Livestock biodiversity and sustainability

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A B S T R A C T

Sustainable development equally includes environmental protection including biodiversity, economic growth and social equity, both within and between generations. The paper first reviews different aspects related to the sustainable use of livestock biodiversity and property regimes that influence their management. The different dimensions of livestock biodiversity, from the gene to the ecosystem, have characteristics of common pool resources, club goods and private goods that affect the way they are managed, researched, invested in and exchanged. In the second part, the paper uses a country-level dataset to assess trade-offs between livestock genetic diversity and economic development goals. Despite the low resolution of country data, the results of the analysis tend to confirm the importance of economic development drivers for the risk status of breeds. Therefore, research in the valuation of non-market products and services, including ecosystem services, provided by diverse breeds would need to be intensified in order to close the mismatch between the private and public interests in breed conservation.

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1. Introduction

Sustainability is a complex and sometimes contested concept. While the overall concept is widely accepted and used, a clear definition is still problematic as different stakeholders – and stakeholders at different levels – have different interpretations (Pretty, 1995). In 1987, the Brundtland Report defined “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” The Johannesburg Declaration on Sustainable Development states that there are three fundamental “pillars” to sustainable development: environmental protection, economic growth and social equity, both in an inter- and intra-generational equity perspective. Similarly, the Convention on Biological Diversity (CBD) (art. 2) defines sustainable use as “the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations”. However, the ‘three pillars’ model is imperfect because it is based on the assumption that trade-offs can be made between the environmental, social and economic dimensions of sustainability. Different concepts aim to tackle this problem: ‘strong’ sustainability does not allow trade-offs whereas ‘weak’ sustainability permits them; and the concept of ‘critical natural capital’ is used to describe environmental goods and services that cannot be traded off (Adams, 2006). The Millennium Ecosystem Assessment (2005) again highlighted trade-offs and made clear that targets in most ‘pillars’ have not been met. In 2012, the United Nations Conference on Sustainable Development — also referred to as ‘Rio +20’ will assess the progress in meeting already agreed commitments, and address implementation gaps and new challenges for the global community.

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The paper consists of two parts. Based on a literature review, it first reviews different aspects related to the sustainable use of livestock biodiversity, property regimes that influence their management, and trade-offs that are being observed between the different dimensions, levels and actors of sustainability. Joost and Matasci (2010) created a GIS-based sustainability index for breed conservation at communal level in Switzerland that included, among others, income levels, rate of unemployment, employment in agriculture and share of farmers, and the share of grazing land. Although such high-resolution country data to identify areas favorable for or in need of conservation are not available at global level, a similar analysis was undertaken in the second part of the paper. Country-level economic and social development indicators and breed numbers available in public international databases were used to test the effects of such parameters on the status of breed diversity and to assess trade-offs between livestock genetic diversity and development goals.

2. Material and methods

A literature review formed the basis for the first part of the paper. For the second part, a dataset of 194 countries and dependent territories from the World Bank's World Development Reports (World Bank, 2008, 2010) and FAO's statistical databases for the years 2005–2007 (FAOStat, 2010) was used.

The production variables were converted into per-capita or per-ha basis. To increase the number of valid cases, combined production of meat, milk and eggs was expressed as meat-equivalent based on the average dry matter content of the different products in relation to meat (43% for milk and 76% for eggs). Also the areas of arable and permanent cropland were combined with those of pasture and meadow.

Data for national breed populations of 35 species from 194 countries and dependent territories reported in FAO's Global Databank in DAD-IS were used as dependent variables. DAD-IS provides the number of local (reported by only one country), regional and international transboundary (reported by several countries within one or across several regions) breeds and the total number of breeds, in different years, depending on the information provided by the country. Breed numbers reported in DAD-IS vary depending on the state of breed characterization; they have increased over the years with improved reporting by countries. DAD-IS also indicates the number of breeds not at-risk and those with unknown risk status, extinct and currently at-risk, in different risk categories\(^1\); such population data spanning over the past decade were available for 52% of national breed populations. Some National Coordinators are currently updating breed population data retroactively. For the analysis, breeds in different risk categories but “maintained” were grouped as being in conservation programs. Regional and international transboundary breeds were combined into transboundary breeds. The shares of local and transboundary breeds, breeds at-risk, those not at-risk and with unknown risk status, at the total breeds, and the share of breeds in conservation programs in at-risk breeds were calculated. The share of extinct-and-at-risk breeds served as a proxy for past and current threats for the survival of breeds in a country.

