4. Livestock and the environment

Policy action is required to mitigate the impact of livestock production on the environment and to ensure that the sector makes sustainable contributions to food security and poverty reduction. Livestock production, like any economic activity, can be associated with environmental damage. Unclear property rights and the lack of adequate governance of the livestock sector can contribute to the depletion and degradation of land, water and biodiversity. At the same time, the livestock sector is affected by the degradation of ecosystems and faces increasing competition for these same resources from other sectors. Climate change represents a special "feedback loop", in which livestock production both contributes to the problem and suffers from the consequences. Unless appropriate action is taken to improve the sustainability of livestock production, the livelihoods of millions of people will be at risk.

The livestock sector suffers from market and policy failures at many levels, including problems associated with open-access resources, externalities and perverse incentives that encourage damaging practices. While some countries have made progress in reducing pollution and deforestation associated with livestock production, many more require appropriate policies and enforcement capacity. Given the likely continued strong growth in global demand for livestock products and the reliance of many people on livestock for their livelihoods, there is an urgent need to enhance the efficiency of natural-resource use in the sector and to reduce the environmental footprint of livestock production. Given better management practices, the livestock sector can reduce its footprint and contribute substantially to climate change mitigation. Achieving these objectives requires action on policy, institutional and technical levels.

Livestock production systems and ecosystems

The interaction of livestock with ecosystems is complex and depends on location and management practices. Most traditional livestock production systems are resource-driven in that they make use of locally available resources with limited alternative uses or, expressed in economic terms, low opportunity costs. Examples of such resources include crop residues and extensive grazing land not suitable for cropping or other uses. At the same time, in mixed production systems, traditionally managed livestock often provide valuable inputs to crop production, ensuring a close integration between the two.

The rising demand for livestock products is changing the relationship between livestock and natural resources. Modern industrial production systems are losing the direct link to the local resource base and are based on bought-in feed. At the same time, some of the resources previously available to livestock at a low cost are becoming increasingly costly, either because of growing competition for the resources from other economic sectors and other activities (such as production of biofuels; see Box 10) or because society is placing greater value on the non-market services provided by these resources (such as water and air quality).

The separation of industrialized livestock production from the land used to produce feed also results in a large concentration of waste products, which can put pressure on the nutrient absorptive capacity of the surrounding environment. In contrast, grazing and mixed farming systems tend to be rather closed systems, in which waste products of one production activity (manure, crop residues) are used as resources or inputs to the other.

The livestock sector is also a source of gaseous emissions that pollute the atmosphere and contribute to the

BOX 10
Expansion of biofuels production

Growing use of cereals and oilseeds to produce fossil fuel substitutes – ethanol and biodiesel – represents a significant challenge for the livestock sector in terms of competition for resources. The global biofuel industry has experienced a period of extraordinary growth, driven by a combination of high oil prices, ambitious goals for use of renewable energy set by governments around the world and subsidies in many OECD countries.

This rapid growth has had important consequences for the price and availability of crops, such as maize and oilseed rape, that are used as biofuel feedstocks. Most studies to date have focused on impacts on the crop sector. However, the livestock sector has also been strongly affected. The most obvious consequence of large-scale liquid biofuel production for the livestock industry is higher crop prices, which raise feed costs. Biofuel production also increases returns to cropland, which encourages conversion of pastureland to cropland.

On the other hand, producing biofuels creates valuable by-products, such as distillers' dried grains with solubles (DDGS) and oilseed meals, that can be used as animal feed and can substitute for grain in animal rations. Production of these by-products has increased dramatically in recent years as a result of the boom in biofuel production. The prices of these by-products have fallen relative to other feedstuffs, and, as a result, they have been increasingly used in feeds in some countries and production systems.

This suggests that biofuel by-products have helped to offset some of the adverse cost implications of the biofuels boom for the livestock industry. At the same time, biofuel by-products represent an important component of biofuel industry revenues. If the livestock industry could not absorb these by-products, their prices would fall sharply, thereby making biofuel less economically viable.

The impact of large-scale biofuel production on the livestock industry varies across regions and across livestock types. The strongest impact is being felt in those countries that are actively pursuing efforts to increase biofuel use (e.g. the United States of America and countries of the European Union), as well as those countries that are closely tied into the global agricultural economy. The impacts across different livestock sectors are also quite diverse. For example, dairy and beef producers traditionally use DDGS in their feed rations as it is palatable to cattle and well digested. They are thus better positioned to gain from increased DDGS availability than are other livestock producers, who may not be able to adjust their feed rations as readily to absorb the increased supply of DDGS.

Sources: Taheripour, Hertel and Tyner, 2008a and 2008b.

greenhouse effect. Continued growth in livestock production will exacerbate pressures on the environment and natural resources, calling for approaches that allow for increased production while lowering the environmental burden.

Livestock and land

Livestock is the world's largest user of land resources, with grazing land and cropland dedicated to the production of feed representing almost 80 percent of all agricultural land. The sector uses 3.4 billion hectares for grazing (Table 12) and 0.5 billion hectares for feed crops (Steinfeld *et al.*, 2006); the latter figure corresponds to one-third of total cropland.

The total land area occupied by pasture is equivalent to 26 percent of the ice-free terrestrial surface of the planet. Much of this area is too dry or too cold for cropping, and is only sparsely inhabited. Management practices and use of pastureland vary widely, as does the productivity of livestock per hectare. In arid and semi-arid rangelands, where most of the world's grasslands

TABLE 12
Land use by region and country group, 1961, 1991 and 2007

REGION/COUNTRY GROUPING	ARABLE LAND				PASTURE				FOREST[1]		
	Area			Share of total land	Area			Share of total land	Area		Share of total land
	1961	1991	2007	2007	1961	1991	2007	2007	1991	2007	2007
	(Million ha)			*(Percentage)*	*(Million ha)*			*(Percentage)*	*(Million ha)*		*(Percentage)*
Baltic states and CIS[2]	235.4	224.4	198.5	9.2	302.0	326.5	362.1	16.9	848.8	849.9	39.6
Eastern Europe	48.7	45.0	39.7	34.9	20.0	20.4	16.6	14.6	34.7	35.9	31.6
Western Europe	89.0	78.6	72.8	20.4	69.7	60.7	58.9	16.5	122.5	132.9	37.2
Developing Asia	404.4	452.5	466.4	17.6	623.4	805.1	832.8	31.5	532.8	532.6	20.1
North Africa	20.4	23.0	23.1	3.8	73.4	74.4	77.3	12.9	8.1	9.1	1.5
Sub-Saharan Africa	133.8	161.3	196.1	8.3	811.8	823.8	833.7	35.3	686.8	618.2	26.2
Latin America and the Caribbean	88.7	133.6	148.8	7.3	458.4	538.5	550.1	27.1	988.3	914.6	45.1
North America	221.5	231.3	215.5	11.5	282.3	255.4	253.7	13.6	609.2	613.5	32.9
Oceania	33.4	48.5	45.6	5.4	444.5	431.4	393.0	46.3	211.9	205.5	24.2
DEVELOPED COUNTRIES	**633.8**	**632.4**	**576.2**	**10.9**	**1 119.0**	**1 094.1**	**1 083.4**	**20.5**	**1 815.7**	**1 829.0**	**34.7**
DEVELOPING COUNTRIES	**647.6**	**770.9**	**834.9**	**10.8**	**1 967.8**	**2 242.6**	**2 294.8**	**29.7**	**2 252.6**	**2 108.4**	**27.3**
WORLD	**1 281.3**	**1 403.2**	**1 411.1**	**10.8**	**3 086.7**	**3 336.8**	**3 378.2**	**26.0**	**4 068.3**	**3 937.3**	**30.3**

[1] Forest data available only from 1991.
[2] CIS = Commonwealth of Independent States.
Source: FAO, 2009b.

are found, intensification of pastures is frequently technically unfeasible or unprofitable. Also, in much of Africa and Asia, pastures are traditionally common-property areas. As a result of weakening traditional institutions and increased land pressure, many of these have become open-access areas. In these and other major grassland-based systems, incentives and technology to improve pasture management are lacking; thus potential productivity gains and ecosystem services are lost.

