Rev. sci. tech. Off. int. Epiz., 2010, **29** (1), 73-86

Livestock biodiversity

I. Hoffmann

Animal Production Service, Animal Production and Health Division, Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, 00153 Rome, Italy
E-mail: Irene.Hoffmann@fao.org

Summary
This paper describes the institutional background against which invasiveness is considered with regard to livestock genetic diversity. The human-made nature and extensive spread of a few domesticated animal species for global food production is a feature of agricultural diversity that complicates the simple, negative view of invasive species. The different impacts of livestock species on natural biodiversity, of breed diversity within species, and of within-breed diversity on agricultural biodiversity are discussed. Livestock production continues to threaten natural biodiversity. The increasing demand for food of animal origin, the productivity and technology differentials, as well as the information and awareness bias, tend to favour international high-output breeds over local breeds. This will increase their 'invasiveness' in the market economy if current policy distortions continue. Several measures are proposed to control genetic erosion through uncontrolled gene flow. Countries are responsible not only for control of invasive alien species under the Convention on Biological Diversity but also for sustainable use and conservation of animal genetic resources, and for food security; they must balance trade-offs between these broad policy objectives.

Keywords
Agricultural biodiversity – Invasive alien species – Livestock breeds.

Institutional setting and concepts

The Convention on Biological Diversity (CBD) was adopted at the 1992 Earth Summit. The objectives of the CBD are the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits that arise out of the use of genetic resources. The CBD introduced several new concepts: first, it recognises different levels of biodiversity (gene, species and ecosystem), including genetic resources developed by humans; second, it deals not only with biodiversity conservation but also with sustainable use, within and outside protected areas. The special nature of agricultural diversity was recognised in the CBD's Programme of Work on Agricultural Biodiversity (Conference of the Parties [COP] to the CBD Decision II/15). The CBD has established several working groups such as the *ad hoc* Open-ended Working Group on Access and Benefit-sharing and the Working Group on Article 8(j) on Traditional Knowledge, Innovation and Practices, and has worked on cross-cutting issues regarding invasive alien species in support of Article 8(h), all of which are of relevance to agricultural biodiversity. In addition, the ecosystem approach is relevant to agricultural biodiversity.

The Commission on Genetic Resources for Food and Agriculture (CGRFA) of the Food and Agriculture

Organization of the United Nations (FAO) keeps under continuous review all matters relating to policies, programmes and activities of FAO in the area of genetic resources for food and agriculture, including their characterisation, conservation and sustainable use, and the fair and equitable sharing of benefits derived from their utilisation. The Food and Agriculture Organization is crucial in supporting the CBD Programme of Work on Agricultural Biodiversity (e.g. COP Decisions VIII/23 and IX/1); CBD and FAO recently prepared a joint work plan on biodiversity for food and agriculture (4, 5, 8, 9). The CBD noted that there are certain gaps and inconsistencies in the international regulatory framework from the perspective of the threats of invasive alien species to biological diversity, and they invited FAO, among others, to consider the incorporation of criteria related to the threats to biological diversity posed by invasive alien species as it develops further standards and agreements (COP 6 Decision VI/23). The CGRFA has negotiated and developed several international agreements, voluntary undertakings and codes of conduct to promote and facilitate good management and access, and benefit-sharing. It recommended that FAO contribute to further work on access and benefit-sharing in order to ensure that it moves in a direction that is supportive of the special needs of the agricultural sector with regard to all the components of biological diversity of interest to food and agriculture (16, 19, 24, 28). In 2007, FAO member countries adopted the 'Global Plan of Action for Animal Genetic Resources' (20), the first international framework for the promotion of the wise management of animal genetic resources for food and agriculture (AnGR) in all production systems.

Agricultural biodiversity, like natural biodiversity, is based on diversity in ecosystems, species and genes. Its specificities are explained in the following paragraphs. The paper then analyses the invasiveness of domestic livestock in a historical, ecological and economic context. As a result of its focus on invasiveness, the paper does not describe the varied and substantial positive contributions of livestock to biodiversity, which have been reviewed in detail by FAO (21, 23, 25).

Ecosystems

Ecosystem 'means a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit' (Article 2 of the CBD). Most classification systems for ecosystems use geological, climatic and biological characteristics, but also cultural or anthropogenic factors. Ecosystems can occur at any scale, from a pasture to the entire biosphere, and they interact with each other. Each of these systems relies on a unique mix of animal, microbial and plant genetic resources – species, breeds and varieties that are adapted to local conditions. The well-being of humans and other species on earth depends on a broad variety of ecosystem goods and services. The levels and the relative share of the goods and services vary greatly between ecosystems. Agriculture is supported by a variety of ecosystem services, and is itself a service (39). The CBD's ecosystem approach is a strategy for the integrated management of water, land and living organisms that promotes conservation and sustainable use of biodiversity in an equitable way. Diverse animal genetic resources – particularly in developing countries – provide a range of ecosystem services and commonly are a key to human community and economic development. The various contributions of livestock to human needs are described in Box 1; livestock provisioning services predominate in most systems.

Species

Inter-species diversity refers to the major genetic differences between the species (animals, plants and microbes) on the planet. The total number of species is still unknown, with only a small proportion of species having been classified and described so far. Unlike most natural biodiversity, agricultural biodiversity is the result of human intervention. It has been consciously selected and improved by pastoralists and farmers, has co-evolved with economies, cultures, knowledge systems and societies, and requires continuous active human

Box 1
Ecosystem services provided by livestock species

Provisioning services: food (meat, milk and dairy produce, eggs), fibre for clothes and resources for temporary and permanent shelter, manure for fertiliser and fuel, biochemical and medicinal products, genetic resources, marketable assets. Livestock currently provide 43% of global agricultural output in value terms, with a projected increase. Approximately 70% of the world's rural poor depend on livestock as an important component of their livelihoods
Cultural services: spiritual and religious values, knowledge systems, education and inspiration, and recreational and aesthetic values. Animals and foods of animal origin have strong socio-economic and cultural functions in many societies, in addition to playing important roles in nutrition and diets. Domestic animals often play key roles in myths, cultures, religions, traditions and social practices
Supporting services: nutrient cycling, recycling waste products, provision of habitat, hunting assistance, transport, draught power
Regulating services: seed dispersal, means of accumulation (savings and insurance)

Source: (39) adapted

management.

Agricultural biodiversity is also unique because the number of plant and animal species chosen, used and improved by selection is limited. A total of 37 species are currently included in the FAO Global Databank for Animal Genetic Resources (http://dad.fao.org/). Domestication of animals started in the Fertile Crescent about 14,000 years ago. Modern molecular techniques show that there were several centres of domestication for most livestock species. Several species originated from the same area, implying that they have similar environmental envelopes. Today's 11 most valuable species had all been domesticated 6,000 years ago (21). Diamond (11) provides the phenological, reproductive and behavioural reasons why only 14 of 148 large terrestrial mammalian herbivores and omnivores that weigh 45 kg or more were actually domesticated. Only 11 of the domesticated mammalian and bird species provide 98% of the human food supply from terrestrial animals (Table I).