In a first analysis, the effect of a wide range of putative independent social, economic, trade, natural resource endowment, agricultural and livestock production and productivity variables on the dependent breed variables was tested in linear regression models (stepwise procedure PROC REG, SAS 9.2) with a significance level of 0.05 for entry in the model. The analysis centered on agricultural production variables, as data on environmental and climate change as well as on research or energy intensity are scarce. In a second step, independent variables that showed a significant effect on most of the dependent variables (not shown) were included in a full linear regression model (PROC REG, SAS 9.2) for 110 countries. For single effects that had too few cases to be included in the full model, the share of extinct-and-at-risk breeds was tested in simple linear regression models.

Independent effects included in the full model were economic development indicators, natural resource endowment indicators, livestock productivity indicators.

3. Part one: Dimensions of sustainability and trade-offs

3.1. Levels and actors

In a hierarchy of systems from global to local in which each level acts autonomously but its management decisions are influenced by the other levels (Cornelissen, 2003), sustainability definitions vary at each level with the different stakeholders' goals and their ability to manage resources and take decisions. At the global level, sustainable development includes the maintenance of the global ecosystem and the continuation of human well-being as central goals. This is ideally the level addressing global public goods such as greenhouse gas mitigation, biodiversity conservation, poverty reduction, contagious disease control or knowledge and data systems (Fig. 1). Pelletier and Tyedmers (2010) proposed sustainability boundary conditions for the livestock sector, addressing the sector's aggregate greenhouse gas emissions, biomass appropriation and reactive nitrogen mobilization; they did not cover biodiversity which is more difficult to aggregate at global level.

From an agricultural perspective, the next lower levels are those of societies or countries within which agricultural

\(^1\) Risk categories in DAD-IS: Endangered, endangered-maintained, critical, and critical-maintained.
production systems are embedded. For mainly agricultural societies, FAO (1995) has combined the two levels in its definition of “sustainable agriculture and rural development” (SARD). SARD refers to a process which is ecologically sound, environmentally sustainable, economically viable, socially just, culturally appropriate, humane, based on a holistic scientific approach and productive over the long term. However, agriculture is just one of many activities at societal level – usually one of declining importance as incomes rise. Societies expect from agriculture both the provision of safe and inexpensive food and the maintenance of environmental quality (FAO, 2010a). The continued provision of products and services by farmers is a measure of sustainability of the agricultural production system (Cornelissen, 2003). Equally, continued management of livestock populations ensures the breeds’ further development and survival.

Considering the livestock holding or farm as the lowest sustainability and management level, farmers are usually interested in farm productivity for their own food security and livelihoods. In market oriented systems, productivity is commonly measured as input–output or cost–benefit ratio. Optimal productivity allows the individual farm or corporation to continue its operation and, in market economies, to stay in business (Cornelissen, 2003). This level of sustainability definition is also used by the commercial sector (Adams, 2006); for example the Code of Good Practice for Farm Animal Breeding and Reproduction Organisations (EFFAB, 2009; FABRE-TP, 2006) describes “Sustainable breeding” as balancing food safety and public health, product quality, genetic diversity, efficiency, environment, animal health and welfare in an economically viable way by professional organizations.

3.2. Dimensions of livestock biodiversity

According to the CBD, agricultural biodiversity includes all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute and sustain key functions of the agro-ecosystem.2 Agricultural biodiversity has several dimensions: the variety and variability of animals, plants and micro-organisms at the genetic, species and ecosystem levels, biotic factors, and socio-economic and cultural factors. As domesticated animals used for food and agriculture are a part of wider agricultural ecosystems, the paper uses ‘livestock biodiversity’ in the same wide sense as agricultural biodiversity. At the species level, more than 35 species are currently reported in FAO’s global databank. Livestock gene level ‘genetic diversity’ and options for its utilization are usually discussed in terms of the genetic components of breeds. ‘Breeds’ are cultural concepts rather than physical entities, and these concepts differ from country to country, making characterization only at the genetic level rather difficult (Boettcher et al., 2010).

In April 2010, a global total of 8075 breeds have been reported to FAO (DAD-IS, 2010). This includes 1053 transboundary breeds, of which 490 are regional transboundary breeds occurring only in one region and 563 are international transboundary breeds with a wider distribution (Table 1). These breed populations represent unique combinations of genes for production and functional traits but also the ability to adapt to local conditions, including feed and water availability, climate and diseases.

