (expensive to measure directly) and longevity (sow longevity is a sex-limited trait that is not recorded until the animal is culled from the herd).

In addition to quantitative traits (and arguably to an even greater degree) the use of genomic information has increased our ability to manage Mendelian traits, i.e. those traits controlled by a single or small number of genes. In particular, genomic approaches have been used to identify causative mutations or genomic regions associated with deleterious recessive traits, and genetic markers have been developed to help eliminate these genetic defects or attempt to fix beneficial traits within a population.

Deleterious recessive traits are often characterized by a completely homozygous chromosomal region that includes the mutation responsible for the defect and flanking regions on either side of it. Such completely homozygous regions can be relatively simply detected by sequencing or genotyping a small group of affected animals (even as few as ten) and comparing their genotypes to those of unaffected animals (Charlier *et al*., 2008). For example, in dairy cattle, a rare recessive genetic defect affecting cow fertility has been identified in the Holstein breed. The defect, known as brachyspina syndrome, is caused by a 3.3 kb (kilo base pair) deletion in the so-called *FANCI* gene (Charlier *et al*., 2012). Despite the low incidence of brachyspina syndrome (thought to be less than 1 in 100 000), the frequency of the carrier state may be greater than 7 percent. The large discrepancy between the low incidence and relatively large percentage of carriers is accounted for by the fact that almost all homozygous mutant calves die during pregnancy. Identifying this mutation would not have been possible without state of the art genomic tools. Producers can now select against animals carrying a single copy of the gene and thereby improve fertility in the Holstein breed.

Arachnomelia is a monogenic recessive defect affecting skeletal development in cattle. The causative mutation, mapped to chromosome 5, was identified using array-based sequence capture and parallel sequencing technologies (Drögemüller *et al*., 2010), state of the art genomic tools at the time. A healthy, partially inbred cow known to be carrying one copy of the mutation was re-sequenced and a single heterozygous position was identified. As in the case of brachyspina syndrome, homozygous recessive offspring die before birth, which negatively affects fertility. Again, animals carrying the gene can be selected against in order to improve the fertility of the population.

Genomic information can also be utilized to correct pedigree errors (Seroussi *et al*., 2013) and reconstruct pedigrees when parentage data have not been recorded (Kirkpatrick *et al*., 2011). Using genomic information in this way not only increases the accuracy of genome-enhanced BLUP (Munoz *et al*., 2014), but can also improve traditional BLUP EBVs. Correcting pedigree errors allows more accurate understanding of the true relationships among individuals in the herd. This is important when establishing contemporary groups to estimate breeding values.

2.4 Reproductive technology

The state of the art in the use of reproductive technologies has not changed greatly in recent

Box 4C2
Genetically modified animals in agriculture

Technologies related to genetic modification (GM) have advanced significantly in recent years. Classical gene transfer techniques have been complemented by new tools such as genome editing, a technique that allows the identification and modification (small insertions or deletions) of a specific DNA sequence instead of the insertion of a foreign DNA sequence into the cell (Carlson *et al.*, 2013).

Many transgenic animals have been developed, both for biomedical purposes (production of biomolecules, xenotransplantation, medical models, etc.) and for potential use in agriculture, including in the improvement of economically important traits such as growth rate, wool growth, feed conversion, milk composition, meat quality, disease resistance and survival. One example is the development of a transgenic chicken expressing a short-hairpin RNA (an RNA sequence whose structure can be used to silence the expression of specific genes) that interferes with H5N1 propagation and thereby confers resistance to avian influenza (Lyall *et al.*, 2011).

In comparison to conventional breeding, transgenic strategies may allow faster introduction of new alleles and genes of interest. However, the production of GM animals is labour intensive and costly. Moreover, unforeseen negative pleiotropic side effects (when a gene influences multiple unrelated phenotypes) are a possibility. It also has to be borne in mind that genetic progress often involves a multiplicity of genes and that in such cases transgenesis is of little interest.

In a large majority of cases, the development of GM animals for potential use in food production is only at the research stage. A few cases are close to final approval. As yet, no GM animals have been approved for commercial use in food production.

There are still many unresolved ethical issues related to the use and development of GM animals, including concerns related to the invasiveness of procedures and their effects on welfare and health and those related to intellectual property issues. Attitudes towards GM animals vary from country to country. In Europe, for example, the development of GM animals is subject to many restrictions. However, some developing countries have adopted a more permissive approach. For instance, Argentina and China have invested massively in the development of GM animals for food production. Such animals may play a growing role in the coming years. The extent to which this occurs is likely to depend on consumer attitudes to the use of GM technology.

For more information see Forabosco *et al.*, 2013; Jonas *et al.*, 2014.

years, at least in terms of application in the field. One area of advancement has been increased commercial use of semen sexing, predominantly in cattle and particularly in dairy cattle (see Boxes 3E6 and 3E7 in Part 3 Section E). This process involves the use of a molecular biology technology known as flow cytometry to sort X and Y sperm cells (Johnson and Welch, 1999). The obvious advantage is that sexed semen can be used to obtain offspring of the desired sex (more than 90 percent accuracy can be achieved). This allows the rate of genetic improvement to be increased, as selection intensity can be increased and the generation interval shortened. Given that in some production systems young animals of the undesired sex often suffer from neglect, the use of sexed semen can also indirectly enhance animal welfare.

Challenges associated with the use of sexed semen include a slight decline in conception rate (a fall to 80 or 85 percent of the rate obtained using conventional semen) and the fact that sexed semen is not available from all potential sires (Van Doormaal, 2010). These challenges are likely to be overcome as more experience is gained in the use of sexed semen and as companies make sexed semen routinely available for all sires. Another challenge is that semen sexing does

not work well in all species. In cattle, for example, overall semen and sperm volumes are low and the technology works well. Pigs, however, have relatively large semen and sperm volumes, which means that a lot of time (up to a day per sample) is needed to sort a single semen collection into X and Y sperm cells. To enable widespread use of semen sexing in this species, flow cytometry technology will need to be improved so as to allow sorting to be done much more quickly, as many commercial boar studs collect semen from as many as 100 boars in a day.

Reproductive technologies targeting the female animal (multiple ovulation, embryo transfer, *in vitro* fertilization and cloning) have been available for most major livestock species for some time (all had already been developed at the time the first SoW-AnGR was prepared – 2005/2006). Active research into these technologies continues to improve their success rates and their efficiencies, hence decreasing their costs. Nevertheless, cost remains a major constraint to their more widespread use. Genomic developments could, however, help change this. As discussed above, genome-enabled BLUP and related approaches have increased the accuracies of EBVs. In particular, the EBVs of female animals, especially young females, have become more accurate. This improved accuracy has increased the monetary value of the best females (Pryce *et al.*, 2012). In theory, this increases the expected return on investments in reproductive technologies that increase the number of offspring per female.

Cloning and genetic modification (GM) have been available for many years, but have not gained widespread commercial use. This is largely for economic reasons, but there are also potential ethical concerns. Among livestock species, cloning is most frequently undertaken in horses, where individual animals can have extremely high values because of their earning potential in racing and other riding competitions. Since the first SoW-AnGR was prepared, technologies involving "genome editing" have been developed. These techniques tend to be much more efficient than more traditional GM approaches. Moreover, as genome editing does not involve transfer of genes across species, it may also raise fewer ethical questions. Research on this technology is increasing and has the potential to have a significant effect on animal production and the management of AnGR (see Box 4C2).

3 The elements of a breeding programme

Genetic improvement strategies fall into three main categories: selection between breeds; selection within breeds or lines; and cross-breeding. The choice of which strategy to pursue will depend on the characteristics of the production system and of the types of animal available (i.e. already present in the local area or potentially introduced). To reduce the risk of costly failures, any options under consideration need to be thoroughly assessed. Detailed advice on planning a breeding strategy is provided in the FAO guidelines *Breeding strategies for sustainable management of animal genetic resources* (FAO, 2010).

All within-breed selection programmes (straightbreeding programmes) have a number of common elements. Setting up a breeding programme involves defining a breeding goal and the design of a scheme that is able to deliver genetic progress in line with this goal. This requires, *inter alia*, the identification of selection criteria, recording of animals' performances and pedigrees, genetic evaluation, selection and mating, progress monitoring and dissemination of genetic improvement.

A breeding goal is a list of traits to be targeted by the breeding programme, including their relative importance, and a description of how they should be changed genetically (increased, decreased or maintained the same). Breeding goals inevitably shift over time in response to the changing requirements of livestock producers and ultimately the demands of consumers and society at large. For many years, production traits were the primary target. Later, traits affecting function such as longevity, health and reproductive ability were added, as it was observed that selection for production had led to deterioration in these

traits. Today, as a result of societal pressures, increasing attention is being given to behaviour, well-being and other novel traits. For example, in response to the elimination of gestation stalls in pig husbandry, the breeding industry has started to select for more docile sows, which it is hoped will be more tractable in situations where animals are housed in groups during gestation.

As breeding objectives become broader, breeders increasingly have to deal with antagonisms between different sets of traits. When the genetic correlation between two traits is favourable, selecting for one trait can bring a correlated beneficial response in the other trait. However, when traits are antagonistically correlated, selecting for one trait will lead to an undesirable response in the other. In such cases, it is common practice to include both traits in the selection objective and select animals with desirable attributes for both traits. This strategy allows all traits to be improved over time (Neeteson-van Nieuwenhoven *et al.*, 2013). Typically, the most efficient way to select for multiple traits is to combine them into a "selection index" (Phocas *et al.*, 2013). Traits are weighted according to index coefficients that consider the economic importance of traits and their genetic relationships and maximize the correlation between the selection index and the breeding goal.

The outcomes of breeding programmes, particularly in species with long generation intervals, are realized many years after selection decisions are made. Even in poultry, a genetic change implemented in a breeding nucleus will take at least three years to have a noticeable effect at commercial level. This underlines the need to anticipate future demands when defining breeding goals. Breeders and breeding organizations need to be tuned into societal pressures and how they are likely to affect future demand.

Animal identification and the recording of animals' performance and pedigrees are the driving forces of genetic improvement. Detailed advice on the development of animal recording systems is provided in the FAO guidelines on the *Development of integrated multipurpose animal recording systems* (FAO, 2015). Abundant and accurate measurements lead to efficient selection. As described above (Subsection 2), developments in the field of genome-enabled selection are creating significant new opportunities to improve animal breeding. A key prerequisite is to have sufficient phenotypic information recorded for the traits that potentially benefit the most from the use of this technology (e.g. health traits, sex-limited traits and traits that are difficult or impossible to measure in live animals).

Genetic evaluation is the process of determining which animals have a superior genotype for the traits of interest so that decisions can be taken as to which animals should be used to breed the next generation. As performance is influenced both by the animal's genetics and by its environment, genetic evaluation involves separating environmental components from genetic components. As described above in Subsection 2, genetic evaluation methods based on information on the performance of animals and their relatives are now being supplemented by methods that involve the use of molecular genetic information. The extent to which these new methods have moved beyond the research level and into commercial production varies from species to species (see Subsection 4 and also Part 3 Section E).

Capacity to store performance and pedigree data for use in genetic evaluations is continuously increasing as more sophisticated computer hardware becomes more widely available. It is likely that technology will continue to improve and that capacity to run yet more complex genomic evaluations will not be limited by hardware availability. The greatest limitation may prove to be a lack of progress in the development of software for these types of analysis because of a lack of trained personnel in the field of animal breeding and genetics and a lack of labs working on the development of the specialized software required.

Family information in genetic evaluation increases the probability of co-selecting close relatives, which in turn leads to increased inbreeding. Various methods are used to reduce inbreeding

while maintaining high rates of genetic gain. All are based on the principle of reducing the average relationship between the individuals selected. Computer programmes have been developed to optimize selection decisions for a given list of candidates for which pedigree information and EBVs are available (Weigel and Lin, 2000). Other mating rules or methods for reducing the accumulation of inbreeding in a population were outlined in the first SoW-AnGR[2] (see also Part 4 Section D and FAO, 2013). These rules have been utilized in commercial poultry and pig breeding to maintain inbreeding at relatively low levels. Many breeding companies have moved towards using programs such as "Mate Select" to control inbreeding more systematically.

The progress achieved in a breeding programme is usually assessed by regressing average phenotypic and breeding values on year of birth. In addition, breeders run regular internal and external performance testing. An external testing scheme needs to cover a wide range of production environments to ensure that selected animals can perform well under a wide range of conditions. Other sources of information, and probably the most important, are field results and feedback from customers. Frequently, companies test their products against those of their competitors.

The impact of a breeding programme depends on the dissemination of genetic progress to customers or into the wider livestock population. Reproductive technologies, particularly AI, play an important role in many species. They allow genetic material to be transported around the world and greatly increase the number of offspring that can be obtained from a superior breeding animal. As discussed above (Subsection 2.3), recent years have not seen major technological advances in this field. However, the use of reproductive technologies is becoming more widespread in many countries (see Part 3 Section E).

Despite the ever-increasing sophistication of breeding technologies, it is important to recall that all the elements of a breeding programme can be implemented even under very basic conditions. Success is possible without the use of elaborate data recording and genetic evaluation systems, without genomic tools and without the use of reproductive technologies (see Subsection 5 for further discussion of breeding programmes in low-input systems).

4 Breeding programmes in high-input systems

4.1 Dairy and beef cattle

The characteristics of the cattle breeding industry highlighted in the first SoW-AnGR[3] included:

- a relatively decentralized structure (compared to the pig and poultry sectors), with different organizations performing complementary tasks in the breeding scheme (identification, performance recording, genetic evaluation, selection and commercialization of genetics), the most distinctive feature being the role played by commercial producers in the provision of data used in genetic evaluation;
- (in the dairy sector) a historical emphasis on production traits (milk yield and components) that had led to a great increase in milk output, but also to a deterioration in so-called functional traits, i.e. those related to the animal's health and fertility; this had led breeding organizations to increase the weight of functional traits in selection indices;
- (in the beef sector) a focus on increasing growth rates that had caused an increase in calving problems associated with calf size, as well as creating potential fertility problems associated with heifers being unable to meet higher nutritional demands associated with a larger size;
- a need to improve the recording of functional traits, particularly in beef cattle;

[2] FAO, 2007a, page 395.

[3] FAO, 2007a, pages 396–400.

- a lack of capacity to implement direct selection for feed efficiency, resulting from a lack of capacity to obtain feed-intake data for sufficient numbers of animals;
- a lack of market mechanisms that reward producers for improved meat quality;
- (in the beef sector) a lack of well-organized cross-breeding programmes;
- a major role played by breeders' associations, along with significant input from public institutions in terms of data management and genetic evaluation; and
- a trend towards the internationalization of AI companies.

These characteristics have changed little in the years since the first SoW-AnGR was prepared (2005/2006). Decentralization remains a common theme. Ownership of individual animals remains with private livestock keepers, particularly in the case of female animals, although there is a general trend towards concentration. Breed associations continue to play a major role. The trend towards globalization continues, both in terms of the organization of AI companies and the use of breeds in a transboundary manner. Cross-breeding is a routine practice in dairy cattle as a means of increasing profitability by improving functionality and fitness. As discussed in more detail below, the adoption of genomic selection has been nothing short of revolutionary. The evaluation, acquisition and marketing of AI bulls have been transformed, with a much greater emphasis now given to younger bulls with no progeny.

The breeding objectives listed in the first SoW-AnGR[4] are still relevant to most selection programmes worldwide, but some changes have occurred. In many countries, selection indices for dairy cattle have been adjusted so as to reduce the emphasis given to production traits and to accentuate functional traits such as fertility, longevity and udder health. The major obstacle to including more health traits and novel traits such as feed efficiency in selection programmes is a lack of reliable phenotypic records, either because of logistical problems or because of high costs. The automation of milking procedures has become significantly more widespread during the past decade and is generating a large volume of new records that could potentially be used to expand the portfolio of traits evaluated. The practice of breeding companies establishing contracts with the owners of large herds to collect data on novel traits is foreseen to become more common in the future and to play an increasingly important role in genetic evaluation of these traits. These practices may increase the accuracy of genetic evaluation, but perhaps only for the specific standardized environment in which they are recorded. In beef cattle, growth and carcass traits continue to be the main selection objectives, although calving and fertility traits are receiving increasing attention. Difficulties with reliable recording are even more acute in beef than in dairy operations. Assessing the sophisticated carcass classification data collected by slaughterhouses (e.g. the EUROP carcass classification system)[5] for genetic evaluation purposes would improve the selection process. However, it would require a consistent animal identification infrastructure, from birth to slaughter (or, perhaps, much more widespread reliance on DNA-based measures of animal identification and genetic relationships) that would allow the development of consolidated databases. Current breeding objectives in dairy and beef cattle are summarized in Tables 4C1 and 4C2.

The development of technologies that allow fast, accurate and affordable determination of SNPs has enabled the AI industry to make efficient use of genetic markers for selection purposes and represents the most significant advance in cattle breeding since the adoption of AI (see Subsection 2 for a general description of the role of genetic markers in animal breeding). The completion of the bovine genome sequence and reference assembly (Elsik *et al.*, 2009) enabled the

[4] FAO, 2007a, Table 99 (page 397).

[5] See Commission Regulation (EEC) No 2930/81 of 12 October 1981 adopting additional provisions for the application of the Community scale for the classification of carcasses of adult bovine animals (available at http://tinyurl.com/qejooac).

TABLE 4C1
Selection criteria in dairy cattle

Traits		Comments
Production traits	Milk quantity	More frequently the quantity of protein and/or fat
	Milk quality	Concentration of protein and/or fat
	Feed efficiency	Rarely measured directly
Reproduction traits	Conception rate	For males, it may be calculated based on mates or daughters
	Ease of calving	Often used for mating, rather than selection
Robustness traits	Survival	Measured as longevity
	Mastitis resistance	Either directly based on incidence or indirectly based on somatic cell concentration in milk and udder conformation of daughters
	Leg soundness	Usually based on conformation traits and observed mobility
	Body conformation	Decreased body size has a positive association with feed efficiency and longevity

Note: This table updates and expands upon information provided in Table 99 of the first SoW-AnGR (FAO, 2007a).

TABLE 4C2
Selection criteria in beef cattle

Traits		Comments
Production traits	Body size	Ideal size depends on environment
	Growth rate	Weight at various ages (e.g. birth, weaning, one year of age)
	Milking ability	Measured indirectly based on growth, has an intermediate optimum because high milk production results in waste
	Carcass quality	Carcass yield, loin muscle area
	Feed efficiency	
	Meat quality	Marbling (intramuscular fat), tenderness
Reproduction traits	Male fertility	Measured by using scrotal circumference
	Mothering ability	
	Ease of calving	Based on scores provided by breeders
	Calving interval	Seasonal production requires regular yearly calving
Robustness traits	Survival	Longevity
	Conformation	Leg soundness is important for function in rangeland conditions
	Temperament	To improve safety and increase ease of management

Note: This table updates and expands upon information provided in Table 99 of the first SoW-AnGR (FAO, 2007a).

identification of the several thousands of SNPs used to develop low-cost SNP chips. Genomic screening of a large proportion of the population facilitates the discovery of haplotypes associated with economically important traits such as recessive disorders, reproductive performance, coat colour and polledness. Carriers of such haplotypes are now regularly identified among genotyped cattle (Table 4C3).

Adoption of genomic selection has been extremely rapid in the dairy sector and has already replaced the progeny testing schemes that were the state of the art for several decades. Males, and a rapidly increasing number of females, are

PART **4**

TABLE 4C3

Recessive haplotypes tracked in the genomic evaluation system in the United States of America

Breed	Haplo-type	OMIA 9913 ID[1]	Gene name	Condition/trait	Frequency (%)	Chromosome	Reference
Ayrshire	AH1	001934	*UBE3B*	Conception rate	13.0	17	Cooper *et al.*, 2014, Venhoranta *et al.*, 2014
Brown Swiss	BH1	001825	—	Abortion	6.67	7	VanRaden *et al.*, 2011
	BH2	001939	—	Abortion	7.78	19	Schwarzenbacher *et al.*, 2012
	BHD	001247	*SPAST*	Spinal dysmyelination	2.19	11	Hafner *et al.*, 1993, Thomsen *et al.*, 2010
	BHM	000939	*KDSR (FVT1)*	Spinal muscular atrophy	3.61	24	El-Hamidi *et al.*, 1989, Krebs *et al.*, 2007
	BHW	000827		Progressive degenerative myeloencephalopathy (Weaver syndrome)	1.56	4	McClure *et al.*, 2013
Holstein	HBR	—	*MC1R (MSHR)*	Black/red coat colour	0.8	18	Lawlor *et al.*, 2014
	HDR	—		Dominant red coat colour	0.04	3	Lawlor *et al.*, 2014
	HH0	000151	*FANCI*	Brachyspina	2.76	21	Agerholm *et al.*, 2006, Charlier *et al.*, 2012
	HH1	000001	*APAF1*	Abortion	1.92	5	Adams *et al.*, 2012
	HH2	001823	—	Abortion	1.66	1	VanRaden *et al.*, 2011, McClure *et al.*, 2014
	HH3	001824	*SMC2*	Abortion	2.95	8	Daetwyler *et al.*, 2014, McClure *et al.*, 2014
	HH4	001826	*GART*	Abortion	0.37	1	Fritz *et al.*, 2013
	HH5	001941	—	Abortion	2.22	9	Cooper *et al.*, 2013
	HHB	000595	*ITGB2*	Leukocyte adhesion deficiency, type I (BLAD)	0.25	1	Shuster *et al.*, 1992
	HHC	001340	*SLC35A3*	Complex vertebral malformation	1.37	3	Agerholm *et al.*, 2001
	HHD	000262	*UMPS*	Deficiency of uridine monophosphate synthase (DUMPS)	0.01	1	Shanks *et al.*, 1984
	HHM	000963	*LRP4*	Syndactyly (mule foot)	0.07	15	Eldridge *et al.*, 1951, Duchesne *et al.*, 2006
	HHP	000483	*POLLED*	Polled/horns	0.71	1	Medugorac *et al.*, 2012, Rothammer *et al.*, 2014
	HHR	001199	*MC1R (MSHR)*	Red coat colour	5.42	18	Joerg *et al.*, 1996
Jersey	JH1	001697	*CWC15*	Abortion	12.10	15	Sonstegard *et al.*, 2013
	JH2	001942	—	Abortion	1.3	26	VanRaden *et al.*, 2014

Note: [1] Online Mendelian Inheritance in Animals (http://omia.angis.org.au/) identification number for *Bos taurus* (National Center for Biotechnology Information species code 9913).
Source: Cole *et al.*, 2015.

genotyped at very young ages and not used as breeding animals if their GEBVs do not meet the selection criteria. In combination with advances in multiple ovulation and embryo transfer (MOET), genomic selection has shortened the generation interval to such an extent that the sires of the currently active AI bulls do not yet have any recorded progeny. The replacement of progeny testing has been a revolution in dairy cattle breeding, but yet another paradigm shift is now taking hold. The relatively low reproductive capacity of cattle and the rates of involuntary culling have traditionally meant that the female offspring from all cows were needed as replacements within a given herd. Therefore, genetic improvement via the dam-of-daughters pathway has been negligible. Now, the combination of sexed-semen technologies and low-density, low-cost SNP chips has increased both the selection intensity and the selection accuracy within this pathway, thus creating a new opportunity for additional genetic improvement.

Because the accuracy of GEBVs is highly dependent on the size of reference populations (Hayes *et al.*, 2009b), even the largest cattle populations greatly benefit from international exchanges of genomic data. Exporting countries took the lead in adopting genomic technologies and formed consortia to share genotypes. Interbull, a subcommittee of the International Committee for Animal Recording (ICAR), has continually adapted its activities to account for the use of genomic information in genetic evaluation. The market has become polarized into two major blocks, the importers and the exporters of genetics. The technological gap between these two blocks has widened rapidly, both because of the investments required and because of a relative lack of expertise in the importing countries. Poor results from multibreed genomic predictions have hindered genomic applications in smaller, non-mainstream, populations and the hegemony of the Holstein has been increasing at a greater speed. The potential uses of genomics are seemingly limitless. New actors coming from sectors not directly related to dairy or beef breeding (e.g. pharmaceutical companies) have started to take the lead and supply innovative and customized services to dairy breeders in a manner similar to that already pertaining in the poultry and pig industries. Data ownership has become a key issue and control over the genetic-improvement process may shift from breeders to corporations (Dürr, 2013).

Genomic selection has advanced more slowly in the beef sector. This is mainly because of differences in population structure (in dairy breeds, the large number of offspring produced per bull through AI improves the precision of genomic selection), the fact that major production traits such as growth rate can be measured in all animals relatively early in life and the lack of large phenotypic and animal-pedigree databases for beef cattle.

4.2 Sheep

The first SoW-AnGR presented an overview of the state of sheep breeding in high-input systems, noting the selection criteria utilized and describing the organization of the breeding sector in different parts of the world.[6] Table 4C4 summarizes the traits most commonly considered in current sheep breeding programmes. While the broad characteristics of the sheep breeding industry remain similar to those described in the first SoW-AnGR, breeding programmes for high-input systems have undergone considerable change in the past decade. Although developments in genomic prediction are exciting and have attracted considerable research investment in a number of countries, structural and economic effects are also very important.

While in general, sheep breeding programmes have typically aimed to improve production and reproduction traits, identification of molecular markers for major genes that directly affect sheep health has led to the incorporation of selection for health traits. Selection for the ARR haplotype at the *PRNP* locus and against the VRQ haplotype has been used in several countries to reduce susceptibility to scrapie (Hunter, 2007). Selection

[6] FAO, 2007a, pages 400–402.

TABLE 4C4
Selection criteria in sheep

Traits		Comments
Production traits	Body size	Ideal size depends on environment
	Growth rate	Weight at various ages (e.g. birth, weaning, one year of age)
	Meat yield	Proportion of fat in the carcass and lean distribution across carcass regions
	Meat quality	Marbling (intramuscular fat), tenderness
	Wool quantity and quality	Fleece weight, fibre diameter, advanced processing characteristics (e.g. coefficient of variation of fibre diameter, staple strength)
	Milk yield and quality	
Reproduction traits	Litter size	Twinning rate, larger numbers of offspring may be detrimental
	Mothering ability	Number of lambs weaned, milk yield, early growth
	Weaning rate	Number of lambs weaned, combining effects of litter size and lamb survival
Robustness traits	Survival	Longevity
	Parasite resistance	Helminths, blowfly strike
	Scrapie resistance	Based on molecular tests
	Mastitis resistance	Trait indirectly selected for based on somatic cell concentration in milk
	Udder conformation	

Note: This table updates and expands upon information provided in Table 99 of the first SoW-AnGR (FAO, 2007a).

against day blindness in Awassi sheep is being undertaken via the *CNGA3* locus (Reicher *et al.*, 2010) and resistance to maedi visna infection has been shown to have favourable alleles at the *TMEM154* locus (Heaton *et al*., 2012).

In the very intensive sheep-farming systems of Europe and the Middle East, where high prolificacy is economically important, use of genetic technologies such as introgression of the *FecB* mutation with the aid of molecular genotyping (Gootwine *et al*., 2008) and the advent of genomic selection (Larroque *et al*., 2014) have created substantial opportunities to increase the rate of genetic progress. Breeding programmes for improving milk production traits are in place in several European counties. Most milk recording is carried out in France, Italy and Spain, where large-scale use of AI facilitates breeding work. According to an ICAR survey reported in 2013 (Astruc, 2014), there are about 2 million sheep under recording, almost exclusively in European countries.

The potential to exploit genomic selection is less in small milking ruminants than in dairy cattle breeds such as the Holstein, which have larger values per animal, longer generation intervals in progeny testing schemes, smaller effective population sizes and larger numbers of historical individuals with accurately recorded phenotypes and genotypes. However, because genomic selection simplifies the AI cooperative structure, a shift towards genomic breeding strategies is occurring, at least in some French milking sheep breeding programmes (Duchemin *et al*., 2012; Larroque *et al*., 2014) (see Box 4C3).

In the meat and wool sectors, programmes such as the National Sheep Improvement Program in the United States of America[7] and LAMBPLAN[8] in Australia evaluate records of on-farm performance

[7] www.nsip.org
[8] http://www.sheepgenetics.org.au/Breeding-services/LAMBPLAN-Home

Box 4C3

Adoption of genomic selection in French dairy sheep breeds

Given the importance of ewe-milk production in France, there is growing interest in implementing genomic selection in dairy sheep breeds. The reliabilities of genomic breeding values for the Lacaune and Blond-Faced Manech sheep breeds are similar to those of the Montbéliard and Normande dairy cattle breeds, as they all have reference populations of a similar size (Duchemin, 2012; Baloche *et al.*, 2014). A simulation study of the Lacaune has indicated that genomic selection could increase annual genetic gain by 15 percent as a result of an increase in the intensity of selection of young rams (Buisson *et al.*, 2014). The simulation predicted that the increased income obtained would compensate for the extra costs of genotyping. Based on this information, Lacaune breeders decided, in 2015, to shift to a genomic breeding programme. It is assumed that genotyping costs will continue to decrease in the future, thus increasing the potential economic benefits of genomic selection. Breeders of the Blond-Faced Manech breed are planning to adopt routine genomic selection in the near future.

records and provide the industry with EBVs for many traits for elite and young rams belonging to a range of breeds. Some EBVs are combined to calculate indexes for specific breeding goals.

Breed shifts and the introduction of composite breed types have been transformational in New Zealand and Australia over recent decades. This has been driven, at least partly, by shifts in focus from wool production to meat production. Interestingly, in New Zealand, although higher performance composites rapidly took substantial market share following the introduction of novel breeds from Europe, much of this market share has since been recovered by breed types (including lower-performance composites) identified by farmers as having higher levels of robustness in breeding ewes. Sheep flocks in New Zealand are increasingly being forced into harsher production environments due to rapid expansion of the dairy industry (Morris and Kenyon, 2014). The three test sites of the country's central progeny testing structure, widely recognized as a key facilitator of accelerating rates of genetic progress, have recently been supplemented by two additional sites, both of which are commercial farms operating in very harsh production environments.

Despite considerable investment in genomic approaches, there are still challenges to the integration of these technologies into breeding programmes. Both the Australian approach, based on a very large reference population with intensive phenotypic recording, and the New Zealand approach, based on industry sires as the training resource, have produced relatively modest improvements in selection accuracy compared, for example, to those achieved in Holstein cattle (Dodds *et al.*, 2014; Swann *et al.*, 2014). To date, adoption of genomic selection approaches in both countries has been limited to highly progressive breeders who wish to be at the forefront of technology and are content with marginal gains in the rate of genetic progress. Work on how to integrate genomic predictions into novel breeding programme structures and attempts to reduce testing costs per animal and per breeding scheme via two-stage selection strategies (Sise *et al.*, 2011) and combination with reproductive technologies (Granleese *et al.*, 2013) have been identified as keys to increased adoption. Research is also being undertaken into higher-density chips and gene sequences, although there is little evidence of practical benefits. Exploiting the ever-decreasing costs of genome sequencing remains an exciting challenge for the future.

Formal industry structures and coordinated provision of genetic improvement services such as databases and genetic evaluation systems are critical to the success of genetic evaluation systems. However, even where such systems exist, rates of adoption of new technologies may be poor and rates of penetration into the commercial sector by rams from flocks in which the latest technologies are used may be very low (Amer *et al.*, 2007). An

example of steps that can be taken to overcome challenges of this kind is provided in Box 4C4.

4.3 Goats

The first SoW-AnGR provided a short review of the state of goat-breeding programmes in high-input systems, noting that such programmes were mainly concentrated in Europe and North America and focused mainly on dairy breeds. Breeding programmes for meat goats were described as being present in a few countries with well-developed goat-meat sectors, such as Australia, South Africa and the United States of America.[9] This overall picture has not changed greatly in the recent years. Well-structured goat breeding programmes are generally found only in developed countries where the production, processing and commercialization of goat products are well organized. Table 4C5 lists the most important traits considered in contemporary breeding programmes for dairy and meat breeds.

All effective goat breeding programmes are based on straight-breeding. They rely on the existence of well-characterized breeds and breeders' associations that can manage herd books and performance-recording systems. As with other

[9] FAO, 2007a, page 402.

Box 4C4

Improving the system of sheep breeding in Ireland

In Ireland, a new and modern support structure has been put in place to support sheep breeding. The initial challenge has been to engage with a breeding sector that historically relied on basic phenotypes and physical type traits as primary selection criteria, and to overcome the barrier of having many small breeder flocks with low levels of genetic connectedness among them. A central progeny testing scheme has been established, which originally had the goal of increasing levels of genetic connectedness. More recently, the focus has switched to identifying sires of sires that excel for a balance of maternal and carcass traits (Pabiou *et al.*, 2014). If these sires get used through AI in a large number of flocks that market rams for natural service, it will be possible to multiply the elite genetic material across a substantial proportion of the industry. This strategy is less reliant on widespread uptake of recording by all breeders, for many of whom ram production and marketing is a secondary source of income. In addition, interest is growing in Ireland in the potential of genomic selection, and also imported genetics, to accelerate genetic progress.

TABLE 4C5

Selection criteria in goats

Traits		Comments
Production traits	Body size	
	Growth rate	Weight at various ages (e.g. birth, weaning, one year of age)
	Meat quality	Marbling (intramuscular fat), tenderness
	Milk yield and quality	
	Fibre quantity and quality	Fleece weight and fibre diameter (for mohair and cashmere producers)
Reproduction traits	Litter size	Twinning rate, larger numbers of offspring may be detrimental
	Mothering ability	Number of kids weaned, combining effects of litter size and kid survival
Robustness traits	Survival	Longevity
	Mastitis resistance	

Note: This table updates and expands upon information provided in Table 99 of the first SoW-AnGR (FAO, 2007a).

species, goat breeds are monitored for inbreeding, and the selection and diffusion of AI bucks is modulated to minimize inbreeding (Colleau *et al.*, 2011; Palhiere *et al.*, 2014). Obtaining EBVs that are sufficiently reliable for efficient selection requires the recording of pedigree information and at least a minimum of genetic connection between herds. Schemes based on progeny testing and the collective use of sires have become somewhat more common in recent years. In addition to the French and Norwegian programmes noted in the first SoW-AnGR (the former involving the use of AI and the latter the sharing of sires among cooperating breeders), examples now include selection schemes for Spanish dairy breeds (Murciano-granadina, Malagueña, Florida and Payoya), based on progeny-tested males and the use of their semen for planned matings throughout the whole selection nucleus (Seradilla, 2014). Although some of these schemes have achieved a degree of success (Menendez-Buxadera *et al.*, 2014), several constraints to their further development remain to be resolved, particularly with regard to their economic sustainability (Serradilla, 2008).

There have also been some notable developments in Latin America. In Brazil, selection schemes for improving meat and milk production have been implemented in small selection nuclei of imported and locally adapted breeds (Lôbo *et al.*, 2010). In Mexico, a small selection nucleus has been organized by a group of breeders from the state of Guanajuato, which also progeny tests sires through AI and undertakes genetic evaluation of sires and dams (Torres Vázquez *et al.*, 2009).

The main technological innovation in recent years has been the development of tools for the exploitation of molecular genomics in advanced selection schemes. Gene-assisted selection is currently applied in France and Norway to improve milk protein content (Manfredi and Ådnøi, 2012). The International Goat Genome Consortium[10] has worked with a private company to develop a commercially available SNP chip for goats (Tosser-Klopp, 2012). France has investigated the adoption of genomic selection and has established reference populations for the popular Alpine and Saanen breeds (Larroque *et al.*, 2014). Study of these populations suggests that the reliability of genomic evaluation would be less than in dairy cattle breeds with large populations, but similar to that in cattle breeds with equivalent population sizes (ibid.). In addition, in contrast to the findings of most studies in dairy cattle (e.g. Kemper *et al.*, 2015), joint genomic evaluation of goat breeds tends to improve the accuracy of GEBVs (Carillier *et al.*, 2014).

[10] http://www.goatgenome.org/

4.4 Pigs

The basic structure of the pig breeding sector remains similar to that described in the first SoW-AnGR.[11] In the typical breeding programme, pedigree selection occurs only within pure-bred lines (designated as sire or dam lines) in the nucleus (i.e. the top layer of the production pyramid). Sire lines are selected for growth and carcass traits, meat quality and robustness. Dam lines are also selected for reproduction traits. New lines are regularly developed by crossing existing lines and/or by specialized selection in a particular direction. A breeding organization's final products are parent sows (two- or three-way crosses) and parent boars (pure lines or two-way crosses). These parent animals are used by producers to breed pigs for slaughter.

The pig-breeding sector is less concentrated than the poultry sector (see Subsection 4.5). There are still many breed associations and many countries have some kind of national, often semi-governmental, genetic evaluation scheme (e.g. the National Swine Registry in the United States of America, the Canadian Centre for Swine Improvement Inc. and LGPC-IFIP-INRA[12] in France). These schemes compete with pig-breeding companies that may be owned by cooperatives (e.g. Topigs, Danavl, Nucléus and ANAS) or by families (e.g. ACMC, Grimaud, Hendrix and JSR) or may be

[11] FAO, 2007a, pages 402–405.

[12] Livres Généalogiques Porcins Collectifs - Institut de la Filière Porcine - Institut National de la Recherche Agronomique.

corporations (e.g. PIC). Over the years, pig-breeding companies have tended to amalgamate into larger and more cost-efficient entities.

Pig-breeding programmes have been very successful in improving economically important traits (e.g. Chen *et al.*, 2002; Tribout *et al.*, 2010), with growth and carcass performance (growth rate, leanness and feed efficiency) having been targeted since the 1970s and greater attention given to reproductive performance (litter size, piglet survival and farrowing interval) and meat quality (water binding capacity, colour and intramuscular fat content) from the 1990s onwards. Since the 2000s, the focus has been shifting towards breeding for more robust and efficient animals to meet the needs of a more diverse range of production environments (Merks *et al.*, 2012). This has required strategies for dealing with genotype by environment interactions. One popular approach is the combined cross-bred and pure-bred selection (CCPS) scheme, which involves recording the cross-bred progeny of AI nucleus boars under commercial conditions and using the data to estimate the breeding values of pure-bred relatives that are selection candidates in the nucleus (Wei and Van der Steen, 1991). This approach implies increasing the emphasis given to robustness traits such as survival rates, leg soundness, disease resistance, stress susceptibility and longevity. Table 4C6 presents a summary of current selection objectives in pig breeding. Recent changes have been quantitative rather than qualitative: a gradual shift towards robustness traits and efficiency. An important development for the late 2010s will be the introduction of boar taint as a breeding goal trait in the European Union, where piglet castration is likely to end in 2018.