Table I
Share of species used for global meat, milk and egg production, and breeds at risk, 2007

Species	Meat (%)	Milk (%)	Eggs (%)	Percentage of breeds currently at risk and already extinct
Pig	36.86			34.85
Cattle	22.24	83.46		30.87
Goat	1.79	2.23		15.74
Sheep	3.09	1.33		26.63
Buffalo	1.23	12.75		7.97
Rabbit	0.66			22.32
Chicken	28.17		92.98	37.29
Turkey	2.18			34.58
Duck	1.33			26.64
Goose and guinea fowl	0.83			22.50

Source: Food and Agriculture Organization of the United Nations Statistical Database, Databank for Animal Genetic Resources, Domestic Animal Diversity Information System and Food and Agriculture Organization of the United Nations (2009)

Genes

Intra-species diversity encompasses the genetic variability among individuals within and among populations of a species. Agricultural biodiversity is the best known example of intra-species diversity. Since livestock species were first domesticated, breeds have continued to be developed and improved, both within the historic centres of domestication and elsewhere, through the diffusion of agriculture and the prominent role of livestock in human migrations. Today's diversity is the result of many years of natural and human-directed selection, genetic admixture, mutational events and genetic drift, as production environments have changed (28).

Livestock genetic diversity and options for its use are usually discussed in terms of the genetic components of breeds. 'Breeds' are cultural concepts rather than physical entities, and the concept differs from country to country. This makes characterisation at the genetic level rather difficult. Breeds can be categorised as local (reported by only one country) or transboundary (reported by several countries). The latest assessment by FAO found that, from the 11 species, as many as 6,685 breeds have been developed and used worldwide (including 5,214 local, 414 regional and 462 international transboundary breeds) (26). These breed populations represent unique combinations of genes. Genetic diversity not only defines the production and functional traits of breeds but also their ability to adapt to local conditions, including food and water availability, climate, pests and diseases.

In Europe and the Caucasus, Asia, and the Near and Middle East, local breeds make up about three-quarters of the total; in Africa, and in Latin America and the Caribbean, the figure is more than 60%. Conversely, international transboundary avian and mammalian breeds dominate in the South-West Pacific and North America (26). The vast majority of local breeds have been developed by natural selection and simple techniques of mating control and selection used by the local farmers, without access to modern genetic and breeding technologies. They are mostly found in grassland-based pastoral and small-scale mixed crop–livestock systems with low-to-medium use of external inputs. They deliver a wide range of services and products – each at a low level of output – that support the livelihoods of their keepers as integral components of agricultural ecosystems, economies and cultures. Some of these breeds are very localised (21). In contrast, transboundary breeds of the five major livestock species (cattle, sheep, goats, pigs and chickens), which have now been developed for a century or more in intensive production systems, have spread globally. They generally provide a single primary product for the market, based on the use of high levels of external inputs (15), although so-called dual-purpose breeds have also been developed. Within this transboundary group, a very small number of international transboundary breeds accounts for an ever-increasing share of total production (21).

Dynamics and threats

Species extinction is a natural process. However, extinction rates have increased substantially over the past 100 years when compared with the natural rate. Extinctions are mostly generated by human activities, particularly as a result of habitat destruction, fragmentation and degradation (39), and the invasion of an ecosystem by exotic species. Extinction rates are expected to increase with climate change (48).

Although the CBD, in 2002, set the target to 'achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth', it has been difficult to measure biodiversity loss. The rate of change in one aspect of biodiversity, such as loss of species richness, does not necessarily reflect the change in another, such as habitat loss. In AnGR, in particular, the loss of within-breed diversity is difficult to assess. At the breed level, FAO has made significant progress in the assessment of biodiversity, in particular with the publication of the *State of the World's Animal Genetic Resources* (21), and the maintenance of the Domestic Animal Diversity Information System (DAD-IS), which is the CBD-recognised clearing house mechanism for AnGR. The Global Databank for Animal Genetic Resources produced by FAO, which is the core of DAD-IS, provides countries with a secure means to control data entry, and to update and access their national data. It provides searchable databases of breed-related information and images, management tools, and a library of references, links and the contact details of more than 155 Regional and National Coordinators for the Management of Animal Genetic Resources.

Like natural biodiversity, livestock biodiversity has always been dynamic; new breeds have emerged and others have disappeared as environments and societies have changed. Similarly, agricultural diversity, like natural biodiversity, is fast declining globally as specialisation in plant and animal breeding and the harmonising effects of globalisation advance. Today, the global livestock sector is characterised by a growing dichotomy between the livestock kept by large numbers of smallholders and pastoralists in support of livelihoods and rural food security, and the livestock kept in intensive commercial production systems. While traditional livestock systems contribute to the livelihoods of 70% of the world's rural poor, increasing numbers of large-scale operations, using sophisticated technology and based on internationally sourced feed and animal genetics, support the global food supply system and provide employment in production and in the associated processing, distribution, marketing and support services (18).

Between 1980 and 2007, global beef output per animal grew at 0.4% per year, milk at 0.3%, pork at 0.8% and poultry at 1.1% (FAO Statistical Database [FAO-STAT]). These general trends mask high variability in production between species, breeds and livestock production systems, both within and between regions. The differences are larger in ruminants than in monogastrics, for which industrial systems prevail in both developed and developing regions; globally, 55% of pork, 68% of eggs and 74% of poultry meat are derived from industrial systems (14, 47). A higher share of global beef is estimated to be produced in feedlots (43%) (40) than on pasture (30%) (15).

A consequence of the increasing uniformity of production environments is the need for fewer breeds. This process leads to a narrowing genetic base, as breeds, and indeed species, are discarded in response to market forces (49). About 9% of reported breeds are extinct and 20% are currently classified as being at risk. For another 36% of breeds the risk status is unknown (26). Moreover, within commercial breeds, high selection pressure, particularly when combined with poor design of breeding programmes, leads to a narrowing genetic base.

Livestock as invasive alien species

The CBD has defined invasive alien species as 'species whose introduction and/or spread outside their natural past or present distribution threatens ecosystems, habitats or species'. Invasive alien species occur in all taxonomic groups and can affect all types of ecosystems, with a small gene flow having potentially extensive negative impacts. Most species introductions are vectored by human transportation, travel and trade associated with globalisation and human population expansion (6, 7). However, for an alien species to become invasive, it must:

a) arrive, survive and establish. Successful invasive alien species are more likely to be generalists than specialists. They usually have a high phenotypic plasticity and the ability to survive on various food types and in a wide range of environments, including under pressure from disease;

b) reproduce and disperse. Successful invasive alien species usually have a short generation interval or high reproduction rates, fast growth rates and high dispersal ability;

c) out-compete indigenous species for resources, thereby changing community structure and species composition. The effect can range from niche displacement to extinction, and changes in related ecosystem functions may occur.