Genetic diversity is the basis of global food supply. Livestock’s so-called ‘provisioning services’ predominate in most production systems (MEA, 2005): Livestock currently provides 43% of global agricultural output in value terms, with a projected increase (FAO, 2010a). Traditional livestock systems based on local breeds contribute to the livelihoods of 70% of the world’s rural poor. Equally important but economically undervalued are the ‘cultural’, ‘supporting’

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2 COP decision V/5, appendix.
and 'regulating' services (CBD, 2010b; MEA, 2005) provided by livestock: Many local breeds deliver a wide range of ecosystem services and products – each at a low level of output – that supports the livelihoods of their keepers as integral components of agricultural ecosystems, economies and cultures. In addition to playing important roles in nutrition and diets, animals and foods of animal origin have strong socio-economic and cultural functions in many societies. They assist in nutrient cycling, waste product recycling and seed dispersal, provide transport, draught power and serve as means of wealth accumulation (FAO, 2009b). Those diverse products and services are not usually accounted for, partly due to data collection and methodological problems in dealing with non-market products; however, their value can exceed that of market products in many production systems.

Sustainable use of livestock genetic resources depends on the continued use of between and within breed genetic diversity. However, 676 breeds (8%) are classified as extinct, of which only 7 are transboundary breeds. A total of 1 677 breeds (21%) are classified as being at risk, 21% of all local, 24% of all regional and 11% of all international transboundary breeds. For another 36% of breeds the risk status is unknown (DAD-IS, 2010; Table 1). In comparison, the IUCN Red List reports 14% of species with insufficient data and 36% of species threatened with extinction (CBD, 2010b).

Because of the degree of human management, the conservation of livestock genetic diversity is inherently linked to its sustainable use in production systems. Under-utilization is a bigger threat to genetic resources for food and agriculture than over-use – this is in contrast to natural biodiversity. The use value far exceeds the option and existence value, therefore benefits arising from the current or potential use provide the major incentives for conservation (Drucker et al., 2005). Nonetheless, much genetic diversity is now conserved *ex situ* in public gene banks or breeders’ collections (FAO, 2007a).

### Table 1

<table>
<thead>
<tr>
<th>Breed Status</th>
<th>Local breeds</th>
<th>Regional breeds</th>
<th>International breeds</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>At-risk</td>
<td>511</td>
<td>33</td>
<td>19</td>
<td>563</td>
</tr>
<tr>
<td>Critical</td>
<td>73</td>
<td></td>
<td></td>
<td>73</td>
</tr>
<tr>
<td>Endangered</td>
<td>678</td>
<td>84</td>
<td>36</td>
<td>798</td>
</tr>
<tr>
<td>Endangered-maintained</td>
<td>243</td>
<td></td>
<td></td>
<td>243</td>
</tr>
<tr>
<td>Extinct</td>
<td>669</td>
<td>7</td>
<td></td>
<td>676</td>
</tr>
<tr>
<td>Not at risk</td>
<td>2101</td>
<td>282</td>
<td>431</td>
<td>2814</td>
</tr>
<tr>
<td>Unknown</td>
<td>2747</td>
<td>84</td>
<td>77</td>
<td>2908</td>
</tr>
<tr>
<td>Total</td>
<td>7022</td>
<td>490</td>
<td>563</td>
<td>8075</td>
</tr>
</tbody>
</table>

3.3. Property regimes

Sustainability is a result of the way natural resources and social, economic and political processes are managed; therefore property regimes that influence resource management play a crucial role. The different dimensions of livestock biodiversity, from the gene to the ecosystem, have characteristics of common pool resources, club goods and private goods that affect the way they are managed, researched, invested in and exchanged (Fig. 1).

Pure private goods are rival and excludable, therefore usually easy to manage, as costs for their use are attributable to individual users. Several pure private goods such as input supplies (e.g. provision of breeding animals), or reproduction and breeding services occur at herd level where the individual animals are kept and breeding decisions taken. At the society level, the economically complex impure public goods (common-pool resources such as communal rangelands, water (volume and quality), and club goods such as standards and certification schemes) come to play.