With ongoing intensification of the production sector, pig health is becoming ever more important. This requires, in the first place, improving sanitary status and biosecurity at the breeding-farm level, so that diseases are not introduced from the breeding farms into the production pyramid. It has also triggered attempts to breed for disease resistance and against metabolic disorders. However, this work is only in its initial stages. Globally, pig

TABLE 4C6
Selection criteria in pigs

Traits		Comments
Production traits	Growth rate	At various ages
	Carcass quality	Carcass yield, carcass leanness, uniformity
	Feed efficiency	
	Meat quality	Water-holding capacity, colour, intramuscular fat content
Reproduction traits	Litter size	
	Piglet survival	Mothering ability of the sow, viability of the piglets, litter uniformity
	Farrowing interval	
Robustness traits	Stress susceptibility: halothane sensitivity	Allele eradication at a single gene; still relevant in a few extreme sire lines only
	Congenital defects	Atresia ani, cryptorchidism, splayleg, hernias, hermaphrodites, etc.
	Leg soundness	Osteochondrosis and many other aspects
	Disease resistance	Specific *Escherichia coli* strains
	Survival	Piglet viability (effect of the sire); postweaning survival rates
	Sow longevity	

Note: This is an updated version of Table 100 of the first SoW-AnGR (FAO, 2007a).

production is gradually shifting from temperate to warmer climatic zones and this has created requirements for animals that are resilient to hot conditions. This has led to the introduction of novel breeding–goal traits such as lactation feed intake (Renaudeau *et al.*, 2014). In Western societies, increasing attention to animal welfare is leading to the introduction of novel housing systems, which in turn is leading to the adoption of a new set of breeding-goal traits, mainly related to various aspects of animal behaviour. Growing concern about environmental efficiency (e.g. greenhouse gas emission, phosphorus retention and nitrogen excretion) is likely to increase the emphasis given to feed efficiency in genetic improvement programmes.

Because of the competitive nature of the industry and its high levels of investment, commercial breeding companies usually spearhead the use of technologies. Many use MAS in one form or another and a handful have implemented full-scale genomic selection (Van Eenennaam *et al.*, 2014). These are expensive technologies, and studies have been undertaken to evaluate their financial feasibility in various breeding systems (e.g. Abell *et al.*, 2014). Another important innovation has been the development of optimization routines that balance between genetic improvement and inbreeding in the planning of selection and mating schedules at nucleus level (see Subsections 2.1 and 3). At present, a major focus of development is accommodating genomic information in mate-selection procedures.

4.5 Poultry

The first SoW-AnGR provided an overview of the poultry-breeding industry, noting its hierarchical structure, often referred to as the "breeding pyramid", and its concentration in the hands of a small number of companies.[13] It also discussed the main selection criteria in poultry breeding programmes, noting a trend towards the inclusion of ever more traits in breeding objectives.

A typical poultry breeding programme includes a biosecure breeding nucleus from which genetic improvement is disseminated to the wider industry through multiplication tiers at great-grand parent, grandparent and parent levels. Improved birds are multiplied and crossed, in three or four steps, in the lower tiers of the breeding structure to produce broiler or layer birds (see Table 4C7). It is important to note, however, that the traditional portrayal of the structure of the poultry industry as a pyramid, with the breeding programme at the apex, is something of an over simplification (Laughlin, 2007). The structure can more accurately be represented by two pyramids: a small supporting pyramid at the base, representing the specialized breeding programmes, and a larger inverted pyramid above, representing the other tiers of production, with the consumer at the top (see Figure 4C1). The supporting pyramid contains all the elements needed to maintain a breeding programme: experimental lines, test lines and pure lines, along with the various support systems of modern genetics, including a strong research

[13] FAO, 2007a, pages 404–405.

TABLE 4C7

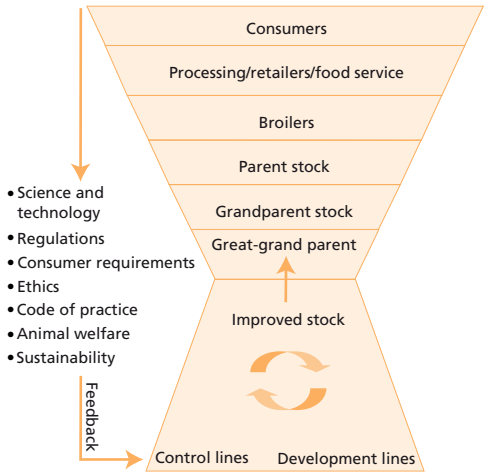
Cross-breeding scheme and relative numbers in a typical broiler breeding programme

Level in breeding pyramid	Paternal lines		Maternal lines	
Pedigree stock	A♂ × A♀	B♂ × B♀	C♂ × C♀	D♂ × D♀
Great grand parents	1 A♂ × 10 A♀	10 B♂ × 100 B♀	3 C♂ × 30 C♀	25 D♂ × 250 D♀
Grand parents	250 A♂ × 2 500 B♀		1 500 C ♂ × 12 500 D♀	
Parents	62 500 AB♂ × 625 000 CD♀			
Broilers	87 million ABCD			

Source: Adapted from Hiemstra and Napel, 2013.

PART **4**

FIGURE 4C1
Structure of the poultry breeding industry



and development base geared towards responding to feedback from every tier of the industry and from society.

The poultry-breeding industry remains concentrated in few hands. Fewer than five groups of primary breeders dominate the market for breeding stock (Fuglie and Heisey, 2011) and some of these are involved in the production of more than one poultry species. Most breeding companies are based in Europe or North America, with subsidiaries in major production regions.

The main breeding objectives and selection criteria in commercial poultry breeding are summarized in Table 4C8. Since the 1960s, breeding goals have evolved from a narrow starting point emphasizing production traits to now encompass a very broad range of considerations, including reproduction, animal health, product quality and environmental impact. This expansion has been particularly notable during the last two decades (Neeteson-van Nieuwenhoven *et al.*, 2013). The trend has been driven by the need for efficiency, including in environmental terms, as well as by the need for robustness and adaptability to varying production environments.

Poultry breeding is a global business and poultry are raised in production environments that vary substantially in terms of ambient temperature, humidity, altitude, disease exposure, feed quality and management capacity. Many regions where poultry are produced are highly vulnerable to climate change, and the development of resilient strains able to cope with climate change-affected production environments has become a focus of many breeding programmes. The high cost of recording and the need to maintain strict biosecurity mean that breeding companies typically undertake selection at a limited number of sites, rather than at many sites spread around the world. There is therefore a high potential for genotype × environment interactions (Neeteson-van Nieuwenhoven *et al.*, 2013). To reduce the problem, poultry breeders have developed crosses that are robust to minor changes in the production environment. This is achieved by testing the siblings of selection candidates, different lines or different cross-bred progeny in multiple production facilities and field environments. The field data are then combined with data obtained in the breeding nucleus.

Increasing attention is also being paid to the need to reduce the carbon footprint of poultry production systems. This has led to an increased focus on the efficiency of production and a consequent shift in breeding objectives. Life-cycle analyses have indicated that the feed supply chain contributes a large proportion of the poultry sector's share of global greenhouse gas emissions (Pelletier *et al.*, 2014). Improving feed efficiency is thus a key factor in reducing the environmental impact of poultry production (Olori, 2010; Pelletier *et al.*, 2014). It has been estimated that an improvement in feed efficiency resulting in a saving of 15 g feed per kg body weight gained would reduce global poultry feed requirements by around 1.85 million tonnes per year, freeing up about 4 000 km^2 of arable land[14] (Neeteson-van Nieuwenhoven *et al.*, 2013). Feed intake, feed conversion ratio and residual feed intake are included in breeding objectives in

[14] Based on 2010 harvest yield of 466 tonnes of wheat per km^2.

TABLE 4C8
Selection criteria in poultry

Traits		Comments
Egg production	Egg number Hen house production Hen-day percentage	Chickens, ducks and geese: number of saleable eggs per bird
Egg weight	Egg weight/size, shape index	
Egg quality – external	Shell breaking strength Shell thickness Shell porosity/egg weight loss Shell colour, egg shape	Broiler and layer chickens: shell breaking strength, puncture score, dynamic stiffness, resonance frequency; egg weight loss between setting and transfer as a measure of shell porosity
Egg quality – internal	Haugh unit, albumen height, yolk percentage	
Meat production	Growth rate Body weight at various ages Breast meat percentage Leg meat percentage Fat percentage Eviscerated yield percentage	Chickens, turkeys and ducks: high emphasis on selection against fat in meat-type ducks; fat percentage assessed on live birds using multidimensional ultrasound measures as well as condition scoring
Feed efficiency	Feed intake Residual feed intake Feed conversion ratio	Feed conversion ratio is feed intake per kg weight gain in meat-type birds and per kg egg mass in layers
Health, welfare and metabolic fitness	Liveability, leg health and walking Gait, bone strength Gut health Heart and lung function Feather-pecking behaviour Feather cover End of lay condition score	Selection for improved robustness, disease resistance and liveability traits and for decrease of (for example) tibial dyschondroplasia assessed with a lixiscope, valgus/varus, osteoporosis, toe defects, footpad dermatitis, femoral head necrosis and hockburn; heart and lung function assessed by measuring blood oxygen saturation using an oximeter
Reproductive efficiency	Fertility and hatchability Early and late embryo mortality Chick viability (survivability beyond day of hatch)	Broiler and layer chickens and turkeys: hatchability in terms of hatch of fertile eggs or hatch of set eggs
Plumage	Plumage colour Feather quality	

Note: This is an updated version of Table 101 of the first SoW-AnGR (FAO, 2007a).

the turkey, layer and broiler sectors. To account for group dynamics in feeding, some breeding programmes have invested in feed recording systems based on transponder technology that allow continuous recording of the feed intake of individual birds in housed groups (Bley and Bessei, 2008; Howie *et al.*, 2010; Tu *et al.*, 2011). This technology also allows the genetic basis of feeding behaviour under competition to be studied (Howie *et al.*, 2009; Howie *et al.*, 2010).

One problem that has been highlighted by some authors (e.g. Dawkins and Layton, 2012) is the risk that rapid growth potential may pose to the welfare and the fertility of breeding birds. Feed management has been effective in optimizing reproductive performance while avoiding obesity and associated welfare problems in breeding birds. However, welfare concerns about hunger have also been raised (D'Eath, 2009). Recent research has focused on behavioural and neurophysiological measures of hunger (Dixon *et al*, 2014; Dunn *et al.*, 2013) and the development of feeding strategies that optimise reproductive performance while avoiding both obesity and hunger (Van Emous, 2015).

Reproductive ability is not only vital to the profitability of the breeding companies' customers, it also affects the intensity of selection within the breeding nucleus. Increased longevity, egg fertility and hatchability, chick viability and persistency of

performance are therefore key breeding objectives. These traits are significantly affected by hen age. New methodologies based on random regression models are now used to evaluate these traits (Wolc *et al.*, 2009; 2010) and this facilitates examination of the persistency of performance over time.

Livability (survival to the end of the production cycle) and persistent performance require healthy birds that are free of physical and physiological defects. Breeding objectives therefore include traits that contribute to the health and welfare of the birds. For example, in the egg-layer sector, efforts are made to minimize cannibalism and feather pecking in group-housing systems. Traits monitored include feather coverage at various ages. Some companies select breeding stock while the birds are housed in groups, particularly in the case of broilers. A strategy based on group selection using so-called social interaction models has also been shown to be feasible (Bijma, 2010) and is being evaluated (Ellen *et al.,* 2011). However, it is generally difficult to estimate genetic parameters for such effects, especially when group sizes are large, and this may limit the use of such methods. Livability also requires reduction in the incidence of cardio-vascular problems (sudden death syndrome and ascites) and leg problems in broilers and turkeys. However, the causes of these problems are multifactorial and have been the focus of research efforts for decades. Many breeding programmes regularly select against contact dermatitis (foot pad and hock burn) (Kapell *et al.*, 2012a) and for improved clinical and subclinical leg health (Kapell *et al.*, 2012b), as well as for measures of heart rate and oxygen saturation as indicators of ascites and sudden death.

Poultry breeders have adopted genomic selection (see Subsection 2.3) as a means of increasing selection accuracy and reducing generation intervals (Avendano *et al*., 2010; Avendano *et al*., 2012; Sitzenstock *et al*., 2013; Wolc *et al.*, 2014). The greatest benefit from genomic selection is expected to be seen in the improvement of traits expressed in only one sex and/or at a late age (e.g. egg production, fertility and hatchability), carcass traits that hitherto required the sacrifice of potential selection candidates, and disease-resistance traits that could otherwise only be meaningfully selected for on the basis of challenge tests (i.e. tests involving exposure to disease). It is now clear that despite these developments traditional data recording remains important, as the accuracy of genomics-predicted breeding values relies on accurate phenotypic data. Further statistical and technological developments that reduce the cost of genotyping individual birds will be key to the widespread application of genomic selection and its contribution to poultry breeding in the coming decades.

4.6 Rabbits

Intensive rabbit-meat production is based on three-way or four-way cross-breeding (Baselga and Blasco 1989; Lebas *et al*. 1997). In maternal lines, litter size remains the most common selection criterion because of its high economic value (Prayaga and Eady, 2000; Cartuche *et al*., 2014). However, functional traits, such as doe longevity, kit survival, maternal traits and genetic resistance to bacterial disease, are emerging as criteria in breeding programmes targeting more sustainable production (Piles *et al*., 2006; Eady *et al*., 2007; Garreau *et al*., 2008a; Sanchez *et al*., 2008). Paternal lines are commonly selected for post-weaning daily gain or for weight at a point close to market age (Rochambeau *et al*., 1989; Lukefahr *et al*., 1996; Piles and Blasco, 2003; Larzul *et al*., 2005). These criteria are easy to record and have a favourable genetic correlation with feed conversion index (Piles *et al*., 2004), which is very important for efficient production, as feeding accounts for the highest proportion of total costs. In Europe, demands from slaughterhouses mean that carcass yield is becoming increasingly important. Disease resistance has also become a major issue. Thus, in addition to weight at slaughter age or average daily gain, some paternal lines are now selected for carcass traits and against susceptibility to digestive disorders (Eady *et al*., 2007; Garreau *et al*., 2008b). Breeding objectives in rabbits are summarized in Table 4C9.

Meat-rabbit selection schemes are found mainly in France, Spain, Italy, Hungary, Egypt and Saudi

TABLE 4C9
Selection criteria in rabbits

Traits		Comments
Meat production	Growth rate or weight at slaughter	
	Carcass yield	
	Thigh muscle volume	Using computerized tomography
Reproductive efficiency	Litter size	
	Litter weight	
	Individual weaning weight	Direct and maternal effects
	Number of teats	
Longevity	Length of productive life	
Health and welfare	Homogeneity of birth weight	Indirect criterion for kit survival
	Genetic resistance to diseases	Mainly digestive disorders
Fibre production	Total fleece weight at each harvest (every 80-120 days)	
Fur size	Live body weight	
Fur density	Density of fibres per skin unit area	
Fur structure and composition	Bristliness or guard-hair content	
Fur priming	Scoring extent of the moult and hair follicle activity	

Arabia. Pedigree selection occurs strictly in specialized paternal and maternal lines, mainly using the BLUP methodology. Genetic improvement is diffused from the breeding nucleus into the wider population via pyramidally structured multiplication units. Some public research organizations are deeply involved in meat-rabbit breeding, either providing scientific and logistic support to private breeding companies (e.g. the Institut National de la Recherche Agronomique in France) or directly managing breeding nuclei (e.g. the Polytechnic University of Valencia and Instituto de Investigación y Tecnología Agroalimentarias in Spain and the University of Kaposvar in Hungary).

In contrast to meat-rabbit breeding, fibre (Rafat *et al*., 2008) and fur production in rabbits is based on pure-bred selection in specialized breeds: Angora for fibre and Rex for fur. Genetic improvement of fibre and fur production in rabbits targets:

- increasing production of fibre or fur to give greater economic return per animal and production unit; and
- improving the quality of the fibre or fur so that it can be processed into superior end-products and thus attract a higher unit value.

Functional and adaptation traits (reproduction, health, growth and maternal traits) are also taken into consideration, but to a lesser extent than in meat production. BLUP methodology is used for genetic evaluation. Programmes are mainly located in France and China and are operated by public organizations and some private companies.

The main objectives of selection in commercial rabbit lines (i.e. prolificacy and feed efficiency) have not changed in recent years. However, research has provided information on the feasibility of improving traits such as the length of does' productive lives (Sanchez *et al*., 2008; Larzul *et al*., 2014), homogeneity of litter weight at birth (Garreau *et al*., 2008a), carcass dressing percentage, heat tolerance (Sanchez and Piles, 2013), resistance to pasteurellosis and diseases causing digestive disorders (Garreau

et al., 2008b; Eady *et al.*, 2007), and efficient production of semen doses for AI (Tusell *et al.*, 2012). As a consequence, new breeding programmes targeting kit and doe survival, carcass dressing percentage and digestive health have been implemented in commercial lines, with successful results. In addition, new selection criteria for improving prolificacy (ovulation rate and litter size – Ziadi *et al.*, 2013) and feed efficiency (residual feed intake and daily weight gain under feed restriction – Drouilhet *et al.*, 2013) have also been introduced. Results from experiments on Angora rabbits have shown that selection for total fleece weight, a simple trait that is easy to measure on-farm, positively affects both quantitative and qualitative traits in wool production (Rafat *et al.*, 2007; Rafat *et al.*, 2008).

Future priorities in rabbit breeding relate to the intensification of production to cope with the expected growth in global demand for animal protein in a way that is economically, environmentally and socially sustainable and to the need to adapt to changing environmental conditions. Breeding for improved disease resistance (robustness) has become a major challenge because of the effect that some infectious diseases (e.g. epizootic rabbit enteropathy and pasteurellosis) have been having on efficiency and productivity, the safety of rabbit products, animal welfare and public perceptions of rabbit production. Research objectives are increasingly focusing on quantifying the genetic control of the host–pathogen interactions, as well as on identifying SNPs associated with resistance.

The recent development of high-throughput genomic tools and statistical methods for dealing with massive amounts of data could allow selection based on SNPs associated with resistance traits. The rabbit genome has been sequenced (Carneiro *et al.*, 2014) and the implementation of gene-based and genomic selection is an emerging area of research in rabbit breeding. Its suitability in this species is still under discussion. As with other species, the use of genomic information could also lead to better understanding of the biological processes underlying important traits.

The design and implementation of recording systems for specific difficult-to-measure traits, such as individual feed intake, would allow consideration to be given to new breeding strategies for improving the efficiency of production. The development of advanced statistical models and procedures involving, *inter alia*, direct and indirect effects (e.g. social effects for traits recorded in animals raised in groups), genetic × environment interactions and the use of information from cross-bred animals in commercial farms is also a major issue for future research.

5 Breeding programmes in low-input systems

The first SoW-AnGR provided an overview of the various challenges involved in establishing breeding programmes (including those involving cross-breeding) in low-input systems.[15] It highlighted the importance of involving livestock keepers from the outset in the planning and implementation of such programmes and of paying attention to traits related to the efficiency of production (i.e. taking input use into account rather than simply targeting increased output). This subsection provides an updated account, beginning with a short description of the main options currently available for establishing breeding programmes in low-input systems and then addressing the specific considerations that need to be taken into account in the implementation of such programmes.

5.1 Breeding strategy options

As noted above (Subsection 3), a genetic improvement strategy can involve selection among breeds, cross-breeding and/or within-breed selection. In a low-input system it is particularly important to ensure that any breeds introduced

[15] FAO, 2007a, pages 405–419.

and any crosses produced are able to thrive in the local production environment. As in all circumstances, breeding strategies for low-input systems should be based on careful assessments of the current state of the targeted production systems, the trends affecting them and the needs and objectives of the local livestock keepers and of society more broadly (FAO, 2010).

A properly implemented cross-breeding scheme offers the opportunity to combine the positive attributes of two different breeds. In a low-input system, this will often involve an attempt to combine the adaptive qualities of a locally adapted breed with the higher production potential of an exotic breed. There are several different types of breeding schemes that can be considered:

- pure-bred or terminal crossing systems – mating of animals from separate pure-bred populations over one or two generations to produce a generation of cross-bred animals that "terminates" the system, i.e. has desirable qualities in production terms, but is not used for breeding;
- rotational crossing – producing an initial two-way cross and then, in each subsequent generation, alternating the sire breed used (can include the incorporation of additional breeds); and
- creation of a new synthetic breed – crossing two or more breeds in order to achieve a desired proportion of each, followed by *inter se* mating of these animals.

The two first options have the advantage of continuously producing a heterosis effect. However, they may present logistical difficulties, and maintaining an exotic parental line in low-input conditions may be problematic (see Serradilla, 2001 for discussion of this issue in goats). As with any other kind of breeding scheme, determining what is possible in the specific local circumstances is a key element of planning a cross-breeding strategy. It has to be emphasized that if cross-breeding efforts are not carefully planned, or if plans are not properly followed, activities of this kind may create serious problems, both in terms of producing animals that are not well suited to local conditions and in terms of eroding the existing locally adapted animal genetic resources. Uncontrolled cross-breeding is regarded as major threat to animal genetic resources in many countries (see Part 1 Section F).

Meta-analyses of studies on dairy and beef cattle in tropical environments (Burrow, 2006; Galukende *et al.*, 2013) have shown that in most cases F1 crosses perform better than other genotypes. For instance, Galukande *et al.* (2013) showed that 50 percent *B. taurus* × *B. indicus* cross-breeds had on average 2.6, 2.4 and 2.2 times higher milk yield than local *B. indicus* in highland, tropical wet and dry and semi-arid climatic zones, respectively. However, harsher production environments can lead to increasing problems with a lack of adaptedness (including reproductive problems) in cross-bred animals and particularly in exotic parental lines. When evaluating a programme involving cross-breeding with exotics, it is therefore important to consider a multiyear time horizon, accounting both for the lifetime profitability of individual animals (i.e. considering input costs, lifespan, reproductive success, etc., in addition to product output) and the costs of maintaining the various populations needed to keep the programme operating in the long term.

Improving a breed through straight breeding is a long-term commitment. In low-input systems it generally involves either a programme based on a central nucleus or a community-based breeding programme. Central nucleus schemes involve genetic improvement in a nucleus flock or herd and subsequent dissemination of improved genetic material directly or indirectly (via a multiplier layer) into the base population. The scope of the operation is, in principle, the whole population of the respective breed. The nucleus may be "closed" (gene flow occurs in one direction only – from the nucleus to the base population) or "open" (gene flow can also occur in the opposite direction, i.e. superior animals from the base population may be used to supplement the nucleus).

The advantage of a programme based on a central nucleus is that it allows the use of advanced genetic evaluation methods (BLUP) and hence rapid genetic progress. Performance and pedigree recording is usually limited to the nucleus. A weakness is that such schemes depend heavily on organizational, technical and financial support (Mueller *et al*., 2015). They also tend to be hierarchical rather than participatory in their planning and operation and hence often fail adequately to address the needs of livestock keepers in low-input systems (e.g. Gizaw *et al*., 2013). Over the years, schemes of this type, entirely managed and controlled by governments or state operators – and with minimal, if any, participation on the part of livestock keepers – have been established in many developing countries (Wurzinger *et al.,* 2013a). A large proportion of them have failed. Such schemes have proven to be effective only when governments and other funding agencies have a long-term perspective and continue to provide technical and financial support until the programmes have achieved self-sustainability (Wurzinger *et al*., 2011).

Community-based schemes (Mueller; 2006; Mueller *et al*., 2015) operate at the scale of a single community rather than at the scale of the whole breed population. As well as operating at community scale, they are also community-based in the sense that livestock keepers are the main players in their design and operation, although support of various kinds may be provided by external stakeholders. A number of different types of structure are possible (Haile *et al*., 2011; Gizaw *et al*., 2013). Schemes may operate with or without a nucleus and, if present, the nucleus may be open or closed. The nucleus may also have a "dispersed" character, i.e. rather than being maintained as a single unit the nucleus animals are maintained in several different flocks or herds. Table 4C10 contrasts the typical characteristics of conventional and community-based breeding programmes.

The number of community-based breeding programmes implemented in low-input systems has increased in recent years (e.g. Kosgey *et al*., 2006; Mueller, 2006; Pastor *et al*., 2008; Wurzinger *et al*., 2008; Tadele *et al*., 2010; Valle Zárate and Markemann, 2010; Wurzinger *et al*., 2011; Abegaz *et al*., 2013). A review prepared by Mueller *et al.* (2015) describes eight case studies of community-based programmes. An overview of the main characteristics of these programmes is provided in Table 4C11, along with some additional examples.

Experience indicates that establishing a successful community-based programme requires the involvement of a range of stakeholders (livestock keepers, local government, NGOs, universities, etc.) (Wurzinger *et al.,* 2013a). Adopting a participatory approach from the start of the planning process will help to ensure commitment and ownership and to clarify the roles and responsibilities of the various stakeholders involved.

5.2 Specific challenges involved in establishing and operating breeding programmes in low-input systems

The recording scheme of a community-based breeding programme needs to be cost-effective and should not be too elaborate for local conditions (Wurzinger *et al.,* 2011). Performance testing at central stations and visual appraisal in herds are commonly used in recording schemes for meat and fibre production. A milk-recording scheme is more challenging, as it requires repeated measurements. Timely feedback is needed in order to maintain livestock keepers' interest in the recording scheme (Wurzinger *et al.,* 2011; Iñiguez *et al.,* 2013).

As most livestock keepers are interested in improving many different traits, the use of an economic selection index (see Subsection 3) to determine which animals should be used for breeding is generally recommended (e.g. Gizaw *et al*., 2010). In the case of breeding schemes based on dispersed nuclei, livestock keepers will need to be more involved in the implementation of the animal identification and recording activities, and they will also need to agree on arrangements for sharing males to establish genetic linkages between herds/flocks.

TABLE 4C10

Characteristics of conventional and community-based livestock breeding programmes

Characteristic	Conventional breeding programme	Community-based breeding programme
Geographical limit	Regional – inter-regional	Communities
Market orientation	Commercial	Subsistence – commercial
Agent of programme	Breeding company – breeder organization	Livestock keeper – breeder
Breeding objective	Defined by company – breeder organization	Defined by breeder – livestock keeper
Breeding structure	Large scale, pyramidal	Small scale, one or two tiers
Genetic resources	International	Local
Infrastructure	Available	Limited
Management	Intensive – high input	Extensive – low input
Risk taker	Company – livestock keeper organization	Livestock keeper
Decision on share of benefits	Variable	Livestock keeper

Source: Mueller *et al.*, 2015.

TABLE 4C11

Selected community-based breeding programmes

Country	Species	Main product	Period	Location	Total animal population	Breeding system	Key references
Argentina	Goats	Mohair	1987 – ongoing	Dispersed	62 000	Open nucleus	Mueller, 1995; Lanari *et al.*, 2009; Mueller, 2013b
Bolivia (Plurinational State of)	Llamas	Fibre	2008 – 2012	Villages	2 500	Open nucleus	Wurzinger *et al.*, 2008
Ethiopia	Sheep	Meat	2009 – ongoing	Communal	10 000	All flock	Haile *et al.*, 2011; Duguma *et al.*, 2011; Mirkena *et al.*, 2012
Iran (Islamic Republic of)	Goats	Cashmere	2009 – ongoing	Nomad	2 800	Open nucleus	Mueller, 2013
Kenya	Goats	Dairy	1997 – ongoing	Dispersed groups	20 000	Open nucleus	Ojango *et al.*, 2010
Mexico	Goats	Dairy	2007 – ongoing	Village	200	All flock	Wurzinger *et al.*, 2013b
Mexico	Goats	Dairy	2000 – ongoing	Villages	1 500	Open nucleus	Valencia-Posadas *et al.*, 2012
Peru	Sheep	Wool	1996 – ongoing	Communal	160 000	Open nucleus	Mueller *et al.*, 2002; Mueller, 2013
Uganda	Chickens	Eggs	2003 – ongoing	Dispersed groups	>120 000	Multilevel cross-breeding	Roothaert *et al.*, 2011
Viet Nam	Pigs	Meat	2000 – ongoing	Villages	700	Open nucleus	Valle Zárate and Markemann, 2010; Roessler *et al.*, 2012

Sources: Mueller *et al.*, 2015; Valencia-Posadas *et al.*, 2012.

Box 4C5

GENECOC – the breeding programme for meat goats and sheep in Brazil

In 2003, the Brazilian Agricultural Research Corporation (EMBRAPA) launched the Breeding Program for Meat Goats and Sheep – GENECOC*. Up to that time, there had been no structured breeding programmes for goats and sheep in Brazil and there was a lack of recorded information on the performance of these species.

GENECOC is a genetic advisory service that aims to encourage and assist programme participants with record keeping in their flocks and the generation of reliable information that can be used in selection decisions. GENECOC targets all kinds of animals and breeders, focusing particularly on locally adapted breeds and low-input systems. Breeding strategies are matched to local production systems. However, the main feature of the scheme is the use of web-based software to record, organize, store and manage the information generated. The system includes tools for selecting animals for total genetic merit through the use of (breed specific) selection indexes and identifying the set of matings that maximizes the genetic gain of the flock, while controlling inbreeding.

One important action undertaken under the programme targets the Morada Nova sheep, a locally adapted breed that was once at risk of extinction. Participatory methodologies are used in the implementation of a community-based programme, including in the definition of breeding objectives, performance testing in young rams and the organization of monthly planning meetings.

Today, in addition to its activities in Brazil, GENECOC also participates in projects in other countries, including Ethiopia and the United States of America.

The principal impacts of the programme have been in adding value to locally adapted sheep and goat breeds and optimizing their use while respecting environmental concerns. Experience has shown that it is important to identify and involve key stakeholders, to use a well-organized and well-trusted data-collection system backed-up by government funding and, when designing breeding objectives and selection criteria, to consider not only traits related to market trends, but also traits that livestock keepers judge to be important. Future plans include expanding activities to include additional sheep and goat breeds and expanding the system for multiplying improved animals to cover additional local production systems.

Provided by Raimundo Nonato Braga Lôbo.
For further information see Lôbo *et al.* (2010); Lôbo *et al.* (2011) and Shiotsuki *et al.* (2014).
*http://srvgen.cnpc.embrapa.br/pagina/english/principal.php

Morada Nova sheep in Northeast region of Brazil

Photo credit: Olivardo Facó.

Weighing Morada Nova lambs

Photo credit: Olivardo Facó.

Box 4C6

Establishing a cross-breeding scheme for dairy goats in the United Republic of Tanzania

Toggenburg goats were introduced into Babati, United Republic of Tanzania, as the result of a Farm Africa project in 1990. The project originally brought in four pure-bred Toggenburg does and one Toggenburg buck and established a women's group that operated a goat-in-trust* scheme. Because of the poor performance of the women's group, a sister project was initiated, under which commercial groups (groups of goat keepers raising animals for commercial as well as subsistence purposes) were established through a goat-in-trust scheme.

In 1997, the commercial goat raisers formed the Toggenburg Breed Association (TOBRA) as a commercial dairy goat production association. In 1998, TOBRA was registered by the Ministry of Home Affairs. At the time it had only 12 members. In 2001, TOBRA established eight dairy goat production groups. By the end of 2007,** the number of groups had expanded to 52, involving 188 farmers, with an average of eight goats each. People were initially very reluctant to join the groups, but following sensitization efforts they began to join voluntarily. Association members raise pure Toggenburgs, 75 percent Toggenburg crosses and 50 percent Toggenburg crosses. The cross-bred animals are carefully evaluated by analysing their pedigrees and productive and reproductive performances.

TOBRA started with 249 000 shillings*** in the form of registration fees and other contributions. As of 2007, it had more than 12 000 000 shillings. It has employed a treasurer and manages the costs of its meetings and agricultural shows at district, region, zonal and national levels.

The main objectives in forming the association were:

- to increase milk productivity from goats through cross-breeding Toggenburg and indigenous goats, taking advantage of the high milk production of the former and the disease resistance of the latter;
- to produce pure Toggenburgs so that genetics could be exchanged with farmers from Kenya and Uganda; and
- to improve the income of the members though selling milk and live animals (pure-breeds and crosses).

*A scheme in which the loan of a goat is paid back in the form of another goat that can be passed on to another participant.
**This is the most recent date for which published figures are available. Since then the farmers have continued their goat breeding and production activities under the supervision of the local extension services.
*** Equivalent to approximately US$400 at the time.
Provided by Yacobo Msanga, National Coordinator for the Management of Animal Genetic Resources, the United Republic of Tanzania.
For further information see Msanga and Bee (2006) and Bee *et al.* (2006).

Participatory approaches to setting breeding goals and identifying traits to be recorded have been recommended as a means of promoting the involvement of livestock keepers in the operation of community-based programmes (Gizaw *et al*., 2010; Wurzinger *et al.,* 2011). Potential methods include individual interviews with livestock keepers, workshops with groups of livestock keepers and exercises involving the use of choice cards or the ranking of live animals (e.g. Duguma *et al*., 2010; Haile *et al*., 2011). More generally, a participatory approach that engages the various actors involved will help ensure their commitment and ownership, prerequisites for the long-term sustainability of a breeding programme.

Controlling inbreeding can be a major issue in breeding schemes in low-input systems, especially in closed central nucleus schemes and in community-based schemes operating on a limited scale. Gizaw *et al*. (2009) recommend that for an acceptable rate of inbreeding, sheep breeding schemes should include at least 600 ewes and 15 rams. Rotation of males between livestock keepers' herds/flocks or between the nucleus and livestock keepers' herds/flocks can help to limit inbreeding. The use of sire-reference schemes (i.e. schemes in which each cooperating livestock keeper agrees

Box 4C7

Community-driven breeding programmes for locally adapted pig breeds in Viet Nam

Demand for pork in Viet Nam has increased substantially since the 1990s, driven by economic development and urbanization. Although large-scale private enterprises have benefited from subsidies introduced with the aim of expanding exports, smallholder farmers still represent the backbone of the Vietnamese pig sector, especially in the northern part of the country. To cope with increasing competition and quality requirements, market-oriented smallholders increasingly raise modern pig lines and hybrids, often in unsystematic cross-breeding schemes. This has reduced the population sizes of autochthonous breeds and pushed them into remote areas.

Under a pilot project implemented by German and Vietnamese research institutions in collaboration with the provincial veterinary department and private partners (funded by the German Research Foundation, DFG), a community-driven pig-breeding and marketing programme was established in the mountainous Son La province in northwestern Viet Nam. The farmers' pig-breeding cooperative involves ten villages, representing communities with different resource endowments, production objectives and consequently different requirements from their pig genetic resources.

Initially, pure-bred indigenous Mong Cai and Ban gilts were distributed among 179 cooperative members and a revolving fund was established with the aim of enabling the smallholders to be independent in terms of supplying replacement animals and improving genetic stocks. Prolific Mong Cai gilts were distributed mainly to semi-intensive producers and robust Ban sows to less market-oriented smallholders.

Although some of the collective actions planned under the project were successfully implemented – for instance, improving the access of rural small-scale pig producers to veterinary services and establishing multipronged market outlets – the attempt to establish a community-based stratified cross-breeding scheme proved to be difficult. The organizational structures of a cross-breeding scheme must be accompanied by a well-balanced business plan that accounts for the greater burden placed upon nucleus breeders. In this example, although farmers preferred to use pure-bred dam lines, and Mong Cai breeders could therefore obtain a good price for sows, this was

Ban sow and litter

Photo credit: Kerstin Schöll.

Mog Cai sow and fatteners

Photo credit: Kerstin Schöll.

(Cont.)

Box 4C7 *(Cont.)*
Community-driven breeding programmes for locally adapted pig breeds in Viet Nam

not sufficient to compensate them for the low prices obtained for pure-bred Mong Cai finishers. The market for the latter completely collapsed because of rapid shifts in customer preferences towards leaner pork. In the future, farmers will probably turn to breeding centres or commercial farms to obtain pure-bred Mong Cai sow replacements. In contrast, marketing of pure-bred Ban products via a short supply chain, avoiding a large number of intermediaries, proved to be successful in linking remote resource-poor Ban keepers to highly remunerative specialty markets in the Red River Delta. Because of the prices that can be realized in these niche markets, farmers will probably continue pure-breeding the Ban breed and this will create a pool of sow replacements for farmers that exclusively practice cross-breeding.

In conclusion, this case illustrates how a self-sustained community-driven pig breeding and marketing programme can only sustainably contribute to rural development and breed conservation if it can be flexibly adapted to market conditions.

Note: This box updates Box 89 of the first SoW-AnGR (FAO, 2007a). Provided by Philipp Muth and Anne Valle Zárate.

to use sires or semen from a group of high-quality so-called "reference" sires – Simm *et al*., 2001) in the implementation of dispersed-nucleus schemes may reduce inbreeding in the short term but increase it in the long term at herd level. Systems for regularly providing males from other herds/flocks are particularly important in situations where introducing animals (or semen or embryos) from outside is not feasible.

When calculating the economic efficiency of a given breeding programme, it is important to take into account both the tangible and the intangible benefits that accrue to various different groups of stakeholders (livestock keepers, retailers, government, etc.). Advice on how to evaluate investment decisions in breeding programmes is provided in FAO's guideline publication *Breeding strategies for sustainable management of animal genetic resources* (FAO, 2010). Computer simulation of the breeding programme can be used to predict changes in targeted traits and their sensitivity to changes in various factors affecting genetic response (e.g. Gebre *et al*., 2014).

Finally, in addition to genetic considerations, factors related to market chains usually have a major influence on the success of breeding programmes in low-input environments. The absence of effective marketing chains will present a significant challenge. This is true for both output and input markets (Haile *et al*., 2011). Although a multi-trait breeding objective is likely to be optimal, such breeding programmes are usually designed so as to increase production to some degree. In theory, the increased production may be used simply to improve food security and nutrition within a subsistence system, but more commonly the programme is designed so as to generate excess product that can be marketed. Genetic improvement requires investment of human and financial capital, and these inputs will be wasted if no market channel is available. Improvements to productivity achieved by breeding programmes in low-input systems are rarely due only, or even primarily, to genetic improvement. Successful genetic improvement programmes are usually complemented by enhanced veterinary care and nutrition, so reliable access to these resources is also important. Organization of livestock keepers into associations or cooperatives to coordinate activities and increase access to input and output markets is usually beneficial. In the longer term, establishing a marketing system for superior breeding stock will also be beneficial, as it will provide breeders with another source of income and incentive for genetic improvement.

5.3 Genomics and future developments

As discussed in Subsection 2, techniques that enable the use of genomic information in animal breeding have advanced greatly in recent years, particularly in the case of cattle, pigs and poultry. While these techniques offer major potential benefits, particularly in terms of allowing the selection of animals at earlier ages and reducing generation intervals, there are several concerns regarding their use in low-input production systems. Effective use of these techniques requires more than just vague information on the phenotypes and genotypes of the breeds concerned. A reliable data-recording scheme is absolutely necessary in order to provide the basis for associating genotypes to phenotypes. Such schemes are lacking in most low-input situations. There are nevertheless steps that can begin to be taken towards the use of these new technologies in developing countries. Efforts to identify genes or genomic regions associated with adaptation or variation in production traits in harsh environments need to be stepped up in developing countries and in low-input smallholder and pastoralist production systems (Rothschild and Plastow, 2014). Once relevant genes have been characterized, livestock populations can potentially be improved through genetic introgression or gene-assisted breeding programmes. With regard to genomic selection more specifically, implementation requires the establishment of training and validation populations, in which both phenotypes and genotypes are recorded, so that the prediction model can be established. Indigenous populations with low linkage disequilibrium generally do not meet these requirements (Akanno *et al*., 2014). The use of widely used international transboundary breeds as reference populations for genomic selection in locally adapted breeds seems to have little or no value, except perhaps in cross-bred populations, but this has not been studied. Any attempt to implement genomic improvement programmes needs to take into account the need for adequate infrastructure, technical skills, policies and communication strategies, and the need for a long-term perspective in planning and implementation (Rothschild and Plastow, 2014).