In particular, ecosystems that have undergone human-induced disturbance are often more prone to alien species invasions because there is less competition from native species. Such effects are expected to be exacerbated by climate change. Invasive alien species have contributed to 40% of all animal extinctions, for which the cause is known, since the 17th Century, and the rate and risk of extinction associated with alien species introductions have increased significantly in recent decades (39). Today, invasive alien species constitute a major threat affecting globally threatened species (30% of birds, 11% of amphibians and 8% of mammals for which data are available) (2). It has been estimated that alien species invasions cause annual damages of more than US$330 billion in six countries (43).

Using the CBD definition of invasive alien species (which is derived on the basis of natural biodiversity), agriculture, including livestock farming, can be interpreted as being based on the successful introduction and management of alien species for human needs within production systems – which are by definition ecosystems altered by human activity. Today, most livestock production systems worldwide depend on species that were originally domesticated elsewhere and on breeds developed in other countries; they are therefore 'alien' to their current area of distribution. Like crops, livestock were deliberately transplanted from one continent to another. Nearly all livestock species of economic importance are not native to the Americas and Australia, but were introduced by European colonists (and originally domesticated in Asia and the Near East). Australia and the United States are highly dependent upon species originating in other parts of the world for their major livestock-produced food and industrial crops (13). In such newly colonised regions, the introduced species and the agriculture-related changes in ecosystems led to a reduction in biodiversity on a continental scale, e.g. the introduction of rabbits and dogs to Australia (35).

Contrary to the deliberate human-assisted introduction to and management within agricultural ecosystems, livestock, like many other alien species, may become accidentally invasive, with their uncontrolled dispersal and establishment resulting in harm to natural biodiversity (43). In several cases, populations of livestock species have become feral, thereby competing with wildlife and possibly introducing animal diseases. The introduction of domestic herbivores has had an impact on local wild herbivores because they are a source of competition for access to feed, water and space. It has also undoubtedly had an impact on wild carnivores, which were initially only associated with wild herbivores. Changes in ecosystems and ecosystem function may have been severe. The Global Invasive Species Database of the International Union for Conservation of Nature/Species Survival Commission (IUCN)/(SSC) classifies feral cattle, goats, sheep, pigs, rabbits, donkeys, mallard ducks and geese as invasive alien species (among a total of 36 mammalian and 24 avian invasive species) (34). Feral pigs, goats and rabbits are classified among the top 100 of the world's worst invasive alien species (36). The impact of feral goats and pigs on the vegetation of small islands has been significant. The animals were left to provide food for sailors and later caused harm to, or even extinction of, native species (e.g. in the Galapagos Islands). The DAD-IS lists 135 feral livestock populations: sheep (30 populations), pig (19), cattle, goat and horse (18 each), donkey (13), buffalo and duck (4 each), partridge (2), and chicken, guinea fowl, deer, dog, pigeon and ostrich (1 each). The countries with the largest number of feral populations reported in DAD-IS are the United States (19 populations), India and New Zealand (10 each), the United Kingdom (UK) (6), Australia (4) and Kyrgyzstan (3).

Linked to the introduction of livestock species was the concomitant introduction of alien plants, often to improve the fodder quality of native rangelands. The planned introduction of plants, often assisted by fire, led to massive changes in vegetation species composition in Australia, New Zealand, South America and the western part of North America. The IUCN/SSC Global Invasive Species database lists 95 invasive plant species, many of which (e.g. *Bromus inermis*, *Glyceria maxima, Melinus minutiflora, Pennisetum ciliare* and *Urochloa maxima*) were introduced as livestock improvement crops and later invaded natural grasslands, out-competing native grasses and decreasing biodiversity. Grazing livestock contributes in turn to seed dispersal and triggers habitat changes that facilitate invasions. Trampling and grazing by domestic ungulates – especially in ecosystems that may have been inhabited by completely different fauna (e.g. marsupials) before colonisation – increase disturbance.

Introduced livestock species may also be vectors of disease, either to humans or to other livestock. Measles and possibly tuberculosis may have arisen from diseases of cattle, and influenza from a disease of pigs and poultry. Rinderpest dates back 9,000 years in Asia; historically, waves of rinderpest have devastated buffalo and cattle regularly in Asia and Europe, and occasionally in North Africa. Animals in sub-Saharan Africa were hit severely when rinderpest was introduced unwittingly into the Horn of Africa in 1887. The resulting panzootic changed the flora and fauna of the continent permanently. Rinderpest infected Belgian farms in the 1920s after a shipload of Indian zebu cattle bound for Brazil disembarked for 24 h in the port city of Antwerp. Old World screwworm was introduced to the Gulf countries in the late 1980s by sheep shipped from Australia which were infested en route in Asia.

In addition to the direct impact on biodiversity they exert as invasive alien species, livestock contribute directly or indirectly to all drivers of biodiversity loss as defined by the Millennium Ecosystem Assessment (39), at the local and global levels. This complex picture is complicated further by the fact that livestock first started to affect biodiversity millennia ago, when their domestication provided humans with a way to exploit new resources and territories. These historical changes continue to affect biodiversity while more recent processes are superimposed. Livestock are one of the major drivers of land-use change (deforestation, destruction of riparian forests, drainage of wetlands), whether for livestock production itself or for feed production, thereby modifying or destroying the ecosystems that are the habitats for various wild species. Livestock contribute to climate change, which in turn has a modifying impact on ecosystems and species. Terrestrial and aquatic ecosystems are affected by emissions into the environment (discharge of nutrients and pathogens into marine and freshwater ecosystems, ammonia emissions, acid rain) (18). These impacts vary widely between livestock production systems.

Although, strictly speaking, the definition of invasive alien species based on natural biodiversity should not apply to agricultural biodiversity, which is mostly expressed at the within-species level, the three above-mentioned conditions apply equally to agricultural biodiversity. If we accept this concept and regard livestock invasiveness from a perspective within an agricultural ecosystem, two more aspects have to be taken into consideration:

– the provisioning services (Box 1) that were the original reasons to domesticate wild animals for what later became livestock farming. Livestock production follows societal and economic rules, and there are parallels between the factors that determine a successful invasion of an ecosystem and the factors that determine success in a new market;

– the high intra-species genetic diversity that is a characteristic of agricultural biodiversity.

Invasiveness related to livestock production – or: what is the 'natural past or present distribution' for livestock species and breeds?