There are three major trends relating to pasturelands: valuable ecosystems are being converted to pastureland (e.g. clearing of forest); pastureland is being converted to other uses (cropland, urban areas and forest); and pastureland is degrading.

Ranching-induced deforestation is a common feature in Central and South America (Wassenaar *et al*., 2006). At the same time, grasslands are increasingly fragmented and encroached upon by cropland and urban areas. White, Murray and Rohweder (2000) estimate that more than 90 percent of the North American tallgrass prairie and almost 80 percent of the South America cerrado have been converted to cropland and urban uses. In contrast, the Asian Daurien steppe and the Eastern and Southern Mopane and Miombo woodlands in sub-Saharan Africa are relatively intact, with less than 30 percent converted to other uses.

About 20 percent of the world's pastures and rangeland have been degraded to some extent, and the proportion may be as high as 73 percent in dry areas (UNEP, 2004). The Millennium Ecosystem Assessment estimated that 10–20 percent of all grassland is degraded, mainly by overgrazing. Pasture degradation is generally a consequence of a mismatch between livestock density and the capacity of the pasture to recover from grazing and trampling. Ideally, the land-to-livestock ratio should be continuously adjusted to the conditions of the pasture, especially in dry climates. However, because of weakened traditional institutions, increased pressures on resources and increased obstacles to livestock movements, such adjustment is often not possible. This is particularly the case in the arid and semi-arid communal grazing areas of the Sahel and Central Asia. In these areas, increasing human population and encroachment of arable farming on grazing lands have severely restricted the mobility of the herds and limited options for their management. Among the environmental consequences of pasture degradation are soil erosion, degradation of vegetation, release of carbon from organic matter deposits, reduction in biodiversity and impaired water cycles.

Pasture degradation can be reversed to some extent, although how quickly this can occur and what methodologies are best remain matters of debate. There is little doubt, however, that current productivity is constrained by high stocking rates in parts of Africa and Asia, where grazing lands are overexploited. Grazing lands can be sustainably managed under common-property systems. However, where common-property systems have broken down, overexploitation is often observed. The economic rationale by which individual livestock holders attempt to maximize their personal benefits when common-property systems break down is clear: maximizing the number of animals per hectare allows for the harvesting of more of the resource for individual gain. This encourages overexploitation of land resources to the detriment of overall productivity.

Land dedicated to feed-crop production

Most of the world's feed-crop production occurs in OECD countries, but some developing countries are rapidly expanding their production of feed crops, notably maize and soybean in South America. Intensive feed-crop production can lead to severe land degradation, water pollution and biodiversity losses, while expanding arable land into natural ecosystems often has serious ecological consequences, including the loss of biodiversity and of ecosystem services such as water regulation and erosion control.

While increases in grain production have been mostly achieved through intensification on existing areas, much of the rapid increase in soybean production has been achieved through expansion of cropping into natural habitats. Pressure on land resources for feed inputs has been mitigated in recent decades by the shift away from ruminants towards pigs and poultry, which have better feed conversion, and high-yielding breeds and improved management practices.

Meeting future demand for livestock products will, however, require further improvements in livestock and land productivity as well as expanding feed production area, at the expense of pastureland and natural habitats.

Livestock and water

Livestock production systems differ in the amount of water used per animal and in how these requirements are met. In extensive systems, the effort expended by animals in search of feed and water increases the need for water considerably compared with intensive or industrialized systems. However, intensive production has additional service water requirements for cooling and cleaning facilities, generally resulting in much higher overall water consumption than extensive systems. Both intensive and extensive systems can contribute to water pollution through waste runoff, although the concentration of livestock associated with intensive systems exacerbates this problem. The processing of livestock products also uses large amounts of water.

The livestock sector accounts for about 8 percent of global water use, primarily for irrigation of feed crops. The growth of industrial production systems is increasing the need for water for feed-crop production. Water used directly for livestock production and processing is less than 1 percent of water use globally, but often represents a much greater percentage of water use in dry areas. For example, the water consumed directly by livestock represents 23 percent of total water use in Botswana (Steinfeld *et al*., 2006).

The livestock sector can harm water quality through the release of nitrogen, phosphorus and other nutrients, pathogens and other substances into waterways and groundwater, mainly from manure in intensive livestock operations. Poor manure management often contributes to pollution and eutrophication of surface waters, groundwater and coastal marine ecosystems and to the accumulation of heavy metals in soils. This may lead to harm to human health and loss of biodiversity, and contribute to climate change, soil and water acidification and degradation of ecosystems.

The separation of industrialized livestock from its supporting land base interrupts the nutrient flows between land and livestock. This creates problems of depletion of nutrients at the source (land, vegetation and soil) and problems of pollution at the sink (animal wastes, increasingly disposed of into waterways instead of back on the land). The magnitude of the issue is illustrated by the fact that the total amounts of nutrients in livestock excreta are as large as or larger than the total contained in all chemical fertilizers used annually (Menzi *et al*., 2009).

There are a number of options available to reduce the impact of the livestock sector on water resources. These include reducing water use (e.g. through more efficient irrigation methods and animal cooling systems), reducing depletion or harm to water supplies (e.g. through increased water-use efficiency and improved waste management and feed-crop fertilization practices) and greater replenishment of water resources through better land management.

Looking at manure treatment in particular, there is a wide range of proven options, including separation technologies, composting and anaerobic digestion. These offer a number of benefits, including: allowing safe application of manure on food and feed crops; improved sanitation; better odour control; production of biogas; and improved fertilizer value of the manure. Most importantly, replacing mineral fertilizer with manure would lower the environmental impact of food production (Menzi *et al*., 2009).

The increased number of livestock needed to meet the projected growth in demand for livestock products is likely to have substantial impacts on water resources and on competition for their use. However, livestock–water interactions have been largely neglected in both water and livestock research and planning to date (Peden, Tadesse and Misra, 2007). This oversight will have to be addressed if the livestock sector is to continue to develop without causing greater harm to the environment.

Livestock and biodiversity

Biodiversity refers to the range of animal, plant and microbial species (interspecific biodiversity) on earth as well as the richness of genes within a given species (intraspecific biodiversity). It encompasses the genetic variation among individuals within the same population and among populations. Ecosystem diversity is another dimension of biodiversity.

Agricultural biodiversity is a particular case of intraspecific diversity that is an artefact of human activity. It includes domesticated animals and plants as well as non-harvested species that support food provision within agro-ecosystems. Knowledge about biodiversity is often embedded in social structures and may not be equally distributed or necessarily freely communicated between different groups of people, including ethnic groups, clans, gender or economic groups (FAO, 2004b). For example, women who process wool may have very different knowledge about breed characteristics, focusing as they do on wool, than men who herd livestock and focus on fodder and water consumption or disease resistance.

Livestock production systems affect biodiversity differently. Intensive systems rely on a limited number of crop species and animal breeds, although each may be quite rich in terms of genetic background. These systems depend on intensively managed feed crops, which are often blamed for ecosystem degradation. However, intensive land use may actually protect non-agricultural biodiversity by reducing pressure to expand crop and pasture areas. Extensive systems may host a larger number of breeds and make use of a wider variety of plant resources as feed, but their lower productivity may increase pressure to encroach more on natural habitats. In general, the effect of livestock on biodiversity depends on the magnitude of livestock impacts or the extent to which biodiversity is exposed to those impacts, how sensitive the biodiversity in question is to livestock and how it responds to the impacts (Reid *et al*., 2009).

Many livestock breeds – a component of agricultural biodiversity – are at risk of disappearing, in large part as a result of increasing use of a narrow range of livestock breeds in intensive systems. Box 11 addresses the need to conserve domestic animal diversity.