6 Conclusions and research priorities

The main advances in breeding programmes and related technologies over recent years have been in the application of genomic information, particularly in high-input production systems. Genotyping costs have dropped precipitously and for some species nearly all of the important selection candidates are genotyped, as have been the major ancestors from which genetic material is available. Genomic selection increases the accuracy of EBVs, particularly for those animals for which no phenotypic data are yet available. The impact on the commercial dairy breeding industry has been revolutionary. Progeny testing now plays a minor role. Breeding goals have seen various adjustments. In particular, greater emphasis is now being placed on profit, rather than output, and therefore on health, survival and other traits that influence production costs.

The genomic revolution has yet to affect developing countries to a significant degree. Accurate genomic selection depends on the availability of phenotypic data, which are usually lacking in the low-input production systems typically found in developing countries. Nevertheless, the situation in these countries has not remained static. Formal breeding programmes, usually community-based, have become more common and are improving the productivity of animals and livelihoods of their keepers. However, significant work is still required. Animal identification and pedigree and performance recording need to be expanded. This is necessary even to take advantage of traditional approaches to breeding, let alone genomic selection.

Little if any direct progress has occurred since the first SoW-AnGR was prepared in terms of determining the underlying genetics of phenotypic adaptation to the environment. However, the

tools with which to do this are in place. Genomic analysis should allow breeders to determine actual genetic by environment interactions, although a tremendous amount of work remains to be done in order to obtain the phenotypic information needed to accurately predict such interactions.

Future research will need to address the need for new modes of production that can help meet the expected growth in global demand for animal protein in ways that are economically, environmentally and socially sustainable and address the need to adapt livestock production to changing environmental conditions. In other words, efficiency of production will be an increasingly important consideration. This will include a wide range of efficiencies and involve not only increasing product yield per unit of input, but also addressing negative effects such as environmental damage (see Box 4C8 for an example). Improvement in the use of feed resources, reproductive efficacy and prolificacy, and animal health will be key topics for research, both in developed and in developing countries.

The following list of research priorities draws on the Strategic Research Agenda of the Sustainable Farm Animal Breeding and Reproduction Technology Platform, an extensive review of research priorities in livestock breeding in Europe (FABRE TP, 2011).

Selection to balance functionality and production

- improving knowledge of the genetics of:
  - disease resistance, resilience and immune response;
  - host–pathogen interactions;
  - gut functionality and its relationship with gut microbiota in different environments;
  - emission of methane and production of other greenhouse gases;
  - variation in digestion of specific amino acids and phosphorus – along with improving knowledge of nutrient (e.g. amino acid) requirements under different production conditions; and
  - uniformity;
- developing economically viable means of including traits of increasing consumer concern in breeding goals, including traits with uncertain economic value;
- developing strategies for improving disease resistance without compromising production;
- developing phenotype definitions for novel traits;
- establishing standard phenotypic trait ontologies encompassing production traits, disease traits and other welfare traits and environmental sensitivity;
- developing tools to estimate and exploit non-additive genetic variation;
- developing social-interaction models including, male–female interactions, to facilitate the improvement of reproductive, health and welfare traits;

Genomics and other "-omics"

- characterizing the genome sequences (and variation therein, including epigenetic transmissible variants) of species, populations and individuals;
- developing methods for optimal incorporation of genomic information in breeding-value estimation;
- developing proteomic and immunological metabolomic technologies for high-throughput analyses;
- developing schemes incorporating large-scale genotyping at embryo level;
- metagenomic sequencing of gastro-intestinal microbial communities;

Bioinformatics and biostatistics

- developing statistical programming tools relevant to new traits and new phenotypes;
- supporting continued annotation and maintenance of public genome databases;
- developing scalable bioinformatics tools to handle high-throughput data (e.g. genomic selection procedures or inference of genome-wide diversity parameters);

Box 4C8

Genetic selection for reduced methane production – a future tool for climate change mitigation

The expanding world human population will require greater food production within the constraints of increasing societal pressure to minimize impact on the environment. Animal breeding has in the past achieved substantial reductions in environmental load per unit of product, despite no explicit inclusion of environmental load in breeding goals. Higher gains can be expected if breeding goals focus more specifically on environmental objectives. One important objective is to reduce the amount of enteric methane – a greenhouse gas with a warming potential 25 times that of carbon dioxide – produced by ruminants. However, a successful breeding strategy requires measurements on a large population of animals. To facilitate genetic selection for reduced methane production, it would therefore be highly desirable to combine individual national datasets to produce a multicountry database. However, data are collected using different protocols, and combining them requires intensive consultation among contributing scientists across a range of disciplines. More importantly, however, scientists planning to undertake future studies on methane production have not yet agreed protocols for how to proceed with the collection of data.

The networks of METHAGENE (www.methagene.eu) and ASGGN (www.asggn.org) have joined forces with the International Committee for Animal Recording (www.icar.org) to develop consensus on protocols for the collection of methane production data, with the aim of facilitating the harmonization and combination of existing and future data obtained from different countries and with different collection methods. The project will also facilitate discussions among experts aiming to identify possible predictor traits for methane production (e.g. biomarkers in milk) that could be easily exploited. Methane production is currently not directly included in any national cattle breeding objective anywhere in the world. This is not only because of a lack of sufficient data with which to make selection decisions, but also because of a lack of consensus on how to optimally include methane production in a breeding objective. The project will develop standards for expressing methane production, taking into account the advantages and disadvantages of expressing methane per unit (digestible) feed and per unit of consumable product (i.e. milk and/or meat) and also the need to consider the time horizon of emissions via a life-cycle assessment and to ensure that selection for low emissions does not compromise production efficiency.

Provided by Yvette de Haas.

- developing means of exploiting distributed computing technologies (GRID, Cloud) for more effective data storage, sharing, integration and analysis;
- improving the use of genomic sequences for predicting genetic values and detection of *de novo* mutations;
- developing transcriptomic tools (arrays and RNA-seq);

Breeding strategies in low-input production systems

- improving methods for planning and implementing breeding strategies in production systems where there is little or no organizational infrastructure, including means of determining where breeding programmes are feasible and appropriate and how they can be adapted to local circumstances;
- exploiting the use of telecommunications and informatics technologies to improve data collection;

- improving strategies for the establishment of stable cross-breeding systems; and
- developing simulation tools to predict the consequences of introducing exotic breeds into local populations (as part of genetic impact assessment).

Improving research cooperation

Research in the field of animal breeding could be strengthened by promoting greater cooperation among the various stakeholders involved. Relevant measures include:

- promoting even greater collaboration between the breeding industry, academia and the public sector;
- exploring the feasibility of capturing and using production data from commercial producers (e.g. encouraging the use of commercial populations for high-resolution genetic analyses); and
- developing data-sharing policies that allow the value extracted from complex datasets to be maximized without compromising legitimate commercial interests.

References

Abegaz, S., Sölkner, J., Gizaw, S., Dessie, T., Haile, A. & Wurzinger, M. 2013. Description of goat production systems and morphological characteristics of Abergelle and Western low-land goat breeds in Ethiopia: implications for community-based breeding programmes. *Animal Genetic Resources,* 53: 69–78 (available at http://www.fao.org/docs/eims/upload//314794/I3445Tri.pdf).

Abell, C.E., Dekkers, J.C., Rothschild, M.F., Mabry, J.W. & Stalder, K.J. 2014. Total cost estimation for implementing genome-enabled selection in a multi-level swine production system. *Genetics Selection Evolution*, 46: 32.

Adams, H.A., Sonstegard, T., VanRaden, P.M., Null, D.J., Van Tassell, C. & Lewin, H. 2012. Identification of a nonsense mutation in *APAF1* that is causal for a decrease in reproductive efficiency in dairy cattle. In *Proceedings Plant and Animal Genome XX Conference, January 14–18 2012, Sandiego, CA, USA.* (Abstract P0555) (available at https://pag.confex.com/pag/xx/webprogram/Paper3932.html).

Agerholm, J.S., Bendixen, C., Andersen, O. & Arnbjerg, J. 2001. Complex vertebral malformation in Holstein calves. *Journal of Veterinary Diagnostic Investigation,* 13: 283–289.

Agerholm, J.S., McEvoy, F. & Arnbjerg, J. 2006. Brachyspina syndrome in a Holstein calf. *Journal of Veterinary Diagnostic Investigation,* 18: 418–422.

Aguilar, I., Misztal, I., Johnson, D.L., Legarra, A., Tsuruta, S. & Lawlor, T.J. 2010. Hot topic: a unified approach to utilize phenotypic, full pedigree, and genomic information for genetic evaluation of Holstein final score. *Journal of Dairy Science,* 93: 743–752.

Akanno, E.C., Schenkel, F.S., Sargolzaei, M., Friedship, R.M. & Robinson, J.A. 2014. Persistency of accuracy of genomic breeding values for different simulated pig breeding programs in developing countries. *Journal of Animal Breeding and Genetics*, 131: 367–378.

Amer, P.R., Nieuwhof, G.J., Pollott, G.E., Roughsedge, T., Conington, J. & Simm, G. 2007. Industry benefits from recent genetic progress in sheep and beef populations. *Animal,* 1(10): 1414–1426.

Astruc, J.M. 2014. Performance recording of dairy sheep. In *Proceedings of the 38th ICAR Session, 28–31 May, 3012, Cork, Ireland* (presentation available at http://tinyurl.com/nzs9d7s).

Avendano, S., Watson, K. & Kranis, A. 2010. Genomics in poultry breeding – from utopias to deliverables. In *Proceedings of the 9th World Congress on Genetics Applied to Livestock Production, Leipzig, Germany, 1–6 August 2010* (available at http://www.kongressband.de/wcgalp2010/assets/pdf/0049.pdf).

Avendano, S. & Kranis, A. 2012. Genomics in poultry breeding – into consolidation phases. In *Proceedings XXIV World's Poultry Congress, 5–9 August 2012 Salvador, Bahia, Brazil* (available at http://www.facta.org.br/wpc2012-cd/pdfs/plenary/Santiago_Avendano.pdf).

Baloche, G., Legarra, A., Sallé, G., Larroque, H., Astruc, J.-M., Robert Granie, C. & Barillet, F. 2014. Assessment of accuracy of genomic prediction for French Lacaune dairy sheep. *Journal of Dairy Science*, 97(2): 1107–1116.

PART **4**

Baselga, M. & Blasco, A. 1989. *Mejora genética del conejo de producción de carne*. Madrid, Mundi-Prensa.

Bee, J.K.A., Msanga, Y.N. & Kavana, P.Y. 2006. Lactation yield of crossbred dairy cattle under farmer management in Eastern coast of Tanzania. *Livestock Research for Rural Development.* Volume 18, Article #23 (available at http://www.cipav.org.co/lrrd/lrrd18/2/bee18023.htm).

Bijma, P. 2010. Estimating indirect genetic effects: precision of estimates and optimum designs. *Genetics,* 186: 1013–1028.

Bley, T.A.G. & Bessei, W. 2008. Recording of individual feed intake and feeding behaviour of Pekin ducks kept in groups. *Poultry Science*, 87: 215–221.

Boichard, D., Fritz, S., Rossignol, M.N., Guillaume, F., Colleau, J.J. & Druet, T. 2006. Implementation of marker-assisted selection: practical lessons from dairy cattle. In *Proceedings of the 8th World Congress on Genetics Applied to Livestock Production August 13–18, 2006, Belo Horizonte, MG, Brazil*, No. 22–11.

Buisson, D., Lagriffoul, G., Baloche, G., Aguerre, X., Boulenc, P., Fidele, F., Frégeat, G., Giral-Viala, B., Guibert, P., Panis, P., Soulas, C., Astruc, J.-M. & Barillet, F. 2014. Genomic breeding schemes in French Lacaune and Manech dairy sheep: design and expected genetic gain. In *Proceedings of the 10th World Congress of Genetics Applied to Livestock Production, 17–22 August 2014, Vancouver, Canada* (available at http://tinyurl.com/qxaau3z).

Burrow, H.W. 2006. Utilization of diverse breed resources for tropical beef production. In *Proceedings of the 8th World Congress on Genetics Applied to Livestock Production August 13–18, 2006, Belo Horizonte, MG, Brazil*.

Carillier, C., Larroque, H. & Robert-Granié, C. 2014. Comparison of joint versus purebred genomic evaluation in the French multi-breed dairy goat population. *Genetics Selection Evolution*, 46: 67.

Carlson, D.F., Tan, W., Hackett, P.B. & Fahrenkrug, S.C. 2013. Editing livestock genomes with site-specific nucleases. *Reproduction Fertility and Development,* 26: 74–82.

Cartuche, L., Pascual, M., Gómez, E.A. & Blasco, A. 2014. Economic weights in rabbit meat production. *World Rabbit Science*, 22: 165–177.

Charlier, C., Coppieters, W., Rollin, F., Desmecht, D., Agerholm, J.S., Cambisano, N., Carta, E., Dardano, S., Dive, M., Fasquelle, C., Frennet, J.C., Hanset, R., Hubin, X., Jorgensen, C., Karim, L., Kent, M., Harvey, K., Pearce, B.R., Simon, P., Tama, N., Nie, H., Vandeputte, S., Lien, S., Longeri, M., Fredholm, M., Harvey, R.J. & Georges, M. 2008. Highly effective SNP-based association mapping and management of recessive defects in livestock. *Nature Genetics,* 40: 449–454.

Charlier, C., Agerholm, J.S., Coppieters, W., Karlskov-Mortensen, P., Li, W., de Jong, G., Fasquelle, C., Karim, L., Cirera, S., Cambisano, N., Ahariz, N., Mullaart, E., Georges, M. & Fredholm, M. 2012. A deletion in the bovine *FANCI* gene compromises fertility by causing fetal death and brachyspina. *PLoS ONE*, 7:e43085.

Chen, P., Baas, T.J., Mabry, J.W., Dekkers, J.C.M. & Koehler, K.J. 2002. Genetic parameters and trends for lean growth rate and its components in U.S. Yorkshire, Duroc, Hampshire, and Landrace pigs. *Journal of Animal Science,* 80: 2062–2070.

Christensen, O.F. & Lund, M.S. 2010. Genomic prediction when some animals are not genotyped. *Genetics Selection Evolution*, 42: 2.

Cole, J.B., VanRaden, M., Null, D.J., Hutchison, J.L., Cooper, T.A. & Hubbard, S.M. 2015. *Haplotype tests for recessive disorders that affect fertility and other traits.* AIP Research Report Genomic3 (09-13) (updated 22 January 2015). Beltsville, MD, USA, Animal Improvement Program, Animal Genomics and Improvement Laboratory, Agricultural Research Service, USDA (available at http://aipl.arsusda.gov/reference/recessive_haplotypes_ARR-G3.html).

Colleau, J-J., Clément V., Martin, P. & Palhière, I. 2011. Optimized diffusion of buck semen for saving genetic variability in selected dairy goat populations. *BMC Genetics*, 12: 25.

Cooper, T.A., Wiggans, G.R., VanRaden, P.M., Hutchison, J.L., Cole, J.B. & Null, D.J. 2013. Genomic evaluation of Ayrshire dairy cattle and new haplotypes affecting fertility and stillbirth in Holstein, Brown Swiss and Ayrshire breeds. In *Proceedings ADSA-ASAS Joint Annual Meeting* (Poster T206) (available at https://aipl.arsusda.gov/publish/presentations/ADSA13/ADSA2013_TAC.pptx).

Cooper, T.A., Wiggans, G.R., Null, D.J., Hutchison, J.L. & Cole, J.B. 2014. Genomic evaluation, breed identification, and discovery of a haplotype affecting fertility for Ayrshire dairy cattle. *Journal of Dairy Science,* 97: 3878–3882.

Daetwyler, H.D., Capitan, A., Pausch, H., Stothard, P., van Binsbergen, R., Brøndum, R.F., Liao, X., Grohs, C., Jung, S., Baur, A., Esquerré, D., Gollnick, N., Legrain, S., Laurent, P., Djari, A., Rossignol, M.N., Klopp, C., Rocha, D., Fritz, S., Eggen, A., Bowman, P., Coote, D., Chamberlain, A., VanTassel, C.P., Hulsegge, I., Goddard, M., Guldbrandtsen, B., Lund, M.S., Veerkamp, R., Boichard, D., Fries, R. & Hayes, B.J. 2014. Whole-genome sequencing of 234 bulls facilitates mapping of monogenic and complex traits in cattle. *Nature Genetics*, 46: 858–865.

Dawkins, M.S. & Layton, R. 2012. Breeding for better welfare: genetic goals for broiler chickens and their parents. *Animal Welfare*, 21: 147–155.

D'Eath, R.B., Tolkamp, B.J., Kyriazakis, I. & Lawrence, A.B. 2009. 'Freedom from hunger' and preventing obesity: The animal welfare implications of reducing food quantity or quality. *Animal Behaviour,* 77: 275-288.

Dekkers, J.C.M. 2007. Prediction of response to marker-assisted and genomic selection using selection index theory. *Journal of Animal Breeding and Genetics,* 124: 331–341.

De Roos, A.P.W., Hayes, B.J., Spelman, R.J. & Goddard, M.E. 2008 Linkage disequilibrium and persistence of phase in Holstein–Friesian, Jersey and Angus cattle. *Genetics*, 179: 1503–1512.

Dixon, L.M., Brocklehurst, S., Sandilands, V., Bateson, M., Tolkamp, B.J. & D'Eath, R.B. 2014. Measuring motivation for appetitive behaviour: food-restricted broiler breeder chickens cross a water barrier to forage in an area of wood shavings without food. *PLoS ONE,* 9: e102322.

Dodds, K., Auvray, B., Lee, M., Newman, S.A. & McEwan, J. 2014. Genomic selection in New Zealand dual purpose sheep. In *Proceedings of the 10th World Congress of Genetics Applied to Livestock Production, 17–22 August 2014, Vancouver, Canada* (available at https://asas.org/wcgalp-proceedings).

Drögemüller, C., Tetens, J., Sigurdsson, S., Gentile, A., Testoni, S., Lindblad-Toh, K. & Leeb, T. 2010. Identification of the bovine arachnomelia mutation by massively parallel sequencing implicates sulfite oxidase (SUOX) in bone development. *PLoS Genetics*, 6: e1001079.

Drouilhet, L., Gilbert, H., Balmisse, E., Ruesche, J., Tircazes, A., Larzul, C. & Garreau, H. 2013. Genetic parameters for two selection criteria for feed efficiency in rabbits. *Journal of Animal Science*, 91: 3121–3128.

Duchemin, S.I., Colombani, C., Legarra, A., Baloche, G., Larroque, H., Astruc, J-M., Barillet, F., Robert-Granié, C. & Manfredi, E. 2012. Genomic selection in the French Lacaune dairy sheep breed. *Journal of Dairy Science*, 95(5): 2723–2733.

Duchesne, A., Gautier, M., Chadi, S., Grohs, C., Floriot, S., Gallard, Y., Caste, G., Ducos, A. & Eggen, A. 2006. Identification of a doublet missense substitution in the bovine *LRP4* gene as a candidate causal mutation for syndactyly in Holstein cattle. *Genomics*, 88: 610–621.

Duguma, G., Mirkena, T., Haile, A., Iñiguez, L., Okeyo A.M., Tibbo, M., Rischkowsky, B., Sölkner, J. & Wurzinger, M. 2010. Participatory approaches to investigate breeding objectives of livestock keepers. *Livestock Research for Rural Development,* 22: 64 (available at http://lrrd.cipav.org.co/lrrd22/4/dugu22064.htm).

Duguma, G., Mirkena, T., Haile, A., Okeyo, A.M., Tibbo, M., Rischkowsky, B., Sölkner, J. & Wurzinger, M. 2011. Identification of smallholder farmers and pastoralists' preferences for sheep breeding traits: choice model approach. *Animal*, 5, 1984–1992.

Dunn, I.C., Wilson, P.W., Smulders, T.V., Sandilands, V., D'Eath, R.B. & Boswell, T. 2013. Hypothalamic Agouti-related protein expression is affected by both acute and chronic experience of food restriction and re-feeding in chickens. *Journal of Neuroendocrinology*, 25: 920–928.

Dürr, J.W. 2013. Impact of genomics on international cooperation for dairy genetics. Book of abstracts No. 19. In *Proceedings of the 64th Annual Meeting of the EAAP. Nantes, France, August 26–30, 2013*. p. 98.

PART **4**

Eady, S.J., Garreau, H. & Gilmour, A.R. 2007. Heritability of resistance to bacterial infection in meat rabbits. *Livestock Science*, 112: 90–98.

Eldridge, F.E., Smith, W.H. & McLeod, W.M. 1951. Syndactylism in Holstein-Friesian cattle: its inheritance, description and occurrence. *Journal of Heredity*, 42: 241–250.

El-Hamidi, M., Leipold, H.W., Vestweber, J.G.E. & Saperstein, G. 1989. Spinal muscular atrophy in Brown Swiss calves. *Zentralblatt für Veterinärmedizin. Reihe A,* 36: 731–738.

Ellen, E.D., Peeters, K., Visscher, J. & Bijma, P. 2011. Reducing mortality due to cannibalism in layers: taking into account social genetic effects. In *Proceedings 7th European Symposium on Poultry Genetics, 5-7 October 2011, Peebles, UK*, pp. 12–14. World Poultry Science Association (available at http://www.roslin.ed.ac.uk/7espg/assets/7espg-edited-proceedings.pdf).

Elsik, C.G., Tellam, R.L. & Worley, K.C. 2009. The genome sequence of taurine cattle: a window to ruminant biology and evolution. *Science*, 324: 522–528.

Erbe, M., Hayes, B.J., Matukumalli, L.K., Goswami, S., Bowman, P.J., Reich, C.M., Mason, B.A. & Goddard, M.E. 2012. Improving accuracy of genomic predictions within and between dairy cattle breeds with imputed high-density single nucleotide polymorphism panels. *Journal of Dairy Science*, 95: 4114–4129.

Erbe, M., Ytournel, F., Pimental, E.C.G., Sharifi, A.R. & Simianer, H. 2010. Power and robustness of three whole genome association mapping approaches in selected populations. *Journal of Animal Breeding and Genetics,* 128: 3–14.

Fabre-TP. 2011. *Strategic Research Agenda 2011*. Wageningen, the Netherlands, FABRE Technology Platform (available at http://www.fabretp.info/StrategicResearchAgenda.aspx).

FAO. 2007a. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2007b. *Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration*. Rome (available at ftp://ftp.fao.org/docrep/fao/010/a1404e/a1404e00.pdf).

FAO. 2010. *Breeding strategies for sustainable management of animal genetic resources*. FAO Animal Production and Health Guidelines No. 3. Rome (available at http://www.fao.org/docrep/012/i1103e/i1103e00.htm).

FAO. 2013. In vivo *conservation of animal genetic resources.* FAO Animal Production and Health Guidelines. No. 14. Rome (available at http://www.fao.org/docrep/018/i3327e/i3327e00.htm).

FAO. 2015. *Development of integrated multipurpose animal recording systems*. FAO Animal Production and Health Guidelines. Rome (in press).

Forabosco, F., Löhmus, M., Rydhmer, L. & Sundström, L.F. 2013. Genetically modified farm animals and fish in agriculture: a review. *Livestock Science*, 153: 1–9.

Fritz, S., Capitan, A., Djari, A., Rodriguez, S.C., Barbat, A., Baur, A., Grohs, C., Weiss, B., Boussaha, M., Esquerré, D., Klopp, C., Rocha, D. & Boichard, D. 2013. Detection of haplotypes associated with prenatal death in dairy cattle and identification of deleterious mutations in *GART*, *SHBG* and *SLC37A2*. *PLoS ONE*, 8:e65550.

Fuglie, K.O. & Heisey, P. 2011. Animal genetic improvement by private sector. *In* K.O. Fuglie, P.W. Heisey, J.L. King, C.E. Pray, K. Day-Rubenstein, D. Schimmelpfennig, S.L. Wang & R. Karmarkar-Deshmukh, eds. R*esearch investments and market structure in the food processing, agriculture input and biofuel industries worldwid*e. ERR-130. Washington DC, United States Department of Agriculture, Economics Research Service (available at http://tinyurl.com/nfdk3my).

Galukande, E., Mulindwa, H., Wurzinger, M., Roschinsky, R., Mwai, A.O. & Sölkner, J. 2013. Crossbreeding cattle for milk production in the tropics: achievements, challenges and opportunities. *Animal Genetic Resources*, 52: 111–125 (available at http://www.fao.org/docrep/018/i3219t/i3219t.pdf).

Garreau, H., Bolet, G., Larzul, C., Robert Granié, C., Saleil, G., San Cristobal, M. & Bodin, L. 2008a. Results of four generations of a canalising selection for rabbit birth weight. *Livestock Science,* 119: 55–62.

Garreau, H., Eady, S., Hurtaud, J. & Legarra, A. 2008b. Genetic parameters of production traits and resistance to digestive disorders in a commercial rabbit population. In *Proceedings of the 9th World Rabbit Congress, Verona, Italy*, pp. 103–107.

Garrick, D.J. 2007. Equivalent mixed model equations for genomic selection. *Journal of Dairy Science,* 90: 376 (abstr.).

Gebre, K.T., Wurzinger, M., Gizaw, S., Haile, A., Rischkowsky, B. & Sölkner, J. 2014. Effect of genetic improvement of body weight on herd dynamics and profitability of Ethiopian meat sheep: a dynamic simulation model. *Small Ruminant Research*, 117(1): 15–24.

Gizaw, S., Getachew, T., Edea, Z., Mirkena, T., Duguma, G., Tibbo, M., Rischkowsky, B., Mwai, O., Dessie, T., Wurzinger, M., Sölkner, J. & Haile, A. 2013. *Characterization of indigenous breeding strategies of the sheep farming communities of Ethiopia: a basis for designing community-based breeding programs*. ICARDA Working Paper. Aleppo, Syria, International Center for Agricultural Research in the Dry Areas (available at http://tinyurl.com/nrx9scr).

Gizaw, S., Komen, H. & van Arendonk, J.A.M. 2009. Optimal village breeding schemes under smallholder sheep farming systems. *Livestock Science,* 124: 82–88.

Gizaw, S., Komen, H. & van Arendok, J. A. M. 2010. Participatory definition of breeding objectives and selection indexes for sheep breeding in traditional systems. *Livestock Science,* 128: 67–74.

Gootwine, E., Reicher, S. & Rozov, A. 2008. Prolificacy and lamb survival at birth in Awassi and Assaf sheep carrying the *FecB* (Booroola) mutation. *Animal Reproduction Science,* 108: 402–411.

Granleese, T., Clark, S.A. & van der Werf, J.H.J. 2013. Benefits of MOET and JIVET in optimised sheep breeding programs. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics,* 20: 94–97.

Hafner, A., Dahme, E., Obermaier, G., Schmidt, P. & Dirksen, G. 1993. Spinal dysmyelination in newborn Brown Swiss x Braunvieh calves. *Zentralblatt für Veterinärmedizin. Reihe B,* 40: 413–422.

Haile, A., Wurzinger, M., Mueller, J., Mirkena, T., Dugumda, G., Mwai, O., Sölkner, J. & Rischkowsky, B. 2011. *Guidelines for setting up community-based sheep breeding programmes in Ethiopia.* ICARDA – tools and guidelines No 1. Aleppo, Syria, International Center for Agricultural Research in the Dry Areas.

Hayes, B.J., Bowman, P.J., Chamberlain, A.C., Verbyla, K., & Goddard, M.E. 2009a. Accuracy of genomic breeding values in multi-breed dairy cattle populations. *Genetics Selection Evolution,* 41: 51.

Hayes, B.J., Bowman, P.J., Chamberlain, A.J. & Goddard, M.E. 2009b. Genomic selection in dairy cattle: progress and challenges. *Journal of Dairy Science,* 92: 433–443.

Heaton, M.P., Clawson, M.L., Chitko-Mckown, C.G., Leymaster, K.A., Smith, T.P., Harhay, G.P., White, S.N., Herrmann-Hoesing, L.M., Mousel, M.R., Lewis, G.S., Kalbfleisch, T.S., Keen, J.E. & Laegreid, W.W. 2012. Reduced lentivirus susceptibility in sheep with *TMEM154* mutations. *PLoS Genetics,* 8(1): e1002467.

Hickey, J.M., Kinghorn, B.P., Tier, B., van der Werf, J.H.J. & Cleveland, M.A. 2012. A phasing and imputation method for pedigreed populations that results in a single-step genetic evaluation. *Genetics Selection Evolution*, 44: 9–19.

Hiemstra, S.J. & Napel, J.T. 2013. *Study of the impact of genetic selection on the welfare of chickens bred and kept for meat production*. Final Report Framework Contract No SANCO/2011/12254: Evaluation impact assessment and related services; Lot3: Food chain (available at http://tinyurl.com/nu2e3ou).

Howie, J.A., Tolkamp, B.J., Bley, T. & Kyriazakis, I. 2010. Short-term feeding behaviour has a similar structure in broilers, turkeys and ducks. *British Poultry Science*, 51(6): 714–24.

Howie, J.A., Tolkamp, B.J., Vandano, S.A. & Kyriazakis, I. 2009. The structure of feeding behaviour in commercial broilers lines selected for different growth rates. *Poultry Science*, 88: 1143–1150.

Hozé, C., Fritz, S., Phocas, F., Boichard, D., Ducrocq, V. & Croiseau, P. 2014. Efficiency of multi-breed genomic selection for dairy cattle breeds with different sizes of reference population. *Journal of Dairy Science*, 97(6): 3918–3929.

Hunter, N., 2007. Scrapie—uncertainties, biology and molecular approaches. *Biochimica et Biophysica Acta*, 1772: 619–628.

PART **4**

Iñiguez, L.R. (ed.). 2013. *La producción de rumiantes menores en las zonas áridas de Latinoamerica*. Brasilia, EMBRAPA, ICARDA, IFAD.

Joerg, H., Fries, H.R., Meijerink, E. & Stranzinger, G.F. 1996. Red coat color in Holstein cattle is associated with a deletion in the *MSHR* gene. *Mammalian Genome*, 7: 317–318.

Johnson, L.A. & Welch, G.R. 1999. Sex preseletion: high-speed flow sytometric sorting of X and Y sperm for maximum efficiency. *Theriogenology*, 52: 1323–1341.

Jonas, E., Rydhmer, L. & de Koning, D.J. 2014. *Breeding programmes for GM farm animals.* Presentation at "Breeding genetically modified animals for food production a Mistra Biotech symposium" (available at http://www.slu.se/PageFiles/363253/Jonas_et.al_mistrabiotech_symp.pdf).

Kapell, D.N.R.G., Hill, W.G., Neeteson, A.M., Mc Adam, J., Koerhuis, A.N.M. & Avendaño, S. 2012a. Genetic parameters of foot-pad dermatitis and body weight in purebred broiler lines in 2 contrasting environments. *Poultry Science*, 91: 565–574.

Kapell, D.N.R.G., Hill, W.G., Neeteson, A.M., Mc Adam, J., Koerhuis, A.N.M. & Avendaño, S. 2012b. Twenty-five years of selection for improved leg health in purebred broiler lines and underlying genetic parameters. *Poultry Science*, 91: 3032–3043.

Kemper, K.E., Reich, C.M., Bowman, P.J., vander Jagt, C.J., Chamberlain, A.J., Mason, B.A., Hayes, B.J. & Goddard, M.E. 2015. Improved precision of QTL mapping using a nonlinear Bayesian method in a multi-breed population leads to greater accuracy of across-breed genomic predictions. *Genetics Selection Evolution,* 47: 29.

Kinghorn, B.P. 2011. An algorithm for efficient constrained mate selection. *Genetics Selection Evolution*, 43, 4.

Kirkpatrick, B., Li, S.C., Karp, R.M. & Halperin, E. 2011. Pedigree reconstruction using identity by descent. *Journal of Computational Biology,* 18: 1481–1493.

Kosgey, I.S., Baker, R.L., Udo, H.M.J. & van Arendok, J.A.M. 2006. Successes and failures of small ruminant breeding programmes in the tropics: a review. *Small Ruminant Research*, 61: 13–28.

Krebs, S., Medugorac, I., Röther, S., Strässer, K. & Förster, M. 2007. A missense mutation in the 3-ketodihydrosphingosine reductase *FVT1* as candidate causal mutation for bovine spinal muscular atrophy. *Proceedings of the National Academy of Sciences*, 104: 6746–6751.

Lanari, M.R., Pérez Centeno, M., Arrigo, J., Debenedetti, S. & Abad, M. 2009. Razas locales y fibras caprinas, bases para un desarrollo rural del norte de la Patagonia Argentina. *Animal Genetic Resources Information*, 45, 55–59 (available at ftp://ftp.fao.org/docrep/fao/012/i1102t/i1102t00.pdf).

Larroque, H., Barillet, F., Baloche, G., Astruc, J.M., Buisson, D., Shumbusho, F., Clément, V., Lagriffoul, G., Palhière, I., Rupp, R., Carillier, C., Robert-Granié, C. & Legarra, A. 2014. Toward genomic breeding programmes in French dairy sheep and goats. In *Proceedings 10th World Congress on Genetics Applied to Livestock Production, Vancouver, BC, Canada, August 17–22 2014* (available at http://tinyurl.com/olq3azr).

Larzul, C., Ducrocq, V., Tudela F., Juin, H. & Garreau, H. 2014. The length of productive life can be modified through selection: an experimental demonstration in the rabbit. *Journal of Animal Science*, 92: 2395–2401.

Larzul, C., Gondret, F., Combes, S. & Rochambeau, H. de. 2005. Divergent selection on 63-day body weight in the rabbit: response on growth, carcass and muscle traits. *Genetics Selection Evolution*, 37: 105–122.

Laughlin, K. 2007. *The evolution of genetics, breeding and production*. Temperton Fellowship Report No. 15. Newport, Shropshire, UK, Harper Adams University College.

Lawlor, T.J., VanRaden, P.M., Null, D., Levisee, J. & Dorhorst, B. 2014. Using haplotypes to unravel the inheritance of Holstein coat color. In *Proceedings 10th World Congress on Genetics Applied to Livestock Production, Vancouver, BC, Canada, August 17–22 2014* (available at https://asas.org/wcgalp-proceedings).

Lebas, F., Coudert, P., Rochambeau, H. & Thébault, R.G. 1997. *The rabbit: husbandry, health and production*. FAO Animal Production and Health Series No. 21. Rome, FAO (available at http://www.fao.org/docrep/t1690e/t1690e00.HTM).

Liu, Z., Reinhardt, F., Szyda, J., Thomsen, H. & Reents, R. 2004. A marker assisted genetic evaluation system for dairy cattle using a random QTL model. *Interbull Bulletin*, 32: 170–174.

Lôbo, R.N.B., Facó, O., Bezerra Oliveira Lôbo, A.M. & Vasques Villela, L.C. 2010. Brazilian goat breeding programmes. *Small Ruminant Research*, 89: 149–154.

Lôbo, R.N.B., Pereira, I.D.C., Facó, O. & McManus, C.M. 2011. Economic values for production traits of Morada Nova meat sheep in a pasture based production system in semi-arid Brazil. *Small Ruminant Research*, 96: 93–100.

Lukefahr, S.D., Odi, H.B. & Atakora, J.K.A. 1996. Mass selection for 70-day body weight in rabbits. *Journal of Animal Science*, 74: 1481–1489.

Lyall, J., Irvine, R.M., Sherman, A., McKinley, T.J., Núñez, A., Purdie, A., Outtrim, L., Brown, I.H., Rolleston-Smith, G., Sang, H. & Tiley, L. 2011. Suppression of avian influenza transmission in genetically modified chickens. *Science*, 331: 223–226.

Manfredi, E. & Ådnøi, T. 2012. Génétique des caprins laitiers. *INRA Productions Animales*, 25: 233–244.

McClure, M., Kim, E., Bickhart, D., Null, D., Cooper, T., Cole, J., Wiggans, G., Ajmone-Marsan, P., Colli, L., Santus, E., Liu, G.E., Schroeder, S,. Matukumalli, L., Van Tassell, C. & Sonstegard, T. 2013. Fine mapping for Weaver Syndrome in Brown Swiss cattle and the identification of 41 concordant mutations across NRCAM, PNPLA8 and CTTNBP2. *PLoS ONE*, 8: e59251.

McClure, M.C., Bickhart, D., Null, D., VanRaden, P., Xu, L., Wiggans, G., Liu, G., Schroeder, S., Glasscock, J., Armstrong, J., Cole, J.B., Van Tassell, C.P. & Sonstegard, T.S. 2014. Bovine exome sequence analysis and targeted SNP genotyping of recessive fertility defects *BH1*, *HH2*, and *HH3* reveal causative mutation in *SMC2* for *HH3*. *PLoS ONE*, 9:e92769.

Medugorac, I., Seichter, D., Graf, A., Russ, I., Blum, H., Göpel, K.H., Rothammer, S., Förster, M. & Krebs, S. 2012. Bovine polledness – an autosomal dominant trait with allelic heterogeneity. *PLoS ONE*, 7: e39477.

Menéndez-Buxadera, A., Serradilla, J.M. & Molina, A. 2014. Genetic variability for heat stress sensitivity in Merino de Grazalema sheep. *Small Ruminant Research*, 121(2-3): 207–214.

Merks, J.W., Mathur, P.K. & Knol, E.F. 2012. New phenotypes for new breeding goals in pigs. *Animal,* 6: 535–543.

Meuwissen, T.H.E. 1997. Maximizing response to selection with a predefined rate of inbreeding. *Journal of Animal Science, 75:* 934–940.

Meuwissen, T.H.E., Hayes, B.J. & Goddard, M.E. 2001. Prediction of total genetic value using genome-wide dense marker maps. *Genetics,* 157: 1819–1829.

Mirkena, T., Duguma, G., Willam, A., Wurzinger, M., Haile, A., Rischkowsky, B., Okeyo, A.M., Tibbo, M. & Sölkner, J. 2012. Community-based alternative breeding plans for indigenous sheep breeds in four agro-ecological zones of Ethiopia. *Journal of Animal Breeding and Genetics*, 129, 244–253.

Morris, S.T. & Kenyon, P.R. 2014. Intensive sheep and beef production from pasture – a New Zealand perspective of concerns, opportunities and challenges. *Meat Science,* 98: 330–335.

Msanga, N.Y. & Bee, J.K.A. 2006. The performance of Friesian x Boran bulls managed extensively under agropastoralism with indigenous Tanzanian zebu. *Livestock Research for Rural Development,* 18: Article #20 (available at http://www.lrrd.org/lrrd18/2/msan18020.htm).

Mueller, J.P. 1995. *Impacto genético del Proyecto Caprino en los pequeños productores minifundistas de Río Negro y Neuquén*. Comunicación Técnica INTA EEA Bariloche Nro. PA 198. Bariloche, Argentina, INTA.