Based on the historical global dissemination of the major species and the further targeted breeding in developed countries over the last two centuries, the majority of the current flow of genetics is among countries within the Organisation for Economic Co-operation and Development and more recently also from developed to developing countries, with an estimated annual trade value that exceeds US$1 billion (29, 38, 52). The production differential in terms of different food products between countries with commercial breeding programmes and the rest of the world has been impressive (Table II). Genetic progress contributes on average between 55% and 80% to annual gains in productivity (30, 46). This production differential, however, does not take into account the fact that the low-input low-output local breeds obtain most inputs from within the ecosystem, whereas the high-input high-output breeds must obtain a major portion of their required inputs from outside the system.

Despite many failed introductions of high-output breeds to developing countries through crossbreeding or upgrading schemes, these exchanges of animal genetic resources and associated technology do contribute to production increases in developing countries. Between 1980 and 2007, beef output per animal in Asia grew at 1.1% per year, milk at 5.9%, pork at 1.8% and poultry at 0.4% (FAO-STAT). Ludena *et al.* (37) found that in most of the 116 countries sampled over a 40-year period (1960 to 2000), larger average gains in productivity growth occurred in monogastrics than in ruminant production. They projected that, for the period 2001 to 2040, industrialised countries will maintain their leading role as a source of technology in ruminant production. Most of the catch-up to the technology frontier (efficiency gains) in ruminants and monogastrics will take place in developing regions, especially Asia. Such efficiency gains are high in the farming of pigs and poultry, species for which the genetics, and the husbandry and feeding technology of intensive production, are easily transferable internationally. The authors therefore conclude that a degree of convergence will occur in the production of monogastrics between developing and developed countries. This will, however, occur only where the developing country is capable of supplying the high level of husbandry and feed inputs required by this type of high-output genetics reliably and cost-effectively.

Table II
Production differential (%) between selected developed countries that have commercial breeding programmes and the rest of the world (production output/head)

Product category	1961	1970	1980	1990	2000	2006
Beef and buffalo meat	30.39	40.21	45.37	52.02	74.18	80.94
Sheep and goat meat	24.49	18.98	23.98	18.49	23.67	19.91
Milk, total	244.78	249.00	304.28	315.67	465.56	440.26
Pig meat	33.66	31.51	28.76	15.56	17.74	19.76
Eggs, primary	117.21	95.40	62.53	46.92	45.06	53.46
Poultry meat	23.52	19.32	19.81	27.01	29.02	31.24

Selected developed countries: European Union countries, United States, Canada, Australia, New Zealand
Source: Food and Agriculture Organization of the United Nations Statistical Database, 2009

Invasiveness related to intra-species diversity – or: how much 'evolution' is desirable in livestock biodiversity?

Such convergence may have implications for livestock diversity. The food-producing species with rapid structural changes show high proportions of breeds at risk (already extinct and currently at-risk). This includes 31% of cattle breeds, 35% of pig breeds and 38% of chicken breeds (26) (Table I). In an FAO survey on threats to animal genetic resources across the main species, 28.5% of responses mentioned economic and market drivers as risk factors (27). Pigs and poultry (34% of responses in both cases), followed by cattle (30% of responses), were the species groups in which economic and market-driven threats were most often mentioned. For 952 breeds classified as at-risk in DAD-IS, economic and market drivers (31.6%), poor livestock sector policies (20.9%) and poor conservation strategies (16.7%) were the risk factors most frequently mentioned.

Invasive alien species thrive because their inherent characteristics enable them to compete. In natural ecosystems, the management of invasive alien species can focus on eradication and control. Despite the complex management and multiple objectives linked with the movement of livestock, there are some parallels in the factors that determine the success of invasion from natural ecosystems with the socio-economic and ecological conditions in livestock production systems. Economies of scale and of scope applied in breeding, husbandry and product processing in the different species have to be taken into account (Table III).

In ecology, a good predictor of invasiveness is whether a species has invaded successfully elsewhere. To become invasive, the first step is to arrive, survive and establish. In nature, narrowly adapted and endemic species that rely on a particular environment are more likely to be disadvantaged by changes to their home environments than are generalist species that can survive in a variety of different environments. Marginal ecosystems (e.g. high-altitude or arid systems) are often home to very specialised and rare species that are considered ecologically valuable. In addition to the large number of adapted livestock breeds (17), at least 30% of the world's cultivated plants and innumerable uncharacterised rangeland fodder species originated in drylands (51); these constitute a precious genetic stock for future agriculture.

In livestock, local breeds under traditional management are usually more generalist than high-output breeds. They are relatively resilient to environmental changes, while high-output breeds need specific husbandry practices, healthcare and diet to express their full genetic potential and be economically viable. Thus, it might be supposed logically that local breeds would be quite resistant to invasion by high-output breeds. However, livestock management systems (feeding, disease control, housing) can modify most impacts of the natural environment to varying degrees. Management practices thus expand the environmental envelope of breeds, particularly of those kept in confined systems. In evolutionary terms, the adaptation of high-output breeds to confined production environments is a recent phenomenon. In many cases, the introduction of high-output breeds, combined with the improved, high-input management systems needed to express their genetic potential, has been transferred to developing countries, and is often actively promoted by government policy or donors. Thus today, most of the livestock in developed countries (and increasingly so in developing countries) are kept in more or less controlled conditions. This is particularly true for pigs and poultry, for which a continued and increasing transition from backyard production systems to modern, confined production systems is expected (37).

The second step to becoming invasive is to reproduce and disperse. In nature, evolutionary responses are faster and invasiveness higher in species with short generation intervals, large populations and high reproductive rates. Breeds selected for high growth performance tend to mature more quickly and have their first offspring at a younger age than local breeds. Selection has increased reproductive rates in several species, especially in the multiparous species (e.g. egg production per hen, piglets per sow and year) (Table III). In modern livestock production systems, the application of biotechnologies (artificial insemination, embryo transfer, cloning) has increased reproduction rates in uniparous species as well. These technologies are applied differently across species and have implications for the structure of the breeding industry. The global offspring of one breeding male is highest in commercial dairy cattle, where a bull can have tens of thousands of progeny through artificial insemination. In chickens, high prolificacy and ease of transportation have facilitated market concentration, with a few breeding companies managing the approximately 6,000 great-grandparent hens needed to provide the global supply of 800 billion eggs, and the fewer than 15,000 great-grandparent hens needed to produce the 76 million tons of poultry meat (1, 44). Pigs are third in this ranking of reproduction efficiency because cryopreserved semen is less commonly used than in cattle, and female prolificacy is lower than in poultry. Species such as sheep and goats, or even beef cattle, which are kept in more extensive land-based systems and where transaction costs for herd control and reproductive management are higher, tend to be less competitive. Local breeds in developing countries have hardly been involved in reproductive technologies. In summary, human intervention, through reproduction technologies and selection, has modified the biological basis of expansiveness and changed the comparative advantage of species and breeds.