According to the Millennium Ecosystem Assessment (MEA, 2005), the most important direct drivers of biodiversity loss and ecosystem service changes are: habitat change (such as land-use changes, physical modification of rivers or water withdrawal from them, loss of coral reefs, and damage to sea floors resulting from trawling); climate change; invasive alien species; overexploitation; and pollution. Livestock contribute directly or indirectly to all these drivers of biodiversity loss, from the local to global levels. Typically, biodiversity loss is caused by a combination of various processes

BOX 11
Conserving animal genetic resources

The livestock species contributing to today's agriculture and food production are shaped by a long history of domestication and development. Developments in the late twentieth century – including increased commercialization of livestock breeding, rising demand for animal products in the developing world, production differentials between developed and developing countries, new reproductive biotechnologies that facilitate the movement of genetic material and the feasibility to control production environments independently of the geographical location – have led to a new phase in the history of international gene flows. International transfer of genetic material occurs on a large scale, both within the developed world and from developed to developing countries. These flows are focused on a limited number of breeds. There is also some movement of genetic resources from developing to developed regions, largely for research purposes. Today, the world's most widespread cattle breed, the Holstein-Friesian, is found in at least 128 countries. Among other livestock species, Large White pigs are reported in 117 countries, Saanen goats in 81 countries, and Suffolk sheep in 40 countries.

FAO's Domestic Animal Diversity Information System (http://dad.fao.org), a global databank for animal genetic resources, is the most comprehensive global information source on livestock genetic diversity. A total of 7 616 breeds are recorded in the Global Databank, comprising 6 536 local breeds and 1 080 transboundary breeds. Of these, 1 491 are classified as being "at risk".[1] The true figure is likely to be even higher, as population data are unavailable for 36 percent of breeds. The regions with the highest proportion of their breeds classified as at risk are Europe and the Caucasus (28 percent of mammalian breeds and 49 percent of avian breeds) and North America (20 percent of mammalian breeds and 79 percent of avian breeds). These two regions have highly specialized livestock industries, in which production is dominated by a small number of breeds. However, problems elsewhere may be obscured by the large number of breeds with unknown risk status. In Latin America and the Caribbean, for example, 68 percent of mammalian breeds and 81 percent of avian breeds are classified as being of unknown risk status. The figures for Africa are 59 percent for mammals and 60 percent for birds. This lack of data is a serious constraint to effective prioritization and planning of breed conservation efforts. There is a need for improved surveying and reporting of breed population size and structure, and of other breed-related information.

of environmental degradation. This makes it difficult to isolate the contribution of the livestock sector. A further complication is represented by the many steps in the animal food product chain at which environmental impact occurs.

Livestock-related land use and land-use change modify ecosystems that are the habitats for given species. Livestock contribute to climate change (see "Livestock and climate change", below), which in turn has an impact on ecosystems and species. The sector also directly affects biodiversity through transfer of invasive alien species and overexploitation, for example through overgrazing of pasture plants. Water pollution and ammonia emissions, mainly from industrial livestock production, reduce biodiversity, often drastically in the case of aquatic ecosystems. Pollution from livestock enterprises, as well as overfishing to provide fishmeal for animal feed, reduces biodiversity in marine ecosystems (Reid *et al*., 2009).

Livestock first started to affect biodiversity when animals were domesticated millennia ago and provided humans with a way to exploit new resources and territories that

The rapid spread of intensive livestock production that utilizes a narrow range of breeds has contributed to the marginalization of traditional livestock production systems and the associated animal genetic resources. Global production of meat, milk and eggs is increasingly based on a few high-output breeds – those that under current management and market conditions are the most profitable in industrialized production systems. Policy measures are necessary to minimize the loss of the global public goods embodied in animal genetic diversity.

Acute threats such as major disease epidemics and disasters of various kinds (droughts, floods, military conflicts, etc.) are also a concern – particularly in the case of small, geographically concentrated breed populations. The overall significance of these threats is difficult to quantify.

Threats of this kind cannot be eliminated, but their impacts can be mitigated. Preparedness is essential in this context, as ad hoc actions taken in an emergency will usually be far less effective. Knowledge of which breeds have characteristics that make them priorities for protection, and how they are distributed geographically and by production system, is fundamental to such plans, and more broadly to sustainable livestock diversity management. From a livelihood perspective, local knowledge of men and women continues to be an important asset for resource-poor people, especially in terms of increased food security and health.

In September 2007, the international community adopted the first ever *Global Plan of Action for Animal Genetic Resources* (FAO, 2007b), comprising 23 strategic priorities aimed at combating the erosion of animal genetic diversity and at using genetic resources sustainably. They also adopted the *Interlaken Declaration on Animal Genetic Resources.* The Declaration recognizes that there are significant gaps and weaknesses in national and international capacities to inventory, monitor, characterize, sustainably use, develop and conserve animal genetic resources, and that these need to be addressed urgently. It also calls for mobilization of substantial financial resources and long-term support for national and international animal genetic resources programmes.

[1] A breed is categorized as at risk if the total number of breeding females is less than or equal to 1 000 or the total number of breeding males is less than or equal to 20, or if the overall population size is greater than 1 000 and less than or equal to 1 200 and decreasing and the percentage of females being bred to males of the same breed is below 80 percent.

Sources: FAO, 2007b and 2007c.

had previously been unavailable. Current degradation processes are superimposed on these historical changes, which continue to affect biodiversity.

Differences in impacts between species and production systems

There are significant differences in the environmental impact between species, and between the different forms of livestock production. Both intensive and extensive production systems may damage the environment, but in different ways. Pressure to expand production, either through intensification (increasing output per unit of land by increasing non-land inputs) or area expansion (increasing output by expanding land in production without changing inputs per unit of land), can have negative environmental consequences unless the value of common-property resources and the cost of negative externalities are fully recognized and accounted for.

Species

Cattle provide many products and services, including beef, milk and traction. In many mixed farming systems, cattle are usually well integrated in nutrient flows and can have a positive environmental impact (Steinfeld, de Haan and Blackburn, 1998) (see Table 13). In many developing countries, cattle and buffalo provide draught power for field operations; in some areas, particularly parts of sub-Saharan Africa, use of animal traction is increasing, substituting for fossil fuel use. Cattle manure is a good fertilizer; it presents a low risk of over-fertilization and improves soil structure. Livestock also use crop residues and agro-industrial by-products, such as molasses cake and brewers grains, some of which would otherwise be burned. However, cattle in extensive production systems in developing countries often have limited productivity. As a result, a large share of feed is spent on the animal's maintenance rather than on producing products or services useful to people. The result is inefficient use of resources and often high levels of environmental damage per unit of output, particularly in overgrazed areas.

Dairy cattle require large amounts of bulky fibrous feed in their diets. As a result, dairy herds need to be close to the source of their feed, more so than other forms of market-oriented livestock production. This provides greater opportunities for nutrient cycling, which is beneficial to the environment. However, excessive use of nitrogen fertilizer on dairy farms is one of the main causes of high nitrate levels in surface water in OECD countries (Tamminga, 2003). Manure runoff and leaching from large-scale dairy operations may also contaminate soil and water.

Beef is produced in a wide range of systems that operate at different intensities and scales. At both ends of the intensity spectrum, considerable environmental damage can occur. On the extensive side, cattle are often involved in degradation of vast grassland areas and are a contributing factor to deforestation through clearing of forest to provide pastureland (Table 13). The resulting carbon emissions, biodiversity losses and negative impacts on water flows and quality constitute major environmental impacts. On the intensive side, concentration of livestock in feedlots often results in soil and water pollution, as the amount of manure and urine produced far exceed the capacity of surrounding land to absorb nutrients. Moreover, cattle in feedlots require more concentrate feed per kilogram of output than do poultry or pigs; as a result, they have significantly higher resource requirements and hence greater environmental impact. Greenhouse gas emissions are also substantial from all livestock production systems. In extensive systems, most GHGs result from land degradation and enteric fermentation, whereas in intensive operations manure is the main source of GHGs. The higher relative productivity of animals and lower fibre content of feed rations in intensive operations reduce methane emissions from enteric fermentation when expressed per unit of animal product.