Mueller, J. P. 2006. Breeding and conservation programmes with local communities. *Comunicacion Tecnica INTA Bariloche* No PA 489. Bariloche, Argentina, INTA.

Mueller, J.P. 2013. Experiencias con estructuras genéticas para el mejoramiento de rumiantes menores en las zonas aridas. In L.R. Iñiguez, ed., *La produccion de rumiantes menores en las zonas aridas de Latinoamerica*, pp. 497–513. Brasılia, Editorial EMBRAPA.

Mueller, J.P., Flores, E.R. & Gutierrez, G. 2002. Experiences with a large-scale sheep genetic improvement project in the Peruvian highlands. In *Proceedings of the 7th World Congress on Genetics Applied to Livestock Production. Montpellier (France), 19–23 August 2002*. Communication 25–12.

Mueller, J.P., Rischkowsky, B., Haile, A., Philipsson, J., Mwai, O., Besbes, B., Valle Zárate, A., Tibbo, M., Mirkena, T., Duguma, G., Sölkner, J. & Wurzinger, M. 2015. Community-based livestock breeding programmes: essentials and examples. *Journal of Animal Breeding and Genetics,* 132: 155–168.

Muir, W.M. 2007. Comparison of genomic and traditional BLUP-estimated breeding value accuracy and selection response under alternative trait and genomic parameters. *Journal of Animal Breeding and Genetics,* 124: 342–355.

Munoz, P.R., Resende Jr., M.F.R., Huber, D.A., Quesada, T., Resende, M.D.V., Neale, D.B., Wegrzyn, J.L., Kirst, M. & Peter, G.F. 2014. Genomic relationship matrix for correcting pedigree errors in breeding populations: impact on genetic parameters and genomic selection accuracy. *Crop Science*, 54: 1115–1123.

Neeteson-van Nieuwenhoven, A.M., Knap, P. & Avendaño, S. 2013. The role of sustainable commercial pig and poultry breeding for food security. *Animal Frontiers,* 3: 52–57.

Ojango, J.M.K., Ahuya, C., Okeyo, A.M. & Rege, J.E.O. 2010. The FARM-Africa dairy goat improvement project in Kenya: a case study. *In* J.M. Ojango, B. Malmfors, A.M. Okeyo, eds. *Animal Genetics Training Resource, version 3, 2011*. Nairobi and Uppsala, Sweden, International Livestock Research Institute and Swedish University of Agricultural Sciences.

Olori, V.E. 2010. Poultry breeding and climate change: The role of feed efficiency. *Nigerian Poultry Science Journal*, 7: 89–93.

Pabiou, T., Byrne, T., Wall, E. & McHugh, N. 2014. Genetic improvement of sheep in Ireland. In *Proceedings 10th World Congress on Genetics Applied to Livestock Production, Vancouver, BC, Canada, August 17–22 2014* (available at https://asas.org/wcgalp-proceedings).

Palhiere, I., Clement, V., Martin, P. & Colleau, J-J. 2014. Bilan de la méthode de Sélection à Parenté Minimum après 6 ans d'application dans le schéma de sélection caprin. *Rencontres Recherche Ruminants*, 21 (available at http://www.journees3r.fr/spip.php?article3815).

Pastor, F., Escareño, L., Iñiguez, L., Salinas, H., Sölkner, J. & Wurzinger, M. 2008. Design of a community-based goat breeding program in Northern Mexico. In *9th International Conference on Goats, Queretaro, Mexico, 31 August–5 September 2008.*

Pelletier, N., Ibarburu, M. & Xin, H.W. 2014. Comparison of the environmental footprint of the egg industry in the United States in 1960 and 2010. *Poultry Science*, 93: 241–255.

Phocas, F., Brochard, M., Larroque, H., Laggrifoul, G., Labatut, J. & Guerrier, J. 2013. État actuel et perspectives d'évolution des objectifs de sélection chez les ruminants. *Rencontres Recherche Ruminants*, 20 (available at http://www.journees3r.fr/spip.php?article3604).

Piles, M. & Blasco, A. 2003. Response to selection for growth rate in rabbits. *World Rabbit Science*, 11(2): 53–62.

Piles, M., Garreau, H., Rafel, O., Larzul, C., Ramon, J. & Ducrocq, V. 2006. Survival analysis in two lines of rabbits selected for reproductive traits. *Journal of Animal Science*, 84:1658–1665.

Piles, M., Gomez, E., Rafel, O., Ramon, J. & Blasco, A. 2004. Elliptical selection experiment for the estimation of genetic parameters of the growth rate and feed conversion ratio in rabbits. *Journal of Animal Science*, 82: 654–660.

Prayaga, K.C. & Eady, S. 2000. Rabbit farming for meat production in Australia: preliminary estimates of economic values for production traits. *Asian-Australasian Journal of Animal Science*, 13: 357–359.

Pryce, J.E., Haile-Mariam, M., Goddard, M.E. & Hayes, B.J.E. 2014. Identification of genomic regions associated with inbreeding depression in Holstein and Jersey dairy cattle. *Genetics Selection Evolution*, 46: 71.

Pryce, J.E., Hayes, B.J. & Goddard, M.E. 2012. Genotyping dairy females can improve the reliability of genomic selection for young bulls and heifers and provide farmers with new management tools. In *Proceedings of the 38th ICAR Session* (available at http://tinyurl.com/nr7262u).

Rafat, S.A., Allain, D., Thebault, R.G. & de Rochambeau, H. 2007. Divergent selection for fleece yield in French Angora rabbits: Non-genetic effects, genetic parameters and response to selection. *Livestock Science*, 106: 169–175.

Rafat, S.A., de Rochambeau, H., Thebault, R.G., David, I., Deretz, S., Bonnet M., Pena-Arnaud, B. & Allain, D. 2008. Divergent selection for total fleece weight in Angora rabbits: Correlated response in wool characteristics. *Livestock Science*, 113: 8–13.

Reicher, S., Sroussi, E. & Gootwine, E. 2010. A mutation in gene *CNGA3* is associated with day blindness in sheep. *Genomics,* 95: 101–104.

Renaudeau, D., Gourdine, J.L., Fleury, J., Ferchaud, S., Billon, Y., Noblet, J. & Gilbert, H. 2014. Selection for residual feed intake in growing pigs: effects on sow performance in a tropical climate. *Journal of Animal Science*, 92: 3568–3579.

Rochambeau, H. de, De la Fuente, L.F., Rouvier, R. & Ouhayoun, J. 1989. Sélection sur la vitesse de croissance post-sevrage chez le lapin. *Genetics Selection Evolution*, 21: 527–546.

Roessler, R., Herold, P., Momm, H. & Valle Zárate, A. 2012. Organisation of breeding under difficult framework conditions – the case of smallholder pig breeding in mountainous areas in Northwest Vietnam. *Archives of Animal Breeding,* 55/56: 590–602.

Roothaert, R.L., Ssalongo, S. & Fulgensio, J. 2011. The Rakai chicken model: an approach that has improved fortunes for Ugandan farmers. *International Journal of Agricultural Sustainability*, 9: 222–231.

Rothammer, S., Capitan, A., Mullaart, E., Seichter, D., Russ, I. & Medugorac. I. 2014. The 80-kb DNA duplication on *BTA1* is the only remaining candidate mutation for the polled phenotype of Friesian origin. *Genetics Selection Evolution*, 46: 44.

Rothschild, M.F. & Plastow G.S. 2014. Applications of genomics to improve livestock in the developing world. *Livestock Science,* 166: 76–83.

Sánchez, J.P. & Piles, M. 2013. Sources of individual variation to heat tolerance in a rabbit line. *Journal of Animal Science*, 91: 1059–1066.

Sánchez, J.P., Theilgaard, P., Minguez, C. & Baselga, M. 2008. Constitution and evaluation of a long-lived productive rabbit line. *Journal of Animal Science*, 86: 515–525.

Schierenbeck, S., Pimentel, E.C.G., Tietze, M., Körte, J., Reents, R., Reinhardt, F., Simianer, H. & König, S. 2011. Controlling inbreeding and maximizing genetic gain using semi-definite programming with pedigree-based and genomic relationships. *Journal of Dairy Science,* 94: 6143–6152.

Schwarzenbacher, H., Fürst, C., Fürst-Waltl, B. & M. Dolezal. 2012. A genome-wide search for harmful recessive haplotypes in Brown Swiss and Fleckvieh cattle. In *Book of abstracts of the 63th Annual Meeting of the European Federation of Animal Science. Book of abstracts No 18 (20132) Bratislava, Slovakia, 27–31 August, 2012,* p. 171. Wageningen the Netherlands, Wageningen Academic Publishers.

Seroussi, E., Glick, G., Shirak, A., Ezra, E., Zeron, Y., Ron, M. & Weller, J.I. 2013. Maternity validation using sire-only Bovine SNP50 BeadChip data. *Animal Genetics*, 44: 754–757.

Serradilla, J.M. 2001. Use of high yielding goat breeds for milk production. *Livestock Production Science*, 71: 59–73.

Serradilla, J.M. (ed.). 2008. Objetivos, organización y factores limitantes de los programas de selección de las razas autóctonas en España. *Proceedings XIV Reunión Nacional de Mejora Genética. ITEA*, 104(2): 186–242.

Serradilla, J.M. 2014. Breeding programs for small ruminants in Spain. In *Proceedings of the Internationally Participated Small Ruminant Congress. 16–18 October 2014. Konya, Turkey*.

Shanks, R.D., Dombrowski, D.B., Harpestad, G.W. & Robinson, J.L. 1984. Inheritance of UMP synthase in dairy cattle. *Journal of Heredity*, 75: 337–340.

Shiotsuki, L., Pernambuco de Oliveira, D., Lobo, R.N.B. & Facon, O. 2014 Genetic parameters for growth and reproductive traits of Morada Nova sheep kept by smallholder in semi-arid Brazil. *Small Ruminant Research,* 120(2-3): 204–208.

Shuster, D.E., Kehrli Jr., M.E., Ackermann, M.R. & Gilbert, R.O. 1992. Identification and prevalence of a genetic defect that causes leukocyte adhesion deficiency in Holstein cattle. *Proceedings of the National Academy of Sciences of the United States of America*, 89: 9225–9229.

Simm, G., Lewis, R.M., Collins, J.E. & Nieuwhof, G.J. 2001. Use of sire referencing schemes to select for improved carcass composition in sheep. *Journal of Animal Science*, 79: E255–259.

PART **4**

Sise, J.A., Linscott, E.M. & Amer, P.R. 2011. Predicting the benefits of two stage genomic selection in young breeding rams. *Proceedings of the New Zealand Society of Animal Production*, 71, 266–269.

Sitzenstock, F., Ytournel, F., Sharifi, A.R., Cavero, D., Taubert, H. & Preisinger, R. 2013. Efficiency of genomic selection in an established commercial layer breeding programme. *Genetics Selection Evolution*, 45: 29.

Sonstegard, T.S., Cole, J.B., VanRaden, P.M., Van Tassell, C.P., Null, D.J., Schroeder, S.G., Bickhart, D. & McClure, M.C. 2013. Identification of a nonsense mutation in *CWC15* associated with decreased reproductive efficiency in Jersey cattle. *PLoS ONE*, 8: e54872.

Swann, A., Brown, D., Daetwyler, H., Kelly, M., Hayes, B., Moghaddar, N. & van der Werf, J. 2014. Genomic Evaluations in the Australian Sheep Industry. In *Proceedings 10th World Congress on Genetics Applied to Livestock Production, Vancouver, BC, Canada, August 17–22 2014* (available at https://asas.org/wcgalp-proceedings).

Tadele, M., Duguma, G., Willam, A., Haile, A., Iñiguez, L., Wurzinger, M. & Sölkner, J. 2010. Indigenous sheep genetic improvement schemes for Ethiopian smallholder and pastoralists. In *Proceedings of the 9th World Congress on Genetics Applied to Livestock Production, Leipzig, Germany, 1–6 August 2010* (available at http://www.kongressband.de/wcgalp2010/assets/pdf/0937.pdf).

Thomsen, B., Nissen P.H., Agerholm, J.S. & Bendixen, C. 2010. Congenital bovine spinal dysmyelination is caused by a missense mutation in the *SPAST* gene. *Neurogenetics*, 11: 175–183.

Torres Vázquez, J.A., Valencia, M., Castillo-Juarez, H. & Montaldo, H.H. 2009. Genetic and phenotypic parameters of milk yield, milk composition and age at first kidding in Saanen goats from Mexico. *Livestock Science,* 126: 147–153.

Tosser-Klopp, G. 2012. *Goat genome assembly. Availability of an international 50K SNP chip and RH panel: an update of the International Goat Genome Consortium projects.* Paper presented at Plant and Animal Genome XX, San Diego, CA, USA, 14–18 January 2012 (available at https://pag.confex.com/pag/xx/webprogram/Paper2190.html).

Tribout, T., Caritez, J.C., Gruand, J., Bouffaud, M., Guillouet, P., Billon, Y., Péry, C., Laville, E. & Bidanel, J.P. 2010. Estimation of genetic trends in French Large White pigs from 1977 to 1998 for growth and carcass traits using frozen semen. *Journal of Animal Science,* 88: 2856–2867.

Tu, X., Du, S., Tang, L., Xin, H. & Wood, B. 2011. A real-time automated system for monitoring individual feed intake and body weight of group housed turkeys. *Computers and Electronics in Agriculture*, 75: 313–320.

Tusell, L., Legarra, A., García-Tomás, M., Rafel, O., Ramon, J. & Piles, M. 2012. Genetic basis of semen traits and their relationship with growth rate in rabbits. *Journal of Animal Science*, 90: 1385–1397.

Valencia-Posadas, P., Gutiérrez-Chávez, A.J., Ángel-Sahagún, C.A., Mendoza-Carrillo, J.M., Mejía-Haro, J., Martínez-Yáñez, A.R. 2012. Goat milk production in central Mexico; the genetic improvement program. In *Proceedings of the 15th AAAP Animal Science Congress of the Asian-Australasian Association of Animal Production. Bangkok, Thailand, November 26–30*, pp. 1791–1795.

Valle Zárate, A. & Markemann, A. 2010. Community-based breeding programmes. Incorporating local breeds: Concept, research, results and implementation strategy on pigs in Northern Vietnam. In *Proceedings of the 9th World Congress on Genetics Applied to Livestock Production, Leipzig, Germany, 1–6 August 2010* (available at http://www.kongressband.de/wcgalp2010/assets/pdf/0845.pdf).

Van Doormaal, B. 2010. *The impact of sexed semen on breeding, management and profitability of the dairy herd*. Canadian Dairy Network (available at http://www.cdn.ca/articles.php).

Van Eenennaam, A.L. & Kinghorn, B.P. 2014. Use of mate selection software to manage lethal recessive conditions in livestock populations. In *Proceedings 10th World Congress on Genetics Applied to Livestock Production, Vancouver, BC, Canada, August 17–22 2014* (available at https://asas.org/wcgalp-proceedings).

Van Eenennaam, A.L., Weigel, K.A., Young, A.E., Cleveland, M.A. & Dekkers, J.C. 2014. Applied animal genomics: results from the field. *Annual Review of Animal Biosciences,* 2: 105–39.

Van Emous, R. 2015. *Body composition and reproduction in broiler breeders: impact of feeding strategies.* Wageningen University and Research Centrum, the Netherlands (PhD Thesis).

VanRaden, P.M. 2007. Genomic measures of relationship and inbreeding. *Interbull Bulletin,* 37: 33–36.

VanRaden, P., Null, D., Huthcison, J., Bickhart, D. & Cooper, T. 2014. *Jersey haplotype 2 (JH2). Changes to evaluation system (August 2014)*. Reynoldsburg, OH, USA, Council on Dairy Cattle Breeding.

VanRaden, P.M., Olson, K.M., Null, D.J. & Hutchison, J.L. 2011. Harmful recessive effects on fertility detected by absence of homozygous haplotypes. *Journal of Dairy Science,* 94: 6153–6161.

Venhoranta, H., Pausch, H., Flisikowski, K., Wurmser, C., Taponen, J., Rautala, H., Kind, A., Schnieke, A., Fries, R., Lohi, H., & Andersson, M. 2014. In frame exon skipping in *UBE3B* is associated with developmental disorders and increased mortality in cattle. *BMC Genomics*, 15: 890.

Wei, M. & Van der Steen, H.A.M. 1991. Comparison of reciprocal recurrent selection with pure-line selection systems in animal breeding (a review). *Animal Breeding Abstracts,* 59: 281–298.

Weigel, K.A. & Lin, S.W. 2000. Use of computerized mate selection programmes to control inbreeding of Holstein and Jersey cattle in the next generation. *Journal of Dairy Science,* 83: 822–828.

Wolc, A., Kranis, A., Arango, J., Settar, P., Fulton, J.E., O'Sullivan, N., Habier, D., Avendaño, S., Watson, K.A., Preisinger, R., Lamont, S.J., Fernando, R., Garrick, D.J. & Dekkers, J.C.M. 2014. Application of genomic selection in poultry. In *Proceedings 10th World Congress on Genetics Applied to Livestock Production, Vancouver, BC, Canada, August 17–22 2014* (available at https://asas.org/wcgalp-proceedings).

Wolc, A., White, I.M.S., Hill, W.G. & Olori, V.E. 2010. Inheritance of hatchability in broiler chickens and its relationship to egg quality traits. *Poultry Science*, 89: 2334–2340.

Wolc, A., White, I.M.S., Olori, V.E. & Hill, W.G. 2009. Inheritance of fertility in broiler chickens. *Genetics Selection Evolution*, 41: 47.

Wurzinger, M., Escareño, L., Pastor, F., Salinas, H., Iñiguez, L. & Sölkner, J. 2013b. Design and implementation of a community-based breeding program for dairy goats in Northern Mexico. *Tropical and Subtropical Agroecosystems*, 16, 289–296.

Wurzinger, M., Rodriguez, A. & Gutierrez, G. 2013a. Design of a community-based llama breeding program in Peru: a multi-stakeholder process. In *64th EAAP Annual meeting, 25-30 August, 2013, Nantes, France, Symposium on South American Camelids and other Fibre Animals.*

Wurzinger, M., Sölkner, J. & Iñiguez, L. 2011. Important aspects and limitations in considering community-based breeding programmes for low-input smallholder livestock systems. *Small Ruminant Research*, *98: 170–175.*

Wurzinger, M., Willam, A., Delgado, J., Nürnberg, M., Zárate, A.V., Stemmer, A., Ugarte, G. & Sölkner, J. 2008. Design of a village breeding programme for a llama population in the High Andes of Bolivia. *Journal of Animal Breeding and Genetics*, 125: 311–319.

Zhang, Z., Todhunter, R.J., Buckler, E.S. & Van Vleck, L.D. 2007. Technical note: Use of marker-based relationships with multiple-trait derivative-free restricted maximal likelihood. *Journal of Animal Science,* 85: 881–885.

Ziadi, C., Moce, M.L., Laborda, P., Blasco, A. & Santacreu, M.A. 2013. Genetic selection for ovulation rate and litter size in rabbits: Estimation of genetic parameters and direct and correlated responses. *Journal of Animal Science*, 91: 3113–3120.

Section D

Conservation

1 Introduction

A substantial proportion of the world's livestock breeds are at risk of extinction (see Part 1 Section B). The need for action to protect them is recognized in the Global Plan of Action for Animal Genetic Resources (FAO, 2007a), whose Strategic Priority Area 3 is devoted to conservation. The state of implementation of conservation programmes (comprehensiveness of coverage, extent of use of different conservation methods, extent of involvement of different stakeholder groups, etc.) is described in Part 3 Section D. The present section describes the "state of the art" in the field, i.e. the methods, tools and approaches that can be drawn upon in order to design and implement effective conservation programmes and strategies. It serves as an update of the equivalent section of the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007b). It draws heavily on two guideline publications on conservation prepared by FAO since 2007 – *Cryoconservation of animal genetic resources* (FAO, 2012) and In vivo *conservation of animal genetic resources* (FAO, 2013) – and focuses in particular on recent developments.

Various methods can be used to conserve animal genetic resources (AnGR). Conservation activities can be categorized according to whether they involve the maintenance of genetic material *in vivo* or *in vitro* (see Box 4D1). *In vivo* conservation can, in turn, be classified according to whether it takes place *in situ* or *ex situ*. *In situ* conservation is undertaken in the traditional production system of the conserved AnGR. *Ex situ* conservation is undertaken elsewhere (clearly, all *in vitro* conservation is *ex situ*). *In situ* and *ex situ* conservation are usually regarded as complementary (FAO, 2012; 2013)[1] and in combination they can form the basis of a powerful conservation strategy.

The first part of the section focuses on themes common to all conservation methods: planning tools; methods for identifying breeds at risk of extinction (including a description of the updated risk classification system developed by FAO since the first SoW-AnGR was published); and methodologies for determining the conservation value

[1] See also the "rationale" of Strategic Priority 9 of the Global Plan of Action for Animal Genetic Resources (FAO, 2007a).

Box 4D1
Glossary: *in vivo* and *in vitro* conservation

***In vivo* conservation** is conservation through the maintenance of live animal populations. It encompasses both *in situ* conservation and *ex situ in vivo* conservation.

***In situ* conservation** is conservation through continued use of live animal populations by livestock keepers in the production system in which the respective populations evolved or are now normally found and bred.

***Ex situ in vivo* conservation** is conservation through the maintenance of live animal populations not kept under normal management conditions (e.g. in a zoological park or a governmental farm) and/or outside the area where they evolved or are now normally found and bred.

***Ex situ in vitro* conservation** is conservation through the maintenance, under cryogenic conditions, of cells or tissues that have the potential to be used to reconstitute live animals and populations at a later date.

of a breed as a basis for priority setting. This is followed by in-depth discussions of the two major categories of conservation: first *in vivo* conservation methods and then *in vitro* methods (otherwise referred to as cryoconservation). The subsection on *in vivo* conservation includes a look at institutional arrangements, methods for maintaining genetic variability in small populations, and strategies and methods for increasing demand for at-risk breeds. The subsection on *in vitro* conservation discusses the infrastructure and institutional frameworks for the operation of a gene bank, strategies for the development and assessment of gene bank collections, developments in cryobiology and reproductive physiology, developments in information systems and documentation of gene banked material, and legal aspects of gene banking.

A number of different arguments have been put forward as to why efforts should be made to conserve AnGR (see the first SoW-AnGR[2] for more detailed discussion). Conservation programmes for AnGR usually address one or more of the following objectives:

- economic – maintaining the livestock sector's capacity to respond to ecological changes (e.g. those caused by climate change), changing market demands, changing regulatory frameworks, changes in the availability of inputs, and so on;
- social and cultural – maintaining the roles of livestock in the cultural and historical identities of the communities that developed them (and for the social and cultural benefit of society more broadly);
- environmental – AnGR make an intrinsic contribution to biodiversity and they also contribute to maintaining capacity to utilize livestock in the provision of ecosystem services and to reduce the negative environmental effects of livestock production; and
- research and training – maintaining resources that are valuable for research or educational purposes (e.g. in the fields of immunology, nutrition, reproduction, genetics, genomics and adaptation to climatic and other environmental changes).

As well as considering arguments for conservation, the discussion presented in the first SoW-AnGR also addressed differences between genetic resources conservation in the plant and animal sectors.[3] A number of biological (e.g. reproductive rates, generation intervals and level of diversity within breeds/varieties), operational (e.g. feasibility and costs of activities such as in vitro conservation, germplasm collection and clonal propagation) and institutional (e.g. patterns of ownership and use of genetic resources and the state of development of gene banks) differences between the two sectors were identified. The combined effect of these differences is that AnGR conservation programmes are generally more complicated to organize than those for plant genetic resources. A particular difference is the primary role of the private sector in managing AnGR. Individual animals are usually owned by individuals or groups of individuals, which can make implementation of organized conservation programmes more complex. Owner prerogative as to the direction of selection and mating strategies adds a unique and dynamic nature to conservation actions in this sector.

The various types of conservation programme each have advantages and disadvantages with respect to addressing particular conservation objectives. These advantages and disadvantages are summarized in Table 4D1. This summary refers to situations in which only one of the types of conservation is used. For example, if only *in vitro* conservation is used and no *in vivo* population is present, the conserved AnGR will be making no ongoing contribution to rural development.

In situ conservation is considered to have a number of advantages, including:

- allowing the conserved breed to continue adapting to its production environment as it changes over time;

[2] FAO, 2007b, pages 444–488.

[3] FAO, 2007b, pages 449–451.

- facilitating the maintenance of local knowledge regarding the breed and its management; and
- providing opportunities for the development of strategies that enable the breed to become self-supporting (i.e. that remove the need for external support).

However, *in situ* conservation is not without risks. For example, a population maintained *in situ* may be struck by a disease outbreak or other disaster or may be affected by inbreeding, genetic drift or introgression from another breed. *Ex situ* conservation decreases these risks by providing a backup that can be drawn upon if required. *Ex situ* conservation as a stand-alone strategy does not allow for adaptation. However, if the population is also maintained *in situ*, regularly collecting and conserving new samples *in vitro* can help to maintain the potential for future adaptation.

As described above, *ex situ* conservation can be undertaken either *in vivo* or *in vitro*. While in many circumstances maintaining a live *ex situ* population adds little to a conservation strategy that already includes *in situ* and *in vitro* components, it can have some advantages. For example, *ex situ in vivo* programmes are usually under centralized control, which can facilitate management actions such as the control of mating. In cases where the population size is very small and no facilities are available for cryopreservation, *ex situ in vivo* conservation may be the only viable option. One weakness of *ex situ in vivo* conservation is that, because the populations are usually small (and thus highly subject to genetic drift) and animals are often kept in a single location that may not replicate their original production environments, the conserved population will usually not maintain the complete genetic diversity of the original founder population.

Table 4D1 helps demonstrate the benefits of using complementary approaches to conservation. If an *in vivo* population is maintained along with an *in vitro* collection, then the living population can be periodically sampled to enrich the *in vitro* collection and account for changes in gene frequency that occur via the adaptive process. Likewise, although in the absence of an *in vivo* population an *in vitro* collection cannot contribute to the ongoing development of rural areas, if both types of programme are in place then material from the *in vitro* collection can be actively used in the management of genetic variation in the *in vivo* population.

TABLE 4D1

Conservation methods and their potential to contribute to various objectives

Objective	Type of conservation (if implemented as a stand-alone measure)		
	In situ	*Ex situ in vivo*	Cryoconservation
Maintaining flexibility for the future			
Insuring against changes in production conditions	Yes	Yes	Yes
Safeguarding against diseases, disasters, etc.*	No	No	Yes
Providing opportunities for research	Yes	Yes	Yes
Genetic factors			
Allowing continued evolution/genetic adaptation	Yes	Limited	No
Increasing knowledge of breed characteristics	Yes	Limited	Limited
Limiting exposure to genetic drift**	Yes	No	Yes
Sustainable management of rural areas			
Providing opportunities for rural development	Yes	Limited	No
Maintaining agro-ecosystem diversity	Yes	Limited	No
Maintaining rural cultural diversity	Yes	Limited	No

Note: *Risk from disease in *in vivo* programmes can be decreased by maintaining animals in geographically dispersed locations.
**The extent of genetic drift will depend on the population size *in situ* and the number of animals sampled for cryoconservation. Genetic drift cannot be eliminated in *in vivo* populations, but proper management can limit drift to an acceptable level.
Source: FAO, 2013.

Box 4D2

Analysis of strengths, weaknesses, opportunities and threats (SWOT analysis) of Groningen White Headed cattle in the Netherlands

The Groningen White Headed is a native Dutch cattle breed. The first description of the breed dates from the fourteenth century. Pictures of red and of black White Headed cows were painted during the Middle Ages. A herdbook was founded at the end of the nineteenth century. Around that time, 90 percent of all cattle in the Province of Groningen (in the northern part of the Netherlands) were White Headed cattle. They were dual-purpose animals used for milk and beef production. Animals belonging to the breed were also found near the cities of Utrecht and Leiden (in the southwest), where their milk was used for cheese production. Around 1970, the breed had 20 000 milk-recorded females, but due to cross-breeding with Holstein-Friesians, the number of milk-recorded pure-bred females had fallen to approximately 600 in 2014.

A number of national and regional groups of farmers and breeders are interested in the breed. One of them, the "Blaarkop Stichting", is very active in promoting it.

A SWOT analysis undertaken for this breed produced the following results:

Strengths: good performance in terms of functional traits and milk quality; distinctive appearance.

Weaknesses: relatively low milk yield; risk of genetic drift and loss of genetic variation.

Opportunities: renewed interest in functional traits is increasing the use of pure-bred Groningen White Headed sires for cross-breeding with Holstein-Friesians; increasing use of the breed for beef production and as suckler cows.

Threats: the abolition of milk quotas in the European Union will increase the emphasis given to the efficiency of milk production.

Based on the results of the SWOT analysis, the breed interest groups decided to initiate three strategic actions:

1. stimulating farmers to keep the breed or to use pure-bred sires for cross-breeding with Holstein Friesians (some 20 sires are marketed by artificial insemination studs), thus taking advantage of the breed's strength of having good functional traits;
2. making Groningen White Headed semen from the National Gene bank (CGN) available to breeders when its use will increase the genetic variability in the population of pure-bred females (CGN has collected semen from 70 sires since 1973), thus addressing the weakness related to genetic variation; and
3. producing cheese and beef for niche markets and using the breed in the provision of ecological services, thus addressing the threat posed by the abolition of milk quotas by providing alternative sources of income.

Source: Adapted from Hiemstra *et al.*, 2010.

Photo credit: Veeteelt.

Photo credit: Zwanet Faber.

2 Planning a conservation strategy

The planning process for a conservation strategy for a region or a country should start with a review of the status of each breed or breeding population potentially targeted for conservation activities. If inventories of breeds and populations are incomplete, effort should be made to improve them (see Part 4 Section A), as unrecorded breeds will clearly not be included in the planning process and not accounted for in the conservation strategy (although they may benefit indirectly from measures that support the sustainability of the production systems in which they are kept).

The characteristics of each breed should be described, along with its production environment and its uses, roles and values. It is also important to evaluate drivers of change and how they are affecting production systems and the breed's roles within them. Data on the size and structure of the breed population and how these are changing over time are also essential. See Part 4 Section A for a discussion of data collection methods. The estimation of risk status is discussed in greater detail below in Subsection 3. Specific threats – whether associated with production system trends, weaknesses in management or exposure to risks such as disease outbreaks or climatic disasters – should, as far as possible, be identified and evaluated (see Part 1 Section F). The overall objectives of the conservation strategy also need to be considered, i.e. which of the objectives described above in Subsection 1 are to be prioritized?

Once the relevant information has been assembled, priorities can be set (see Subsections 3 and 4) and management strategies for individual breeds can be developed. One approach to planning a conservation strategy for an individual breed is to undertake a SWOT (strengths, weaknesses, opportunities and threats) analysis of the breed and its production system (Martin-Collado *et al.*, 2013) (see Box 4D2 for an example). Threats or opportunities can be identified by analysing trends and drivers of change in the production system. Strengths and weaknesses can be determined by considering the characteristics of the breed in relation to the requirements of production systems and national objectives for conservation and livestock development. Also relevant are population-level factors that affect risk of extinction (e.g. the size, structure and distribution of the breed population, the demographics of the livestock-keeping population) or affect capacity to implement conservation and other management activities (e.g. the presence or absence of breeders' organizations).

3 Identifying breeds at risk

Population size and rate of change in population size are the most important criteria for determining a breed's risk of extinction and should be recorded regularly. The two aspects of breed extinction – loss of animals and loss of gene variants – are deeply interconnected. The loss of breeding animals and consequently a low number of parents available to breed the next generation increases the average relationship between parents and may lead to a higher occurrence of genetic defects and inbreeding depression.

Species differ greatly in terms of their reproductive capacity, and this influences the ability of populations to recover after a decline. For example, a small population size creates a higher risk of extinction in horses than in pigs. In order to account for differences of this kind, FAO's amended risk categorization system (FAO, 2013) distinguishes between species with low and high reproductive capacities and includes different risk-status thresholds for each group (see Tables 4D2 and 4D3; note also that a new category – "vulnerable" – has been added to the classification system).

Once a breed's risk category has been assessed, different objectives for the management of its population can be considered. Four (non-mutually exclusive) means of strengthening the position of the breed can be distinguished:

- enlarging the population;
- managing diversity;

- selecting for improved productivity; and
- establishing a store of cryoconserved genetic material.

The relevance of each of these objectives for breeds in the various risk-status categories is indicated in Table 4D4.

In addition to population size and trends, other demographic factors can influence risk status. Concentration of the population in a restricted area or in a limited number of herds may place it at greater risk of extinction (Carson *et al.*, 2009). Another factor to consider is the possible presence

TABLE 4D2

Risk categories for species with high reproductive capacity

Population trend and pure-breeding proportion[1]	Population size[2] (n)							
	Males (n)	≤80	81 – 120	121 – 800	801 – 1 200	1 201 – 1 600	1 601 – 2 400	>2 400
Increasing trend and >80% pure-breeding	≤5							
	6 – 20							
	21 – 35							
	>35							
Stable or decreasing trend or ≤80% pure-breeding	≤5							
	6 – 20							
	21 – 35							
	>35							

= Critical = Endangered = Vulnerable = Not at risk

Note: High reproductive capacity species = pigs, rabbits, guinea pigs, dogs and all avian species.
[1] Many countries do not have historical data with which to determine population trends or do not regularly monitor the proportion of pure-breeding. When this information is not available, the lower part of the table should be used.
[2] Some combinations with large numbers of females relative to males are not realistic, especially in the absences of artificial insemination. However, they illustrate that increasing numbers of one gender may not compensate for small numbers of the other.
Source: FAO, 2013.

TABLE 4D3

Risk categories for species with low reproductive capacity

Population trend and pure-breeding proportion[1]	Population size[2] (n)							
	Males (n)	≤240	241 – 360	361 – 2 400	2 401 – 3 600	3 601 – 4 800	4 801 – 7 200	>7 200
Increasing trend and >80% pure-breeding	≤5							
	6 – 20							
	21 – 35							
	>35							
Stable or decreasing trend or ≤80% pure-breeding	≤5							
	6 – 20							
	21 – 35							
	>35							

= Critical = Endangered = Vulnerable = Not at risk

Note: Low reproductive capacity species = horses, donkeys, cattle, yaks, buffaloes, deer, sheep, goats and camelids.
[1] Many countries do not have historical data with which to determine population trends or do not regularly monitor the proportion of pure-breeding. When this information is not available, the lower part of the table should be used.
[2] Some combinations with large numbers of females relative to males are not realistic, especially in the absences of artificial insemination. However, they illustrate that increasing numbers of one gender may not compensate for small numbers of the other.
Source: FAO, 2013.

TABLE 4D4
Relative importance of population management objectives according to risk status

Risk category	Enlarging the population	Managing diversity	Selection for productivity	Cryoconservation
Critical	+++	+++	-	+++
Endangered	++	+++		++
Vulnerable	+	+	+++	+
Not at risk		+	+++	

Note: The larger the number of plus (+) signs, the more important the objective. Minus (-) signs indicate that the objective should not be pursued. Absence of a sign means that the objective can or should be pursued, but the decision as to whether to do so should take other factors (e.g. the cost) into account.
Source: FAO, 2013.

of controlled or uncontrolled cross-breeding. The average age of breeders, their plans to continue livestock-keeping activities and their "exit strategies" and "legacy plans", if any, can also be significant. In many developed countries, significant proportions of livestock keepers are quite advanced in years and sufficiently financially secure to keep relatively unprofitable breeds because of tradition or as a hobby. When these breeders retire from active livestock keeping, the breeds they raise may be lost if younger breeders are not willing to take their place.

4 Determining the conservation value of a breed

All breeds or breeding populations categorized as being at risk of extinction can be considered candidates for inclusion in a conservation programme. However, it may be necessary to set priorities among these candidates. Risk status is often considered the most important criterion in setting conservation priorities. However, the value of conserving a given breed will be affected by a range of factors. Potentially relevant criteria include genetic uniqueness, within-breed genetic variation, traits of economic importance, unique traits and traits related to adaptation to a specific environment. The sociocultural value of the breed or its role in maintaining a unique ecosystem may also be reasons for assigning it a high priority.

When multiple factors need to be taken into account in establishing conservation priorities, one approach is to develop a "conservation priority index" that assigns different weights to the various factors (FAO, 2013). Once breeds have been prioritized, the costs of potential conservation programmes, along with their probability of success, need to be taken into account. Breed-ranking methods that include non-market values along with genetic variation and market values continue to be developed (e.g. Martin-Collado *et al.*, 2014; Zander *et al.*, 2013). However, to date such methods have mainly been limited to research. They are not widely used by countries when prioritizing breeds for conservation. Developments in this field are discussed in greater detail in Part 4 Section E.

In the case of transboundary breeds (see Part 1 Section B), prioritization may be complicated by the need to consider risk status not just at national level, but also across several countries. Collaboration at regional or global levels in the prioritization and planning of conservation activities should help ensure that transboundary breeds are not neglected because stakeholders at national level assume that they will be conserved elsewhere.

Molecular genetic data can contribute to the setting of conservation priorities (e.g. Tadano *et al.*, 2013). The panel of 30 species-specific microsatellite markers recommended by ISAG-FAO Advisory Group (FAO, 2011) still has some utility, especially for minor species, but is quickly being superseded

by more advanced approaches. Genomic techniques, such as detecting large numbers of single nucleotide polymorphisms (SNPs) or whole genome sequencing, allow the variety of alleles, haplotypes and genotypes within the genome to be established and the presence of rare alleles and unique genome sequences to be verified. The state of the art in the use of molecular tools is discussed in Part 4 Section B.

5 *In vivo* conservation

In vivo conservation programmes can involve a range of different types of action. In the case of *in situ* conservation, the general objectives are to support livestock keepers that raise at-risk breeds, to promote the sustainability of production systems in which at-risk breeds are kept and to promote developments that enable at-risk breeds to become more self-sustaining. More specifically, *in situ* programmes can involve (*inter alia*):

- breeding programmes that focus on increasing the productivity of at-risk breeds while managing their genetic diversity;
- efforts to promote the marketing of products from at-risk breeds;
- efforts to promote alternative uses for at-risk breeds;
- efforts to promote community-level initiatives to improve the management of at-risk breeds;
- the provision of advice on the management of at-risk breeds; and
- the provision of support payments to the keepers of at-risk breeds.

The range of activities that can be undertaken at an *ex situ in vivo* conservation site is more limited. Direct support payments are generally considered to be feasible only on a short-term basis.

The success of an *in vivo* conservation programme is likely to depend on the presence of an appropriate institutional framework. The tasks involved in organizing such a framework are discussed below in Subsection 5.1. Specific tools and approaches are discussed in Subsections 5.2 and 5.3.