Table III
Biological, technical and sub-sector-structure differences for the 'big five' species
(lower figures: developing countries; upper figures: commercial breeding)

Type of difference	Ruminants				Monogastrics	
	Dairy cattle	Beef cattle	Sheep	Goats	Pigs	Chickens
Birth type	Single	Single	Single > twins, triplets	Single > twins, triplets	5 to 15	Many
Age at first delivery	22 months to 4 years	22 months to 4 years	1 to 2 years	1 to 2 years	10 to 18 months	5 to 18 months
Time between two deliveries (calving/litter interval) (days)	350 to 730	350 to 730	180 to 360	180 to 360	6 to 12 months	
Offspring per female per year	0.5 to 0.9	0.5 to 0.9	1 to 3	1 to 3	8 to 22	20 to 200
Generation interval for breeding (years)	> 4	> 4	2	2	1	1
Artificial insemination and reproductive biotechnology	Widespread	Medium to rare	Rare	Rare	Medium	Rare
Breeding programmes (commercial)	Pure breeding	Pure and crossbreeding	Pure breeding	Pure breeding	Crossbreeding, line hybrids	Line hybrids
Ownership of breeding programmes	Breeder organisations, private companies	Breeder organisations	Breeder organisations	Breeder organisations	Private companies	Private companies
Market concentration and control of genetic progress in breeding	High	Medium	Low	Low	High	Very high
Production stages in commercial systems	Calf – heifer – cow	Cow – calf – growing – fattening			Farrowing – finishing	Hatching – growing – laying
Natural feeding type	Herbivore	Herbivore	Herbivore	Herbivore	Omnivore	Omnivore
Feed	Roughage > concentrates; high share of concentrates in intensive systems	Roughage > concentrates, high share of concentrates in feedlot systems	Roughage > concentrates	Roughage > concentrates	Concentrates	Concentrates
Land dependence	Variable	Variable	High	High	Low	Low
Geographical concentration	Medium	Medium	Low	Low	High	High
Products	Milk > meat	Meat	Meat, milk, wool	Meat, milk, fibre	Meat	Meat, eggs
Products perishable within a few days	Milk	Meat	Milk, meat	Milk, meat	Meat	Meat
Mechanisation of slaughter and meat/ milk/egg processing	High	High	Medium	Medium	High	High

The third step for successful invasion is to out-compete indigenous species. New species or breeds may replace the current ones as single new components in a production system or they may be introduced together with other components, including knowledge. In human-managed systems, 'establishment' of a new species or breed depends on how many components of the old production system can be transferred to the new area/system, and on the socio-economic conditions. The introduction of new breeds into the United States has been successful when based on several production traits and when the private sector has been interested, while introduction aiming to take advantage of single traits has not proved sustainable, especially when other economically important traits were compromised (3).

In the context of agricultural biodiversity, 'out-competing' can refer to other species or breeds of the same species. At the inter-species level, two pathways dominate: in extensive systems, to adapt to changing environmental conditions, and in intensive systems, to adapt to market drivers.

One example of the adaptation to changing environmental conditions in extensive systems was the replacement of cattle by dromedaries, and of sheep by goats, that followed the droughts of the 1980s in the Sahel. In countries such as Niger and Mauritania, and in northern Nigeria, camel rearing is now a common activity. Unlike cattle and sheep, which feed largely on herbaceous vegetation, camels browse on shrubs and trees, while goats use both strata (33), thereby extending resource limits in space and time. Climate change is projected to accelerate species shifts. Several species-level livestock models (31, 45) that take into account the direct effects of climate change, together with changes in agro-ecological conditions, production systems and comparative cost structure, indicate that farmers will change their breed portfolio as temperature or rainfall rises.

In addition to policies that favour intensive livestock production (18), relative production costs and income elasticities of demand may change the comparative advantages of species in market-driven systems. The most important supply drivers over recent decades were cheap grain and cheap energy, technological change, especially in genetics, feeding and transport, together with a policy environment favourable to intensive production that, in many countries, provided incentives such as market infrastructure, credit, labour and environmental policies (18). Income elasticity values for different animal-source food commodities show that preferences for additional milk and beef decrease marginally when countries get richer, while preferences for poultry are stable across wealth groups and preferences for pork and mutton rise with income levels (10, 37). As a consequence of the increases in productivity that were transmitted to consumers through relative declines in prices, the share of poultry in world meat production increased from 13% in the mid-1960s to 28% in 2003. Per caput consumption increased more than threefold over the same period, particularly in countries that were the traditional producers of beef (15).

Within species, differentials in output levels and economic returns between high performance and local breeds tend to disadvantage local breeds in areas where the necessary high level of inputs can be supplied to the high-output breeds. A high ratio of intensive livestock production with high-output breeds in the total market supply makes it easier for countries to fulfil food security goals. It may also be easier to achieve food safety standards owing to the ease of control of standardised production environments. Increasingly demanding international animal health standards that draw on international codes and standards set by the World Organisation for Animal Health and Codex Alimentarius also tend not to be scale-neutral and to favour intensive over small-scale or backyard production.

Local breeds are disadvantaged further because of the prevailing information bias. They are usually not well characterised phenotypically or genetically, and their level of adaptation to specific environments and stressors is not well understood. Few structured breeding programmes support their development, and few breeds are included in conservation programmes. In contrast, several international transboundary breeds are well characterised and their genetic improvement is supported by efficient, sometimes global, structured breeding programmes. Some gene banks exist, often as back-ups from regular artificial insemination programmes. Many international transboundary breeds of cattle, pigs and poultry have effective international marketing and distribution networks. In some countries, their introduction, for example, through crossbreeding programmes, is supported by subsidies (18, 21).

As with reproductive technologies, many modern breeding technologies are not scale-neutral. The high-throughput genotyping and the phenotypic characterisation, with the sophisticated measurements and bioinformatics tools needed for their calibration, are most likely to be used in developed countries (50). The advantages and applicability of genomic selection for developing countries with low institutional capacity remain to be seen. In the meantime, the performance differentials between locally adapted breeds and high-output breeds, the ease of import and the long-term commitment required for genetic improvement contribute to discouraging developing countries from initiating their own breeding programmes. In addition, developed countries are more likely to be capable of planning and conducting the necessary well-designed genetic comparisons of local and introduced breeds before a widespread introduction. These factors may further increase the divide between the scientific 'haves and have-nots' (41) and contribute to worsening the income disparities between developed and developing countries.

In parallel to the small breeding companies in developed countries ceasing activity or being merged into the larger companies, the 'decoupling' of developing countries from breeding science and technology also has implications for their participation in trade. Most flows of genetic material occur amongst developed countries that fulfil the animal health regulatory requirements for international trade in genetic material, and involve animals suited to high-input production systems. The share of international trade in genetic material from developed to developing countries increased from 20% in 1995 to 30% in 2005; however, only the wealthier developing countries import genetic material. The poorest countries are not engaged in any trade of animal genetic resources at all (29).

