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.

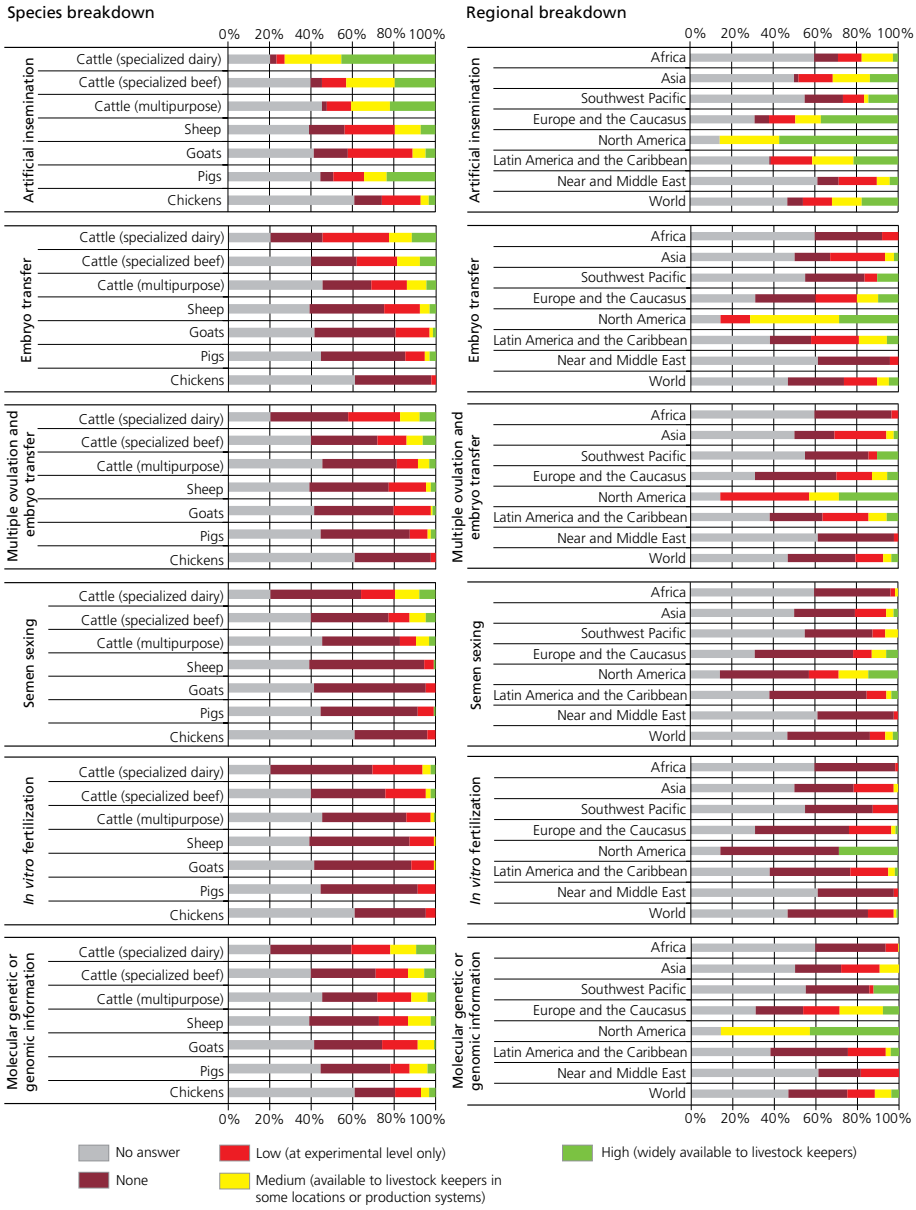
The figures shown in Tables 3E1 and 3E2 conceal big differences in the level of availability of the various technologies and in the extent of their use in different species and different production systems. Table 3E3 presents a species breakdown of the reported scores (see above) for the availability 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).