5.1 Institutional arrangements

The context for *in vivo* conservation programmes will vary greatly between countries and between species. However, sustainable and realistic plans and appropriate mechanisms for involvement of livestock keepers and other stakeholders will always be required. An *in vivo* conservation programme, particularly an *in situ* programme, is likely to involve a wide array of stakeholders. Depending on the circumstances, these may include livestock keepers and breeders, government institutions, breeders' associations, breeding companies, research and education institutes, NGOs, consumers and marketers. Livestock keepers and breeders are the cornerstones of any *in situ* conservation programme and ensuring their commitment to the goals of the programme is essential.

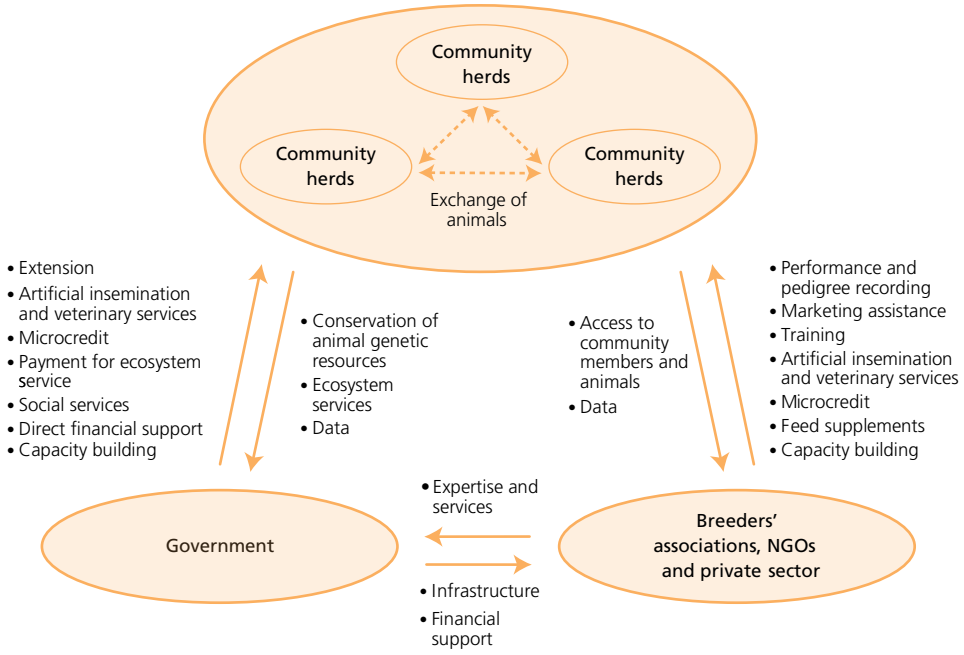
In some countries, mechanisms for livestock-keeper participation in conservation programmes are well developed, particularly via the activities of breeders' associations. Elsewhere, involving livestock keepers in organized conservation activities often remains very challenging. Initiatives to promote so-called community-based conservation programmes have been taken in various countries (FAO, 2003). Establishing a programme of this kind is normally a multi-faceted task and requires careful assessment of the current and potential future roles of the targeted breed(s) in the livelihoods of local people. A top-down approach is unlikely to be successful. In other words, the livestock keepers potentially involved in the conservation activities will need to participate, from the start, in assessing the feasibility of the scheme and its relevance to their livelihoods and future objectives. New measures introduced to support the maintenance of the targeted breeds (e.g. breeding or marketing activities) will need to be planned in close collaboration with livestock keepers and other relevant stakeholders.

The long-term success of a community-based scheme is likely to depend on its being able to operate effectively with relatively little outside support (e.g. from government agencies).

Establishing or strengthening organizations within the community that are able to undertake the various tasks involved in implementing the programme (breeders' associations, marketing cooperatives, etc.) will therefore be essential. Nevertheless, as illustrated in Figure 4D1, some outside support from government or NGOs is likely to be necessary, particularly during the early phases of the programme. For example, at the start of a programme it may be necessary to create infrastructure such as new facilities for processing livestock products. Capacity-building to strengthen livestock keepers' abilities to undertake any new activities introduced as part of the programme is likely to be essential.

In many instances, particularly in developing countries, a livestock-keeping community that is a potential player in a conservation programme will have a very strong cultural tie to their breed and strong interactions are likely to exist between the community, the breed and the production environment. In such cases, the survival of the breed *in situ* will depend on the sustainability of these interactions. The community will often have indigenous knowledge on how to co-manage the animals and the local environment and have clear goals and ideas about selection. Documenting a community's role in the maintenance of AnGR diversity (and biodiversity more broadly) may encourage the development of policies that are favourable to the continued existence of the community and thus to the conservation of the breeds they keep. One approach that has been attracting increasing interest in recent years is to record such information in

FIGURE 4D1
Interactions among the potential stakeholders of a community-based conservation programme



Note: The ellipses indicate the major stakeholders. The bulleted lists indicate the goods and services exchanged between each pair of stakeholders, with the solid arrows indicating the flow of these goods and services.

the form of a biocultural community protocol, a formal document prepared on the basis of consultations between community members, lawyers and experts in indigenous knowledge (see Box 4D3).

Breeders' associations can contribute in many ways to conservation activities, as well as to other aspects of AnGR management. Promoting the establishment of well-organized and well-functioning breeders' associations, where they do

Box 4D3
Biocultural community protocols

Biocultural community protocols (BCPs) are a tool developed in response to the Nagoya Protocol on Access and Benefit-Sharing. The Protocol mandates governments to support indigenous and local communities, including women within these communities, to develop "community protocols in relation to access to traditional knowledge associated with genetic resources and the fair and equitable sharing of benefits arising out of the utilization of such knowledge."

BCPs are established through a facilitated process in which a community or group of livestock keepers reflect about the meaning and importance of their breeds and their production system, their own role in maintaining these resources and their vision and concerns for and about the future. The facilitators help the community to put these reflections down on paper, and provide information and advice about existing national rules and international legal frameworks that support the role of communities in *in situ* conservation and provision of ecological services.

BCPs make visible the linkages between breeds and the communities that have developed them. They establish breeds as the "prior art" of communities and therefore represent community claims over animal genetic resources. With regard to the implementation of the Nagoya Protocol, BCPs are potential tools in the process of establishing prior informed consent and mutually agreed terms when animal genetic resources sourced from indigenous and local communities are either utilized for research within the country or moved across international borders for that purpose.

BCPs also document community assets, including genetic resources, customary rights and traditional knowledge, and raise awareness about the value and potential of local production systems. They may also be important when public–private partnerships that involve livestock keepers are set up, and could be a first step towards payment for environmental services.

The process itself is extremely empowering for communities, as a means of self-reflection and understanding their existing rights. In addition, having at hand a written document that details their rights puts communities in a much better negotiating position with outside actors.

By October 2014, about eight livestock-keeping communities in India, Kenya and Pakistan had established BCPs. Interest in and demand for this approach are also increasing in other countries, especially in Africa and Latin America. A programme to develop more BCPs in India is ongoing.

Communities that have benefitted from the BCP process include the Brela pastoralists of Pakistan, who are nomadic and keep chickens and camels. The Brela camel breed is highly valued by the camel dairy industry in oil-rich countries because of its exceptional dairy potential. After going through the BCP process and becoming aware of the value of their genetic resource, the Brela pastoralists were able to double, triple and even quintuple the prices obtained for their female camels – increases of such a magnitude that sale of even one camel will provide sellers with enough income for the rest of their lives (Abdul Raziq Kakar and Rao Qadeer, personal communication).

Provided by Ilse Köhler-Rollefson and Evelyn Mathias.
For further information see UNEP and Natural Justice (2009) and the "Community Protocols" website maintained by Natural Justice (http://www.community-protocols.org/).

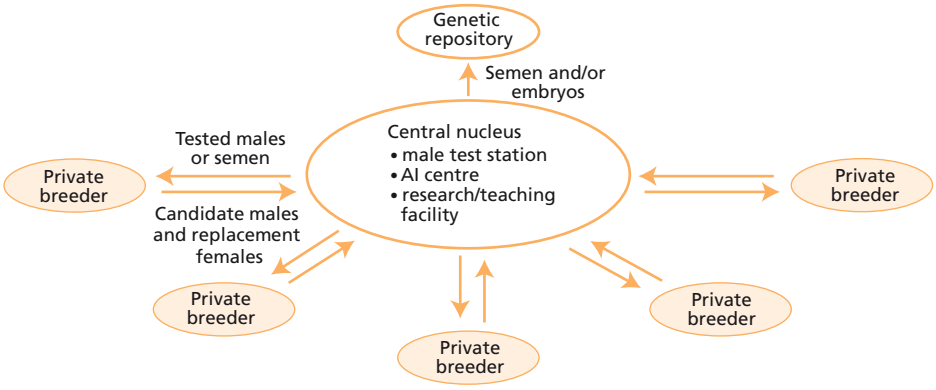
not already exist, is therefore an important objective. However, this can again be a challenging task. For example, potential members may lack the relevant organizational skills or there may be a lack of agreement over objectives for the management of the targeted breed. Elements that need to be considered in the establishment of a breeders' association include rules on eligibility for membership, procedures for registering animals and validating pedigrees, by-laws for the operation of the association (election procedures, composition of the board of directors, etc.), procedures for communication among the membership, procedures for conflict resolution and procedures for evaluating the performance of the association.

Where a range of different stakeholders are involved in conservation activities (e.g. both commercial farmers and hobbyists) and the animals are kept for a variety of purposes (e.g. for food production and for the management of landscapes and wildlife habitats) different objectives may result in different views about what breeding goals are appropriate (Lauvie *et al*., 2011). However, the populations concerned will often be too small to allow the simultaneous operation of several different conservation and/or selection programmes. In these circumstances, it is important to ensure effective communication among stakeholders and discussion of any tensions that may arise.

Breeding goals may change over time and this will affect the genetic variability of a breed population conserved *in vivo*. For example, as noted by Martyniuk *et al.* (2014), many dual-purpose (milk and beef) cattle breeds in Europe are no longer used primarily for mainstream food production and their numbers have decreased sharply. Animals belonging to these breeds are now used for a variety of purposes, mainly in suckler cow systems, where improving beef production from the offspring is an important objective. This has meant that the breeding goal (in the past a balance between milk and beef production) has shifted more towards beef production. This, in turn, means that genetic diversity in the populations maintained *in situ* will come to differ from that present in the original dual-purpose populations. This phenomenon calls for storage of genetic material from the original populations in a gene bank.

The maintenance of *ex situ in vivo* populations can also play an important role in conservation strategies. For example, they may provide a means of sustaining a breed whose population

FIGURE 4D2
A decentralized *ex situ* conservation programme involving institutional herds and private breeders



Source: FAO, 2013.

has declined to such an extent that it is difficult to maintain *in situ* or a breed for which there are few current options for promoting profitable production *in situ*. Establishing and operating an *ex situ in vivo* facility involves a substantial investment and provides little return in the short term. Programmes of this type are typically operated by governments, research institutes or NGOs and their long-term existence may be threatened by financial shortfalls.

One potential means of overcoming the constraints imposed by the cost of operating a centralized institutional farm is through the use of a dispersed model in which a breeding nucleus is linked to herds kept by NGOs and by private individuals who are willing to raise animals on a commercial or hobby basis. A network of several herds can provide a basis for an integrated conservation programme and systematic genetic improvement. The basic design of this type of model is illustrated in Figure 4D2. This approach is promoted in India as a means of conserving several of its indigenous cattle breeds.

5.2 Conserving genetic variability in small populations

The probability that a breed will survive depends greatly on the amount of genetic diversity it harbours. A high level of genetic diversity allows the population to adapt to changes in the production environment. It prevents the rise of inbreeding and its detrimental effects. In very small populations, i.e. breeds whose risk status is critical or endangered, the management of genetic diversity is crucial to survival, and breeding programmes should focus on this task (see Subsection 3 for an explanation of the risk-status categories). In populations that are somewhat larger, i.e. breeds whose risk status is vulnerable, there is more opportunity to implement programmes aimed at genetic improvement. However, maintaining genetic variation remains essential.

A strategy aimed at maintaining a breed's genetic variability needs to focus on managing the relationships among the breeding animals. Measures that can be taken include:

- involving as many animals as possible in the programme from the start in order to minimize genetic drift;
- increasing the number of males used for breeding;
- lengthening the generation interval;
- optimizing the contribution of each individual to the next generation;
- banking genetic material at the start of the programme and then at regular intervals, so that it can be used in subsequent generations; and
- in species with low reproductive rates, using embryo transfer to increase the population size.

It is also possible to adopt a mating strategy aimed at reducing inbreeding. This can involve:

- setting a limit to the degree of relationship between mates;
- using algorithms and software that determine the ideal set of matings for the entire population; and
- simple strategies that can be implemented even if no pedigree information is available (e.g. fixed rotation of males between herds).

Determining molecular coancestry using SNP-chip technology is a very effective tool in the management of genetic diversity within a population (Gómez-Romano, 2013). Several strategies for maintaining molecular genetic diversity in conserved populations have been developed (Fernandez *et al.*, 2011; Toro *et al.*, 2014). In general, molecular coancestry is a better descriptor of genetic relationships in a population than pedigree coancestry and is a better indicator of inbreeding and inbreeding effects. Pedigrees only indicate expected genetic relationships, whereas molecular coancestry provides information about the actual transmission of genes from parents to offspring. Moreover, pedigree registration occasionally includes errors (e.g. Kugonza *et al.*, 2012). Errors occur in genotyping as well, and these errors can affect the accuracy of estimates of genetic parameters (Hinrichs and Suarez, 2005). However, they tend to be less serious than incorrect assignments of parentage in pedigrees.

It is, however, important to pay particular attention to determining whether genetic similarity between animals at molecular level indicates identity by state or identity by descent (Powell *et al.*, 2010; Stevens *et al.*, 2011). Where maintaining diversity in a conserved population is concerned, identity by descent is of primary interest (Toro *et al.*, 2011).

Use of genomic technology in small conserved populations is very informative and highly recommended where possible (e.g. Pertoldi *et al.*, 2014). Clearly, however, costs and requirements for technical expertise will limit such applications, especially in developing countries. Accuracy of inference depends on the amount of genomic information available (e.g. the number animals genotyped and the number of SNPs per animal) (Toro *et al.*, 2011).

Further information on the various tools and approaches discussed in this subsection can be found in FAO's guidelines on *in vivo* conservation (FAO, 2013).

5.3 Potential strategies for increasing demand for at-risk breeds

Breeds may face the risk of extinction because their productivity is low and therefore keeping them provides inadequate economic returns. Breeding strategies can be a means of addressing this problem. Options include within-breed selection programmes (balancing between genetic progress in terms of increasing production and avoiding an increase in inbreeding) and strategies based on cross-breeding. The optimal approach will depend on the situation. As in all circumstances, any breeding strategy adopted must be well-matched to the production system (FAO, 2010). The size of the population is also an important consideration. If populations are too small, within-breed selection may not be a viable option. Genetic drift is likely to negate any potential for progress through selection.

Cross-breeding may not, at first sight, appear to be a good means of promoting the conservation of an at-risk population. However, there are situations where cross-breeding can be extremely useful. For example, if a breed population has become so small that it is non-viable, limited crossing with a genetically similar breed to increase the population size and increase genetic variability may be an option to consider. Moreover, cross-breeding strategies that involve ongoing maintenance of pure-bred populations (e.g. terminal crossing systems) may create a profitable means of utilizing breeds that in their pure-bred form are not sufficiently competitive to encourage livestock keepers to maintain them.

Aside from breeding strategies, a number of other methods can potentially be used to increase the value of at-risk breeds to livestock keepers (or other potential users) and hence promote their continued use. Techniques such as SWOT analysis (see Subsection 2) can help in the identification of appropriate strategies for specific breeds.

One potential, and relatively straightforward, approach is to provide practical support to livestock keepers that raise at-risk breeds. This can both increase the likelihood that the livestock keepers will be willing and able continue raising the targeted breeds and help ensure that they are appropriately managed in genetic terms. The type of support needed will clearly vary depending on the circumstances. Where an organized community-based conservation programme (see Subsection 5.1) is being implemented, the aim should be to tailor advice and support to the specific conservation activities being undertaken. More broadly, the provision of appropriate services that support the sustainability of diverse livestock-keeping communities – particularly smallholder and pastoralist communities – is likely to promote the continued use of the locally adapted breeds associated with these communities. In many circumstances there will be potential for increasing the profitability of livestock keeping by improving management at farm (or herd/flock) level (improving feeding, housing, disease control, etc.). Where "hobby farmers" (largely a developed-country phenomenon) are concerned, enthusiasm for keeping locally adapted breeds may not be matched by sufficient experience in breeding and in other aspects of animal husbandry. Advice on these matters may

therefore be needed. One option for disseminating breed-specific knowledge is to implement a "role model breeders" programme that enables the experience accumulated by long-standing and successful breeders to be passed on to others (see FAO, 2013 for further discussion of schemes of this kind).

Another means of increasing the profitability of keeping an at-risk breed is to increase the marketability of its products (see Box 4D4). This may enable lower production levels to be compensated for by higher per-unit prices. Particularly in developed countries, a lot of attention has been paid in recent years to the development of niche markets for the products of "non-mainstream" breeds (e.g. Ligda and Casabianca, 2013). In some cases, this involves marketing on the basis of some unique and desirable characteristic of the product itself (e.g. superior taste). In others, it involves some desirable aspect of the breed's production system (e.g. the appeal of buying a locally grown product). Initiatives of this kind can be facilitated by the existence of labelling schemes that increase consumer confidence in the provenance of the products (see Part 3 Section F Subsection 4.4 for a discussion of legal frameworks for schemes of this type).

As well as providing marketable goods and services, livestock also have the potential to deliver various other kinds of benefits within the

Box 4D4

Identifying keys to success in breed conservation and development in France: the VARAPE project

About 30 percent of French local breeds are considered to be endangered according to thresholds set by national legislation (fewer than 5 000 breeding females for cattle, 8 000 for sheep and goats, 1 000 for pigs). Most of these breeds declined until the 1970s, at which time the introduction of national conservation policies and programmes helped to stabilise or increase their population sizes.

The VARAPE project (valorization of rare breeds with short supply chains), which ran from 2012 to 2014 and targeted 13 breeds, was coordinated by France's Institut de l'Elevage, working in association with seven technical partners. Based on 13 breed surveys (involving inventories of production and marketing, and meetings with local committees) and 16 case studies, the project aimed to assess factors influencing the success of collective projects targeting the development of short supply chains for breed products.

One output was a diagnostic tool that can be used to formalize breed valorization projects and choose optimal organizational structures. Eight keys to success were identified:

- building a network involving all relevant stakeholders (farmers, processors, retailers, etc.);
- ensuring long-term coordination of the network;
- sharing a common vision and common objectives;
- highlighting links to history and culture;
- developing products and markets in a way that is consistent with the production capacity of the livestock keepers involved;
- establishing adequate quality indicators or labels;
- identifying relevant economic and technical indicators; and
- maintaining links with partners.

The results of the study showed that breed associations generally wanted to improve marketing structures, with the aim of increasing the number of livestock keepers raising the breed and improving the protection of their products from unfair competition (misleading labelling, etc.). They also showed that quality indicators (individual brands or schemes such as the European Union's Protected Designation of Origin or Traditional Specialities Guaranteed) need to be chosen according to the specific context of the breed, considering factors such as the size of the breed population and the type of product involved.

Provided by Lucie Markey and Christèle Couzy.
For further information on the VARAPE project (in French) see www.varape.idele.fr

ecosystems in which they are kept, for example by maintaining landscapes and wildlife habitats (see Part 1 Section D and Part 4 Section E for further discussion). Given that these benefits tend to be public goods, they generally cannot be marketed (i.e. directly sold to consumers) to provide additional income for livestock keepers. However, governments may be willing to pay for services of this kind. For example, so-called "conservation grazing" has become a significant tool in the management of wild biodiversity in a number of countries, mainly in developed regions. This trend has created opportunities to keep locally adapted breeds of grazing animals such as cattle, sheep, goats and horses in use and hence to promote their conservation. Locally adapted breeds are often the best suited to this role because of their ability to cope with the harsh environments (mountains, heaths, wetlands, etc.) where such services are often required.

Touristic value is another attribute that can potentially be exploited to promote conservation. This is more likely to be the case where the breed has some kind of distinctive appearance or is closely linked to local products or cultural traditions. Some communities hold festivals celebrating traditional customs associated with raising local breeds of livestock. Such events, although they may not provide direct economic support to livestock keepers, may improve the economic status of the communities in general (e.g. by promoting tourism) and can provide marketing opportunities for the breeds' products.

When possible, combining a number of different conservation activities is a logical approach. Box 4D5 describes a proposed programme to conserve Pantaneiro dairy cattle in Brazil. The programme aims to combine practical support for breeding with the marketing of a breed-specific product. In addition, opportunities have been identified to exploit specific genes from the Pantaneiro in breeding programmes for other breeds, as well as to leverage the ecosystem services provided by the breed in its traditional production environment.

6 Cryoconservation

As described in Part 3 Section D, recent years have seen an increase in the number of national gene banks and in the sizes of their collections (see also Boettcher and Akin, 2010; Pizzi *et al*., 2010). National gene banks are a relatively new element of AnGR management and there have been ongoing efforts to develop the protocols and facilities needed to increase their operational efficiency.

All the available scientific evidence indicates that cryopreserved biological material can be stored without deterioration for several thousand years (Mazur, 1985). The possibility of long-term storage opens opportunities to conserve and utilize animal genetic diversity in ways that were impossible in the past when *in vivo* conservation was the only option available. Cryoconservation programmes can serve a number of purposes. FAO (2012) identified the following major objectives:

- One common reason for gene banking is to provide the possibility of recreating breeds or breeding lines if they are lost as the result of a catastrophic event or deliberately allowed to go extinct for financial reasons (e.g. the discontinuation of a specialized research line). In such cases, having sufficiently large and genetically diverse collections of germplasm from the affected breeds can allow them to be reconstituted.
- Cryoconserved material can be used to introduce genetic diversity into *in vivo* populations for the purposes of reducing inbreeding levels and broadening diversity. It can also be used to provide flexibility to the livestock industry when selection goals are found not to be as desirable as initially thought.
- Gene bank collections are invaluable if breeds are threatened with extinction because of an extreme genetic condition such as high frequency of a genetic defect resulting from selection or genetic drift. Stored material

PART **4**

Box 4D5

Indigenous people and scientists team up to conserve Pantaneiro cattle in Brazil

Pantaneiro cattle have lived in Brazil's Pantanal Biome since their introduction by the Portuguese some 400 years ago. They are believed to be resistant to trypanosomosis, myiasis, worms and ticks. They are able to survive under the challenging ecological conditions of the Pantanal, which include both floods and droughts, as well as coarse native pastures and jaguar predation.

At the beginning of the twentieth century there were several thousand Pantaneiro cattle. However, the breed's population has since fallen to a few hundred. Intermixing with commercial breeds is the main threat to its survival. Today, only 500 pure-bred animals, split between two herds, are left. This small population size and the accompanying loss of genetic variation threaten to erode the breed's capacity to adapt and survive.

Commercial breeds have lost some alleles associated with fitness and survival in harsh environments. One example is the G1 allele of the bovine growth hormone gene, dubbed the "thrifty gene", which has become essentially extinct in commercial breeds, but can be found in some traditional cattle (Dani *et al.*, 2010), including the Pantaneiro.

As part of efforts to protect the Pantaneiro breed and the ecosystem to which it is adapted, as well as their own livelihoods and culture, indigenous people from the Pantanal region have teamed up with scientists from several Brazilian research institutes to develop the Pantanal Biome Cheese Project. As the true "Nicola cheese", a traditional local product of the Pantanal, is prepared with the milk of Pantaneiro cows, it is threatened with extinction along with the breed. However, it may also hold the key to the breed's conservation. The production and commercialization of Pantaneiro cattle and Nicola cheese may provide the Pantaneiro people with regular income, while also helping them conserve the local ecosystem.

One of the activities undertaken by the scientists working on the Pantanal Biome Cheese Project is to screen the Pantaneiro cattle for genetic polymorphisms associated with milk protein and fat composition, as well with the "thrifty" phenotype of these cattle. This molecular characterization will not only help identify valuable genetic resources for breeding, but will also serve as the basis for marker-assisted certification to ensure accurate identification of the genetic material of Pantaneiro animals and the breed's products. The scientists believe that a conservation programme that includes marker-assisted selection, distribution of genetic material such as semen and embryos, and marker-assisted certification of origin may help save the Pantaneiro cattle from extinction and also contribute to the conservation of the Pantanal Biome and the life and traditions of its people.

The Pantanal Biome Cheese Project capitalizes on the fact that the Pantanal Biome is a Biosphere Reserve included in UNESCO's World Heritage and the MAB-Man and Biosphere programme of the United Nations.

Photo credit: José Medeiros.

Provided by Sergio Ulhoa Dani and Marcus Vinicius Morais de Oliveira. For further information see Dani and Oliveira (2013) and http://biomacheese.blogspot.it/

from animals not carrying the deleterious allele can be used to decrease the frequency of the defect to a manageable level.

- Gene bank collections can be used to develop new lines or breeds, introgress desired characteristics from one breed into another or quickly reorient the evolution or selection of a population.
- Gene banks serve as a ready source of genetically diverse and specialized DNA for genetic diversity studies, genome-wide association studies, exploration of gene function and other types of research. Importantly, gene banks can, over time, provide multigenerational samples that contribute to increasing the accuracy of genomic selection. These latter benefits will be more easily realized if information on animals' phenotypes is maintained along with their genetic material (see Subsection 6.4).

6.1 Gene bank operations, infrastructure and institutional frameworks

A national gene bank should be designed in accordance with the needs and capacities of the country. Staffing a gene bank requires, in particular, expertise in genetics, cryobiology/reproduction and data management. The necessary physical infrastructure also needs to be developed. Figures presented by FAO (2012) illustrated that, in the case of small repositories, the cryopreservation component of a gene bank could potentially be established for less than US$50 000 in equipment costs. Greater access to commercial genotyping and potentially to large amounts of genomic data implies that a gene bank needs either to develop within-house capacity to conduct statistical analysis and interpret genetic and genomic data or contract out the analysis phase of genetic diversity studies. Hardware costs associated with the development of information systems are relatively minor. The largest recurrent costs in the operation of a gene bank are usually those associated with human resources.

A cryoconservation programme can involve the collection of various types of genetic material. Semen is the most commonly banked material. Embryos are more complicated and expensive to collect and store (Gandini *et al*., 2007). However, if a breed needs to be reconstituted, embryos have an advantage over semen in that they provide the full genetic complement of the reconstituted breed in a single generation. Reconstitution with semen requires several generations of backcrossing and will never achieve 100 percent reconstitution of the original genome. Moreover, the mitochondrial genome of the original breed is totally lost if only semen is stored. As well as semen and embryos, gene bank collections can include oocytes and various gonadal and non-gonadal tissues.

Because of the role of the private sector in maintaining breeds *in situ*, it is essential that gene banks have close links to individual breeders and to breed organizations or livestock-keeping communities. This allows stakeholders to communicate their needs and helps establish working relationships that facilitate the collection of samples.

Gene bank collections should be viewed dynamically, with samples entering and exiting the gene bank as a matter of routine and being used for a variety of purposes. This type of approach is relatively new in the livestock sector. Each gene bank should have a set of protocols and procedures for assessing requests for germplasm. One option is to establish an advisory committee (e.g. consisting of industry and public-sector representatives) to review and make recommendations concerning requests. Issues for consideration when reviewing such requests can include the availability of the respective genetic resource *in situ*, whether the gene pool needs to be expanded, current and projected inbreeding levels, selection options available to the breeders and the way in which the progeny obtained using the gene bank material are to be utilized. Depending on the policies or regulations of the country, the advisory committee may also be interested in knowing whether,

and if so how, germplasm from the progeny will eventually be made available to help replenish the gene bank.

Choice of breeds for inclusion in a gene bank collection can be politically sensitive. Gene bank managers should recall that while breeds do not need to be treated equally they should be treated equitably and reasonably.

Because of the increasing number of national gene banks (see Part 3 Section D) the question of potential international cooperation in gene banking is becoming increasingly prominent. Potential cooperative activities need to be evaluated on the basis of the needs and capabilities of the potential partners and the potential benefits that might be gained. Establishing linkages between gene banks is likely to be easiest at regional level, as there are likely to be shared interests, similar breed types and similarities in collection protocols. For example, groups of countries in the Americas and in Europe have identified common goals and interests. These are generally based on broad initiatives such as the development of shared databases (or at least some level of commonality among databases) and the exchange of experiences and technical know-how. Protocols used to cryopreserve samples or to genetically evaluate collections are another area of collaboration.

In the plant genetic resources sector, pairs or groups of countries have agreed to back up each other's gene banks by holding a complementary collection of some or all samples. However, for several reasons this approach has rarely been employed in the AnGR sector. Sanitary regulations restricting germplasm movement across national boundaries are a major limitation. It may, however, be possible to overcome constraints of this kind by classifying material "for gene bank storage only" (i.e. not for use within the importing country). If the material is not used in the importing country, then the risk of disease transmission will be low. Administratively, the most direct and effective means for a country to back up samples from another country is via a bilateral agreement. Such an approach also facilitates the identification of the specific needs of the cooperating countries and their rights, limitations and obligations with respect to storing and using the material.

6.2 Establishment and assessment of gene bank collections

Collection strategy

The establishment and ongoing operation of a gene bank collection require strategic decisions regarding what material to collect. Consideration needs to be given to the intended scope of the collection. For example, some countries have focused gene bank collections on at-risk breeds (Mariante *et al.*, 2009; Paiva *et al.*, 2014), while others are developing collections that include both at-risk and mainstream breeds (e.g. Pizzi *et al.*, 2010; Blackburn, 2009; Woelders and Hiemstra, 2011). While it is possible to argue that widely used transboundary breeds are not priorities for inclusion in conservation programmes, there are several reasons why countries may wish to include such breeds in their collections. For example:

- widely used transboundary breeds are likely to be important for the future of commercial agriculture and therefore need to be included in the gene bank to ensure a backup that can be drawn upon in case of need;
- large collections of material from such breeds have been shown to be invaluable in providing specific alleles or allelic combinations for use in industry or research; and
- collecting samples from such breeds will ensure that changes in allelic frequencies that may confer adaptation to environmental variables are captured and available for use as needed.

Regardless of what types of breed a country chooses to target, there will be a need to assess the genetic diversity captured and the quantity of germplasm accumulated and to optimize the collection in accordance with associated costs. Theoretical methods for prioritizing breeds (e.g. Boettcher *et al.*, 2010; Martin-Collado *et al.*, 2013) and animals

(e.g. Blackburn, 2009; Engelsma *et al*., 2011) have been developed. Blackburn (2009 and 2012) discusses practical approaches to building collections at both within-breed and between-breed levels. In practice, effective development of a collection requires flexibility in the selection of animals within a population and the capacity to adjust and adapt cryopreservation protocols to the given situation. For example, theoretical approaches to selecting the optimal set of gene bank donors typically lack the flexibility needed to account for real-life circumstances such as the death or poor fertility of an animal targeted for collection or the refusal of its owner to allow access.

In developing a collection there is need to determine the minimum quantities of germplasm and genetic variation needed to meet the objectives of the gene bank. In general, the primary objective will be to store enough germplasm to reconstitute a breed that is extinct (*in vivo*) to create a new population with an effective population size of 50 animals. Population reconstitution is generally the objective that requires the greatest quantity of germplasm. The quantity required will depend on a number of factors, including the type of germplasm stored, the species involved and the reproductive efficiency achieved (see FAO, 2012 for further information). In general, breed reconstruction requires fewer embryos than units of semen. Species with multiple offspring per pregnancy, such as chickens, rabbits and pigs, will require fewer doses of semen than species, such as cattle, horses and small ruminants, that produce one or few offspring. The higher the expected pregnancy and survival rates, the less germplasm is needed.

Once minimum quantities for a given cryoconservation objective have been achieved (i.e. sufficient numbers of donors and quantities of germplasm per donor have been acquired), gene banks can consider various approaches to the management of their collections. For example, the national gene bank in the United States of America has developed an index that gives equal weight to quantities of germplasm and number of donors and uses this index to monitor the inventories of breeds with material in the bank (Blackburn, 2012). The index provides a simple means of identifying breeds for which additional collection would be beneficial. Closer examination of the data contributing to the index can then determine whether a given breed simply requires collection of additional material (i.e. from the same animals or their close relatives) or whether genetically diverse material from new, unrelated donors is needed.

While meeting targets is a first objective in the development of a gene bank collection, gene bank managers may choose to expand the scope of their collections for a variety of reasons. Smith (in FAO, 1984) showed that the probability of capturing an allele in 10 or more units of semen is equal to $1 - (1 - P)^{2N}$, where P is the allelic frequency and N is the number of males sampled (equation modified by Blackburn, 2004). As this equation demonstrates, increasing the number of males collected raises the probability of capturing an allele, but with a trend of diminishing returns. For example, with an allele frequency of 0.005, sampling 100 males will result in a 63 percent probability of capturing the allele. With 300 males, this value jumps to 95 percent. However, increasing the number of males sampled to 500 will raise the probability only another 4 percentage points, to 99 percent. This suggests that big collections may be necessary in order to capture and preserve extremely rare alleles. For example, the United States of America's gene bank has a large collection of samples from Holstein cattle. This has allowed the cryoconservation of semen from bulls that carry rare Y chromosomes that are no longer present in the *in situ* population (Yue *et al.,* 2015).

Assessing and ensuring genetic diversity

There are several approaches that gene bank managers can use to assess the genetic diversity of the collection and to identify the animals in the *in vivo* population that they wish to sample to broaden the diversity of the collection. These approaches may use pedigrees, molecular markers and/or geographic location as indicators of diversity. In addition to genetic variability, there is a

need to consider variability in phenotypic or genetic measurements (e.g. breeding values) for economically important characteristics.

A broad array of analyses can be applied to pedigree information to estimate genetic parameters and compare the diversity of animals in the collection and in the *in situ* population. For example, Danchin-Burge *et al*. (2011) used the parameter "effective number of founders" to demonstrate that both the French and the Dutch gene banks have fully captured the level of genetic diversity present in the *in situ* Holstein population. They also showed that the effective number of Holstein-Friesian founders stored in the United States of America's gene bank substantially exceeds that of the current *in situ* population. With pedigree information available, the genetic coefficient of relationship between animals in the collection and the *in situ* population can be computed. This information can be extended, through various clustering routines, to determine the status of germplasm already in the collection (in terms of influential founders and their descendants) and identify groups of animals that might be targeted for procurement to increase the genetic variability in the collection (Blackburn, 2009; FAO, 2012; Blackburn, 2012).

The development of collection strategies can also be supported by the use of DNA markers (either microsatellites or SNPs) to assess differences among and within populations. For example, a comprehensive assessment of microsatellite genotypes among sheep breeds in the United States of America determined that the Warhill population should be classified as a strain of Rambouillet and not as a separate breed (Blackburn *et al*., 2011). As a result, collection strategies were adjusted. Numerous characterization studies have evaluated breed similarities and differences at the molecular level, both within and across countries (for a review, see Groeneveld *et al*., 2010). Countries should consider such results and consult with each other when developing gene banking strategies, particularly for transboundary breeds. As the functional role of genes marked by particular SNPs is determined, it will become possible to incorporate such information into strategies for the assessment and acquisition of gene bank collections.

Geographic approaches to planning and evaluating collections have been used for wild animal species and plant genetic resources (e.g. Hijmans *et al*., 2000). However, in the case of AnGR, the utility of developing or evaluating collections solely on the basis of geographic location seems to vary from situation to situation. At the breed level, pedigree or molecular data suggest that in some instances there are only slight to modest differences between geographically distant populations. For example, Maswashie and Blackburn (2004) found no evidence of substantial subpopulations of Navajo Churro sheep across the United States of America. Based on SNP data on African goat breeds, Huson *et al*. (2014) suggest that there is little genetic differentiation among goat breeds found in the various countries of East Africa.

Comparing average phenotypes or estimated breeding values (EBV) of animals with material stored in gene bank collections to those of *in situ* populations serves to gauge the completeness of the collection in terms of diversity and its utility for various functions. Whenever possible, highest and lowest values for animals in the bank should, respectively, be superior and inferior to the mean by at least one standard deviation. "Bounding" the breed's mean in this way helps ensure that two important goals are met: first, the choice of animals with both high and low values ensures that genetic variability is captured; second, the choice of animals with high (i.e. favourable) EBVs means that samples in the collection are likely to have industry relevance for two to five decades. If this approach is followed, taking a large number of traits into account and with periodic resampling, there is no reason for gene bank collections to become obsolete.

6.3 Cryobiology and reproductive physiology

At one time, the advice was that gametes for cryoconservation should be collected only at artificial insemination centres (FAO, 1998). However,

the experiences of the last decade show that this is not necessary, particularly for material to be utilized at country level (i.e. that is not going to be exported). Assuming the sanitary restrictions of the respective country allow (and if proper collection, cryopreservation and health procedures are followed), germplasm and tissue from nearly all livestock species can be acquired in the field with little to no negative consequences in terms of viability or veterinary hygiene. This provides additional opportunities to capture genetic diversity and reduce collection costs. Once germplasm has been collected, it can generally be stored for 24 to 36 hours while being transferred to a cryopreservation laboratory. Fresh semen from various species has been routinely moved from place to place prior to being used successfully for insemination, suggesting that semen transported in this way can also be cryopreserved and banked. For example, Purdy *et al*. (2010) found that ram semen could be held for 24 hours before cryopreservation and still achieve acceptable fertility and prolificacy levels when subsequently used for artificial insemination.

If traditional semen collection and processing are not feasible because of a lack of facilities or expertise near the area where the targeted animals are raised, or if genetically valuable animals die before collection is possible, collecting epididymal sperm from deceased or castrated animals may be a useful means of enhancing gene bank collections (Silvia *et al*., 2014). Testes collected from such animals are quite robust, and sperm remain viable after several hours of storage at body temperature or even longer if properly cooled. This allows collection on the farm or at the slaughterhouse and transport to a laboratory. Recent studies on the cryobiology of epididymal sperm from ibex (Pradiee *et al*., 2014) and goats (Turri *et al*., 2014) suggest that storing such material in gene banks is feasible.

Direct freezing of samples in the field may be an option, depending on the type of biological material involved. For example, Groeneveld *et al*. (2008) detailed a method used for collecting pig tissue from the field in Viet Nam. The equipment needed for field collections is relatively inexpensive. For example, samples can be cryopreserved in a simple Styrofoam box and then placed in a portable liquid nitrogen tank.

Cryopreservation involves freezing cells and tissues to -140 °C (the vapour phase of liquid nitrogen) or -196 °C (the liquid phase of liquid nitrogen). The process places cells into a suspended state of animation where most biological processes cease to function. Cells that have been successfully cryopreserved remain suspended until revived by thawing. The type of cell (e.g. whether sperm, embryo or blood), particularly cell size and cell membrane composition, affects the way cells need to be prepared for freezing and the freezing rates that need to be applied. For example, the cooling rate for bovine sperm (-19 °C to -25 °C/minute) is very different from that for embryos (-0.5 °C/minute) (FAO, 2012) and freezing protocols for semen differ among species.