Conclusion

Given that livestock diversity and agricultural ecosystems are developed by humans, human decisions are crucial to their current and future fate. In adopting the 'Global Plan of Action', the international community recognised that animal genetic diversity is critical for food security and rural development because it allows farmers to select stock or develop new breeds in response to changing conditions, including climate change, new or resurgent disease threats, new knowledge of human nutritional requirements, changing market conditions or changing societal needs. Local breeds are key resources in the livelihoods of rural people, but these breeds and their keepers are often neglected. Strategic Priorities five and six of the 'Global Plan of Action' thus stress the promotion of agro-ecosystems approaches to the management of animal genetic resources, and the support of indigenous and local production systems and associated knowledge systems (20). Strategies to support small-scale livestock keepers in maintaining their breeds are:

– first, the provision of public goods such as research, extension, infrastructure and market reform

– second, policies that avoid subsidies to large-scale operations and encourage smallholder investment

– third, institutional development to help them meet global standards regarding food safety and quality (12).

The CBD deals with livestock diversity under various programmes and cross-cutting issues, and the problems perceived from each angle result in different proposed solutions. The invasiveness of alien species, particularly with regard to agricultural biodiversity, has to be seen in a historical context because ecosystems and economies have been connected for millennia while nation states are of more recent origin. The impact of livestock as invasive alien species differs outside and within agricultural ecosystems.

Livestock production continues to threaten natural biodiversity, through the conversion of natural habitats into grazing or cropland for feed production, the introduction of feral populations, and the focus on a limited number of ecosystem services, particularly the production of food and fibre, at the expense of other functions. This highlights the importance of strengthening the application of the ecosystem approach to livestock production and of considering the impacts of livestock on biodiversity within and across agricultural ecosystems.

Within agricultural biodiversity, the increasing demand for food of animal origin, the output and technology differential – which often does not fully consider input differentials – as well as the information and awareness bias tend to favour international high-input, high-output breeds over local breeds. This increases their global spread in the market economy and this situation is likely to persist if current policy distortions of various kinds continue.

Several measures are being proposed to control genetic erosion through uncontrolled livestock introduction. On the other hand, measures to control access to and export of animal genetic resources are being discussed. This highlights the complex societal demands for livestock biodiversity.

The flow of livestock genetic material between countries for agricultural purposes is mainly regulated by animal health standards and takes little if any account of possible impacts on genetic diversity. To increase market transparency and reduce unintended harm to local breeds, some countries have introduced a requirement for genetic impact assessments prior to granting permission for the import of new exotic livestock breeds (42). Drucker *et al.* (12) and Hiemstra *et al.* (32) discuss the need for the regulation of export and import of livestock germplasm, e.g. through establishing protocols for the guidance of donors and non-governmental organisations when importing exotic breeds (e.g. for restocking programmes), or through the development and implementation of genetic impact assessments. The need for and possible modalities of such genetic impact assessments could be addressed by the FAO Commission on Genetic Resources for Food and Agriculture.

An important step to increase transparency in cross-border exchanges would be the description of breeds and of the management requirements for them to perform at their genetic potential, much like the 'technical specification' and 'operating instructions' that accompany the purchase of standard technical consumer goods. Commercial poultry breeding material is usually accompanied by such instructions and commercial pig producers are starting to provide them. These are, however, the species that are kept most frequently in controlled breeding and production systems, while the structure of the breeding industry and the control of the production environment for ruminants are more complex. It can be assumed that such 'operating instructions' will reduce the spread of imported breeds into unsuitable environments, thereby lowering economic losses to producers and reducing harm to local breed diversity. The FAO (22) is working on descriptors for the production environment that will facilitate meaningful comparisons and evaluation of breed performance, and will inform interventions related to the management of animal genetic resources. Production environment descriptors should complement other sources of breed-related information and contribute to an evidence-based approach to decision-making. They should be internationally standardised to allow the comparison of data collected in different countries.

On the export side, special characteristics of certain breeds and their possible future commercial benefit, gene patenting, and exchanges in which there are major differences in knowledge or market position between the suppliers and the recipients of genetic material have spurred discussions about access and benefit-sharing. The international regime on access to genetic resources and benefit-sharing that the Conference of the Parties to the CBD has agreed to finalise and adopt at its Tenth Meeting in October 2010, will also have implications for the livestock sector. Some stakeholders express concern at the prospect of animal genetic resources being included within a general access and benefit-sharing regime that does not take the specific needs of the sector into account and might lead to the imposition of burdensome and unnecessary procedures for access (28, 29).

Although the prediction of which genes in how many breeds will be needed in the future is not feasible with scientific accuracy, irreversible loss of genetic diversity will reduce opportunities to improve an important basis for food security, poverty alleviation and agricultural sustainability. It is expected that future consumer demand, emerging diseases and climate change will increase the pressure to maintain a wide portfolio of and access to animal genetic resources. Therefore, the 'Global Plan of Action' advocates the maintenance of use and non-use values of livestock genetic resources. The challenge confronting the management of animal genetic resources is to develop approaches that allow economic development to occur while maintaining and utilising genetic diversity. Countries that are responsible not only for implementation of the CBD and control of invasive alien species in natural ecosystems, but also for food security and the sustainable use of animal genetic resources, conservation and exchange in agricultural ecosystems, must balance the trade-offs between these broad policy objectives.

■

La biodiversité du bétail

I. Hoffmann

Résumé

Cet article décrit le cadre institutionnel de la prise en compte des espèces envahissantes et de leur rôle au regard de la diversité génétique du bétail. La propagation extensive de quelques espèces d'animaux domestiques destinées à la production mondiale de produits alimentaires est une caractéristique de la diversité agricole qui complexifie le point de vue simpliste et purement négatif porté sur les espèces envahissantes. L'auteur examine les différents impacts provoqués par les espèces d'animaux domestiques sur la biodiversité, ainsi que ceux provoqués par la diversité interraciale au sein des espèces et par la diversité intra-raciale sur la biodiversité agricole. La production animale continue de menacer la biodiversité naturelle. La demande croissante en protéines d'origine animale, les écarts de productivité et de technologie ainsi que les préjugés véhiculés par l'information et intégrés au niveau collectif tendent à privilégier les races internationales à haut rendement au détriment des races locales. De ce fait, les races internationales continueront d'envahir l'économie de marché tant que les politiques actuelles n'auront pas rectifié ces distorsions. Plusieurs mesures sont proposées pour maîtriser l'érosion génétique due à des transferts génétiques incontrôlés. Il incombe aux pays, non seulement de maîtriser les espèces allochtones envahissantes, conformément à la Convention sur la diversité biologique, mais aussi d'assurer l'utilisation et la préservation durables des ressources génétiques animales et de préserver la sécurité alimentaire. Il leur revient d'élaborer un compromis équilibré entre ces objectifs politiques majeurs.