However, the distinction between the dimensions of livestock biodiversity and property regimes is not that clear-cut. While the individual animal is privately owned (individually or collectively; FAO, 2009b) and access to its genetic properties can be controlled, access to the breed population as a whole cannot usually be controlled. Genetic improvement, breeding and reproduction services are normally considered a purely private good in that the livestock keepers capture all benefits. However, insofar as they contribute to food security and poverty reduction which are considered a public good, some level of government support may be warranted (Fig. 1); such government support was critical for the development of structured animal breeding and related services in most developed countries. If breeding services are linked to membership in a breed society, they become something of a club good. Certification schemes such as geographical indication and/or for products from animals of specific breed are also club goods (World Bank, 2009).

As property rights to all – or at least some – attributes of a good may be imperfect, externalities arise and generate problems of open access or moral hazard. Unlike pure public goods, which are not subtractable, common pool resources face problems of overuse. Club goods which are excludable are generally easier to manage than common pool resources (Fig. 1). Externalities occur in that price for livestock inputs and products do not normally account for their true environmental costs, costs of resources use may not be attributable to individual users, and transaction costs for resource management can be considerable (FAO, 2010a).

Usually, resource scarcity and institutional governance in property regimes co-evolve. In traditional pastoral societies, exchange of livestock is often a critical component in the maintenance of social assets. As the value of a breed’s unique genetic material becomes understood and recognized, the interests of different stakeholders to exercise property rights over this breed increases. In general, as a livestock species or breed becomes more valuable and the specialized knowledge about it increases, the willingness to share the genetic resources and associated knowledge decreases. This rule applies equally to commercial breeders of developed countries and pastoral breeders of developing countries. For example, in some dryland areas, the special knowledge needed for camel breeding is still in the hands of the traditional camel pastoralists (FAO, 2009b; Hoffmann and Mohammed, 2004). In a similar club good fashion, commercial breeders keep their breeding lines and breeding programs under tight control; this may include the use of contracts, trade secrets or patents (Gura, 2008).

Property rights and values also depend on the state of knowledge and technology: While livestock keepers are
mainly interested in macro-structure such as phenotypic traits (production and reproduction performance, appearance or functionality), the global society tends to explore rather the micro-structure such as genetic variation at the molecular level (Anderson and Centonze, 2006; FAO, 2010d). And although the interaction among the environment, genetic resources and management practices in livestock farming often contributes to maintaining a dynamic portfolio of breed diversity, most research, especially that aimed at increasing production, targets the genetic level, especially as it relates to market output, rather than the ecosystem level. Research and interventions mostly focus on commercially relevant production systems, species and breeds (Ludena et al., 2007), while most local breeds are not well characterized and their adaptation to environmental stresses is not well understood. This is likely the result of both financial and practical reasons, i.e. it may be easier to get funding for such research, because a single donor may benefit, but it is also much simpler to look at very specific one-to-one relationships than at complex systems. The results may be more easy to generalize and distribute, as the effect of a gene may be the same (or at least similar) across many breeds (even species) and production systems.

Disparities also arise in the appreciation of value, partly due to the different technologies used to assess and access the dimensions of animal genetic resources (Anderson and Centonze, 2006). The vast majority of the 7022 reported local breeds (DAD-IS) have been developed by natural selection and simple techniques of mating control and selection used by the local livestock keepers, without access to modern breeding technologies. FAO (2009b) provides an overview of small-scale livestock keepers' breeding management and related exchange practices in property regimes. However, the technology innovation linked with the genomic revolution and the related legal changes (IPRs, patenting) has allowed new players to enter the livestock industry. In the past few years, agrochemical and pharmaceutical companies have heavily invested in gene detection and analysis. Together with the sequencing and the bioinformatics needed to analyze the huge amounts of data generated, these new stakeholders may acquire knowledge over gene functions that are increasingly separate from the genetic material itself. On the other hand, livestock keepers that are part of recording schemes may retain their control as the value of phenotypes increases, especially for traits that are difficult or expensive to measure (Tier, 2010).

Conservation is often characterized by mismatch between costs and benefits, at spatial and stakeholder levels. The World Bank (2009) classified conservation of livestock diversity as a global public good with a high degree of non-rivalry and moderate degrees of “globalness” and non-excludability. “Globalness” means that certain features of global public goods are national but cannot be provided adequately through domestic policy action alone; instead, they require international cooperation to be available locally. The flipside of “globalness” is that many countries need to be involved in the solution whereas the benefits to an individual country’s conservation may be only moderate. The Global Plan of Action for Animal Genetic Resources lists conservation measures for threatened breeds as one of its priorities (FAO, 2007b).