Cells to be cryopreserved are suspended in a medium containing various sugars, lipids and – most importantly – cryoprotectant compounds such as glycerol. Glycerol was the first cryoprotectant agent identified (Polge *et al*., 1949) and is still the primary cryoprotectant used across species. The cryoprotectant compound reduces the formation of ice crystals, which can damage cells of all types. In recent years (i.e. since 2005/2006 when the first SoW-AnGR was prepared), cryopreservation research has continued to advance (e.g. Okazaki and Shimada, 2012; Woelders *et al*., 2012), particularly with regard to the preservation of oocytes and other non-traditional types of germplasm (Pereira and Marques, 2008; Mullen and Fahy, 2012) and the analysis of changes in the cell membrane before and after cryopreservation. As a result of this and other work, new media for cryopreservation are continually being evaluated and improved upon.

Genetic material from all livestock species can be cryopreserved and stored in a gene bank. However, the efficacy of the cryopreservation process and the ease with which germplasm or tissue can be used to generate animals varies substantially across species. Protocols for cryopreservation and

regeneration using either semen or embryos are well established for cattle. Cryopreservation of pig germplasm is also relatively straightforward. However, for sheep and goats, both cryopreservation protocols and regeneration procedures need to be improved. For both these species, infrastructure limitations impede the widespread use of cryopreserved material. Moreover, these species have smaller commercial industries, which means there is less investment in research.

The use of cryopreserved chicken semen has been particularly problematic: not because the sperm do not freeze well, but because the cryoprotectant glycerol is a contraceptive in the hen. Several means of addressing this problem – alternative cryoprotectants such as dimethyl sulfoxide (commonly known by the abbreviation DMSO) or intramagnal inseminations – have been developed and have sometimes been used (e.g. Long *et al*., 2014). However, results have not always been totally satisfactory for a number of reasons. The ground-breaking approach developed by Song and Silversides (2006; 2007a; 2007b) – involving the harvesting of gonads from day-old chicks, cryopreserving them and then transplanting the thawed tissue into chicks of three to seven days of age – represents a quantum step forward in the cryoconservation of avian genetic resources. Using this approach, entire breeds or lines can be reconstituted and ready for mating in approximately one year (see Box 4D6).

Lack of a stable, long-term and financially affordable source of liquid nitrogen can be a severe constraint to gene banking. Freeze-drying sperm does not require liquid nitrogen and allows sperm to be stored at 4 °C and transported at room temperature. Offspring have been obtained from oocytes fertilized with freeze-dried rat epididymal sperm stored at 4 °C for five years (Kaneko and Serikawa, 2012). However, further development is needed in order to make this approach viable in livestock species. Other innovative approaches to biobanking are being developed (see Box 4D7). For example, studies are being undertaken on the maintenance of nuclear and cellular viability in somatic cells and female gametes following freeze-drying. The development of dry biobanks of cells and gametes, which rely on protocols that are less costly and more environmentally friendly than current methods, could become a reality in the future (for a review see Loi *et al*., 2013).

6.4 Information systems and documentation

Another important aspect of gene banking is the development and management of a database and the provision of information on the collection to stakeholders. A gene bank information system needs to handle two major categories of data:

- information on the quantities and types of germplasm and tissue maintained in the collection; and
- information on the animals whose genetic material is stored – phenotypic and genetic measures and information on the production systems and environmental conditions in which the animals were raised (FAO, 2012).

If information on a gene bank's holdings is made publicly available on the internet stakeholders will be able to view the collection and make a request for samples or determine what germplasm they might like to contribute to the gene bank. Establishing a comprehensive database takes substantial effort and time. Pooling efforts internationally may be helpful. For example, Brazil and the United States of America have collaborated in the development of the Animal-Genetic Resources Information Network (Animal-GRIN),[4] a database used to manage their respective AnGR programmes.

Web software for the documentation of cryoconserved material in animal gene banks is widely used in Europe. The CryoWEB software (Duchev *et al*., 2010) can record basic information on donor animals, storage facilities, and stored samples and their sites of storage within a gene bank. In order to integrate information from national gene bank collections, the European Regional Focal Point for the Management

[4] http://nrrc.ars.usda.gov/A-GRIN/database_collaboration_page

Box 4D6

A study of the comparative costs of *in vivo* and cryoconservation programmes for chickens

A study estimated and compared the costs, over a 20 year period, of three different approaches to chicken conservation:

1. maintaining live populations;
2. semen cryopreservation followed by reconstitution of the population via backcrossing; and
3. ovary and semen cryopreservation followed by reconstitution of the population via ovarian transplantation and subsequent insemination.

The costs of keeping live populations vary greatly, but for the purposes of the study they were approximated on the basis of typical costs of maintaining a population at an institution in North America. It was assumed that no revenue was derived from the live populations. Costs of cryopreservation and population reconstitution were based on biological parameters derived from the literature. The costs for all three programmes were subdivided into the cost of preservation, the annual cost and the cost of recovering the population.

For populations maintained in living form, there are no costs for preservation and reconstitution. However, the annual costs are high and cumulative: the longer the live population is maintained, the higher the total costs. The costs of cryopreservation are low, and the annual costs of maintaining cryopreserved material are extremely low. The largest cost of a cryoconservation programme relates to recovery of the population.

In this example, keeping live populations was found to be the most cost-effective strategy for periods of up to three years. However, if the population was not going to be used within five years, cryoconservation was the most cost-effective strategy. The least expensive cryoconservation strategy was found to be the one based on storing both ovaries and semen. Over an extended period of time, the estimated savings relative to the costs of maintaining live populations were found to be more than 90 percent (see table). The low cost of cryoconservation suggests that avian genetic material should be cryoconserved, with individual populations reconstituted when needed.

This study focused on chickens and used parameters particular to that species and a particular institutional situation, so the results and conclusions are not universally applicable. However, the principal of estimating and comparing the costs of various conservation programmes by dividing the costs into costs of preservation, yearly maintenance costs and costs of recovery can be used for any mammalian or avian species in any situation.

Provided by Frederick G. Silversides.
For further information, see Silversides *et al.* (2012).

Estimated costs (US$) of different conservation programmes

Conservation method	Years of storage	Number of populations stored/recovered	
		10/1	10/10
Maintaining living birds	1	179 000	179 000
	5	957 000	957 000
	20	5 306 000	5 306 000
Storing semen followed by backcrossing	1	288 000	758 000
	5	298 000	769 000
	20	354 000	825 000
Storing semen and ovaries followed by ovary transplantation and insemination	1	109 000	218 000
	5	118 000	228 000
	20	172 000	281 000

Box 4D7

Use of induced pluripotent stem cells in *in vitro* conservation

Somatic reprogramming (Takahasi and Yamanaka, 2006) has brought about a revolution in the field of stem cell research. Pluripotent stem cells whose developmental potential includes germline colonization can now be obtained via a simple non-invasive biopsy. In other words, it is now possible to transmit the diploid genetic patrimony of an individual (male or female) directly from a somatic cell. While this has so far been demonstrated only in rodents, it is hoped and expected that further research will make it possible in many species. Considerable advances have already been made, particularly in the delivery of the molecular factors able to reprogramme somatic cells without affecting the stability and integrity of the genome, i.e. without generating genetically modified cells. Importantly, the prospect of using induced pluripotent stem cells in regenerative human medicine has greatly stimulated the development of methods for obtaining safe and high-quality cells.

One of the most interesting potential roles of induced pluripotent stem cells in *in vitro* conservation is in preserving, and eventually amplifying, the diploid gene pools of individual animals with extreme phenotypes. Somatic reprogramming would allow a large and diverse group of genetically different individuals to be sampled without killing the donors and without having to produce embryos that contain only half the interesting genetic patrimony. Moreover, the methodology is not limited to males (as is the case with the storage of semen), as female cells can also be stored and reprogrammed.

Further work will undoubtedly reveal differences between species, both in terms of the efficiency of reprogramming and the ease of germline colonization and contribution. Because of their phylogenetic proximity to the model species, the first livestock species in which these techniques can be used will probably be mammalian. The commercial and genetic value of exceptional phenotypes and individuals will help to stimulate the development of innovative methodologies.

It is impossible to know how long it will be before these techniques can be used routinely, as progress will depend on the level of research in each species. Nonetheless, collection of tissues and other sources of somatic cells in anticipation of further development may be a prudent strategy. Collection of such materials is usually simple and inexpensive, and can complement or replace the collection of semen and embryos. Once cryopreserved, the tissues and cells will remain viable indefinitely and can thus be kept until the technology needed to utilize them is well established.

Provided by Bertrand Pain.

of Animal Genetic Resources (ERFP) decided to develop the European Register of Cryomaterial as part of EFABISnet, a regional network of national AnGR information systems linked to FAO's worldwide system, DAD-IS (Hiemstra *et al.*, 2014) (see also Part 4 Section A). Information about national gene bank collections can be automatically uploaded from national databases (CryoWEB) to the European Farm Animal Diversity Information System (EFABIS). ERFP members have also recently established the European Gene Bank Network for Animal Genetic Resources (EUGENA – Hiemstra *et al.*, 2014), which allows for sharing of cryoconservation information at all levels (i.e. not only the content of national gene banks), thus allowing the optimization of conservation efforts at regional level (see Box 3D8).

Information systems for gene banks can be made even more powerful if they are integrated with systems used in *in vivo* conservation. The benefits of integrated databases increase in systems where stored materials are regularly used in the management of the *in vivo* populations.

Box 4D8
Bilateral agreement on sanitary issues in germplasm exchange – an example

Health regulations are a major issue confronting regional gene bank development. As national gene banks may collect germplasm without the intention of distributing it to other countries, collections may include material collected and cryopreserved without the rigorous testing that would be needed to allow it to be exported. Thus, if countries wish to set up a regional gene bank, there may be a need to develop alternative protocols for exporting genetic material.

Arrangements for transboundary exchange of genetic material were required when Jersey cattle breeders from the Island of Jersey wanted the United States of America's gene bank to back up their breed population. In this instance, the breeders had been collecting and storing semen from their cattle since the 1960s. While health tests were performed on the cattle at the time of collection, there were no veterinary certificates that could be used to acquire permits to import samples into the United States of America.

Another complicating issue was that Jersey and the United States of America had no agreements in place to verify the health status of each other's livestock populations (similar to those existing between the United States of America and the European Union). The solution was for the relevant agency in the United States of America to issue a special permit allowing the samples to enter the country but not to be used for breeding purposes. This solution was acceptable to all parties as the intention of the transfer was to provide a mechanism for keeping the samples safely so that in the event of need the genetics could be reintroduced to Jersey. Transmission of disease into American livestock populations was considered to be practically impossible given that no live animals would be produced in the territory of the United States of America.

Provided by Harvey Blackburn, National Coordinator for the Management of Animal Genetic Resources, United States of America.

6.5 Legal aspects of gene banking

Gene banks need to establish policies that ensure they comply with national laws. The two primary areas that need to be considered are interactions with the owners of the livestock from which samples are obtained and compliance with relevant national or international health standards. In the former case, the main issue is normally the question of private property rights over the material as it is collected, stored and distributed. National animal-health regulations may determine which animals can be used as sources of germplasm and how the collected germplasm can be used. Where international transfers are concerned, the country's overall health status will determine the type of testing needed before, during and after collection in order to allow the movement of samples through the normal protocols of international animal germplasm transfer. If countries wish to develop bilateral backup collections of germplasm (e.g. Box 4D8), they will need to evaluate whether current World Organisation for Animal Health (OIE) regulations will allow the required exchanges to take place or whether waivers will be needed (Blackburn and Boettcher, 2010).

In 2010, member countries of the Convention on Biological Diversity adopted the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization (see Part 3 Section F). The protocol, which entered into force in October 2014, may influence the way that livestock germplasm is exchanged internationally and could potentially impede the exchange of AnGR between the national gene banks of countries that are signatories to the agreement.

PART **4**

7 Conclusions and research priorities

Conservation of livestock breeds can have many objectives, and various types of activity can be employed to address them. Comprehensive planning is required in order to identify the breeds with the greatest priority for conservation and to identify the most appropriate strategies for their management. Over recent years, substantial strides have been made in the development and improvement of conservation methods. Both *in vivo* and *in vitro* conservation have their advantages and shortcomings as standalone activities, so a strategy that employs both methods is usually optimal.

In the field of *in vivo* conservation, new methods allow more effective incorporation of economic and social factors into national conservation strategies. A desire to decrease direct public subsidies and make breeds more financially self-sustainable has led to a greater focus on the development of niche markets for breed-related products and spurred interest in methods of capturing other values of locally adapted breeds, such as their contributions to landscape maintenance and agricultural tourism. These approaches based on promoting financial self-sustainability both allow and obligate individual livestock keepers to play the major role in breed management. However, while developments of this kind are providing new opportunities, it should be borne in mind that they do not necessarily provide a strong guarantee that the targeted breeds will survive. For example, niche markets can often be unstable.

An unprecedented number of national gene banks have now been established and more are planned. Effectively building gene bank collections requires countries to improve their capabilities in cryopreservation, reproductive physiology, quantitative and molecular genetics and – above all – effective and openly accessible information systems. With the explosion in the availability of genomic information, there will be a greater need for gene banks to expand their collections to assist in conservation efforts and to serve as a reference of genomic information for various populations. Increasing the efficacy of cryopreservation protocols will facilitate cryoconservation and genetic utilization of stored material in *in situ* populations.

Effective decision-making in conservation strategies requires access to a range of data on breeds and their production environments, as well as appropriate methods for integrating these data into decision-making processes. For example, detailed DNA analysis may reveal the genetic uniqueness of a breed through the presence of rare alleles and rare haplotypes. This will improve estimates of breeds' conservation values and may indicate opportunities for sustainable use in pure- or cross-breeding programmes. New molecular approaches can facilitate the operation of such breeding programmes. Collecting data of this type is the task of characterization studies and inventory and monitoring programmes. Research priorities in these fields are discussed in Part 4 Sections A and B and needs for capacity development in Part 3 Section B.

With regard to decision-support tools in the field of conservation, research priorities include:

- improving methods for estimating breeds' extinction probabilities;
- developing user-friendly methods for prioritizing AnGR for inclusion in conservation programmes, and decision tools to guide resource allocation in conservation programmes, including methods that can effectively combine information of varying degrees of uncertainty; and
- further developing methods for incorporating genomic information into conservation planning.

Research is also required into the socio-economic, infrastructural, technical and policy factors that influence success in establishing and sustaining conservation programmes.

With regard to *in situ* conservation, research priorities include:

- developing strategies through which conservation activities can be implemented in ways that maximize livestock keepers' livelihoods,

including through value-addition methods such as niche marketing and agritourism;
- developing strategies through which genomics and other advanced tools and methods can be efficiently used to improve the genetic merit of conserved breeds while maintaining sufficient genetic variability;
- developing strategies through which breed conservation can be combined with efforts to promote the provision of services such as the maintenance of landscapes and wildlife habitats, as well as developing methods to estimate the value of these services and identify the beneficiaries; and
- determining how organizational structures can be improved so as to allow better integration and coordination among actors involved in conservation.

In the field of *ex situ in vivo* conservation, priorities include:
- identifying approaches that can enable programmes, particularly those in developing countries, to become more self-sustaining and hence less vulnerable to collapse if state support is withdrawn.

In the field of *in vitro* conservation, research priorities include:
- further developing strategies to increase and improve the utilization of stored material in *in situ* populations;
- developing information management systems that allow better monitoring and assessment of gene bank collections;
- designing comprehensive database structures and portals that are dynamic and thereby allow a broad range of users to access gene bank holdings and make requests for material;
- refining cryopreservation and freeze-drying protocols to increase the efficacy of collecting and storing germplasm;
- enhancing reproductive biotechnologies to improve the efficiency and reduce the costs of regenerating live animals from stored germplasm and cell lines;
- developing approaches for quantifying genetic differences among animals within the collection and comparing the status of the collection to *in situ* populations;
- improving methods for optimizing ongoing sampling and storage of genetic material in systems where the primary objective is to provide a backup to ongoing genetic improvement programmes;
- increasing the efficiency of reproductive technologies (in terms of the number of live animals produced per unit of material stored) in order to improve the cost-effectiveness of *in vitro* conservation programmes; and
- identifying policy, legislative and zoosanitary frameworks (and strategies for their implementation) that will facilitate the storage of germplasm in gene banks and access to such material.

References

Blackburn, H.D. 2004. Development of national animal genetic resource programs. *Reproduction, Fertility and Development,* 16: 27–32.

Blackburn, H.D. 2009. Genebank development for the conservation of livestock genetic resources in the United States of America. *Livestock Science*, 120: 196–203.

Blackburn, H.D. 2012. Genetic selection and conservation of genetic diversity. *Reproduction in Domestic Animals*, 47(4): 249–254.

Blackburn, H.D. & Boettcher, P. 2010. Options and legal requirements for national and regional animal genetic resource collections. *Animal Genetic Resources*, 47: 91–100 (available at http://www.fao.org/docrep/013/i1823t/i1823t00.pdf).

Blackburn, H.D., Paiva, S., Wildeus, S., Getz, W., Waldron, D., Stobart, R., Bixby, D., Purdy, P., Welsh, C., Spiller, S. & Brown, M. 2011. Genetic structure and diversity among sheep breeds in the United States: identification of the major gene pools. *Journal of Animal Science*, 89: 2336–2348.

PART **4**

Boettcher, P.J. & Akin, O. 2010. Current arrangements for national and regional conservation of animal genetic resources. *Animal Genetic Resources*, 47: 73–83 (available at http://www.fao.org/docrep/013/i1823t/i1823t00.pdf).

Boettcher, P.J., Tixier-Boichard, M., Toro, M.A., Simianer, H., Eding, H., Gandini, G., Joost, S., Garcia, D., Colli, L., Ajmone-Marsan, P. & The Globaldiv Consortium. 2010. Objectives, criteria and methods for using molecular genetic data in priority setting for conservation of animal genetic resources. *Animal Genetics*, 41 (Suppl. 1): 64–77.

Carson, A., Elliott, M., Groom, J., Winter, A. & Bowles, D. 2009. Geographical isolation of native sheep breeds in the UK - evidence of endemism as a risk factor to genetic resources. *Livestock Science,* 123: 288–299.

Danchin-Burge, C., Hiemstra, S.J. & Blackburn, H. 2011. *Ex situ* conservation of Holstein-Friesian cattle: comparing the Dutch, French, and US germplasm collections. *Journal of Dairy Science*, 94: 4100–4108.

Dani, S.U. & de Oliveira M.V. 2013. Genetics: cattle, cheese and conservation. *Nature*. 502: 448.

Dani, S.U., Dani, M.A., Freire, I.L., Gouvea, S.P., Knackfuss, F.B., Lima, F.P., Mercadante, M.E., Monteiro, E., Paggiaro, S.M., Razook, A.G. & Yehia, H.C. 2010. Survival of the thriftiest: restricted nurture reveals the thrifty nature of a growth gene in *Bos indicus*. *Genetics and Molecular Research*, 9: 1032–1044.

Duchev, Z., Cong, T.V.C. & Groeneveld, E. 2010. CryoWEB: Web software for the documentation of the cryopreserved material in animal gene banks. *Bioinformation*, 5: 219–220.

Engelsma, K.A., Veerkamp, R.F., Calus, M.P.L. & Windig, J.J. 2011. Consequences for diversity when prioritizing animals for conservation with pedigree or genomic information. *Journal of Animal Breeding and Genetics*, 128: 473–481.

FAO. 1984. Genetic aspects of conservation in farm livestock, by C. Smith. In *Animal genetic resources conservation by management, data banks and training. Proceedings of the Joint FAO/UNEP Expert Panel Meeting, October 1983 Part 1,* pp. 18–24. FAO Animal Production and Health Paper No. 44/1. Rome (available at http://www.fao.org/docrep/010/ah808e/ah808e00.htm).

FAO. 1998. *Secondary guidelines for development of national farm animal genetic resources management plans. Management of small populations at risk.* Rome (available at http://www.fao.org/documents/card/fr/c/d074fc39-aca0-58ab-8024-beaf80ba6014/).

FAO. 2003. *Community-based management of animal genetic resources*. Proceedings of the workshop held in Mbabane, Swaziland 7-11 May 2001. Rome (available at www.fao.org/DOCREP/006/Y3970E/Y3970E00.htm).

FAO. 2007a. *The Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration*. Rome (available at http://www.fao.org/docrep/010/a1404e/a1404e00.htm).

FAO. 2007b. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2010. *Breeding strategies for sustainable management of animal genetic resources*. FAO Animal Production and Health Guidelines No. 3. Rome (available at http://www.fao.org/docrep/012/i1103e/i1103e.pdf).

FAO. 2011. *Molecular genetic characterization of animal genetic resources*. FAO Animal Production and Health Guidelines. No. 9. Rome (available at http://www.fao.org/docrep/014/i2413e/i2413e00.htm).

FAO. 2012. *Cryoconservation of animal genetic resources*. FAO Animal Production and Health Guidelines No. 12. Rome (available at http://www.fao.org/docrep/016/i3017e/i3017e00.htm).

FAO. 2013. In vivo *conservation of animal genetic resources.* FAO Animal Production and Health Guidelines No. 14. Rome (available at http://www.fao.org/docrep/018/i3327e/i3327e00.htm).

Fernández, J., Toro, M.A. & Mäki-Tanila, A. 2011. Management of genetic diversity in small farm animal populations. *Animal*, 5(11): 1684–1698.

Gandini, G., Pizzi, F., Stella, A. & Boettcher, P.J. 2007. The costs of breed reconstruction from cryopreserved material in mammalian livestock species. *Genetics Selection Evolution*, 39: 465–479.

Gómez-Romano, F., Villanueva, B., Rodríguez de Cara, M.A. & Fernández, J. 2013. Maintaining genetic diversity using molecular coancestry: the effect of marker density and effective population size. *Genetics Selection Evolution*, 45: 38.

Groeneveld, E., Nguyen Huu Tinha, Kues, W. & Nguyen Thi Vien. 2008. A protocol for the cryo-conservation of breeds by low-cost emergency cell banks – a pilot study. *Animal*, 2: 1–8.

Groeneveld, L.F., Lenstra, J.A., Eding, H., Toro, M.A., Scherf, B., Pilling, D., Negrini, R., Finlay, E.K., Jianlin, H., Groeneveld, E., Weigend, S. & the GLOBALDIV Consortium. 2010. Genetic diversity in farm animals – a review. *Animal Genetics*, 41(suppl. 1): 6–31.

Hiemstra, S.J., Haas, Y., Maki-Tanila, A. & Gandini, G. 2010. *Local cattle breeds in Europe*. Wageningen, the Netherlands, Wageningen Academic Publisher (available at http://tinyurl.com/p852mdj).

Hiemstra, S.J., Martyniuk, E., Duchev, Z. & Begemann, F. 2014. European Gene Bank Network for Animal Genetic Resources (EUGENA). In *Proceedings of the 10th World Congress of Genetics Applied to Livestock Production, Vancouver, BC, Canada, August 17–22, 2014* (available at http://tinyurl.com/nqxl3xl).

Hijmans, R.J., Garrett, K.A., Huamán, Z., Zhang, D.P., Schreuder, M. & Bonierbale, M. 2000. Assessing the geographic representativeness of genebank collections: the case of Bolivian wild potatoes. *Conservation Biology*, 14: 1755–1765.

Hinrichs, A.L. & Suarez, B.K. 2005. Genotyping errors, pedigree errors, and missing data. *Genetic Epidemiology*, 29 (Suppl 1): S120–S124.

Huson, H.J., Sonstegard, T.S., Silverstein, J., Woodward-Greene, M.J., Masiga, C., Muchadeyi, F., Rees, J., Sayre, B., Elbetagy, A., Rothschild, M., Mujibi, F.D., Mwai, O., Kemp, S., Colli, L., Ajmone-Marsan, P., Crepaldi, P., Abegaz, S., Soelkner, J. & Van Tassel, C.P. 2014. Genetic and phenotypic characterization of African goat populations to prioritize conservation and production efforts for small-holder farmers in Sub-Saharan Africa. In *Proceedings of the 10th World Congress of Genetics Applied to Livestock Production, Vancouver, BC, Canada, August 17–22, 2014* (available at http://tinyurl.com/oql9nym).

Kaneko, T. & Serikawa, T. 2012. Successful long-term preservation of rat sperm by freeze-drying. *PLoS ONE*, 7: e35043.

Kugonza, D.R., Kiwuwa, G.H., Mpairwe, D., Jianlin, H., Nabasirye, M., Okeyo, A.M. & Hanotte, O. 2012. Accuracy of pastoralists' memory-based kinship assignment of Ankole cattle: a microsatellite DNA analysis. *Journal of Animal Breeding and Genetics,* 129: 30–40.

Lauvie, A., Audiot, A., Couix, N., Casabianca, F., Brives, H. & Verrier, E. 2011. Diversity of rare breed mangement programmes: between conservation and development. *Livestock Science*, 140: 161–170.

Ligda, C. & Casabianca, F. 2013. Adding value to local breeds: challenges, strategies and key factors. *Animal Genetic Resources*, 53: 107–116 (available at http://www.fao.org/docs/eims/upload//314794/I3445Tri.pdf).

Loi, P., Iuso, D., Czernik, M., Zacchini, F. & Ptak, G. 2013. Towards storage of cells and gametes in dry form. *Trends in Biotechnology*, 31: 688–695.

Long, J.A., Purdy, P.H., Zuidberg, K., Hiemstra, S.-J., Velleman, S.G. & Woelders, H. 2014. Cryopreservation of turkey semen: effect of breeding line and freezing method on post-thaw sperm quality, fertilization, and hatching. *Cryobiology*, 68: 371–378.

Maiwashe, A.N. & Blackburn, H.D. 2004. Genetic diversity in and conservation strategy considerations for Navajo Churro sheep. *Journal of Animal Science*, 82: 2900–2905.

Mariante, A.D., Albuquerque, M.D.M., Egito, A.A., McManus, C., Lones, M.A. & Paiva, S.R. 2009. Present status of the conservation of livestock genetic resources in Brazil. *Livestock Science*, 120(3): 204–212.

Martin-Collado, D., Diaz, C., Drucker, A.G., Carabano, M.J. & Zander, K.K. 2014. Determination of non-market values to inform conservation strategies for the threatened Alistana-Sanabresa cattle breed. *Animal,* 8: 1373–1381.

Martin-Collado, D., Diaz, C., Maki-Tanila, A., Colinet, F., Duclos, D., Hiemstra, S. J., Eureka Consortium & Gandini, G. 2013. The use of SWOT analysis to explore and prioritize conservation and development strategies for local cattle breeds. *Animal*, 7: 885–894.

Martyniuk, E., Sæther, N., Berger, B. & Krupiński, J. 2014. Transformation from dairy to suckling system: an opportunity or a disaster for local dual purpose cattle breeds. *Acta Agriculturae Scandinavica, Section A — Animal Science*, 64(1): 23–35.

Mazur, P. 1985. Basic concepts in freezing cells. *In* L.A. Johnson & K. Larson, eds. *Proceedings of the First International Conference on Deep Freezing of Boar Semen*, pp 91–111. Uppsala, Sweden, Swedish University of Agricultural Sciences.

Mullen, S.F. & Fahy, G.M. 2012. A chronologic review of mature oocyte vitrification research in cattle, pigs, and sheep. *Theriogenology*, 78: 1709–1719.

Okazaki, T. & Shimada, M. 2012. New strategies of boar sperm cryopreservation: development of novel freezing and thawing methods with a focus on the roles of seminal plasma. *Animal Science Journal*, 83: 623–629.

Paiva, S.R., McManus, C. & Blackburn, H. 2014. Conservation of animal genetic resources: the next decade. *Proceedings of the 10th World Congress of Genetics Applied to Livestock Production, Vancouver, BC, Canada, August 17–22, 2014*. Paper 29 (available at http://tinyurl.com/ph7auv9).

Pereira, R. & Marques, C. 2008. Animal oocyte and embryo cryopreservation. *Cell and Tissue Banking*, 9: 267–277.

Pertoldi, C., Purfield, D.C., Berg, P., Hensen, T.H., Bach, O.S., Vingborg, R. & Kristensen, T.N. 2014. Genetic characterization of a herd of endangered Danish Jutland cattle. *Journal of Animal Science,* 92: 2372–2376.

Pizzi, F., Duclos, D., Woelders, H. & Maki Tanila, A. 2010. Role and state of cryopreservation in local cattle breeds. *In* S.J. Hiemstra, Y. De Haas, A. Maki Tanila & G. Gandini, eds. *Local cattle breeds in Europe*, pp. 78–96. Wageningen, the Netherlands, Wageningen Academic Publishers.

Polge, C., Smith, A.U. & Parkes, A.S. 1949. Revival of spermatozoa after vitrification and dehydration at low temperatures. *Nature*, 164: 666.

Powell, J.E., Visscher, P.M. & Goddard, M.E. 2010. Reconciling the analysis of IBD and IBS in complex trait studies. *Nature Reviews Genetics,* 11: 800–805.

Pradiee, J., Esteso, M.C., Castaño, C., Toledano-Díaz, A., López-Sebastián, A. & Santiago-Moreno, J. 2014. Cryopreservation of epididymal sperm from ibexes (*Capra pyrenaica*) using short equilibration time with glycerol. *Theriogenology*, 82: 525–528.

Purdy, P.H., Mocé, E., Stobart, R., Murdoch, W.J., Moss, G.E., Larson, B., Ramsey, S., Graham, J.K. & Blackburn, H.D. 2010. The fertility of ram sperm held for 24 h at 5 °C prior to cryopreservation. *Animal Reproduction Science*, 118: 231–235.

Silva, S., Almeida, F., Silva, E., Souza, H., Moura, T., Vieira, J., Souza, A. & Guerra, M.M. 2014. Cryopreservation of ram epididymis spermatozoa post-slaughter. A feasible biotechnique? *BMC Proceedings*, 8 (Suppl 4): 166.

Silversides, F.G., Purdy, P.H. & Blackburn, H.D. 2012. Comparative costs of programmes to conserve chicken genetic variation based on maintaining living populations or storing cryopreserved material. *British Poultry Science*, 53(5): 599–607.

Song, Y. & Silversides, F.G. 2006. The technique of orthotopic ovarian transplantation in the chicken. *Poultry Science*, 85: 1104–1106.

Song, Y. & Silversides, F.G. 2007a. Offspring produced from orthotopic transplantation of chicken ovaries. *Poultry Science*, 86: 107–111.

Song, Y. & Silversides, F.G. 2007b. Production of offspring from cryopreserved chicken testicular tissue. *Poultry Science*, 86: 1390–1396.

Stevens, E.L., Heckenberg, G., Roberson, E.D., Baugher, J.D., Downey, T.J. & Pevsner, J. 2011. Inference of relationships in population data using identity-by-descent and identity-by-state. *PLoS Genetics,*7: e1002287.

Tadano, R., Nagasaka, N., Goto, N., Rikimaru, K. & Tsudzaki, M. 2013. Genetic characterization and conservation priorities of chicken lines. *Poultry Science*, 92: 2860–2865.

Takahashi, K. & Yamanaka, S. 2006. Induction of pluripotent stem cells from mouse embryonic and adult fibroblast cultures by defined factors. *Cell*, 126: 663–676.

Toro, M.Á., García-Cortés, L.A. & Legarra, A. 2011. A note on the rationale for estimating genealogical coancestry from molecular markers. *Genetics Selection Evolution,* 43: 27.

Toro, M.A., Villaneuva, B. & Fernández, J. 2014. Genomics applied to management in conservation programmes. *Livestock Science*, 166: 48–53.

Turri, F., Madeddu, M., Gliozzi, T.M., Gandini, G. & Pizzi, F. 2014. Effect of testicle postmortem storage on goat frozen-thawed epididymal sperm quality as a tool to improve genebanking in local breeds. *Animal*, 8: 440–447.

UNEP & Natural Justice. 2009. *Bio-cultural community protocols - a community approach to ensuring the integrity of environmental law and policy*. Nairobi (available at http://www.unep.org/communityprotocols/PDF/communityprotocols.pdf).

Woelders, H., & Hiemstra, S.J. 2011. The potential of cryopreservation and reproductive technologies for animal genetic resources conservation strategies. *Cryobiology*, 63: 316–317.

Woelders, H., Windig, J. & Hiemstra, S. 2012. How developments in cryobiology, reproductive technologies and conservation genomics could shape gene banking strategies for (farm) animals. *Reproduction in Domestic Animals*, 47(s4): 264–273.

Yue, V.P., Dechow, C. & Liu, W.S. A limited number of Y chromosome lineages is present in North American Holsteins. *Journal of Dairy Science*, 98: 2738–2745.

Zander, K.K., Signorello, G., Da Salvo, M., Gandini, G. & Drucker, A.G. 2013. Assessing the total economiv value of threatened livestock breeds in Italy: implications for conservation policy. *Ecological Economics*, 93: 219–229 (available at http://tinyurl.com/qe4f9xq).

Section E

Economics of animal genetic resources use and conservation

1 Introduction

Economic analysis can play an important role in the sustainable management of animal genetic resources (AnGR). The first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (first SoW-AnGR) (FAO, 2007a) included a section on methods for economic evaluation[1] that provided an overview of the various types of value that can be distinguished (direct and indirect use values, option values, bequest values and existence values) and described potential methods and tools for assessing them. It also presented some examples of the use of these methods and tools and the findings obtained. This updated section provides an overview of recent developments in the economics of AnGR use and conservation. The revised title reflects the way in which this field of work has moved beyond just the development and testing of methods.[2]

Significant research on AnGR-focused economic valuation methods largely began following an FAO/International Livestock Research Institute (ILRI) workshop (Rege, 1999) that identified relevant methodologies (see also Drucker *et al.*, 2001). Work on the testing of these methods was subsequently undertaken by ILRI (Economics of AnGR Conservation and Sustainable Use Programme) and its partners. The discussion presented in the first SoW-AnGR drew on the findings generated by the ILRI programme, many of which were reported in a special issue of the journal *Ecological Economics* (Drucker and Scarpa, 2003) and in a CGIAR System-wide Genetic Resources Programme (SGRP) report that reviewed the applied economics literature related to the valuation and sustainable management of crop and livestock biodiversity (Drucker *et al.*, 2005, subsequently published as Smale and Drucker, 2007).

The first SoW-AnGR concluded that research in this area had led to the development of a range of methods that could be used to value livestock-keepers' breed or trait preferences and support the design of policies to counter trends towards the marginalization of locally adapted breeds. It noted that, despite the easing of some methodological/analytical constraints as a result of this body of work, data constraints remained critical. Challenges identified included the need to raise awareness regarding the important role of economic analysis in improving the sustainable use and conservation of AnGR, the need to strengthen national capacities so that relevant methods and decision-support tools could be applied and the need to integrate such tools and methods into wider national livestock development processes, including through the design of appropriate incentive mechanisms. The report also noted that there had been little practical application of such tools and methods in contexts that could influence policy-making and livestock keepers' livelihoods.

A subsequent analysis (Drucker, 2010) of the country reports prepared for the first SoW-AnGR supported the view that the field of AnGR economics had had relatively little influence on "real-life" design and implementation of conservation policy. It indicated that, at best, there was a patchy

[1] FAO, 2007a, pages 429–440.

[2] The title of the equivalent section in the first SoW-AnGR was "Methods for economic valuation".

recognition of the importance of valuation and the potential role of economics in the design of cost-effective conservation programmes. In addition to challenges related to a lack of awareness regarding the existence of appropriate methods and tools, a lack of capacity to collect the necessary economic characterization and valuation data through participatory mechanisms and to carry out subsequent analysis was also identified as a constraint. A further conclusion was that economic characterization and valuation was also constrained by deficiencies in the broader characterization of AnGR (for example related to genetic analysis, performance recording and the monitoring of breed status and trends). Thus, while the importance of economics is recognized in the Global Plan of Action for Animal Genetic Resources (FAO, 2007b) (e.g. with regard to the development of standards and protocols,[3] strengthening of policies,[4] provision of support to indigenous and local production systems[5] and establishment of national conservation policies)[6] translating economic valuation into a mainstream activity in AnGR management would require significant awareness-raising and capacity-building. In this context, it should also be noted that calls for biodiversity valuation work and for the design of positive incentive mechanisms have been made by the Conference of the Parties to the Convention on Biological Diversity (CBD) (Decision VIII/25) and that the CBD's Strategic Plan for 2011–2020 (CBD, 2011) calls for the removal of subsidies harmful to biodiversity. As a basis for the preparation of this section, a review of AnGR economics literature published after the first SoW-AnGR was drafted (covering the period 2006[7] to mid-2014) was undertaken by consulting bibliographic databases[8] and key AnGR experts, including through the Domestic Animal Diversity Network (DAD-Net)[9] a discussion group with 2 100 members (as of December 2014), the latter with a view to identifying literature not included in bibliographic databases, including grey literature and academic theses.

In order to ensure a focus on the economics of AnGR *per se*, rather than the broader field of livestock economics, the scope of the literature review was limited to studies involving economic assessments focused either on the valuation (direct or indirect) of locally adapted breeds by livestock keepers or on production inputs and outputs for different breeds. Broader livestock economics studies, including a substantial body of literature based on productivity assessments (e.g. feed conversion efficiency), as well as those comparing breed performances in research-station settings, were considered beyond the scope of the review.

The literature review revealed that a significant body of work has been generated in recent years. Thirty-nine publications (including five theses) broadly related to the economic valuation of breeds were identified, covering a number of species and geographical areas and making use of a range of valuation methods; a further 35 publications related more broadly to AnGR economics and conservation policy were also identified. A large literature (65 publications identified) addressing the broader field of the economics of agrobiodiversity (i.e. covering, *inter alia,* concepts, ecosystem service frameworks and models related to agrobiodiversity and biodiversity in general) can also be considered relevant.

The literature identified can be grouped into the following categories:

- the economic conceptual framework for AnGR and the link between the range of AnGR economic values and specific ecosystem services;
- analytical tools used for economic valuation of breeds;
- valuation of traits to inform breeding decisions;
- public willingness to pay for conservation services; and
- incentive mechanisms for conservation services.

The following subsection provides an overview of this literature based on these categories.

[3] FAO, 2007b, Strategic Priority 2, Actions 1 and 2.
[4] FAO, 2007b, Strategic Priority 3, Action 2.
[5] FAO, 2007b, Strategic Priority 6, Action 1.
[6] FAO, 2007b, Strategic Priority 7.
[7] The first SoW-AnGR covered references up to 2005.
[8] Web of Science, Google Scholar, ResearchGate, open thesis, JURN, etc.
[9] https://dgroups.org/fao/dad-net

2 Developments in animal genetic resources economics

Since 2006, a body of literature has emerged that provides a more formal economic conceptual framework within which to understand the erosion of AnGR as part of a replacement or conversion process that is amplified by a divergence between the private- and public-good values associated with the maintenance of biodiversity. These effects had previously been described in the context of biodiversity in general by Swanson (1997) (conversion process) and Pearce and Moran (1994) (value divergence), among others. The latter authors also note that recognition of the broader total economic values (TEV) associated with biodiversity can be instrumental in altering decisions about resource use.[10] While evidence-based policy-making has its limitations (Sumburg *et al.*, 2013) and biodiversity valuation is not a panacea, it may help to "recalibrate faulty economic compasses that have led to poorly informed decision-making" (TEEB, 2010).