The production of sheep and goats is usually extensive, except for small pockets of feedlots in the Near East and West Asia and in North America. The capacity of small ruminants, particularly goats, to grow and reproduce under conditions that cannot support any other form of agricultural production makes them useful and very often essential to poor farmers pushed into these environments for lack of alternative livelihoods. However, sheep and goats can severely reduce land cover and the potential for forest regrowth. Under overstocked conditions, they are particularly damaging to the environment through degradation of vegetative cover and soil.

Pigs in traditional mixed systems, fed on household waste and agro-industrial by-products, turn biomass that would otherwise go to waste into high-value animal protein. Pigs also require less feed per unit of output than ruminants. As such, they have lower demand for land for feed production. However, it is estimated that pigs in mixed systems now account for only about 35 percent of global production. Pig manure can be a valuable fertilizer but crop producers generally prefer cattle and poultry waste because pig manure has a strong odour and often comes in a slurry form. It is, however, well adapted to use in biogas digestors.

Poultry production systems have undergone the most extensive structural change of any livestock subsector. In OECD countries, production is almost entirely industrial, while in many developing countries it is already predominantly industrial. Among traditional livestock species (excluding fish), poultry is the most efficient feed converter, and industrial poultry production is thus the most efficient form of livestock production, despite its dependence on feedgrains and other high-value feed material. Poultry manure has a high nutrient content, is relatively easy to manage and is widely used as fertilizer; it is also sometimes used in feed for ruminants. Other than that caused by feed-crop production, the environmental damage caused by poultry is much less than that caused by other species, although it may be locally important.

Production systems

As discussed in Chapter 2, in response to escalating demand for livestock products, the livestock sector is undergoing structural change towards more capital-intensive systems, specialized and larger production units relying on purchased inputs, higher animal productivity and greater geographical concentration. This has altered the environmental impacts of the sector. It has also offered the sector new options for mitigating such impacts, with a range of cost, socio-economic and gender implications.

The structural changes in livestock production are often detrimental to the environment but also bear opportunities for mitigation. Table 13 shows preliminary observations on the environmental impacts associated with different level of intensity in production, also discussed below. With the specialization of crop and livestock activities and in areas of animal waste concentration, nutrient cycles traditionally achieved in mixed crop–livestock systems are being broken. The cost of transporting nutrients to cropland is often prohibitive (especially for water-rich slurries), and manure is disposed of in the local environment, often exceeding its absorption capacity. This often causes severe water and soil pollution, particularly in densely populated areas. However, on the positive side, the growing scale and geographical concentration of livestock production facilitate the implementation of environmental policies by reducing enforcement costs; the higher profitability of production units attenuates costs of compliance, while the concentration of production in a smaller number of easily accessible units minimizes monitoring costs.

Longer food chains, driven by the concentration of consumers in urban centres, mean that production systems have to bridge long geographical distances between the site of feed production and the consumer. Decreasing transport costs have allowed the relocation of production and processing activities to minimize production costs. Globally, this process has helped to overcome local resource constraints and allowed people located in food-deficit areas to be fed. However, it also involves large-scale extraction and transfers of nutrients and virtual water embedded in feed and animal products, with detrimental long-term consequences for ecosystems and soil fertility.

Improved animal productivity and feed conversion efficiency have been achieved through the application of a wide range of technologies, including feeding, genetics, animal health and housing. The shift towards monogastric species, and poultry in particular, has further improved the sector's feed conversion efficiency. This has resulted in substantially less land and water being needed to produce feed to achieve the levels of production to meet current demand.

Productivity gains are, however, also associated with a number of environmental concerns. The relatively low resistance to

TABLE 13
Major environmental impacts of different production systems[1]

	RUMINANT SPECIES (CATTLE, SHEEP, ETC.)		MONOGASTRICS (PIGS, POULTRY)	
	Extensive grazing[2]	Intensive systems[3]	Traditional systems[4]	Industrial systems
GREENHOUSE GAS EMISSIONS				
CO_2 emissions from land use and land-use change for grazing and feed-crop production	- - -	-	ns	- -
CO_2 emissions from energy and input use	ns	- -	ns	- -
Carbon sequestration in rangelands	+ +	ns	ns	ns
Methane emissions from digestion	- - -	- -	ns	ns
Nitrous oxide from manure	-	- - -	ns	- -
LAND DEGRADATION				
Expansion into natural habitat	- - -	ns	ns	- -
Overgrazing (vegetation change, soil compaction)	- - -	ns	ns	ns
Intensive feed production (soil erosion)	ns	- -	ns	- -
Soil fertilization	+	+	+	+ +
WATER DEPLETION AND POLLUTION				
Alteration of water cycle	- -	-	ns	ns
Pollution with nutrients, pathogens and drug residues	ns	- -	ns	- - -
BIODIVERSITY				
Habitat destruction from feed-crop production and animal wastes	- - -	-	ns	- - -
Habitat pollution from feed-crop production and animal wastes	ns	- -	ns	- - -
Loss of domestic animal genetic diversity	ns	- -	ns	- - -
Ecosystem maintenance	+ +	ns	ns	ns

[1] Observed relationships under common management practices.
[2] Extensive grazing systems for ruminants are predominantly based on natural grasslands in marginal environments.
[3] Intensive systems for ruminants are generally based on improved grasslands (using irrigation, fertilizers, improved varieties and pesticides), with supplementary feeding or confined feeding of grain and silage.
[4] Traditional systems for monogastrics include mixed farming systems or backyard scavenging systems.
Note: ns = not significant.
Source: FAO.

diseases of highly productive breeds, the concentration of large numbers of animals in large production units and the need to avoid disease outbreaks has led producers to use substantial amounts of drugs, often as routine preventive measures. Residues from these drugs pass into the environment, harming ecosystems and public heath. In particular, the sometimes indiscriminate use of antibiotics has led to the selection of antibiotic-resistant strains of bacteria, now threatening human health in Europe and North America (Johnson *et al*., 2009). Highly productive breeds also require a tighter control of their environment (temperature, light) than traditional breeds, thus increasing water and energy consumption.

Deforestation and land degradation are the main processes through which extensive grazing systems emit GHGs. Range management can be improved to prevent carbon losses and sequester carbon, turning extensive systems into net GHG removers. Intensification and restoration of pasture and fodder production, driven by rising land prices, generally also have other positive environmental consequences as they limit land expansion and improve feed quality. The latter, in turn, contributes to the reduction of methane emissions from enteric fermentation. Nutrient overloads in dairy production areas have generally been related more to the import of nutrients through supplementary feed and fertilizer for silage production than to deficiencies in pasture management.

Overall, the change from traditional mixed and extensive systems to more intensive systems has probably had a positive effect in improving land- and water-use efficiency but negative effects on water pollution, energy consumption and genetic diversity. Moreover, traditional and mixed systems have been unable to meet the burgeoning demand for livestock products in many developing countries, not only in terms of volume but also in terms of sanitary and other quality standards. Intensification of production appears thus indispensable, while avoiding excessive geographical concentration of animals.

The potential to improve the environmental performance of intensive systems is also greater than for traditional and extensive systems. Experience shows that when economic incentives are properly set, productivity gains associated with capital and labour intensification significantly improve the efficiency of natural-resource use; where resources and pollution are priced appropriately, intensification of production has been associated with improved environmental efficiency (less consumption of natural resources and lower emissions per unit of animal product). This is already the case for land use on a global scale, but also for water and nutrients in an increasing number of OECD countries.

Livestock and climate change

Global average surface temperatures have increased by about 0.7 °C in the last century (IPCC, 2007). Ocean temperatures have risen, there has been significant melting of snow and ice in the polar regions and sea levels are projected to rise. The Intergovernmental Panel on Climate Change (IPCC) concludes that anthropogenic GHGs, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halocarbons, have been responsible for most of the observed temperature increase since the middle of the twentieth century.

Amid growing concerns over climate change, agriculture, particularly livestock, is increasingly being recognized as both a contributor to the process and a potential victim of it. Policy interventions and technical solutions are required to address both the impact of livestock production on climate change and the effects of climate change on livestock production.