Discourse about global public goods also takes place in research. It is argued that not all public goods need to be produced by the public sector itself and that research deals with many impure public goods. Consequently, various forms of partnership with interested stakeholders should invest in and deliver quasi-public research and development results (Beintema and Elliott, 2009). The private sector has become an increasingly important contributor to research and development in agriculture, especially for the agricultural input and processing sectors and in countries where markets have been liberalized and intellectual property rights strengthened (OECD-FAO, 2009).

3.4. Sustainability of livestock genetic diversity

Livestock biodiversity has always been dynamic; new breeds have emerged and others have disappeared as environments and societies have changed. Livestock genetic diversity today is rapidly declining globally as specialization in plant and animal breeding and the harmonizing effects of globalization advance (CBD, 2010b). One reason for this are trade-offs that exist between genetic management at farm or herd level and a) economic development goals, b) broader environmental goals and c) conservation of breeds in the interest of society.

The considerable negative environmental externalities of livestock production are not reflected in the costs of livestock products (FAO, 2010a). Trade-offs occur between goals at each level, and between levels, influenced by property regimes and scales. In most cases, governments and businesses that allow trade-offs in their development decisions put the highest emphasis on the economic dimensions of sustainability with provisioning services taking predominance over the other ecosystem services (Adams, 2006).

3.4.1. On-farm diversity, economic development goals and food security

Local breeds are mostly found in grassland-based pastoral and small-scale mixed crop–livestock systems with low to medium use of external inputs, where they are kept in support of livelihoods and rural food security. 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%. Some of these breeds occur very localized (FAO, 2009a).

In addition to policies that favor intensive livestock production, 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 favorable to intensive production that in many countries provided incentives such as market infrastructure, credit, labor and environmental policies (FAO, 2010a). 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 (Delgado et al., 1999).

Between 1980 and 2009, global meat output grew on average at 3.7% per year, milk at 1.7% and eggs at 5.0% (FAO Stat, 2010). Globally, this production increase was due to
increases in stocks rather than productivity and has been accompanied by rapid structural change and a growing dichotomy between large-scale and small-scale production (FAO, 2010a). However, the global production trends mask high variability between species, breeds and livestock production systems, both within and between regions. The differences are larger in ruminants than in monogastrics (Ludena et al., 2007), for which industrial systems prevail in both developed and developing regions.

Livestock kept in large-scale operations utilizing sophisticated technology and based on internationally sourced feed and animal genetics is playing an increasing role in global food supply. Extrapolating the figures of Steinfeld et al. (2006) and assuming that the production increase between the early 2000s and 2009 is 100% attributable to industrial systems, we can now estimate that industrial systems provide 79% of global poultry meat, 73% of egg and 63% of global pork production.

Genetic improvement is estimated to contribute between 50% (Shook, 2006) and 80% (Havenstein et al., 2003) to overall productivity increase, and countries with commercial breeding programs far exceed the production output per animal of the rest of the world (Fig. 2). Some breeds of the five major livestock species (cattle, sheep, goats, pigs and chickens) have now been developed for a century or more in intensive production systems; they generally provide a single primary product for the market, based on the use of high levels of external inputs. Some of these breeds have spread globally. International transboundary avian and mammalian breeds dominate in the South–West Pacific and North America. Within this transboundary group, a very small number of international transboundary breeds account for an ever increasing share of total production (FAO, 2007a). In poultry, the majority of genetic material is today supplied by less than five globally operating corporations, and a similar concentration trend is ongoing in pig, followed by dairy breeding.

Most flows of genetic material occur among developed countries that fulfill the animal health regulatory require-
ments 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 is increasing, however, from 20% in 1995 to 30% in 2005 (Gollin et al., 2008).

In a global economy where livestock keepers are mere price-takers, information asymmetry, various biases and market imperfections have implications for breed diversity (Hoffmann, 2010):