The economic conceptual framework has provided the basis for improved understanding of the incentive mechanisms required to help reduce AnGR erosion by better aligning private- and public-good values, including through the application of payments for ecosystem services concepts to AnGR (Narloch *et al.*, 2011a; Silvestri *et al.*, 2012; Bojkovski, forthcoming). Such frameworks have also been used to support analysis of the economics of agrobiodiversity conservation (both animal and plant genetic resources) for food security under climate change (Pascual *et al.*, 2011). Most of this body of literature refers to *in situ*/on-farm use and conservation, with only limited references (e.g. McClintock *et al.*, 2007) to *ex situ* conservation.

Finally, in recent literature, the links between nature (encompassing AnGR) and the economy have increasingly tended to be described using the concept of ecosystem services or flows of value to human societies as a result of the state and quantity of natural capital (Jackson *et al.*, 2007; TEEB, 2010). As a result, there are increasing opportunities to consider the ecosystem services concept in the context of AnGR management and the role that economic valuation of AnGR can play within such a framework. Zander *et al.* (2013) and Martin-Collado *et al.* (2014) have demonstrated how the quantification of the different components of TEV and the underlying ecosystem services with which they may be associated can provide a useful guide to the design of policies for the sustainable use and conservation of AnGR.

2.1 Economic conceptual framework and ecosystem services

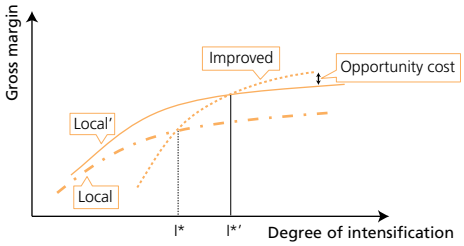
Narloch *et al.* (2011a) – drawing on Drucker and Rodriguez (2009), Steinfeld (2000) and Swanson (1997) – note that the erosion of agrobiodiversity can be understood in terms of the replacement of the diverse existing pool of locally adapted animal and plant genetic resources with a smaller range of specialized improved ones. Given that the latter are likely to have a higher responsiveness to external inputs, agricultural intensification (where this is possible) may make breed substitution and cross-breeding increasingly profitable (see Figure 4E1) and hence lead to a reduction in locally adapted breed numbers (Drucker and Rodriguez, 2009; Marshall, 2014).

There are a number of reasons to suppose that the replacement process is resulting in less than socially desirable levels of AnGR being maintained. In particular, it is likely that significant non-market and/or public-good values associated with the various ecosystem services provided by genetic resources (see Box 4E1) are not reflected in market prices and that this creates a bias against their maintenance. Another set of values that are often not reflected in market prices and conventional economic analyses are private-good values not directly related to production outputs, but instead associated with the role of agrobiodiversity in minimizing farm-level risks related

[10] See FAO, 2007a, Box 93 (page 430) for a discussion of TEV in the context of AnGR.

FIGURE 4E1

Breed production functions, public-good values and replacement opportunity costs



Note: "Local" AnGR (market profitability function represented by the dash–dot line [-·-]) outperform "improved" AnGR (market profitability function represented by the dotted line [···]) up to a given level of production system intensity (I*). The term "intensity" is used here in a broad sense and includes, *inter alia*, factors related to access to markets and extension services. Once the degree of intensification passes I*, livestock keepers face increasing financial incentives to replace the local AnGR with the improved ones. Accounting for public-good values not reflected in market prices would lead to an upward shift in the "Local" curve (to the position indicated by the solid line [—]), and a shift in the replacement point to I*'.
Source: Adapted from Drucker and Rodriguez, 2009, and Zander *et al.*, 2013.

to external shocks such as extreme climatic events and disease outbreaks (e.g. Rege and Gibson, 2003).[11]

The framework illustrated in Figure 4E1 suggests that in certain contexts livestock-keepers will need to be compensated for the financial opportunity costs of continuing to maintain socially desirable levels of locally adapted AnGR. Incentive mechanisms that permit fuller "capture" of the economic values arising from the maintenance of genetic resources would have the effect of shifting the curve for the locally adapted AnGR upwards to the left (as shown by the solid line). Such mechanisms could involve direct support payments, such as those provided under the European Rural Development Programmes, as well as payments for ecosystem services. In addition, private values could be enhanced through niche marketing and value-chain development for products and services (including agritourism initiatives) associated with AnGR (see further discussion below and in Part 4 Section D).

It is within this conceptual context that it becomes apparent that an understanding of non-market and public-good values is important from a conservation policy perspective (Zander *et al.*, 2013). Accounting for TEVs can be used to determine, *inter alia*, whether the benefits of intervention outweigh the costs, as well as to determine appropriate intervention strategies, including for situations in which specific AnGR have little or no current market-development potential. Where conservation funds are limited, understanding the "true" (i.e. total) economic value of different breeds and their contribution to the public good can be an important tool in prioritization and fund allocation (Fadlaoui *et al.*, 2006).

An understanding of the relative values of the different components of TEV can also be used to provide insight into the viability of different use and conservation strategies. It is possible to identify the relevance of different types of economic value and associated ecosystems services to different types of stakeholder and their willingness to pay for the services provided by the maintenance of breeds (Zander *et al.*, 2013). For example, indirect use values, such as cultural and landscape maintenance values, are likely to be of more relevance to local residents and visitors to a local area, while option values are likely to be of relevance to a much broader range of stakeholders. Given the importance of the public-good values associated with breed maintenance, Martin-Collado *et al.* (2014) argue that, in order to maximize societal welfare, *in situ*/on-farm conservation interventions and strategies need to be designed with a view to maintaining the ongoing provision of the public-good breed-related functions that people value most.

[11] Narloch *et al.* (2011) also identify market failures (e.g. externalization of environmental impacts) leading to an overestimation of the performance of improved AnGR, as well as important intervention failures (e.g. subsidies and support prices) that increase the financial profitability of improved AnGR. Accounting for such factors would result in a downward shift (not shown) of the "Improved" curve in Figure 4E1, resulting in the socially optimal replacement point being even further to the right than indicated by I*'.

Box 4E1
Biodiversity valuation, ecosystem services and animal genetic resources

Agriculture can be understood as a multifunctional activity that not only produces food, but also sustains rural landscapes, protects biodiversity, generates employment and contributes to the viability of rural areas. The benefits that humans derive from the functioning of the world's ecosystems, including agricultural ecosystems, are increasingly being discussed in terms of "ecosystem services". All these services are underpinned by biodiversity, and livestock and livestock-keeper custodianship/stewardship make an important contribution to the maintenance of many of them (WRI, 2005; Hodges *et al.*, 2014; FAO, 2014). Biodiversity-related ecosystem services are considered to be particularly significant in rural areas, where up to 75 percent of the world's poor people derive their livelihoods under continuous exposure to ecological and economic risks.

The Economics of Ecosystems and Biodiversity initiative (TEEB, 2010) defined the following four categories of ecosystem services that contribute to human well-being:

- provisioning services;
- regulatory services;
- habitat services; and
- cultural services.

The contributions of animal genetic resources (AnGR) to **provisioning services** (the supply of products and services such as food, fibre, manure, hides, transport, traction, savings and insurance) can often be quantified and evaluated using mainstream economic tools such as cost–benefit analysis, farm-simulation models and breeding-programme evaluations. These tools tend to rely on revealed preference methods that depend on the existence of market data on prices and volumes.

In contrast, accounting for AnGR's contributions to the non-market, indirect use values associated with the **regulatory services** (processes such as nutrient cycling, soil fertility improvement, water and soil conservation and agro-ecosystem resilience – including pest and disease resistance, control of weeds and invasive species, stress buffering and adaptation to change) and **habitat services** (creation and maintenance of habitats for wild biodiversity) frequently requires the use of stated preference methods (see Box 4E2). Valuation of these contributions is further complicated by the fact that the ecological mechanisms that define many of them are not well understood (Jackson *et al.*, 2007).

AnGR-related **cultural services** include those associated with recreation, aesthetics (both of landscapes and the animals themselves) and the maintenance of traditional knowledge and sociocultural practices. Once again, non-market dimensions can complicate valuation and require the use of stated preference methods. Cultural services have been shown to play an important role in breed maintenance. For example, Widi *et al.* (2014) show that the unique cultural roles and values associated with Indonesian Madura cattle facilitate the maintenance of the breed despite the fact that crossing it with exotic breeds results in bigger animals with better body condition scores. The cultural role and value of the Javanese Pelung chicken breed, known for its singing capabilities, has similarly been found to play a positive role in ensuring its continued maintenance (Asmara, 2014).

2.3 Breed valuation studies

Given the existence of a range of economic values, many of which are non-market values, it is perhaps unsurprising that most of the 39 publications related to breed valuation identified in the literature review (see Subsection 1 for details) use survey-based preference-eliciting approaches. In other words, these studies determine the economic values of AnGR by assessing people's preferences (often the preferences of livestock keepers). The use of stated preference methods is the dominant approach, with 20 studies using choice experiments or contingent valuation (see Box 4E2 for explanations of these terms). Hedonic pricing, a revealed preference method, is used in two studies. Eleven studies present results from preference-ranking techniques

Box 4E2
Environmental valuation methods

There are many different approaches to, and views regarding, the valuation, pricing and costing of environmental and public goods and services. On the demand side, economists differentiate between **stated** and **revealed preference methods**, the choice of method often depending on the degree of availability of market data.

Stated preference methods are survey-based techniques that seek to elicit people's maximum willingness-to-pay (WTP) for an environmental good/service or their minimum willingness-to-accept (WTA) compensation to forgo such a good or service. This is done by creating a hypothetical market in which people are then asked to state, either directly or indirectly, their WTP/WTA for changes in the quality or quantity of the good/service. Hypothetical markets of this kind can be used to assess non-market (non-use) aspects of environmental goods and services and also to assess hypothetical goods and services that do not yet exist but could do in the future.

Contingent valuation studies, one of the most widely applied non-market valuation methods, directly ask people about their WTP/WTA for an environmental good or service *per se.* Indirect approaches include **choice experiments/choice modelling**, **choice ranking** and **contingent rating**. **Conjoint analysis**, a term often used in marketing, is considered a form of choice experiment, often without a monetary attribute to trade-off. **Preference ranking** is similar. In all cases, surveys present people with a range of hypothetical options. People are then asked to choose their preferred option or to rank or rate them. By trading off the various characteristics of the presented options, which include the price/costs of the option, people indirectly indicate their WTP/WTA for the characteristics. **Hedonic pricing**, a **revealed preference method** that relies on the existence of market information, works in a similar way; implicit prices for socio-environmental attributes are estimated through people's actual demand for market goods that incorporate such attributes (e.g. different product characteristics such as taste or organic production status). **Production function** approaches use information regarding input costs (such as feed, veterinary and labour costs) and the benefits associated with different yield effects (e.g. on meat, milk and/or egg production) in order to compare the gross margins of different breeds.

Source: Adapted from Madureira *et al.*, 2007.

without explicit monetary valuation and six studies use methods based on the use of production functions of different breeds to approximate values.

Twenty-five (64 percent) of the 39 studies assess cattle, five poultry, five small ruminants and four pigs. Most of the studies from 2006 onwards relate to the economic valuation of traditional breeds in developing countries, where the livelihood functions of such breeds are particularly important. In fact, only eight of the 39 studies (21 percent: six in Asia and two in Europe) were not conducted in Africa.

The studies in Africa cover a range of breeds, including Ankole, Borana, Nguni and Zebu cattle (Table 4E1). While many studies focus on a single breed, Duguma *et al*. (2011) assessed the importance of traits in four sheep breeds (Afar, Bonga, Horro and Menz) in Ethiopia. In Europe, Zander *et al.* (2013) assessed the TEV of two Italian cattle breeds (Modicana and Maremmana), while Martin-Collado *et al.* (2014) assessed the TEV of the Spanish Alistana–Sanabresa cattle breed. The majority of studies, however, do not refer to any particular breed, but instead seek to assess the value of specific traits (such as disease resistance) that can then be linked to locally adapted breeds. Interestingly, no Latin American studies were identifiable, although Marshall (2014) (see below) cites two breeding-related studies from the region.

TABLE 4E1

Overview of livestock breed and trait valuation studies by region (2006 to 2014)

Method	Region/Country	Species	Locally adapted breed(s)	Reference
	Africa			
Choice experiment	Benin	Chickens	No specific breed	Faustin *et al.*, 2010
	Ethiopia, Kenya	Cattle	Borana	Zander, 2006 Zander and Holm-Müller, 2007 Zander and Drucker, 2008 Zander *et al.*, 2009a
	Ethiopia	Cattle	No specific breed	Kassie *et al.*, 2009; 2010
	Ethiopia	Goats	No specific breed	Amanu Abetu, 2013
	Kenya	Cattle	Zebu	Ruto *et al.*, 2008 Ruto *et al.*, 2010
	Kenya	Cattle	No specific breed	Ouma *et al.*, 2007
	Kenya	Goats	No specific breed	Omondi *et al.*, 2008a
	Kenya	Sheep	No specific breed	Omondi *et al.*, 2008b
	South Africa	Pigs	No specific breed	Madzimure, 2011
Conjoint analysis	Ethiopia	Sheep	Afar, Bonga, Horro and Menz	Duguma *et al.*, 2011
	Kenya	Chickens	No specific breed	Bett *et al.*, 2011
Contingent valuation	United Republic of Tanzania	Cattle	Tarime Zebu	Ngowi *et al.*, 2008
Hedonic pricing	Ethiopia	Cattle	No specific breed	Kassie *et al.*, 2011
	Ethiopia	Sheep	No specific breed	Terfa *et al.*, 2013
Preference ranking	Burundi, Rwanda, Uganda, United Republic of Tanzania	Cattle	Ankole	Wurzinger *et al.*, 2006
	Ethiopia	Poultry	No specific breed	Dana *et al.*, 2010
	Ethiopia	Cattle	No specific breed	Desta *et al.*, 2011
	South Africa	Cattle	Nguni	Tada *et al.*, 2012; 2013
	Uganda	Cattle	Ankole	Ndumu *et al.*, 2008
	Zimbabwe	Chickens	No specific breed	Muchadeyi *et al.*, 2009
Production function/ gross margin analysis	Ethiopia	Cattle	No specific breed	Dayanandan, 2011
	Kenya	Cattle	Orma and Sahiwal Zebu	Maichomo *et al.*, 2009
	Asia			
Choice experiment	Viet Nam	Pigs	No specific breed	Roessler *et al.*, 2008
Contingent valuation	Indonesia	Chickens	No specific breed	Asmara, 2014
Preference ranking	Indonesia	Cattle	No specific breed	Widi *et al.*, 2014
Production function/ gross margin analysis	Bangladesh	Cattle	No specific breed	Islam *et al.*, 2010
	Bangladesh	Cattle	No specific breed	Mondal *et al.*, 2010
	India	Cattle	No specific breed	Islam *et al.*, 2008
	Viet Nam	Pigs	Ban	Lemke *et al.*, 2006
	Europe			
Choice experiment	Italy	Cattle	Modicana and Maremmana	Zander *et al.*, 2013
	Spain	Cattle	Alistana–Sanabresa	Martin-Collado *et al.*, 2014

2.3 Valuation of traits to inform breeding decisions

In the context of the economic valuation of AnGR, the term "breeding" refers to directing deliberate and lasting changes in the genetic constitutions of livestock populations so as to improve their utilization. In the conventional practices of breeding programmes in developed countries, economic weights of key traits are combined with estimated breeding values to derive selection indices in order to evaluate the effect of the directional genetic changes on overall profit. These tools enable livestock keepers to select, maintain and reproduce animals with the aim of maximizing overall profitability. Conceptually similar, but more loosely articulated breeding objectives, are applied in traditional production systems in developing countries, although these typically consider more diverse and often complex traits, including adaptation or resilience to biotic and abiotic stresses, multiple indirect service functions and the socio-cultural values of the animals.

In this context, it is worth noting Marshall's (2014) overview of studies that have compared performance from the socio-economic or economic viewpoint of the livestock keeper (and of other actors in the value chain). The authors identified 11 studies from Asia and Africa (the focus of their study) that fall within the scope of the current review. These studies took what may be broadly categorized as a production function approach in order to compare the gross margins of different breeds (including cross-breeds) from the point of view of the livestock keeper. They used field, rather than research-station, data related to input costs and yield effects. Six of the studies (undertaken in Ethiopia, India and Bangladesh) focused on dairy cattle (Sayeed *et al*., 1994; Ali *et al*., 2000; Islam *et al.,* 2008; 2010; Mondal *et al*., 2010; Dayanandan 2011), one on dual-purpose cattle in Kenya (Maichomo *et al.,* 2009), one on chickens in Bangladesh (Rahman *et al.,* 1997), one on goats in Ethiopia (Ayalew *et al.,* 2003), and two on pigs in Viet Nam and Zimbabwe (van Eckert, 1993; Lemke *et al.,* 2006). Two additional studies from Latin-America were also mentioned, although neither of these fall within the scope of this review, as they fail to meet the economic analysis (Madalena *et al.*, 2012) or date (Blake, 2004) criteria.

Despite the slow progress in the uptake of the results of policy decision-support tools based on the economics of AnGR (Drucker, 2010), some analytical techniques for systematically estimating relative economic values of complex traits and attributes of AnGR have recently been adopted in mainstream animal breeding. In situations where only limited production and market data are available, the relative economic importance of key traits and attributes can be estimated using stated preference techniques (Tano *et al.*, 2003). For example, Nielson and Amer (2007) used choice experiments to define economic weights for use in animal breeding selection indices where traditional bio-economic models for estimating profits are not practical. Other types of stated preference techniques, such as conjoint analysis and preference ranking, have also been used to identify and prioritize traits, and indeed breeds, for particular production scenarios (Desta *et al*., 2011; 2012; Duguma *et al.*, 2011). These techniques can be used to capture the preferences and choices of livestock keepers for traits/attributes that are not marketed (non-market use values) and are often ignored or only given secondary consideration in the process of deriving breeding objectives and economic weights for different traits. However, further work needs to be done in order to demonstrate how the results of such stated preference methods can be applied in the development of (long-term) breeding programmes for at-risk breeds, not only in developed countries, but also in developing countries – especially for breeds found in marginal production environments (e.g. Hodges *et al.,* 2014).

Apart from allowing the valuation of indirect use values of AnGR, economic valuation methods complement and provide relevant socio-economic context to the results of global and breed-specific molecular genetic studies. For instance, a global study into the genetic structure of cattle breeds (Bovine HapMap Consortium, 2009) has

revealed significant hybridization of the rare taurine and trypanotolerant Sheko breed with indicine breeds, which is consistent with earlier molecular genetic evidence of an alarming male-mediated introgression of zebu genes (Hanotte *et al.,* 2000). Related trait and breed preference studies in the Sheko's native production environments in Ethiopia showed that despite its recognized adaptedness to endemic trypanosomosis and tsetse fly challenge, as well as its superior dairy attributes (compared to other local cattle breeds) in these stressful production environments (Lemecha *et al.,* 2006), the breed remains under sustained pressure from deliberate cross-breeding as livestock keepers choose smaller and more docile zebu bulls from adjacent highlands (Stein *et al.*, 2009; Desta *et al.*, 2011; 2012). This is in line with the earlier findings of Jabbar and Diedhiou (2003) from southwest Nigeria, which revealed a gradual shift of breed preferences away from trypanotolerant breeds towards cross-bred and zebu cattle. In addition to shedding light on breed preferences, such studies can also provide the evidence-base for defining breeding objectives for breeding programmes that are capable of meeting the current needs of livestock keepers.

2.4 Public willingness to pay for conservation services

As discussed above, a range of studies have investigated the values of the traits of traditional livestock breeds from livestock-keeper and breeder perspectives. In contrast, Zander *et al.* (2013) and Martin-Collado *et al.* (2014) focused on the full range of TEVs arising from the maintenance of locally adapted breeds, with a view to identifying the broader public's willingness to pay for the breed-related ecosystem services that arise from their maintenance.

Zander *et al.* (2013) show that in the case of two threatened Italian cattle breeds (Modicana and Maremmana), most (85 percent) survey respondents (members of the general public interviewed either in areas where the breeds are kept or in the nearest provincial capital city) supported breed conservation, with their stated willingness-to-pay easily justifying existing European Union support. The high landscape-maintenance, existence[12] and future-option values of both breeds (around 80 percent of their TEVs) suggest that incentive mechanisms are indeed needed in order to allow livestock keepers to capture some of these public-good values and hence motivate them to undertake conservation-related activities. The positive direct use values of both breeds (around 20 percent of their TEVs) imply that niche product markets aimed at enhancing the private-good values associated with the breeds could form an (albeit secondary) element of a use and conservation strategy.

The Spanish Alistana-Sanabresa breed was also shown to be associated with significant non-market values. The value that respondents placed on each specific public-good function was shown to vary significantly. For example, functions related to indirect use cultural values and existence values were much more highly valued than landscape maintenance values. These high cultural and existence values (again totalling approximately 80 percent of TEV) suggest that an *in situ* conservation strategy, as opposed to a purely *ex situ* cryoconservation strategy, would be required and that such a strategy would need to involve livestock-keeper incentive mechanisms (Martin-Collado *et al.*, 2014).

2.5 Incentive mechanisms for conservation services

Given the presence of such significant non-market and public-good values associated with AnGR, it is clear that the development of positive incentives (and indeed the removal of damaging subsidies), as called for under the CBD's 2011–2020 Strategic Framework (CBD, 2011) in the context of biodiversity in general, will often be required in order to ensure that socially desirable levels of livestock diversity are maintained.

One type of positive incentive mechanism that can potentially be used is payment for ecosystem

[12] Existence value is the value that arises from the satisfaction of knowing that something (e.g. a particular breed) exists.

services. Silvestri *et al.* (2012) note that increased demand for, and scarcity of, some of the ecosystem services generated by livestock production systems (see Box 4E1) has created opportunities for implementing approaches of this kind. Examples of emerging and operational payments for ecosystem services in livestock production systems include those related to climate regulation, watershed management and hydrological services and conservation of non-domesticated biodiversity (ADB, 2014).

Of particular relevance to domesticated plant and animal biodiversity is the emerging concept of payments for agrobiodiversity conservation services (PACS),[13] an approach that draws on existing concepts of payments for ecosystem services and can be defined as follows:

> *"an economic instrument to tackle market, intervention, and global appropriation failures associated with the public good characteristics of agrobiodiversity conservation services through the use of (monetary or in-kind) reward mechanisms in order to increase the private benefits from local plant and animal genetic resources, so as to sustain their on-farm utilization"* (Narloch *et al.*, 2011a).

PACS can be combined with prioritization protocols (such as the Weitzman approach – see earlier studies by Simianer *et al.*, 2003; Reist-Marti *et al.*, 2003; and Zander *et al.*, 2009b), the application of safe minimum standards approaches (Drucker, 2006; Zander *et al.*, 2013) and the use of competitive tenders that permit the identification of least-cost conservation service providers and transparent accounting for any efficiency–equity trade-offs that may exist in the selection of service providers (Narloch *et al.*, 2011b; see also Bojkovski [forthcoming] for an emerging livestock application in Slovenia).

In the European context, the use of PACS approaches in the field of AnGR management is in part driven by the need for improved understanding of the type of support that needs to be provided to livestock keepers in order to permit at-risk breeds to reach population targets set under European Union legislation. Incentive payment schemes for livestock-keepers rearing traditional breeds at risk are in place in the European Union (see Part 3 Section F). However, such payment schemes have often proved to be insufficient to cover the true financial opportunity costs faced by the keepers of such breeds (Signorello and Pappalardo, 2003).

The challenges associated with ensuring the sustainable management of AnGR are compounded by the fact that agricultural production does not take place on a level playing field; large amounts of subsidy are directed (mostly) towards specialized agricultural production systems. For example, in 2012 agricultural subsidies totalled an estimated US$486 billion in the top 21 food-producing countries in the world (Worldwatch Institute, 2014). Developing-country studies of subsidies for "improved" breeds include Drucker *et al.* (2006), which estimated the total subsidy for imported pig breeds and their crosses in Viet Nam to be in the region of 19 to 70 percent of the gross margin typically associated with sow production. These were found to be similar to OECD-country subsidy levels (reaching 60 percent of farm receipts in some cases). Although designed with specific social goals in mind, such subsidies are "harmful" in the sense that they affect the competitiveness of locally adapted versus improved breed production systems and thereby affect the extent to which AnGR diversity is used and conserved.

In addition to the direct livestock-keeper payments that could be provided by PACS, attention is also increasingly being given to the potential of existing agricultural market channels to promote the use of at-risk genetic resources (among others, see the "Adding Value" special issue of the journal *Animal Genetic Resources* [FAO, 2013a]; Tienhaara *et al.*, 2013; Lauvie *et al.*, 2011; LPP *et al.*, 2010; Mathias *et al.*, 2010). Niche-marketing mechanisms, such as eco-labelling, certification and denomination of origin schemes (see Part 3 Sections D and F

[13] See www.bioversityinternational/pacs for more information on PACS.

and Part 4 Section D), may allow products from locally adapted breeds to attract higher market prices and thus help to keep the breeds in use. The Schwäbisch-Hällische pig in Germany, for example, is a locally adapted breed that was revived from close to extinction to become the foundation for a regional speciality niche-market (LPP *et al.*, 2010). The population of the Bresse chicken in France has remained stable for decades as a result of similar niche market-based management (Verrier *et al.*, 2005). Niche-market development is, however, often challenging, and not all breeds have the potential to supply products that closely match consumers' current tastes and preferences. Such mechanisms alone are therefore unlikely to be able to correct fully for market failures related to the public-goods characteristics of many of the services associated with the maintenance of agrobiodiversity. Niche-market development and PACS can thus be viewed as complementary approaches (Narloch *et al.*, 2011a). A conceptual basis for PACS financing strategies, through private- and public-sector service beneficiary and purchaser identification/mapping and dialogue, has recently been developed (Drucker *et al.*, 2013).

3 Challenges and opportunities

Recent years have seen a number of significant developments in the field of AnGR-focused economics. An economic conceptual framework within which the erosion of genetic diversity can be analysed has been elaborated and the links between the different types of value associated with AnGR and potential contributions to different kinds of ecosystem services have been better articulated. A wide range of breed-valuation studies have been undertaken, the majority relating to developing-country breeds and livestock-keeper preferences. In line with the importance of AnGR values that are not reflected in the marketplace, these studies have focused particularly on stated preference and ranking methods. A range of AnGR economic studies have also been realized with a specific view to supporting the development of breeding programmes.

While many of the recent valuation studies have drawn on livestock-keeper and breeder preferences, methods for assessing public willingness to pay for breed conservation have also been developed, drawing on both total economic value and ecosystem service frameworks. European case studies based on these approaches have confirmed the existence of very significant non-market values, a number of which can only be secured through the implementation of *in situ* conservation strategies. Such strategies may also be dependent on the development of incentive mechanisms that ensure livestock keepers can capture a sufficient proportion of the non-market public good values to cover the costs they incur in providing public-good conservation services. In this context, the emergence of agrobiodiversity-focused payments for ecosystem services, so-called PACS, is of particular interest, especially as a complementary incentive mechanism alongside niche-product and market/value-chain development.

Despite the positive developments, a range of challenges and opportunities for future work in this subfield of economics remain.

Awareness raising: There is a need to promote awareness and facilitate interaction among both animal and plant genetic resources researchers and development practitioners regarding developments in the economics of genetic resources use and conservation. The development of the economic conceptual framework described above, which originated from the AnGR-focused work of Drucker and Rodriguez (2009) and Steinfeld (2000), has been used to inform analysis related to agrobiodiversity more broadly (e.g. Narloch *et al.*, 2011a; Pascual *et al.* 2011; Krishna *et al.* 2013). Such work has also drawn on the conceptual framework to inform approaches based on agrobiodiversity-focused payments for ecosystem services, which while having been originally applied in a plant genetic resources context are now also beginning to be applied in AnGR contexts (e.g. Bojkovski, forthcoming). The somewhat different conceptual

model developed by Krishna *et al.* (2013) for the application of PACS in a plant genetic resources context could also be adapted to an AnGR context.

Another example of a method developed for use on one component of agrobiodiversity and later used to inform the management of another component is the Weitzman prioritization approach. Originally applied by Weitzman (1993) to non-domesticated animals (wild species of crane), this method was later adapted for application to AnGR by Simianer *et al.* (2003), Reist-Marti *et al.* (2003) and Zander *et al.* (2009). It has recently been usefully applied to a plant genetic resource (cacao) case study (Samuel *et al.*, 2013). While there continues to be relatively limited interaction between animal and plant genetic resources researchers/development practitioners, it is clear that at least in the field of the economics of genetic resources use and conservation, there is high potential for mutual learning and collaboration – and that should be further encouraged.

Assigning breed types: In situations where genotypic information may be absent, as in most developing counties, identifying and verifying the breed type of a given AnGR can prove difficult. Livestock keepers tend to keep multiple genotypes to derive multiple benefits, and breeds tend to be defined in more subjective and less quantitative ways (Marshall, 2014). Under such circumstances, breed and trait valuation tools may be used to facilitate breed characterization through improved understanding of breeds and their values. In such contexts, greater collaboration between geneticists and economists may prove to be particularly valuable.

Research focus: The valuation studies discussed above mainly focused on developing countries and on-farm/*in situ* use and conservation strategies. While further work in these areas is still very much needed (including in Latin America, where relatively little work of this type has been undertaken so far), an increasing number of developed-country studies and studies considering the costs and benefits of *ex situ* conservation would also be welcome.

Costing conservation efforts: A number of studies, including Drucker (2006) for livestock and Narloch *et al.* (2011a) for plants, have suggested that given modest conservation goals (the recently updated FAO [2013b] "not at risk" status category requires 2 000 breeding females in species with high reproductive capacity and 6 000 in species with low reproductive capacity), the costs of conserving a priority portfolio of at-risk breeds may also be quite modest. The assessment of public willingness to pay for conservation by Zander *et al.* (2013) and estimates of the support payments that would be required to achieve stated conservation goals suggest that such conservation costs may well be both economically justifiable (benefits outweighing costs) and relatively low cost. In this context, it is also interesting to note the findings of a plant genetic resources case study conducted by Krishna *et al.* (2013), which suggest that farmer willingness to participate in genetic resources conservation activities for the public good may be more closely related to the consumption values of the genetic resources in question than to their production opportunity costs (which generally do not take into account the existence of farmers' many non-market preferences and values). Hence, conservation costs may be overestimated if based only on conventional economic opportunity cost estimates.

Such considerations are important, as national and global level efforts to cost the resources required in order to secure priority portfolios of AnGR could help to inform policy development. Such costing exercises could address both *in situ* conservation strategies and complementary *ex situ* interventions. It should, however, be noted that the different *in situ* risk-status thresholds adopted by different countries imply different implicit conservation costs.[14]

[14] Alderson (2009) notes differences between the breed status criteria adopted by the FAO and widely applied in AnGR valuation studies, and those independently developed by the European Union (EU), Rare Breeds International (RBI), the European Federation of Animal Science (EAAP) and the Rare Breeds Survival Trust (RBST). The choice of breed risk status criteria can have strong implications for overall conservation costs, insofar as such costs may be proportional to total herd size (Zander *et al.*, 2013).

Linking conservation goals and values to the provision of ecosystem services: The articulation of the link between conservation goals, values and ecosystem services is another area where plant genetic resources and AnGR work could be mutually supportive. CGIAR research[15] on the development of agrobiodiversity-focused ecosystem service indicators/metrics and on PACS includes work that is currently oriented towards plant genetic resources but also has potential AnGR applications. This work also includes consideration of the degree to which private- and public-good values and associated ecosystem services may, in certain contexts, need to be traded-off and the degree to which this can be done transparently and in a socially equitable manner.

A related area of interest for future research addresses conservation goal setting and levels of ecosystem-service provision. There is a need to overcome the current relative lack of knowledge of how different conservation goals and risk-status thresholds actually relate to the provision of specific ecosystem services. For example, one livestock-keeper with 2 000 breeding females of a particular breed maintained in a single herd/location would have quite different implications for ecosystem services related to the maintenance of landscape-level resilience, evolutionary processes/future option values and traditional knowledge and cultural practices than would 200 livestock keepers spread across the countryside, each with a herd of 10 breeding females. Once again, the existing plant genetic resources-focused CGIAR Research Programme work on ecosystem services and indicators could potentially also contribute to work in the AnGR field.

Impact assessment: Finally, in the context of impact assessment, Marshall (2014) identifies the need to provide decision-support information, both to livestock keepers and to policy-makers, through increased evaluation of the impact of different livestock breed types in developing-country livestock production systems. Such assessments (which could draw on the indicator/metric development mentioned above) might address, *inter alia*, food and nutrition security and environmental sustainability. It is important that gender and intrahousehold dimensions are also considered, given that the benefits derived from interventions that affect breed and genotype choices can vary both between and within households, especially in low-input production environments, where both direct and indirect use values of livestock are likely to be important.

[15] Water, Land and Ecosystems and Policies, Markets and Institutions Research Programmes.

References[16]

ADB. 2014. *Making grasslands sustainable in Mongolia: International experiences with payments for environmental services in grazing lands and other rangelands*. Mandaluyong City, the Philippines, Asian Development Bank (available at http://tinyurl.com/qyfw6xe).

Alderson, L. 2009. Breed at risk: definition and measurement of the factors which determine endangerment. *Livestock Science*, 123: 23–27.

Ali, M.H., Miah, A.G., Ali, M.L., Salma, U., Khan, M.A.S. & Islam, M.N. 2000. A comparative study on the performance of crossbred and indigenous (Zebu) cows under the small holder dairy farming conditions in Giabandha District. *Pakistan Journal of Biological Sciences*, 3: 1080–1082.

Amanu Abetu, T. 2013. *Determinants of pastoralists' choice of indigenous goat breeds: the case of Borana zone, southern Ethiopia*. Haramaya, Ethiopia, Haramaya University (M.Sc. thesis).

Asmara, I.Y. 2014. *The risk of extinction of indigenous chicken breeds in Indonesia: driving factors*. Darwin, Australia, Charles Darwin University (PhD thesis) (available at http://espace.cdu.edu.au/view/cdu:39090).

[16] An annotated bibliography of AnGR economics-related literature associated with the SGRP report and updated in 2007 can be found on the IFPRI website at http://tinyurl.com/AnGR-Economics-lit-to-2007. A further update to mid-2011 prepared by Bioversity International can be found at http://tinyurl.com/AnGR-Economics-lit-to-mid-2011. A link to the full list of literature consulted for this section can be found at http://www.fao.org/3/a-i4787e/i4787e196.pdf.

PART **4**

Ayalew, W., Rischkowsky, B., King, J.M. & Bruns, E. 2003. Crossbreds did not create more net benefits than indigenous goats in Ethiopian smallholdings. *Agricultural Systems,* 76: 1137–1156.

Bett, H.K., Bett, R.C., Peters, K.J., Kahi, A.K. & Bokelmann, W. 2011. Estimating farmers' preferences in selection of indigenous chicken genetic resources using non-market attributes. *Animal Genetic Resources*, 49: 51–63 (available at http://www.fao.org/docrep/014/ba0128t/ba0128t00.pdf).

Blake, R.W. 2004. Dairy cattle performance in difficult environments. In *Proceedings of the 7th World Bruna Conference. Fieragricola, Verona*, Italy, pp. 125–131.

Bojkovski, D. Forthcoming. *Identifying cost-effective conservation strategies for animal genetic resources through the use of competitive tender method*. Ljubljana, University of Ljubljana (PhD thesis).

Bovine HapMap Consortium. 2009. Genome-wide survey of SNP variation uncovers the genetic structure of cattle breeds. *Science*, 324: 528–532.

CBD. 2011. *Strategic Plan for Biodiversity 2011–2020, including Aichi Biodiversity Targets*. Montreal, Canada. Convention on Biological Diversity (available at http://www.cbd.int).

Dana, N., van der Waaij, L., Dessie, T. & van Arendonk, J. 2010. Production objectives and trait preferences of village poultry producers of Ethiopia: implications for designing breeding schemes utilizing indigenous chicken genetic resources. *Tropical Animal Health and Production*, 42: 1519–1529.

Dayanandan, R. 2011. Production and marketing efficiency of dairy farms in highland of Ethiopia – an economic analysis. *International Journal of Enterprise Computing and Business Systems,* 1:[online] (available at http://www.ijecbs.com/July2011/16.pdf).

Desta, T., Ayalew, W. & Hegde, B.P. 2011. Breed and trait preferences of Sheko cattle keepers in southwestern Ethiopia. *Tropical Animal Health and Production*, 43, 851–856.

Desta, T.T., Ayalew, W. & Hegde, B.P. 2012. Farmers' perceptions on trypanosomosis and trypanotolerance character of the taurine Sheko. *Tropical Animal Health and Production*, 44: 609–616.

Drucker, A.G. 2010. Where's the beef? The economics of AnGR conservation and its influence on policy design and implementation. *Animal Genetic Resources*, 47, 85–90 (available at http://www.fao.org/docrep/013/i1823t/i1823t00.pdf).

Drucker, A.G., Bergeron, E., Lemke, U., Thuy, L.T. & Zarate, A.V. 2006. Identification and quantification of subsidies relevant to the production of local and imported pig breeds in Vietnam. *Tropical Animal Health and Production*, 38: 305–322.

Drucker, A.G., Gomez, V. & Anderson, S. 2001. The economic valuation of farm animal genetic resources: a survey of available methods. *Ecological Economics*, 36: 1–18 (available at http://www.sciencedirect.com/science/article/pii/S0921800900002421).

Drucker, A.G., Padulosi, S. & Jager, M. 2013. *No free lunches: PES and the funding of agricultural biodiversity conservation – Insights from a competitive tender for quinoa-related conservation services in Bolivia and Peru*. Case study on remuneration of positive externalities (RPE)/payments for environmental services (PES) prepared for the multi-stakeholder dialogue 12–13 September ٢٠١٣, FAO, Rome (available at http://tinyurl.com/pchlmvy).

Drucker, A.G. & Rodriguez, L.C. 2009. Development, intensification and the conservation and sustainable use of farm animal genetic resources. *In* A. Kontoleon, U. Pasqual & M. Smale, eds. *Agrobiodiversity conservation and economic development*, pp. 92–109. Abingdon UK, Routledge.

Drucker, A.G. & Scarpa, R. (eds.). 2003. Special issue on animal genetic resources. *Ecological Economics*, 45(3) (available at http://econpapers.repec.org/article/eeeecolec/default45.htm).

Drucker, A.G., Smale, M. & Zambrano, P. 2005. *Valuation and sustainable management of crop and livestock biodiversity: A review of applied economics literature*. SGRP/IFPRI/ILRI (available at http://tinyurl.com/nva3pw2).

Duguma, G., Mirkena, T., Haile, A., Okeyo, A.M., Tibbo, M., Rischkowsky, B., Sölkner, J. & Wurzinger, M. 2011. Identification of smallholder farmers and pastoralists' preferences for sheep breeding traits: Choice model approach. *Animal*, 5: 1984–1992.