The impact of livestock on climate change

Livestock contribute to climate change by emitting GHGs, either directly (e.g. from enteric fermentation) or indirectly (e.g. from feed-production activities, deforestation to create new pasture, etc.).

Greenhouse gas emissions can arise from all the main steps of the livestock production cycle. Emissions from feed-crop production and pastures are linked to the production and application of chemical fertilizer and pesticides, to soil organic-matter losses and to transport. When forest is cleared for pasture and feed crops, large amounts of carbon stored in vegetation and soil are also released into the atmosphere. In contrast, when good management practices are implemented on degraded land, pasture and cropland can turn into net carbon sinks, sequestering carbon from the atmosphere. At the farm level, methane (CH_4) and nitrous oxide (N_2O) are emitted from enteric fermentation and manure. In ruminant species (i.e. cattle, buffalo, goat and sheep), microbial fermentation in the rumen converts fibre and cellulose into products that can be digested and utilized by the animals. Methane is exhaled by these animals as a by-product of the process. Nitrous oxide is released from manure during storage and spreading, and methane is also generated when manure is stored in anaerobic and warm conditions. Finally, the slaughtering, processing and transportation of animal products cause emissions mostly related to use of fossil fuel and infrastructure development.

The impact of climate change on livestock

Table 14 summarizes the direct and indirect impacts of climate change on grazing and non-grazing livestock production systems. It is likely that some of the greatest impacts of climate change will be felt in grazing systems in arid and semi-arid areas, particularly at low latitudes (Hoffman and Vogel, 2008). Climate change will have far-reaching consequences for animal production through its effects on forage and range productivity. Increasing temperatures and decreasing

BOX 12
Assessing the contribution of livestock to GHG emissions

The IPCC Fourth Assessment Report presents agreed levels of overall anthropogenic GHG emissions for defined categories representing economic sectors (e.g. industry, 19.4 percent; agriculture, 13.5 percent; forestry, 17.4 percent; transport, 13.1 percent) (Barker *et al.*, 2007). The IPPC suggests that these figures should be seen as indicative, as some uncertainty remains, particularly with regard to CH_4, N_2O and CO_2 emissions. In addition, for agriculture and forestry, the above figures are expressed as gross emissions and do not take into account the existing carbon capture that is the basis for photosynthesis. Emissions associated with animal products fall across several of these categories. Feed production causes emissions in the agriculture, forestry (through land-use change), transport and energy categories. Enteric fermentation and manure management associated with livestock rearing lead to methane and nitrous oxide emissions accounted for under agriculture. Slaughtering, processing and distribution cause emissions accounted for in the industry, energy and transport categories. Taken together in a food chain approach, livestock therefore contribute about 9 percent of total anthropogenic carbon-dioxide emissions, 37 percent of methane and 65 percent of nitrous oxide emissions (FAO, 2006). The combined emissions expressed in CO_2 equivalents amount to about 18 percent of anthropogenic GHG emissions.

Along the animal food chain, the major sources and amounts of emissions are:

- Land use and land-use change: 2.5 gigatonnes of CO_2 equivalent. Includes CO_2 release from forest and other natural vegetation replaced by pasture and feed crop in the neotropics and carbon releases from soils, such as pasture and arable land dedicated to feed production.
- Feed production (excluding carbon released from soil and plants): 0.4 gigatonnes of CO_2 equivalent. Includes CO_2 from fossil fuel used in manufacturing chemical fertilizer for feed crops and N_2O and ammonia (NH_3) released by chemical fertilizers applied to feed crops and from leguminous feed crops.
- Animal production: 1.9 gigatonnes of CO_2 equivalent. Includes CH_4 from enteric fermentation and CO_2 from on-farm use of fossil fuel.
- Manure management: 2.2 gigatonnes of CO_2 equivalent. Includes CH_4, N_2O

rainfall reduce yields of rangelands and contribute to their degradation. Higher temperatures tend to reduce animal feed intake and lower feed conversion rates (Rowlinson, 2008). Reduced rainfall and increased frequency of drought will reduce primary productivity of rangelands, leading to overgrazing and degradation, and may result in food insecurity and conflict over scarce resources. There is also evidence that growing seasons may become shorter in many grazing lands, particularly in sub-Saharan Africa. The probability of extreme weather events is likely to increase.

In the non-grazing systems, which are characterized by the confinement of animals (often in climate-controlled buildings), the direct impacts of climate change can be expected to be limited and mostly indirect (Table 14). Reduced agricultural yields and increased competition from other sectors are predicted to result in increased prices for both grain and oilcakes, which are major sources of feed in non-grazing systems (OECD–FAO, 2008). The development of energy-saving programmes and policies promoting the use of clean energy may also result in increased energy prices. A warmer climate may also increase the costs of keeping animals cool.

Climate change will play a significant role in the spread of vector-borne diseases and animal parasites, which will have disproportionately large impacts on the most vulnerable men and women in the livestock sector. With higher temperatures and more variable precipitation, new diseases may emerge or diseases will occur in places where they formerly did not. Moreover, climate

and NH_3 mainly from manure storage, application and deposition.
- Processing and international transport: 0.03 gigatonnes of CO_2 equivalent.

Comparing species, cattle and buffalo are responsible for more of these emissions than are pigs and poultry (see table). Emissions associated with large ruminants are predominantly related to land-use changes (such as deforestation), pasture management, enteric fermentation and manure management. Cattle and buffalo are responsible for an especially large share of the livestock sector's emissions in Latin America and South Asia, where they are estimated to account for more than 85 percent of the sector's emissions, mainly in the form of methane.

Emissions of greenhouse gases along the animal food chain and estimated relative contribution from major species

STEP IN ANIMAL FOOD CHAIN	ESTIMATED EMISSIONS[1]		ESTIMATED CONTRIBUTION BY SPECIES[2]			
	(Gigatonnes)	(Percentage of total livestock sector emissions)	Cattle and buffaloes	Pigs	Poultry	Small ruminants
Land use and land-use change	2.50	36	■■■	■	■	ns
Feed production[3]	0.40	7	■	■■	■■	ns
Animal production[4]	1.90	25	■■■■	■	■	■■
Manure management	2.20	31	■■	■■■	ns	ns
Processing and transport	0.03	1	■	■	■■■	ns

[1] Estimated quantity of emissions expressed as CO_2 equivalent.
[2] ■ = lowest to ■■■■ = highest.
[3] Excludes changes in soil and plant carbon stocks.
[4] Includes enteric methane, machinery and buildings.
Note: ns = not significant.
Source: Adapted from Steinfeld *et al.*, 2006.

TABLE 14
Direct and indirect impacts of climate change on livestock production systems

	GRAZING SYSTEMS	NON-GRAZING SYSTEMS
DIRECT IMPACTS	• Increased frequency of extreme weather events • Increased frequency and magnitude of drought and floods • Productivity losses (physiological stress) due to temperature increase • Change in water availability (may increase or decrease, according to region)	• Change in water availability (may increase or decrease, according to region) • Increased frequency of extreme weather events (impact less acute than for extensive systems)
INDIRECT IMPACTS	• Agro-ecological changes and ecosystem shifts leading to: – alteration of fodder quality and quality – changes in host–pathogen interactions resulting in an increased incidence of emerging diseases – disease epidemics	• Increased resource prices, e.g. feed, water and energy • Disease epidemics • Increased cost of animal housing, e.g. cooling systems

Source: FAO.

change may result in new transmission mechanisms and new host species. All countries are likely to be subject to increased animal-disease incidence but poor countries are more vulnerable to emerging diseases because of the paucity of veterinary services.

Can climate change benefit livestock? There may be some positive outcomes for the livestock sector from warmer temperatures, but this largely depends on when and where temperature changes happen. General conclusions thus cannot be drawn. For example, higher winter temperature can reduce the cold stress experienced by livestock raised outside. Furthermore, warmer winter weather may reduce the maintenance energy requirements of animals and reduce the need for heating in animal housing.

Improving natural-resource use by livestock production

Measures need to be taken to address the impact of livestock production on ecosystems, which otherwise may worsen dramatically given the projected expansion of the livestock sector. Demand for animal products needs to be balanced with the growing demand for environmental services, such as clean air and water, and recreation areas.