- Current agrifood research in developed countries tends to address genomic selection, animal welfare, food quality and safety, environment, climate change and protein-rich alternatives to meat (EU Agri Mapping, 2007; OECD, 2009). Work on livestock production systems and non-molecular biotechnologies, and on technologies in breeding, processing and handling livestock products that are appropriate to small-scale producers and their environments is progressively becoming a smaller part of the agricultural R&D “mix” (FAO, 2010c). Technologies have also become less mobile because of stricter intellectual property rights and other regulatory policies. For developing countries, the decline in productivity-enhancing research in developed countries means that the potential spillover benefits to them will be reduced, just as resource constraints get worse (Pardey et al., 2006) and agricultural production needs to increase (Bruinsma, 2009).
- Many modern reproductive and breeding technologies are not scale-neutral. The high-throughput genotyping, with sophisticated phenotyping and bioinformatics tools needed for their calibration, is most likely to be used in developed countries (Tixier-Boichard et al., 2008). The advantages and applicability of genomic selection for developing countries with low institutional capacity remain to be seen. Tier (2010) concluded that the availability of exact phenotypes needed for genomic selection is already a problem in developed country beef and sheep industries. In the meantime, the performance differentials between locally adapted 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 programs. Developing countries are also less likely to be capable of planning and conducting the necessary well-designed genetic comparisons of local and introduced breeds before a widespread introduction (Reintema and Elliott, 2009; OECD-FAO, 2009).
- The prevailing information bias tends to disadvantage local breeds which are usually not well characterized phenotypically or genetically, rarely improved through structured breeding programs or included in conservation programs. In contrast, several international transboundary breeds are well characterized and their genetic improvement is supported by efficient, sometimes global, breeding programs. Some gene banks exist, often as back-ups from regular artificial insemination programs. Many international transboundary breeds have effective international marketing and distribution networks. In some countries, their introduction is supported by subsidies or development projects (FAO, 2007a).
- Although significant non-market values are associated with the various goods and services provided by many}

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Fig. 2. Production differential (%) between selected developed countries that have commercial breeding programs and the rest of the world (production output/head). Selected developed countries: European Union countries, United States, Canada, Australia, New Zealand. Source: FAO Stat, 2009.
local breeds, livestock keepers are not usually rewarded for their provision (FAO, 2009b). On the contrary, there may be even adverse incentives, such as subsidized inputs, that encourage farmers to move away from local breeds to high-output breeds for market supply. One reason is that at societal level, a high share of intensive livestock production makes it easier for countries to fulfill food security goals. The ‘livestock revolution’ that took place in some emerging economies is based on intensive production systems, usually with high-output transboundary breeds. Differentials in output levels and economic returns tend to disadvantage local breeds in areas where the necessary high level of inputs can be supplied to high-output breeds. It may also be easier for countries to achieve food safety standards owing to the ease of control of standardized production environments. Increasingly demanding animal health and food safety standards also tend not to be scale-neutral and to favor intensive over small-scale production.

3.4.2. On-farm diversity and environmental goals

Increasing productivity and efficiency is a crucial requirement for all livestock production systems because of the need to make efficient use of the available inputs and to reduce the sector’s environmental footprint. FAO (2006a, 2010a) provides an exhaustive overview on the land use changes, biodiversity degradation, water pollution and greenhouse gas emissions from the livestock sector. The impact ranges from local (e.g. soil and water pollution) over regional (e.g. deforestation and watersheds) to global (e.g. greenhouse gas (GHG) emissions).

Globally, most if not all additional feed to support the growing livestock production will have to come from concentrate feed, and indirectly from arable land. Land-use changes related to feed production are a cause of deforestation and related GHG emissions, land degradation, water pollution and loss of wild biodiversity. In order to cope with increasing resource scarcity, it is of critical importance to use concentrate feed as efficiently as possible (FAO, 2010a). The availability and prices of high-quality feed will affect the comparative advantage of different species and the distribution of high-output breeds. Breeding for high performance and improved feed conversion ratio (FCR), and reduced mortality due to better hygienic management, have significantly reduced the amount of food per unit of product — more in monogastrics and in dairy cattle than in beef cattle or sheep (Capper et al., 2009; Flock and Preisinger, 2002). The recent rise in poultry production is also a reflection of the high protein-energy return on investment which is 18% for broiler and 7% for eggs (FAO, 2010a; Pelletier, 2008). Therefore, in concentrate-based systems, monogastric species will continue to out-compete ruminants and the risk of extinction for local breeds, especially of monogastric species will increase.

While relative efficiencies per individual animal or per unit output in the intensively selected transboundary breeds have increased, the scale and concentration of industrial livestock production result in considerable environmental externalities such as water or soil pollution (Pelletier, 2008; Pelletier and Tyedmers, 2010). However, more resource efficient aquaculture or in-vitro meat production may in the future challenge the position of livestock in the food chain.