Mots-clés

Biodiversité agricole – Espèce allochtone envahissante – Race de bétail.

■

Diversidad biológica del ganado

I. Hoffmann

Resumen

La autora describe el telón de fondo institucional desde el que se examina el tema de las invasiones en relación con la diversidad genética del ganado. La gran diseminación de unas pocas especies animales domesticadas con fines de producción alimentaria a escala mundial es un rasgo de la diversidad agrícola que viene a complicar la mera visión simplista y negativa de las especies invasoras. La autora expone asimismo los distintos efectos de las especies ganaderas sobre la biodiversidad natural y la incidencia de la diversidad de razas dentro de una especie y de la diversidad interna a una misma raza sobre la biodiversidad agrícola. La producción ganadera sigue constituyendo una amenaza para la diversidad biológica natural. La creciente demanda de alimentos de origen animal, los factores diferenciales de productividad y tecnología y la presencia de información sesgada y de prejuicios tienden a favorecer a las razas internacionales de elevado rendimiento en desmedro de las razas locales. Si las actuales distorsiones normativas se perpetúan, ello acrecentará la 'invasividad' de esas razas en la economía de mercado. La autora propone varias medidas para atajar la erosión genética que resulta de la circulación descontrolada de genes. Los países son responsables no sólo de luchar contra las especies invasoras, en aplicación del Convenio sobre la Diversidad Biológica, sino también de proteger y utilizar de modo sostenible los recursos genéticos animales y de velar por la seguridad alimentaria. Para ello deben encontrar soluciones de compromiso, que ofrezcan el adecuado equilibrio entre esos grandes objetivos políticos.

Palabras clave

Diversidad biológica agrícola – Especie extranjera invasora – Razas de ganado.

■

References

1. Avendano S. (2009). – Management of poultry genetic resources in a competitive market – A breeder's view. 6th European Poultry Genetics Symposium, 30 September to 2 October, Bedlewo, Poland.

2. Baillie J.E.M., Hilton-Taylor C. & Stuart S.N. (eds) (2004). – 2004 IUCN Red list of threatened species. A global species assessment. IUCN, Gland, Switzerland.

3. Blackburn H. & Gollin D. (2008). – Animal genetic resource trade flows: the utilisation of newly imported breeds and the gene flow of imported animals in the United States of America. *Livestock Sci.*, **120** (3), 240-247.

4. Convention on Biological Diversity (CBD) (2008). – COP 9 Decision IX/1. In-depth review of the programme of work on agricultural biodiversity. CBD, Montreal.

5. Convention on Biological Diversity (CBD) (2008). – COP 9 Decision IX/4. In-depth review of ongoing work on alien species that threaten ecosystems, habitats or species. CBD, Montreal.

6. Convention on Biological Diversity (CBD) (2008). – UNEP/CBD/COP/9/11. In-depth review of ongoing work on alien species that threaten ecosystems, habitats or species. CBD, Montreal.

7. Convention on Biological Diversity (CBD) (2008). – UNEP/CBD/COP/9/3. Report of the Subsidiary Body on Scientific, Technical and Technological Advice on the work of its Thirteenth Meeting. CBD, Montreal.

8. Convention on Biological Diversity (CBD) (2008). – UNEP/CBD/SBSTTA/13/2. In-depth review of the implementation of the Programme of Work on Agricultural Biodiversity. CBD, Montreal.

9. Convention on Biological Diversity (CBD) (2008). – UNEP/CBD/SBSTTA/13/INF/2. In-depth review of the Programme of Work on Agricultural Biodiversity. CBD, Montreal.

10. Delgado C., Rosegrant M., Steinfeld H., Ehui S. & Curbois C. (1999). – Livestock to 2020 – The next food revolution. Food, Agriculture and the Environment Discussion Paper 28. IFPRI, FAO, ILRI.

11. Diamond J. (2002). – Evolution, consequences and future of plant and animal domestication. *Nature*, **418**, 700-702.

12. Drucker A.G., Hiemstra S.J., Louwaars N., Oldenbroek J.K., Tvedt M.W., Hoffmann I., Awgichew K., Abegaz Kebede S., Bhat P.N. & da Silva Mariante A. (2007). – Back to the future: how scenarios of future globalisation, biotechnology, disease and climate change can inform present AnGR policy development. *Anim. genet. resources Info.*, **41**, 75-90.

13. Food and Agriculture Organization of the United Nations (FAO) (1998). – The state of the world's plant genetic resources for food and agriculture. FAO, Rome.

14. Food and Agriculture Organization of the United Nations (FAO) (2002). – World agriculture: towards 2015/2030. Summary report. FAO, Rome, 96 pp.

15. Food and Agriculture Organization of the United Nations (FAO) (2003). – World agriculture: towards 2015/2030 – An FAO perspective (J. Bruinsma, ed.). Earthscan, London.

16. Food and Agriculture Organization of the United Nations (FAO) (2004). – Tenth Regular Session of the Commission on Genetic Resources for Food and Agriculture, CGRFA-10/04/REP, paragraph 76. FAO, Rome.

17. Food and Agriculture Organization of the United Nations (FAO) (2006). – Breed diversity in dryland ecosystems. CGRFA/WG-AnGR-4/06/Inf. 9. FAO, Rome.

18. Food and Agriculture Organization of the United Nations (FAO) (2006). – Livestock's long shadow – environmental issues and options (H. Steinfeld, P. Gerber, T. Wassenaar, V. Castel, M. Rosales & C. de Haan, eds). FAO, Rome.

19. Food and Agriculture Organization of the United Nations (FAO) (2007). – Eleventh Regular Session of the Commission on Genetic Resources for Food and Agriculture, CGRFA-11/07/Report, paragraph 71. FAO, Rome.

20. Food and Agriculture Organization of the United Nations (FAO) (2007). – Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration. FAO, Rome.

21. Food and Agriculture Organization of the United Nations (FAO) (2007). – The state of the world's animal genetic resources for food and agriculture (B. Rischkowsky & D. Pilling, eds). FAO, Rome.

22. Food and Agriculture Organization of the United Nations (FAO) (2008). – Report of the FAO/WAAP Workshop on Production Environment Descriptors for Animal Genetic Resources (D. Pilling, B. Rischkowsky & B. Scherf, eds), 6-8 May, Caprarola, Italy. FAO, Rome. Available at: http://dad.fao.org/cgi-bin/getblob.cgi?sid=-1,593 (accessed on 22 March 2010).

23. Food and Agriculture Organization of the United Nations (FAO) (2009). – Contributions of smallholder farmers and pastoralists to the development, use and conservation of animal genetic resources, CGRFA/WG-AnGR-5/09/Inf.4. FAO, Rome.