Current prices of land, water and feed resources used for livestock production often do not reflect the true scarcity value of these resources. This leads to their overuse and to major inefficiencies in the production process. Policies to protect the environment should introduce adequate market pricing for the main inputs, for example, by introducing full-cost pricing of water and grazing. Defining men's and women's property rights and access rights to scarce shared resources is also a key factor in ensuring efficient resource use and preservation of natural resources.

A host of tested and successful technical options are available to mitigate environmental impacts of agricultural activities (Steinfeld *et al*., 2006). These can be used in resource management, in crop and livestock production, and in reduction of post-harvest losses. However, for these to be widely adopted and applied requires appropriate price signals that more closely reflect the true scarcities of production factors, and correction of the distortions that currently provide insufficient incentives for efficient resource use. The recent development of water markets and more appropriate water pricing in some countries, particularly those facing water scarcity, are steps in that direction.

Correcting for environmental externalities

Although the removal of price distortions at the input and product levels will go a long way to enhancing the technical efficiency of natural-resource use in livestock production, this often may not be sufficient to control the sector's environmental impacts more effectively. Externalities[4], both negative and positive, need to be explicitly factored into the policy framework so that the full costs of pollution and other negative environmental impacts are recognized. The application of the "provider gets – polluter pays" principle can be helpful, although the challenge for society is to decide who has the right to pollute and how much.

Correcting for externalities, both positive and negative, will lead livestock producers to make management choices that are less costly to the environment and to society at large. Livestock holders who generate positive externalities need to be compensated, either by the immediate beneficiary (such as for improved water quantity and quality for downstream users) or by the general public (such as for carbon sequestration from reversing pasture degradation).

While regulations remain an important tool in controlling negative externalities, there is a trend towards taxation of environmental damage and provision of financial incentives for environmental benefits. This may gain momentum in future, initially tackling local externalities but increasingly addressing also transboundary impacts through international treaties, underlying regulatory frameworks and market mechanisms. Government policies may be required to provide incentives for institutional innovation in this regard.

The opportunity cost for livestock to use marginal land is changing. In many regions, livestock occupy land for which there is no viable alternative use. Increasingly, other uses (e.g. biodiversity conservation, carbon sequestration, production of feedstock for biofuels) are competing with pasture in some regions. In future, next-generation ethanol production from cellulosic material may emerge as another competitor for rangeland use. Water-related services will probably be the first to grow significantly in importance, with local service provision schemes the first to be widely applied. Biodiversity-related services (e.g. species and landscape conservation) are more complex to manage because of major methodological issues in the valuation of biodiversity, but they already find a ready uptake where they can be financed through tourism revenues. Carbon sequestration services, through adjustments in grazing management or abandonment of pastures, may also play a much larger role; given the potential of the world's vast grazing lands to sequester large amounts of carbon, mechanisms are being developed to use this potentially cost-effective avenue to address climate change.

Suggesting a shift from current extractive grazing practices to practices that enhance the provision of environmental services raises two questions of paramount importance: How should the profits from environmental services be distributed? And how can poor people who currently derive their livelihoods from extensive livestock benefit from this? *The State of Food and Agriculture 2007* discussed the concept of payments for environmental services and the implications for poverty alleviation in detail (FAO, 2007a).

Accelerating technological change

A number of technical options could lessen the impacts of intensive livestock production. Good agricultural practices can reduce pesticide and fertilizer use in feed cropping and intensive pasture management. Integration of ecological production systems and technologies can restore important soil habitats and reduce degradation. Improvements in extensive livestock production systems can also make a contribution to biodiversity conservation, including, for example, adoption of silvipastoral and flexible grazing management systems that actually increase biodiversity, quantity of forage, soil cover and soil organic matter and thus reduce water loss and drought impact and increase CO_2 sequestration. Combining such local improvements with restoration or conservation of an ecological infrastructure at the watershed level may offer a good way to reconcile the conservation of ecosystem function with the expansion of agricultural production.

In industrial and mixed production systems, there is a large gap between current levels of productivity and levels that are technically

[4] An externality is an unintended or undesired side-effect of an economic activity that harms (negative externality) or benefits (positive externality) another party.

attainable, indicating that considerable efficiency gains can be realized through better management. However, achieving these is more difficult in resource-poor areas, which are often also ecologically more marginal areas.

Improved and efficient production technologies exist for most production systems. However, access to relevant information and the capacity to select and implement the most appropriate technologies are constraining factors. These constraints can be reduced through interactive knowledge management, capacity building and informed decision-making at the policy, investment, rural development and producer levels. Technological improvements need to be oriented towards optimal integrated use of land, water, human, animal and feed resources.

Reducing the negative environmental impacts of intensive livestock production

The environmental problems created by industrial systems mostly derive from their geographical location and concentration. In extreme cases, size may be a problem – sometimes units are so large

BOX 13

The European Union – integrating environmental protection requirements into the Common Agricultural Policy

Since the Agenda 2000 reform (March 1999), the Common Agricultural Policy (CAP) of the European Union (EU) has had two pillars: a market and income policy (first pillar); and a policy to promote the sustainable development of rural areas (second pillar). A number of measures introduced with the 2003 CAP reform (effective as of January 2005) and the Rural Development Policy 2007–2013 are expected to lead to a mitigation of the environmental impact of livestock production through the following:

- **Decoupling.** The Single Farm Payment decoupled from production has replaced most of the direct payments under different Common Market Organizations. This implies reducing many of the incentives for intensive production associated with increased environmental risks, thus encouraging extensification, decreased livestock numbers, reduced fertilizer use, etc. However, Member States have been allowed to keep a part of the payments coupled, *inter alia*, the suckler cow premium (up to 100 percent), the special beef premium (up to 75 percent), the slaughter premium for cattle (up to 40 percent for adults and 100 percent for calves) and the sheep and goat premium (up to 50 percent).
- **Cross-compliance.** The full granting of income support is now conditional on the respect of: statutory management requirements (relating to the environment, animal welfare and public, animal and plant health), including those stemming from five environmental Directives; minimum standards of good agricultural and environmental conditions (GAECs); and the obligation to maintain land under permanent pasture. This is a further incentive to comply with environmental legislation such as the Nitrates Directive (reduced fertilizer use and improved practices, e.g. for manure management). The GAECs have to include, *inter alia*, provisions related to the maintenance of soil organic-matter levels (e.g. crop rotation and arable stubble management), the protection of soils against erosion and the maintenance of carbon sinks (e.g. through the requirement to maintain permanent pasture).
- **Assistance to sectors with special problems** (so-called Article 69 measures). Member States may retain by sector (e.g. livestock sector) up to 10 percent of national budget ceilings for direct payments. Payments are made to farmers in the sector (or sectors) concerned by

(hundreds of thousands of pigs, for example) that waste disposal will always be an issue, no matter where these units are located.

What is required, therefore, is to bring the amount of waste generated into line with the capacity of locally accessible land to absorb that waste. Industrial livestock must be located as much as possible where cropland within economic reach can be used to dispose of the waste, without creating problems of nutrient loading, rather than geographically concentrating production units in areas favoured by market access or feed availability, as at present. Policy options to overcome the current economic drivers of the peri-urban concentration of production units include zoning, mandatory nutrient management plans, financial incentives and facilitation of contractual agreements between livestock producers and crop farmers (see Box 14). In Thailand, high taxes were levied on poultry and pig production within a 100 km radius of Bankok, while areas further away enjoyed tax-free status. This led to many new production units being established away from the major consumption centre (Steinfeld *et al*., 2006).

the retention. They can be spent in specific types of farming important for the protection or enhancement of the environment or improving the quality and marketing of agricultural products.

- **Modulation.** The Agenda 2000 reform introduced the possibility of shifting support from market policy to measures contributing to environmentally benign practices (the concept is referred to as “modulation”). The 2003 CAP reform made modulation a compulsory measure, with direct payments having to be reduced (by 3 percent in 2005, 4 percent in 2006 and 5 percent in the years from 2007 onwards). The funds are being shifted into rural development, increasing the possibility to stimulate the adoption of environmentally friendly production techniques.