FAO. 2007a. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at http://www.fao.org/docrep/010/a1250e/a1250e00.htm).

FAO. 2007b. *The Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration*. Rome (available at http://www.fao.org/docrep/010/a1404e/a1404e00.htm).

FAO. 2013a. Special issue: adding value. *Animal Genetic Resources*, 53 (available at http://www.fao.org/docs/eims/upload//314794/I3445Tri.pdf).

FAO. 2013b. In vivo *conservation of animal genetic resources*. FAO Animal Production and Health Guidelines. No. 14. Rome (available at http://www.fao.org/docrep/018/i3327e/i3327e.pdf).

FAO. 2014. *Ecosystem services provided by livestock species and breeds, with special consideration to the contributions of small-scale livestock keepers and pastoralists*, by I. Hoffmann, T. From & D. Boerma. Commission on Genetic Resources for Food and Agriculture Background Study Paper No. 66 Rev.1. Rome (available at http://www.fao.org/3/a-at598e.pdf).

Fadlaoui, A., Roosen, J. & Baret, P.V. 2006. Setting priorities in farm animal conservation choices—expert opinion and revealed policy preferences. *European Review of Agricultural Economics*, 33, 173–192.

Faustin, V., Adégbidi, A.A., Garnett, S.T., Koudandé, D.O., Agbo, V. & Zander, K.K. 2010. Peace, health or fortune? Preferences for chicken traits in rural Benin. *Ecological Economics*, 69: 1848–1857 (available at http://www.sciencedirect.com/science/article/pii/S0921800910001862).

Hanotte, O., Tawah, C.L., Bradley, D.G., Okomo, M., Verjee, Y., Ochieng, J. & Rege, J.E.O. 2000. Geographic distribution and frequency of a taurine *Bos taurus* and an indicine *Bos indicus* Y specific allele amongst sub-Saharan African cattle breeds. *Molecular Ecology*, 9: 387–396.

Hodges, J., Foggin, M., Long, R. & Zhaxi, G. 2014. Globalisation and the sustainability of farmers, livestock-keepers, pastoralists and fragile habitats. *Biodiversity*, 15: 109–118.

Islam, S., Goswami, A. & Mazumdar, D. 2008. Comparative profitability of cross breed and indigenous cattle in West Bengal. *Indian Research Journal of Extension Education,* 8: 28–30.

Islam, M.M., Topader, A.H. & Rob, A. 2010. Comparative study on the cost benefit between indigenous and cross bred cows reared in rural area of Dinajpur district. *Bangladesh Journal of Animal Science,* 39: 191–196.

Jabbar, M.A. & Diedhiou, M.L. 2003. Does breed matter to cattle farmers and buyers? Evidence from West Africa. *Ecological Economics*, 45: 461–472.

Jackson, L.E., Pascual, U. & Hodgkin, T. 2007. Utilizing and conserving agrobiodiversity in agricultural landscapes. *Agriculture, Ecosystems & Environment*, 121: 196–210.

Kassie, G.T., Abdulai, A. & Wollny, C. 2009. Valuing traits of indigenous cows in Central Ethiopia. *Journal Agricultural Economics*, 60: 386–401.

Kassie, G.T., Abdulai, A. & Wollny, C. 2010. Implicit prices of indigenous bull traits in crop-livestock mixed production systems of Ethiopia. *African Development Review*, 22: 482–494.

Kassie, G., Abdulai, A. & Wollny, C. 2011. Heteroscedastic hedonic price model for cattle in the rural markets of central Ethiopia. *Applied Economics*, 43: 3459–3464.

Keesing, F., Belden, L.K., Daszak, P., Dobson, A., Harvell, C.D., Holt, R.D., Hudson, P., Jolles, A., Jones, K.E., Mitchell, C.E., Myers, S.S., Bogich, T. & Ostfeld, R.S. 2010. Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature*, 468: 647–652.

Krishna, V., Drucker, A.G., Pascual, U., Raghu, P.T. & King, E.D.I.O. 2013. Estimating compensation payments for on-farm conservation of agricultural biodiversity in developing countries. *Ecological Economics,* 87: 110–123 (available at http://www.sciencedirect.com/science/article/pii/S092180091200496X).

Lauvie, A., Audiot, A., Couix, N., Casabianca, F., Brives, H. & Verrier, E. 2011. Diversity of rare breed management programmes: Between conservation and development. *Livestock Science*, 140: 161–170.

Lemecha, H., Mulatu, W., Hussein, I., Rege, E., Tekle, T., Abdicho, S. & Ayalew, W. 2006. Response of four indigenous cattle breeds to natural tsetse and trypanosomosis challenge in the Ghibe valley of Ethiopia. *Veterinary Parasitology*, 141: 165–176.

Lemke, U., Kaufmann, B., Thuy, L.T., Emrich, K. & Valle Zárate, A. 2006. Evaluation of smallholder pig production systems in North Vietnam. Pig production management and pig performances. *Livestock Science,* 105: 229–243.

LPP, LIFE Network, IUCN–WISP & FAO. 2010. *Adding value to livestock diversity. Marketing to promote local breeds and improve livelihoods*. FAO Animal Production and Health Paper. No. 168. Rome (available at http://www.fao.org/docrep/012/i1283e/i1283e00.htm).

Madalena, F.E., Peixoto, M.G.C.D. & Gibson, J. 2012. Dairy cattle genetics and its application in Brazil. *Livestock Research for Rural Development*, 24: Article # 97 (available at http://www.lrrd.org/lrrd24/6/made24097.htm).

Madureira, L., Rambonilaza, T. & Karpinski, I. 2007. Review of methods and evidence for economic valuation of agricultural non-commodity outputs and suggestions to facilitate its application to broader decisional contexts. *Agriculture, Ecosystems & Environment*, 120: 5–20.

Madzimure, J. 2011. *Climate change adaptation and economic valuation of local pig genetic resources in communal production systems of South Africa*. Alice, South Africa, University of Fort Hare (PhD thesis) (available at http://tinyurl.com/ojg6jpk).

Maichomo, M.W., Kosura, W.O., Gathuma, J.M., Gitau, G.K., Ndung'u, J.M. & Nyamwaro, S.O. 2009. Economic assessment of the performance of trypanotolerant cattle breeds in a pastoral production system in Kenya. *Journal of the South African Veterinary Association,* 80: 157–162.

Marshall, K. 2014. Optimizing the use of breed types in developing country livestock production systems: a neglected research area. *Journal of Animal Breeding and Genetics*, 131: 329–340.

Martin-Collado, D., Diaz, C., Drucker, A.G., Carabaño, M.J. & Zander, K.K. 2014. Determination of non-market values to inform conservation strategies for the threatened Alistana–Sanabresa cattle breed. *Animal*, 8: 1373–1381.

Mathias, E., Mundy, P. & Köhler-Rollefson, I. 2010. Marketing products from local livestock breeds: an analysis of eight cases. *Animal Genetic Resources*, 47: 59–71 (available at http://www.fao.org/docrep/013/i1823t/i1823t00.pdf).

McClintock, S., Groeneveld, E., Hiemstra, S. & Blackburn, H. 2007. *Cryobanking animal genetic resources*. Paper presented at The First International Technical Conference on Animal Genetic Resources for Food and Agriculture, 1–7 September, Interlaken, Switzerland (available at http://www.fao.org/ag/againfo/programmes/en/genetics/documents/Interlaken/sidevent/3_4/McClintock.pdf).

Mondal, R.K., Sen, S. & Rayhan, S.J. 2010. A comparative economic analysis of local breed and cross breed milk cow in a selected area of Bangladesh. *Journal of Science Foundation,* 8, 23–29.

Muchadeyi, F.C., Wollny, C.B.A., Eding, H., Weigend, S. & Simianer, H. 2009. Choice of breeding stock, preference of production traits and culling criteria of village chickens among Zimbabwe agro-ecological zones. *Tropical Animal Health and Production*, 41: 403–412.

Narloch, U., Drucker, A.G. & Pascual, U. 2011a. Payments for agrobiodiversity conservation services for sustained on-farm utilization of plant and animal genetic resources. *Ecological Economics*, 70: 1837–1845.

Narloch, U., Pascual, U. & Drucker A.G. 2011. Cost-effectiveness targeting under multiple conservation goals and equity considerations in the Andes. *Environmental Conservation,* 38: 417–425.

Ndumu, D., Wurzinger, M., Baumung, R., Drucker, A., Mwai, O., Semambo, D. & Sölkner, J. 2008. Performance and fitness traits versus phenotypic appearance in the African Ankole Longhorn cattle: a novel approach to identify selection criteria for indigenous breeds. *Livestock Science*, 113: 234–242.

Ngowi, E.E., Chenyambuga, S.W. & Gwakisa, P.S. 2008. Socio-economic values and traditional management practices of Tarime zebu cattle in Tanzania. *Livestock Research for Rural Development*, 20: Article # 94 (available at http://www.lrrd.org/lrrd20/6/ngow20094.htm).

Nielson, H.M. & Amer, P.R. 2007. An approach to derive economic weights in breeding objectives using partial profile choice experiments. *Animal*, 1: 1254–1262.

Omondi, I., Baltenweck, I., Drucker, A., Obare, G. & Zander, K. 2008a. Valuing goat genetic resources: a pro-poor growth strategy in the Kenyan semi-arid tropics. *Tropical Animal Health and Production*, 40: 583–596.

Omondi, I., Baltenweck, I., Drucker, A., Obare, G. & Zander, K. 2008b. Economic valuation of sheep genetic resources: implications for sustainable

utilization in the Kenyan semi-arid tropics. *Tropical Animal Health and Production*, 40: 615–626.

Ouma, E., Abdulai, A. & Drucker, A. 2007. Measuring heterogeneous preferences for cattle traits among cattle-keeping households in East Africa. *American Journal of Agricultural Economics*, 89: 1005–1019.

Pascual, U., Narloch, U., Nordhagen, S. & Drucker, A.G. 2011. The economics of agrobiodiversity conservation for food security under climate change. *Economía Agraria y Recursos Naturales*, 11: 191–220.

Pearce, D.W. & Moran, D. 1994. *The economic value of biodiversity*. Cambridge, UK, IUCN Publications and London, Earthscan.

Rahman, M., Sorensen, P., Jensen, H.A. & Dolberg, F. 1997. Exotic hens under semiscavenging conditions in Bangladesh. *Livestock Research for Rural Development*, 9: Article # 23 (available at http://www.lrrd.org/lrrd9/3/bang931.htm).

Rege, J.E.O. (ed.). 1999. *Economic valuation of animal genetic resources*. Proceedings of an FAO/ILRI Workshop held at FAO headquarters, Rome, Italy, 15–17 March 1999. Nairobi, International Livestock Research Institute (available at http://dad.fao.org/cgi-bin/getblob.cgi?sid=-1,50006343).

Rege, J.E.O. & Gibson, J.P. 2003. Animal genetic resources and economic development: issues in relation to economic valuation. *Ecological Economics*, 45: 319–330 (available at http://www.sciencedirect.com/science/article/pii/S0921800903000879).

Reist-Marti, S.B., Simianer, H., Gibson, J., Hanotte, O. & Rege, J.E.O. 2003. Weitzman's approach and conservation of breed diversity: an application to African cattle breeds. *Conservation Biology*, 17: 1299–1311.

Roessler, R., Drucker, A., Scarpa, R., Markemann, A., Lemke, U. & Thuy, L. 2008. Using choice experiments to assess smallholder farmers' preferences for pig breeding traits in different production systems in North-West Vietnam. *Ecological Economics*, 66: 184–192 (available at http://www.sciencedirect.com/science/article/pii/S0921800907004508).

Ruto, E., Garrod, G. & Scarpa, R., 2008. Valuing animal genetic resources: a choice modeling application to indigenous cattle in Kenya. *Agricultural Economics*, 38: 89–98.

Ruto, E. & Scarpa, R. 2010. Using choice experiments to investigate preferences for cattle traits in Kenya. *In* J. Bennett & E. Birol, eds., *Choice experiments in developing countries: implementation, challenges and policy implications.* Cheltenham, UK, Edward Elgar.

Samuel, A., Drucker, A.G., Andersen, S.B., Simianer, H. & van Zonneveld, M. 2013. Development of a cost-effective diversity-maximising decision-support tool for *in situ* crop genetic resources conservation: the case of cacao. *Ecological Economics*, 96: 155–164.

Sayeed, M.A., Rashman, S.M.A., Alam, J. & Begum J. 1994. Economics of milk production in Dhaka district – a case for Savar Thana. *Asian-Australasian Journal of Animal Sciences,* 7: 49–55.

Signorello, G. & Pappalardo, G. 2003. Domestic animal biodiversity conservation: a case study of rural development plans in the European Union. *Ecological Economics*, 45: 487–499 (available at http://www.sciencedirect.com/science/article/pii/S0921800903000995).

Silvestri, S., Osano, P., de Leeuw, J., Herrero, M., Ericksen, P., Kariuki, J., Njuki, J., Bedelian, C. & Notenbaert, A. 2012. *Greening livestock: assessing the potential of payment for environmental services in livestock inclusive agricultural production systems in developing countries*. Nairobi, International Livestock Research Institute (available at http://tinyurl.com/nva3pw2).

Simianer, H., Marti, S.B., Gibson, J., Hanotte, O. & Rege, J.E.O. 2003. An approach to the optimal allocation of conservation funds to minimize loss of genetic diversity between livestock breeds. *Ecological Economics*, 45: 377–392.

Smale, M. & Drucker, A.G. 2007. Agricultural development and the diversity of crop and livestock genetic resources: a review of the economics literature. *In* A. Kontoleon, U. Pasual & T. Swanson, eds., *Biodiversity economics. Principles, methods and applications*, pp. 623–648. Cambridge UK, Cambridge University Press.

Stein, J., Ayalew, W., Rege, J.E.O., Mulatu, W., Malmfors, B., Dessie, T. & Philipsson, J. 2009. Livestock-keeper perceptions of four indigenous cattle breeds in tsetse infested areas of Ethiopia. *Tropical Animal Health and Production*, 41: 1315–1346.

Steinfeld, H. 2000. Valuing animal genetic resources – some basic issues. In A. Drucker, ed., *Report of the research planning workshop on "Economic Valuation of Animal Genetic Resources"* February 2–4, 2000. ILRI Headquarters, Nairobi.

Sumberg, J., Awo, M., Fiankor, D-D.D., Kwadzo, G.T-M. & Thompson, J. 2013. *Ghana's poultry sector: limited data, conflicting narratives, competing visions*, STEPS Working Paper 56. Brighton, UK, STEPS Centre.

Swanson, T. 1997. *Global action for biodiversity*. London, Earthscan.

Tada, O., Muchenje, V. & Dzama, K. 2012. Monetary value of Nguni cattle and socio-economic profiles of farmers in the low-input communal production system of Eastern Cape Province, South Africa. *African Journal of Business Management,* 6: 11304–11311.

Tada, O., Muchenje, V. & Dzama, K. 2013. Preferential traits for breeding Nguni cattle in low-input *in-situ* conservation production systems. *SpringerPlus*, 2, 195.

Tano, K., Kamuanga, M., Faminow, D. & Swallow, B. 2003. Using conjoint analysis to estimate farmer's preferences for cattle traits in West Africa. *Ecological Economics*, 45: 393–407.

TEEB. 2010. *The economics of ecosystems and biodiversity ecological and economic foundations*, edited by P. Kumar. London and Washington, Earthscan.

Terfa, Z., Haile, A., Baker, D. & Kassie, G. 2013. Valuation of traits of indigenous sheep using hedonic pricing in Central Ethiopia. *Agricultural and Food Economics*, 1: 6.

Tienhaara, A., Ahtiainen, H. & Pouta, E. 2013. Consumers as conservers—could consumers' interest in a specialty product help to preserve endangered Finncattle? *Agroecology and Sustainable Food Systems*, 37: 1017–1039.

van Eckert, M. 1993. *Smallholder pig farms in Zimbabwe. A socio-economic analysis of farming systems in the communal areas (Kleinbäuerliche Schweinehaltung in Simbabwe. Eine sozioökonomische Analyse von Tierhaltungssystemen in den kommunalen Gebieten)*, Aachen, Germany, Alano-Verlag (PhD thesis).

Verrier, E., Tixier-Boichard, M., Bernigaud, R. & Naves, M. 2005. Conservation and value of local livestock breeds: usefulness of niche products and/or adaptation to specific environments. *Animal Genetic Resources Information*, 36: 21–32 (available at ftp://ftp.fao.org/docrep/fao/008/a0070t/a0070t00.pdf).

Weitzman, M.L. 1993. What to preserve? An application of diversity theory to crane conservation. *The Quarterly Journal of Economics*, 1: 157–183.

Widi, T.S.M., Udo, H.M.J., Oldenbroek, K., Budisatria, I.G.S., Baliarti, E. & van der Zijpp, A.J. 2014. Unique cultural values of Madura cattle: is cross-breeding a threat? *Animal Genetic Resources*, 54: 141–152 (available at http://www.fao.org/3/a-i3701t.pdf).

Worldwatch Institute. 2014. *Agricultural subsidies remain a staple in the industrial world* (available at http://www.worldwatch.org/agricultural-subsidies-remain-staple-industrial-world-0). Accessed 4 September 2014.

WRI. 2005. *The wealth of the poor: managing ecosystems to fight poverty*. Washington, DC, World Resources Institute.

Wurzinger, M., Ndumu, D., Baumung, R., Drucker, A., Mwai, O., Semambo, D., Byamungu, N. & Sölkner, J. 2006. Comparison of production systems and selection criteria of Ankole cattle by breeders in Burundi, Rwanda, Tanzania and Uganda. *Tropical Animal Health and Production*, 38: 571–581.

Zander, K. & Holm-Müller, K. 2007. Valuing farm animal genetic resources by using a choice ranking method. *In* J. Meyerhoff, N. Lienhoop & P. Elsasser, eds. *Stated preference methods for environmental valuation: applications from Austria and Germany*, pp. 105–137. Marburg, Germany, Metropolis.

Zander, K.K. 2006. *Modelling the value of farm animal genetic resources – facilitating priority setting for the conservation of cattle in East Africa*. Bonn, Germany, University of Bonn (PhD thesis).

Zander, K.K. & Drucker, A.G. 2008. Conserving what's important: using choice model scenarios to value local cattle breeds in East Africa. *Ecological Economics*, 68: 34–45.

Zander, K.K., Drucker, A.G. & Holm-Müller, K. 2009a. Costing the conservation of animal genetic resources: the case of Borana cattle in Ethiopia and Kenya. *Journal of Arid Environments*, 73: 550–556.

Zander, K.K., Drucker, A.G., Holm-Müller, K. & Simianer, H. 2009b. Choosing the "cargo" for Noah's Ark – Applying Weitzman's approach to Borana cattle in East Africa. *Ecological Economics*, 68: 2051–2057.

Zander, K.K., Signorello, G., De Salvo, M., Gandini, G. & Drucker, A.G. 2013. Assessing the total economic value of threatened livestock breeds in Italy: Implications for conservation policy. *Ecological Economics*, 93: 219–229.

Part 5

NEEDS AND CHALLENGES

Introduction

The major global challenge for the twenty-first century is to sustainably feed a growing population that is expected to reach 9 billion by 2050: the so-called "2050 challenge to our global food system".[1] Further increase in production is needed. At the same time, the ecological footprint of food production needs to be reduced and the quantity and quality of natural resources, including biodiversity, need to be sustained. There is a need to reduce waste, increase efficiency in the use of water, feed and energy and reduce greenhouse gas emissions and the pollution of land, air and water. Ecological and economic challenges are increasingly interconnected and global. Collaboration and cooperation across national boundaries have never been more important.

Since 2007, when the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (FAO, 2007a)[2] was published and the international community adopted the Global Plan of Action for Animal Genetic Resources (FAO, 2007b),[3] the importance of genetic resources for food and agriculture, including animal genetic resources (AnGR), has been highlighted in several major international initiatives and agreements. In 2010, the Conference of the Parties to the Convention on Biological Diversity (CBD) agreed on the Strategic Plan for Biodiversity 2011–2020, including the Aichi Biodiversity Targets.[4] The following two targets are particularly relevant to AnGR management:

> *"Target 7: By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity."*
>
> *"Target 13: By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity."*

In 2012, the Rio+20 International Environmental Summit of Nations agreed to set new multiyear global objectives to succeed the Millennium Development Goals (2000–2015). Biodiversity featured prominently in the outcome document, *The future we want:*

> *"111. We reaffirm the necessity to promote, enhance and support more sustainable agriculture, including crops, livestock, forestry, fisheries and aquaculture, that improves food security, eradicates hunger, and is economically viable, while conserving land, water, plant and animal genetic resources, biodiversity and ecosystems, and enhancing resilience to climate change and natural disasters ...*
>
> *112. We stress the need to enhance sustainable livestock production systems, including through improving pasture land and irrigation schemes in line with*

---

[1] http://www.iatp.org/documents/the-2050-challenge-to-our-global-food-system

[2] FAO. 2007a. *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by B. Rischkowsky & D. Pilling. Rome (available at www.fao.org/3/a-a1250e.pdf).

[3] FAO. 2007b. *The Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration*. Rome (available at http://www.fao.org/docrep/010/a1404e/a1404e00.htm).

[4] http://www.cbd.int/sp/default.shtml

national policies, legislation, rules and regulations, enhanced sustainable water management systems, and efforts to eradicate and prevent the spread of animal diseases, recognizing that the livelihoods of farmers including pastoralists and the health of livestock are intertwined."[5]

and subsequently in the post-2015 Sustainable Development Goals:

"Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture"

"2.5 By 2020 maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at national, regional and international levels, and ensure access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge as internationally agreed"

"2.a Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular in least developed countries"

"Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss"

"15.6 Ensure fair and equitable sharing of the benefits arising from the utilization of genetic resources, and promote appropriate access to such resources"

"15.9 By 2020, integrate ecosystems and biodiversity values into national and local planning, development processes and poverty reduction strategies, and accounts"

"15.a Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems"[6]

The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization[7] entered into force in October 2014. It provides a legal framework for the implementation of one of the three objectives of the CBD: the fair and equitable sharing of benefits arising out of the utilization of genetic resources.

In order to monitor progress in the implementation of the Global Plan of Action for Animal Genetic Resources, the Commission on Genetic Resources for Food and Agriculture has adopted indicators for measuring both the state of implementation of the various elements of the plan itself (so-called process indicators) and outcomes in terms of AnGR diversity (so-called resource indicators).[8] The process indicators were calculated in 2012[9] and 2014,[10] based on country reporting, and the resource indicators are calculated biennially,[11] based on data entered by countries into the Domestic Animal Diversity Information System (DAD-IS)[12].

[5] http://tinyurl.com/czenz9g
[6] http://sustainabledevelopment.un.org/focussdgs.html
[7] https://www.cbd.int/abs/
[8] http://www.fao.org/Ag/AGAInfo/programmes/en/genetics/Targets_and_indicators.html
[9] http://www.fao.org/docrep/meeting/027/mg044e.pdf
[10] http://www.fao.org/3/a-at136e.pdf
[11] http://www.fao.org/3/a-at135e.pdf
[12] http://fao.org/dad-is

Section A

Challenges posed by livestock sector trends

Economic, social and environmental trends in the livestock sector continue to pose many challenges to the sustainable management of AnGR. Rapid growth in demand for animal products has been a major driver of change in the livestock sector in recent decades, particularly in some developing regions, and the associated changes in livestock production systems have had a major effect on AnGR management and often posed a threat to diversity. Traditional production systems that harbour diverse genetic resources have been marginalized and a narrow range of international transboundary breeds have become more widely used. In some circumstances, these breeds have been indiscriminately crossed with locally adapted breeds, a development that is regarded as a major threat to AnGR diversity in many countries. Growth in global demand for animal-source foods is expected to continue over the coming decades, although at a slower pace overall. Africa and South Asia are predicted to be major centres of growth in demand. Both are resource-constrained regions where smallholder and pastoral production is still widely practised and where smallholder milk production has historically been strong. Both are also home to a wealth of locally adapted AnGR.

Economic and market-related factors are frequently highlighted by stakeholders as threats to AnGR. Shifts in market demand or increasing competition may mean that particular breeds can no longer be raised profitably. Shifts of this kind are part of social and economic change, and there are always likely to be some breeds that are at risk of falling out of use and declining towards extinction. However, there may be measures that can be taken to reduce economic threats, either by "valorizing" individual at-risk breeds via marketing initiatives, genetic improvement or the identification of new roles, or by more general policy measures such as eliminating support measures that create favourable economic conditions for breed replacement.

Climate change is placing increasing pressure on the livestock sector, especially on production systems that depend heavily on the state of the local ecosystems. Livestock are recognized as contributors to climate change, but also as an entry point for climate change mitigation. Grazing systems in arid and semi-arid areas are likely to be particularly severely affected, but mixed farming systems will also need to adapt. Grazing and small-scale mixed farming systems harbour many locally adapted livestock breeds that possess characteristics that enable them to thrive in harsh conditions. These breeds, and other AnGR, increase the options available for adapting production systems to the effects of climate change. However, climate change also poses threats to AnGR diversity: for example, because of the increased risk of breed loss as a result of natural disasters. It remains difficult to predict how climate change will affect the future of livestock production and what the consequences will be for AnGR diversity. The uncertainty of climatic projections is a major constraint, but there is also frequently a lack of data on breeds' characteristics, distributions and production environments. Information on the level of threat posed to AnGR by extreme climatic events and other disasters and emergencies remains limited.

Given the major roles of small-scale livestock keepers and pastoralists in maintaining AnGR

diversity, factors that undermine the sustainability of smallholder and pastoralist production systems constitute significant threats to AnGR. These threats may include both market-related factors (e.g. competition from large-scale producers or exclusion from markets because of difficulties in meeting the specific requirements of retailers and consumers) and problems related to the degradation of (or lack of access to) natural resources. The importance of livestock-keeping to the livelihoods of many of the world's poorest people and the major significance of livestock-keeping areas (e.g. grasslands) in the provision of ecosystem services (carbon sequestration, water cycling, provision of wildlife habitats, etc.) imply that the sustainable use and development of livestock populations in pastoralist and smallholder production systems is a challenge that extends well beyond the immediate field of AnGR management. Balancing different objectives is unlikely to be easy. However, there may be scope for synergies in efforts to promote AnGR-management, livelihood and environmental objectives.

One trend affecting the livestock sector in many parts of the world is a movement of people out of livestock keeping and into alternative employment. In most countries, small-scale livestock keeping is unlikely to disappear in the short or medium term. However, where trends of this type are strong, AnGR associated with particular traditional types of livestock keeping or particular communities may be threatened.

International gene flows have continued to expand over recent years. Exchanges are still dominated by North–North and North–South exchanges, with importers taking advantage of the genetic improvements achieved in the world's most advanced breeding programmes. The share of global imports accounted for by imports into developing countries has increased in some subsectors. This represents a large increase in gene flows of high-output international transboundary breeds from the North to the South. For many developing countries, South–South gene flows are also significant.

Gene flows clearly have the potential to increase the options available to livestock keepers and breeders as they seek to improve the productivity of their animals and adapt to change. However, countries are increasingly concerned about the effects of international gene flows on the diversity of their livestock populations and recognize that the establishment of exotic breeds and the production systems needed to maintain them can be challenging in terms of the additional resources and management skills required and the vulnerability of the animals to diseases, feed shortages and climatic hazards. Effective management of gene flow and effective use of imported genetics involve all the main elements of AnGR management: characterization of breeds and production environments to ensure that they are well matched; well-planned breeding strategies; monitoring of outcomes in terms of productivity and genetic diversity; measures to promote the sustainable use and conservation of breeds that may be put at risk of extinction; and appropriate policies and legal frameworks.

Section B

Characterization and monitoring

Characterization and monitoring are the foundations of sustainable AnGR management. However, in most regions of the world, there are still major gaps in the coverage of characterization activities and hence major gaps in knowledge about the characteristics of AnGR. There are also major gaps in programmes for monitoring trends in breed populations and hence the current risk status of many breeds is unknown. These gaps in knowledge inevitably hamper the sustainable use, development and conservation of AnGR.

In many countries, the basic task of establishing a complete inventory of national breeds across the full range of mammalian and avian livestock species has not been completed. For many recognized breeds, phenotypic characteristics – morphology, performance in specific production environments, degree of adaptation to specific diseases or climatic challenges, and so on – have been inadequately studied. Gaps are particularly prominent in developing countries, which means that the characteristics of the locally adapted breeds of these countries have been poorly described and that the comparative performance of different breeds in the production conditions prevailing in these countries has been inadequately assessed. Detailed description of typical production environments has been undertaken only for a limited number of breeds, precluding even the application of basic intuitive or heuristic approaches to breed comparison. At within-breed level, advanced technologies such as those related to the prediction of breeding values for individual animals and genomic selection have huge potential, but require phenotypic data. If developing countries lack characterization and performance data, they will be unable to take advantage of new technologies of this kind.

Reporting on AnGR has improved over recent years. The number of national breed populations recorded in the Domestic Animal Diversity Information System (DAD-IS) has increased. However, breed-related information remains far from complete. For almost two-thirds of all reported breeds, risk status is unknown because of a lack of recent population data. Trends in the global state of AnGR diversity cannot therefore be monitored precisely. However, the available data indicate that genetic erosion is ongoing. Missing population data remains the biggest weakness of the current system for monitoring the global state of AnGR diversity. Another concern is the non-coverage of cross-bred and non-descript populations, which make up a large part of livestock populations worldwide. To obtain a more comprehensive picture, all livestock populations, regardless of their level of cross-breeding, need to be included in the monitoring system.

Breed effect is one of the many factors that influence the composition and quality of animal-source foods. Interest in the relationship between breed diversity and human nutrition has increased to some extent in recent years. Some comparative studies that assess the effect of breed *per se* and identify nutritional differences by controlling for other factors have been undertaken. However, high-quality studies that disentangle genetic and environmental factors are lacking, particularly for locally adapted breeds.

Section C

Sustainable use and development

While the majority of countries report that they have at least some livestock breeding programmes in place, the information provided in the country reports suggest that these programmes are often in a rudimentary state – or in some cases non-existent in the sense of organized programmes involving the establishment of breeding goals, recording of performance and subsequent selection of superior animals for mating. Efficient mechanisms for appropriately distributing improved genetic material are also often lacking.

Recent advances in the field of genomic selection have created opportunities to increase the rate of genetic progress for some traits (particularly those that are difficult to measure in all animals at a young age). However, use of genomic selection has, for the most part, been restricted to particular circumstances that favour its application (extremely large reference populations with extensive phenotypic data, high values of individual animals and established systems for distributing improved germplasm). This has further increased the gap between the most technically advanced breeding programmes and the rest of the sector – for example, Holstein breeding programmes relative to programmes for other breeds of dairy cattle.

Policies aimed at improving the state of livestock breeding are widespread, but in many countries these policies focus mainly on the introduction of exotic breeds for use in cross-breeding, sometimes paying little attention to the establishment of breeding programmes at national level. Introducing exotic AnGR can help countries boost their output of livestock products. However, great care is needed to ensure that these resources are managed appropriately. Exotic breeds are sometimes introduced into production environments where they fail to flourish or prove to be risky investments. Moreover, indiscriminate cross-breeding – often with exotic genetic material – is one of the most widely reported threats to the survival of locally adapted genetic resources. Developing a national breeding strategy can be very challenging, particularly given that the information needed to assess the relative costs and benefits of different approaches is often unavailable. The existence of these knowledge gaps underlines the importance of strengthening efforts to characterize breeds and their production environments and the need to keep track of trends and drivers of change in the livestock sector.

While interest in expanding the use of exotic breeds is practically universal in developing countries, a number have also recognized the need to take greater advantage of the characteristics of their locally adapted breeds, particularly given the challenges associated with climate change and the ongoing need for livestock that are suitable for use by small-scale producers and in low-input production systems. In this context, breeding programmes for locally adapted breeds offer a potential means both of supporting rural livelihoods and of helping to keep a diverse range of breeds in use and hence available as resources for the future. In many countries, however, the underlying preconditions for the establishment of breeding programmes remain weak, particularly the organizational structures needed to facilitate the involvement of livestock keepers and breeders and the relatively high levels of knowledge

and technical skills needed to plan and implement programmes successfully. Experience indicates that while breeding programmes can be initiated by governments and research organizations, the involvement of breeders' associations and/or commercial companies increases the likelihood that they will be sustainable in the longer term.

One significant development in recent years has been a growing interest among developing countries in establishing animal identification schemes. These programmes are introduced primarily with the aim of improving animal health and product traceability, often driven by the incentive of gaining access to export markets that have high animal-health and product-safety standards. However, they may serve as the basis for more comprehensive programmes that include performance and pedigree recording.

Much of the potential of AnGR diversity remains untapped. For example, the inclusion of genetic elements in disease-control strategies has achieved some successes, but knowledge of the genetics of resistance and tolerance remains inadequate. The urgency of adopting more holistic alternative strategies is increasing as greater numbers of microbicides are losing their efficacy. A sign of the commercial recognition of health and other functional traits is that measures of health, robustness and other traits not directly related to performance have acquired an increasing share in selection indices used in breeding programmes in developed countries.

A range of different activities can both help to increase the ongoing benefits derived from AnGR and to maintain genetic diversity for future use. Many breeds that are not at present valued in mainstream livestock production have characteristics that make them potentially valuable in the supply of products valued by a subsection of the market (niche products) or in the provision of public goods, including cultural services. Niche marketing of products from locally adapted breeds is quite widespread in developed regions such as Europe and contributes both to sustaining diversity and to rural livelihoods. Well-managed livestock can contribute to the provision of a number of ecosystem services, including those related to landscape management and the maintenance of wildlife habitats. Because of their ability to thrive in the relevant ecosystems, locally adapted breeds are often effective providers of services of this kind. However, harnessing these roles to promote the use of locally adapted breeds is not straightforward, as the benefits provided are not valued by the market. In this context, the emergence of the concept of payments for ecosystem services is an interesting development. Approaches of this kind potentially have a role in the sustainable management of AnGR.

Section D

Conservation

Conservation activities have become more widespread over the last ten years. Few countries report that they have no conservation measures of any kind in place. However, major gaps remain, both in *in situ* and in *ex situ* conservation programmes. Many breeds remain untargeted or inadequately covered by conservation programmes.

Information on threats to AnGR diversity remains far from complete. The risk status of the majority of breeds is classified as "unknown". Even where population trends are monitored, detailed assessments of threats to specific breeds are not common. This clearly constrains the development of effective conservation programmes and the prioritization of breeds for inclusion in such programmes. Given the complexity of the drivers of change affecting the livestock sector and the potential for rapid shifts in the management of AnGR, there is a need for national early-warning and response systems that can rapidly identify threatened breeds and allow quick and well-defined action to be taken.

In situ conservation programmes can involve a diverse range of activities, including those that aim to create demand for the products and services provided by at-risk breeds, those that support and incentivize livestock keepers and breeders who raise at-risk breeds, those related to breeding programmes, and those that involve promoting participation and empowerment at community level. Careful assessment of livestock-sector trends and the characteristics of particular breeds and production systems will help countries and other stakeholders to identify appropriate *in situ* strategies for particular circumstances.

An increasing number of countries have set up AnGR gene banks. However, inadequate funding, infrastructure and technical skills often remain significant obstacles to the establishment or further development of such facilities. Establishing gene banks at subregional or regional level is a potential option. However, this would require agreements on rules for the transfer of genetic material and the identification of locations considered "safe" by all parties.

Section E

Policies, institutions and capacity-building

Without effective institutions, it is difficult to strengthen AnGR management programmes. Many countries report major gaps and weakness in their institutional frameworks for AnGR management. There have, nonetheless, been several positive developments in recent years, including the more widespread establishment of specifically AnGR-focused institutional structures and policy instruments – in particular the appointment of more National Coordinators for the Management of AnGR and the development of national strategies and action plans for AnGR. The establishment of several additional regional and subregional focal points for AnGR over recent years has strengthened cooperation and capacity to undertake AnGR management actions at supranational level.

Legal and policy frameworks relevant to AnGR management have been supplemented by a substantial number of new instruments over recent years. However, effective implementation remains a problem for many countries. In many cases, the basic prerequisites for effective implementation remain weak or absent. Physical and organizational infrastructure, stakeholder participation, and knowledge and awareness of AnGR-related issues are often inadequate. Financial shortfalls and a lack of well-trained personnel are widely reported to be serious constraints in all areas of AnGR management. Communication and coordination among stakeholders involved in AnGR management and with those in the wider agricultural, rural-development and environmental sectors often need to be improved. Smallholders and pastoralists are often neglected by the private sector, but are also poorly served by public policies and programmes and have little voice in policy development.

There is a big gap between the state of the art in the use, development and conservation of AnGR and the current level of management capacity in many countries. Better education and training of development professionals, livestock keepers and other stakeholders, in animal breeding and all aspects of AnGR management, is needed. Integrating education and research across disciplines and across national boundaries and establishing partnerships spanning academic institutions, ministries and private industry – particularly between developed and developing countries – will help to decrease the gap in capacity.

In 2007, by adopting the Global Plan of Action and the Interlaken Declaration, governments

> *"confirmed their common and individual responsibilities for the conservation, sustainable use and development of animal genetic resources for food and agriculture; for world food security; for improving human nutritional status; and for rural development."*[1]

Governments recognized the need both for "substantial and additional financial resources" and for predictable allocation of these resources. While awareness has increased and some countries have allocated additional resources, the evidence provided in the country reports indicates that sufficient funding has not yet been mobilized,

[1] FAO. 2007. *The Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration*. Rome (available at http://www.fao.org/docrep/010/a1404e/a1404e00.htm).

particularly at national level. Governments must demonstrate the sustained political will needed to ensure the successful implementation of the Global Plan of Action, including through the provision of adequate financial resources. If this does not happen, genetic erosion is likely to continue and world's livestock biodiversity will remain underutilized and underdeveloped. Much of its potential to contribute to sustainably increasing food production will remain unrealized.

Animal genetic resource diversity underpins the supply livestock products and services across a wide range of production environments. It promotes resilience and serves as a basis for adapting livestock management to changing conditions. It is vital to livelihoods of many of the world's poor people. It can contribute to the delivery of ecosystem services such as landscape management and the maintenance of wildlife habitats. However, it is often undervalued, underused and under threat.

This report updates the global assessment provided in the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture,* published in 2007. It focuses particularly on changes that have occurred during the period since the first report was published. It serves as a basis for a review, and potential update, of the Global Plan of Action for Animal Genetic Resources, which since 2007 has provided an agreed international framework for the management of livestock biodiversity. Drawing on 129 country reports, it presents an analysis of the state of livestock diversity, the influence of livestock-sector trends on the management of animal genetic resources, the state of capacity to manage animal genetic resources, including legal and policy frameworks, and the state of the art in tools and methods for characterization, valuation, use, development and conservation.

ISBN 978-92-5-108820-3 ISSN 2412-5474

9 789251 088203

I4787E1/07.15