24. Food and Agriculture Organization of the United Nations (FAO) (2009). – Policies and arrangements for access and benefit-sharing for genetic resources for food and agriculture. CGRFA-12/09/3.1. FAO, Rome. Available at: ftp://ftp.fao.org/docrep/fao/meeting/017/k6123e.pdf.

25. Food and Agriculture Organization of the United Nations (FAO) (2009). – The roles of small-scale livestock keepers as custodians of animal genetic resources, CGRFA/WG-AnGR-5/09/5. FAO, Rome.

26. Food and Agriculture Organization of the United Nations (FAO) (2009). – Status and trends report on animal genetic resources – 2008. CGRFA/WG-AnGR-5/09/Inf. 7. FAO, Rome.

27. Food and Agriculture Organization of the United Nations (FAO) (2009). – Threats to animal genetic resources – their relevance, importance and opportunities to decrease their impact. CGRFA Background Study Paper No. 50. FAO, Rome. Available at: ftp://ftp.fao.org/docrep/fao/meeting/017/ak572e.pdf.

28. Food and Agriculture Organization of the United Nations (FAO) (2009). – The use and exchange of animal genetic resources for food and agriculture. CGRFA Background Study Paper No. 43. FAO, Rome. Available at: ftp://ftp.fao.org/docrep/fao/meeting/017/ak222e.pdf.

29. Gollin D., Van Dusen E. & Blackburn H. (2008). – Animal genetic resource trade flows: economic assessment. *Livestock Sci.*, **120** (3), 248-255.

30. Havenstein G.B., Ferket P.R.M. & Qureshi A. (2003). – Growth, livability, and feed conversion of 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets. *Poult. Sci.*, **82** (10), 1500.

31. Herrero M., Thornton P.K., Kruska R. & Reid R.S. (2008). – Systems dynamics and the spatial distribution of methane emissions from African domestic ruminants to 2030. *Agric. Ecosyst. Environ.*, **126**, 122-137.

32. 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. (2007). – What's on the menu? Options for strengthening the policy and regulatory framework for the exchange, use and conservation of animal genetic resources. *Anim. genet. Resources Info.*, **41**, 65-74.

33. Hoffmann I. & Mohammed I. (2004). – The role of nomadic camels for manuring farmers' fields in the Sokoto Close Settled Zone, Northwest Nigeria. *Nomadic Peoples*, **8** (1), 99-112.

34. International Union for Conservation of Nature (IUCN) (2000). – IUCN Guidelines for the prevention of biodiversity loss caused by alien invasive species. Prepared by the Species Survival Commission Invasive Species Specialist Group, and approved by the 51st Meeting of the IUCN Council. IUCN, Gland, Switzerland.

35. Invasive Animal Cooperative Research Centre Australia (2010). – Available at: www.invasiveanimals.com (accessed on 22 March 2010).

36. Lowe S., Browne M., Boudjelas S. & de Poorter M. (2000). – 100 of the world's worst invasive alien species. A selection from the Global Invasive Species Database. Invasive Species Specialist Group (ISSG), 12 pp. Available at: http://www.issg.org/pdf/publications/worst_100/english_100_worst.pdf (accessed on 22 March 2010).

37. Ludena C.E., Hertel T.W., Preckel P.V., Foster K. & Nin A. (2007). – Productivity growth and convergence in crop, ruminant, and nonruminant production: measurement and forecasts. *Agric. Econ.*, **37**, 1-17.

38. Mathias E. & Mundy P. (2005). – Herd movements: the exchange of livestock breeds and genes between North and South. League for Pastoral Peoples and Endogenous Livestock Development, Ober-Ramstadt, Germany.

39. Millennium Ecosystem Assessment (2005). – Ecosystems and human well-being: biodiversity synthesis. World Resources Institute, Washington, DC.

40. Nierenberg D. (2003). – Factory farming in the developing countries. *World Watch Mag.*, **16** (3). Available at: http://www.worldwatch.org/epublish/1/v16n3 (accessed on 22 March 2010).

41. Organisation for Economic Co-operation and Development (OECD)/Food and Agriculture Organization of the United Nations (FAO) (2009). – OECD–FAO Agricultural Outlook 2009-2018. Highlights. OECD, Paris, 95 pp.

42. Pilling D. (2007). – Genetic impact assessments – summary of a debate. *Anim. genet. Resources Info.*, **41**, 101-109.

43. Pimentel D., McNair S., Janecka J., Wightman J., Simmonds C., O'Connell C., Wong E., Russel L., Zern J., Aquino T. & Tsomondo T. (2001). – Economic and environmental threats of alien plant, animal, and microbe invasions. *Agric. Ecosyst. Environ.*, **84**, 1-20.

44. Preisinger R. (2004). – Internationale Tendenzen der Tierzüchtung und die Rolle der Zuchtunternehmen. *Züchtungskunde*, **76** (6), 395-402.

45. Seo S.N. & Mendelsohn R. (2008). – Measuring impacts and adaptations to climate change: a structural Ricardian model of African livestock management. *Agric. Econ.*, **38**, 151-165.

46. Shook G.E. (2006). – Major advances in determining appropriate selection goals. *J. Dairy Sci.*, **89**, 1349-1361.

47. Steinfeld H., Wassenaar T. & Jutzi S. (2006). – Livestock production systems in developing countries: status, drivers, trends. *In* Animal production food safety challenges in global markets (S.A. Slorach, ed.). *Rev. sci. tech. Off. int. Epiz.*, **25** (2), 505-516.

48. Thomas C.D., Cameron A., Green R.E., Bakkenes M., Beaumont L.J., Collingham Y.C., Erasmus B.F.N., Ferreira de Siqueira M., Grainger A., Hannah L., Hughes L., Huntley B., van Jaarsveld A.S., Midgley G.F, Miles L., Ortega-Huerta M.A., Peterson A.T., Phillips O.L. & Williams S.E. (2004). – Extinction risk from climate change. *Nature*, **427**, 145-148.

49. Tisdell C. (2003). – Socioeconomic causes of loss of animal genetic diversity: analysis and assessment. *Ecol. Econ.*, **45** (3), 365-377.

50. Tixier-Boichard M., Ayalew W. & Jianlin H. (2008). – Inventory, characterization and monitoring. *Anim. genet. Resources Info.*, **42**, 29-44.

51. United Nations Convention to Combat Desertification (UNCCD) (2005). – Economic opportunities in the drylands under the United Nations Convention to Combat Desertification. Background Paper 1. Seventh session of the Conference of the Parties, special segment, 24-25 October, Nairobi.

52. Valle Zárate A., Musavaya K. & Schäfer C. (2006). – Gene flow in animal genetic resources. A study on status, impact and trends. Institute of Animal Production in the Tropics and Subtropics, University of Hohenheim, Germany.