The rural development regulation for the period 2007–2013 provides further opportunities to strengthen the contribution of the CAP to improving the environment. Three key priority areas related to the environment were defined in the Community strategic guidelines for rural development: climate change, biodiversity and water.

In 2008, the CAP underwent a so-called “Health Check” reform. The reform, in addition to eliminating or phasing out some production-constraining measures (abolition of set-aside of arable land and gradual phasing out of milk quotas), strengthened some of the aforementioned instruments. Beef and veal payments, except the suckler cow premium, are to be fully decoupled by 2012 at the latest. Cross-compliance was amplified with a new GAEC standard concerning the establishment of buffer strips along watercourses. Measures to address disadvantages for farmers in certain regions (Article 68 [ex-Article 69] measures) were made more flexible, covering farmers in the dairy, beef and sheep and goat meat sectors (and in the rice sector) in disadvantaged areas as well as economically vulnerable types of farming in these sectors. The modulation rate was increased by 5 percent, in four steps from 2009 to 2012, and an additional reduction in payments by 4 percent is applied to payments exceeding €300 000 (about US$425 000). The funds thus obtained are transferred to rural development for the financing of new operations (biodiversity, water management, renewable energies, climate change, accompanying measures for dairy production, and innovation).

Source: EU Commission Web site (ec.europa.eu/agriculture/index_en.htm).

BOX 14
Reducing nitrate pollution in Denmark

In Denmark, the intensification of agriculture during the last 50 years disturbed the natural nitrogen cycle, causing significant emissions of ammonia to the atmosphere and nitrate pollution of water. High concentrations of nitrates in groundwater and surface water impaired drinking water quality (EEA, 2003) and caused eutrophication of lakes and coastal marine areas. In the early 1980s, public concern over eutrophication of Danish coastal waters helped motivate the Danish Government to regulate nitrogen emission from the country's agriculture sector.

Beginning in 1985, Denmark adopted a series of action plans and regulatory measures that have dramatically increased nitrogen use efficiency in agriculture and reduced nitrogen pollution (Mikkelsen *et al.*, 2009). Among other things, these plans required livestock producers to increase manure slurry storage capacity, stop spreading slurry during the winter months, adopt mandatory fertilizer budgets to match plant uptake to nutrient applications, install covers on slurry tanks, and reduce stocking density in some areas. In 2001, the Ammonia Action Plan provided subsidies to encourage good manure handling in animal housing and improved housing design, required covers on dung heaps, banned slurry application by broadcast spreader, and required slurry to be incorporated into the soil within 6 hours of application.

The main instruments of nitrogen regulation in Denmark are mandatory fertilizer and crop-rotation plans, with crop-specific limits on the amount of plant-available nitrogen that can be applied, and statutory norms for the utilization of nitrogen from animal manure. The norms reflect how much nitrogen in the manure is assumed to be plant-available. This also sets a limit on how much mineral fertilizer each farmer may apply. Each year, farmers are required to inform the Ministry of Food how much mineral nitrogen fertilizer they have purchased. The application of nitrogen from animal manure and mineral fertilizer cannot exceed the total nitrogen norm for a given farm.

The regulations have been very successful in reducing nitrogen leaching from soils. However, nitrogen leaching in some water basins is still high and further regional reduction may be needed to achieve good ecological quality in all coastal waters (Dalgaard *et al.*, 2004).

Regulations are also needed to deal with heavy-metal and drug-residue issues at the feed and waste levels, and to address other public health aspects, such as food-borne pathogens.

Both industrialized and more-extensive livestock production systems need to strive to minimize possible emissions, with waste management adapted to local conditions. In parallel, there is a need to address the environmental impacts associated with production of feedgrain and other concentrate feed. Feed is usually produced in intensive agricultural systems, and the principles and instruments that have been developed to control environmental issues there need to be widely applied.

Dealing with climate change and livestock

Livestock can play an important role in both adapting to climate change and mitigating the effects of climate change on human welfare. Efforts to mitigate the effects of livestock on climate change focus on reducing GHG emissions from livestock. Livestock can also help the poor adapt to the effects of climate change. The ability of communities to adapt to and mitigate climate change depends on their socio-economic and environmental circumstances and their access to the right information and technology.

An important question to consider is how to blend adaptation and mitigation strategies. This requires a careful analysis of the trade-offs between economic growth, equity and environmental sustainability. Dealing with climate change poses challenges for growth and development, particularly in the low-income countries, but there are also significant synergies between adaptation and mitigation actions, e.g. improved range management can both sequester carbon and improve grassland productivity.

Strategies for adaptation

There is an urgent need for effective strategies for adapting to climate change. Climate change is occurring much faster than adaptation. It can exacerbate already existing vulnerabilities and increase the impact of other stresses, such as natural disasters, poverty, unequal access to resources, food insecurity and incidence of animal diseases.

Livestock producers have traditionally adapted to environmental and climate changes. However, increased human population, urbanization, economic growth, growing consumption of foods of animal origin and commercialization have made those coping mechanisms less effective (Sidahmed, 2008). Coping and risk management strategies are urgently needed.

Livestock are key assets held by poor people, particularly in pastoral and agropastoral systems, fulfilling multiple economic, social, and risk management functions. Livestock are also a crucial coping mechanism in variable environments; as this variability increases, they will become even more important. For many poor people, the loss of livestock assets means a decline into chronic poverty with long-term effects on their livelihoods.

There are a number of ways to increase the adaptation capacity of traditional producers in extensive systems (Sidahmed, 2008). These include:

- *Production adjustments* through: (i) diversification, intensification, integration of pasture management, livestock and crop production, changing land use and irrigation, altering the timing of operations, conservation of nature and ecosystems; and (ii) introduction of mixed livestock farming systems, i.e. stall feeding and grazing.
- *Breeding strategies*, such as: (i) strengthening local breeds, which are adapted to local climate stress and feed sources; and (ii) improving local breeds through cross-breeding with heat- and disease-tolerant breeds.
- *Market responses* through promoting interregional trade, credit schemes and market access.
- *Institutional and policy changes*, e.g. introduction of livestock early-warning systems, and other forecasting and crisis-preparedness systems.
- *Science and technology research* to provide greater understanding of the causes of climate change and its impact on livestock, to facilitate development of new breeds and genetic types, to improve animal health, and to improve water and soil management.
- *Livestock management systems* to allow efficient and affordable adaptation practices to be developed for rural poor who are generally unable to purchase expensive adaptation technologies. Systems should: (i) provide shade and water to reduce heat stress from increased temperature, a natural low-cost alternative to air-conditioning; (ii) reduce livestock numbers, using more productive animals to increase efficiency of production while reducing GHG emissions; and (iii) adjust the livestock numbers and herd composition to optimize use of feed resources.

There is reasonable information on the component pieces of livestock systems and how they may be affected by climate change. At the systems level, however, less is known about how these changes may interact to affect livelihoods. These interactions must be understood at the micro level in order to tailor adaptation strategies. At the same time, there is a need to identify vulnerable populations more clearly as a key step in assessing adaptation needs. This urgently calls for research programmes that can support the development of national and regional policies.

Strategies for mitigation

Many impacts of climate change can be avoided, reduced or delayed. It is important to stress that adaptation and mitigation efforts cannot eliminate all impacts of climate change and sometimes are in conflict. In identifying mitigation strategies, it is essential to bear in mind the cost of implementation and potential trade-offs with adaptation needs. Reforestation is considered cost-effective, but other strategies may not be easy to implement or cost-effective.

The impact of livestock on climate change is largely through their production of GHGs (see "The impact of livestock on climate change", above). Greenhouse gas emissions from the livestock sector can be reduced by changes in animal feeding management, in manure management and in management of feed-crop production:

- *Improved feeding management*. Feed composition has some effect on enteric fermentation and emission of methane from the rumen or the hindgut (Dourmad, Rigolot and van der Werf, 2008). Also, the amount of feed intake is related to the amount of waste product. A higher proportion of concentrate in the diet results in a reduction in methane emission (Lovett *et al*., 2005).
- *Reducing methane produced during digestion*. Methane production in the digestive system of the animal (especially ruminants) can be reduced by use of feed additives, antibiotics or vaccines (UNFCCC, 2008).
- *Improved feed conversion*. Reducing the amount of feed required per unit of output (beef, milk, etc.) has the potential to both reduce the production of GHGs and to increase farm profits. Feed efficiency can be increased by developing breeds that are faster growing, and that have improved hardiness, weight gain or

BOX 15

Tapping the climate change mitigation potential of improved land management in livestock systems

Agricultural systems that combine improved pasture management with soil improvements (reduced soil disturbance and improved soil cover) can lock up more carbon in soils and biomass, emit less methane (CH_4) per unit product and release less nitrous oxide (N_2O) than less-well-run systems. Many of these measures can also increase productivity by enhancing the amount of fodder available and increasing the water-holding capacity of the soil. In Latin America, a project that introduced silvipastoral measures (improved feeding practices with trees and shrubs) to increase biodiversity and carbon sequestration, was shown also to increase carbon storage and reduce CH_4 and N_2O emissions (by 21 percent and 36 percent, respectively) (World Bank, 2008b). The land-use changes were also shown to raise incomes by 55.5 percent in Costa Rica and 66.9 percent in Nicaragua (World Bank, 2008b).

More widespread adoption of improved land management techniques for greenhouse gas mitigation is currently hindered, in part, by high costs faced by individual producers trying to access carbon markets. Accessing the carbon market is currently an expensive and complex process, requiring substantial upfront investment in financial and biophysical analysis before carbon credits can be sold. Concerns over permanence and additionality[1] of these sink-enhancing activities, investment risks and accounting uncertainties have prevented most land-based mitigation measures from becoming eligible for offsets under the Kyoto mechanisms. So far, only animal waste management (methane capture and combustion) and afforestation or reforestation activities are allowed as offsets in the compliance market. These offsets account for only about 1 percent of the total value of offsets issued under the Clean Development Mechanism (CDM) in 2007, or about US$140 million out of the total of some US$14 billion available under the CDM.

Land-based mitigation options play a more prominent role in voluntary carbon markets. Currently, there are two voluntary standards issuing carbon offsets for grassland management – the Voluntary milk or egg production. Feed efficiency can also be increased by improving herd health through improved veterinary services, preventive health programmes and improved water quality.

- *Improved waste management*. Most methane emissions from manure derive from pigs, beef cattle feedlots and dairy farms, where production is concentrated in large operations and manure is stored under anaerobic conditions. Methane mitigation options involve the capture of methane by covered manure-storage facilities (biogas collectors). Captured methane can be flared or used to provide a source of energy for electric generators, heating or lighting (which can offset CO_2 emissions from fossil fuels).
- *Grazing management*. Increased use of pasture to provide feed and good pasture management through rotational grazing are potentially the most cost-effective ways to reduce and offset GHG emissions (see Box 15). The resultant increases in vegetation cover and soil organic-matter content sequester carbon, while inclusion of high-quality forage in the animals' diet contributes to reducing methane emissions per unit of product. Improved grazing management also generally improves the profitability of production.
- *Reducing deforestation*. Deforestation to provide new pasture or land to produce feed crops releases more CO_2 than any other livestock-related activity. Intensification of pasture management and feed production can reduce the land requirements per unit of animal product produced, thus curbing land-use expansion. Intensification alone is not sufficient, however, and complementary measures are required

Carbon Standard (VCS) and the Chicago-based Climate Exchange (CCX). The VCS standard, for example, has recently issued guidelines for activities aimed at generating carbon credits for improved grassland management. The improved practices aim at enhancing soil carbon stocks by increasing below-ground inputs or slowing decomposition, enhancing nitrogen-use efficiency of targeted crops, fire management, feed improvements, improved livestock genetics and improved stocking rate management (VCS, 2008). Soil carbon credits account for about half of the credits traded by CCX, and nearly 20 percent of those traded under the voluntary carbon market overall. While the voluntary market is relatively small, it has been growing quickly – from US$97 million in 2006 to US$331 million in 2007 (Hamilton *et al.,* 2008).

The high costs faced by individual producers accessing carbon markets has led to discussions on whether the current offset generation system and its strict accounting requirements are well suited to agricultural activities. These activities could instead be supported under mechanisms that require less stringent monitoring, for example at the sectoral or regional level. An increased awareness of the contribution of land management to control of greenhouse gas emissions and of the important economic and environmental co-benefits associated with some mitigation options is raising the profile of agriculture in the climate change debate in the lead-up to the United Nations Framework Convention on Climate Change (UNFCCC) Post-2012 Climate Agreement negotiations in Copenhagen at the end of 2009.

[1] Additionality refers to activities that would not have happened in the absence of the carbon finance support: (i) the proposed voluntary measure would not be implemented, or (ii) the mandatory policy/regulation would be systematically not enforced and that non-compliance with those requirements is widespread in the country/region, or (iii) the programme of activities will lead to a greater level of enforcement of the existing mandatory policy/regulation. (Adapted from UNFCCC CDM glossary, available at http://cdm.unfccc.int/Reference/Guidclarif/glos_CDM_v04.pdf.)

in order to address the other drivers of deforestation such as unclear land tenure and logging for timber.
- *Changing livestock consumption*. Shifting consumption from animal products with high associated GHG emissions (beef and sheep meat) to products with lower emissions (poultry, vegetable protein) can reduce total global GHG emissions. Increasing the consumption of livestock products by poor consumers with no or limited access to them can provide important human health benefits, but reducing high levels of consumption could help lower emissions with no adverse health effects (McMichael *et al*., 2007).

Constraints on adaptation and mitigation

There are still many gaps in our knowledge about how climate change will affect livestock production. In particular, we need to understand better how climate affects pasture and range composition and the consequences for livestock production. It has been predicted that climate change will bring with it new animal diseases. The World Organisation for Animal Health (OIE) estimates that, to date, 70 percent of all newly emerging infectious human diseases originate in animals (OIE, 2008a). What is more uncertain is to exactly what degree heat affects the biology of animals and the promotion of new diseases. We have quite good understanding of how climate change affects broad regions but are much less certain on its impacts at local levels, on localities and poor households. The way climate change alters the fragile relationship between livelihoods and production dependent on natural resources is particularly fraught with uncertainty.

Key messages of the chapter

- There is an urgent need for governments and institutions to develop and enact appropriate policies, at the national and international levels, that focus more on and account for livestock–environment interactions. Continued growth in livestock production will otherwise exert enormous pressures on ecosystems, biodiversity, land and forest resources and water quality, and will contribute to global warming.
- A key policy focus should be on correcting market distortions and policy failures that encourage environmental degradation. For example, subsidies that directly or indirectly promote overgrazing, land degradation, deforestation, overuse of water or GHG emissions should be reduced or eliminated. Market-based policies, such as taxes and fees for natural-resource use, should cause producers to internalize the costs of environmental damages caused by livestock production.
- Some negative environmental consequences from livestock production stem from problems associated with open-access common-property resources. Clarifying property rights and promoting mechanisms for cooperation are vital to sustainable management of common property.
- The application of technologies that improve the efficiency of land use and feed use can mitigate the negative effects of livestock production on biodiversity, ecosystems and global warming. Technologies that increase livestock efficiency include improved breeds, improved grazing-land management, improved herd-health management and silvipastoralism.
- Payments from public or private sources for environmental services can be an effective means to promote better environmental outcomes, including soil conservation, conservation of wildlife and landscapes and carbon sequestration.
- The livestock sector has enormous potential to contribute to climate change mitigation. Realizing this potential will require new and extensive initiatives at the national and international levels, including: the promotion of research on and development of new mitigation technologies; effective and enhanced means for financing livestock activities; deploying, diffusing and transferring technologies to mitigate GHG emissions; and enhanced capacities to monitor, report and verify emissions from livestock production.