Reducing livestock numbers, increasing individual animal productivity and improving feed quality are the most immediate GHG mitigation options at the animal level. Despite contributing only 25% to GHG emissions from the livestock sector (FAO, 2006a), public discourse focuses on enteric fermentation in ruminants and may increase societal pressure on beef production. A recent life-cycle analysis (FAO, 2010b) found emissions per kg of fat-and-protein-corrected milk (FPCM) to decline sharply from 500 to about 2000 kg FPCM p.a., after which the curve starts to flatten. Therefore, GHG emissions per kg of FPCM were lower in industrialized than developing regions; they were higher in grazing systems than in mixed systems. Local ruminant breeds, which are usually fed on roughage and/or crop residues and have low output, therefore have a high GHG emission per kg of single product and are considered inefficient. Therefore, the pressure to abate GHG emissions from enteric fermentation through increased efficiency may disadvantage local ruminant breeds. On the other hand, cows in several developing regions produce less than 1000 kg FPCM p.a., resulting in a huge abatement potential through increased production that could easily be achieved with improved feeding and within-breed genetic improvement (FAO, 2010b; Gerber et al., 2011).

Many life-cycle analyses do not yet include C sequestration in grasslands which may partially offset GHG emissions from other components of the production process. Improved grazing management has positive environmental effects (soil C sequestration and biodiversity) and a favorable impact on livestock productivity (Smith et al., 2007). Gill and Smith (2008) proposed using ‘human edible return’ as an indicator to assess livestock efficiency, taking account not only of the gross efficiency of converting feed inputs to human food, but of species’ different abilities to use forages that cannot otherwise be used by humans. This would favor the return of herbivore livestock species to forage-based diets and land-based production systems and might offer new opportunities for local breeds (FAO, 2009d). However, besides more research in breed–vegetation–soil interactions, especially in semi-arid rangeland areas, a supportive political and economic environment will be needed. One option could be the inclusion of soil C sequestration, which has the highest GHG mitigation effect in agriculture and which improved grazing could significantly contribute, in a post-Kyoto Protocol Mechanism (FAO, 2009c, 2010a; Smith et al., 2007). However, institutional problems such as land-use rights and secure access to resources need to be solved to enable the diverse and often marginalized livestock keepers in dry and sub-humid lands to partake in decision making and develop and adopt improved rangeland management practices.

3.4.3. On-farm diversity and breed conservation

Within commercial breeds, high selection pressure, particularly when combined with poor design of breeding programs, may lead to a narrowing genetic base as observed in some dairy breeds. The same applies for genetic drift or inbreeding in small populations. However, such direct threats that are under the control of farmers or managers of breed populations seem to be less relevant than indirect threats that originate from the society level. A consequence of the increasing global food chains and uniformity of production environments is the need for fewer breeds (Table 1; Tisdell, 2003). FAO (2007a) indicates that the risk for breed survival in the past century was highest...
in regions that have the most highly-specialized livestock industries with a fast structural change and in the species kept in such systems. About one-third of cattle, pig and chicken breeds are already extinct and currently at-risk (FAO, 2009a). In two FAO questionnaire surveys (one on threats to breed diversity and one on contributors of threats to the extinction of 952 breeds) three threats were mentioned by most respondents and hence can be regarded as the most significant in eroding livestock genetic diversity across all species: 1. economic and market drivers, 2. poor livestock sector policies, and 3. poor conservation strategies (FAO, 2009c).

The conservation-relevant option and existence values of breeds are not usually recognized by the private owners of the animals who are mainly concerned with direct use values. Therefore, a mismatch exists between the private good dimension of animal genetic diversity – the private use value expressed as financial profitability of animals of a specific breed to the farmer – and the public non-use value of the same breed to national or global society. It can therefore be expected that local breeds will continue to play a role in marginal areas and be kept by poor people – areas where this mismatch is small. Most livestock keepers cannot afford and are not willing to safeguard public goods without appropriate incentives (FAO, 2009b; LPP et al., 2010). Equally, breeding organizations focus their responsibility for the maintenance of genetic diversity on the populations under their control (EFFAB, 2009; FABRE-TP, 2006).

After the adoption of the Global Plan of Action for Animal Genetic Resources (FAO, 2007b), conservation activities have been established in several countries (Hoffmann and Scherf, 2010). Many European countries use the national allocation from the European Union Rural Development Programme (RDP) (Council Regulation 1698/2005) to support conservation of animal breeds within their jurisdiction. Most countries pay breeders of breeds at risk, but the breeders may have to fulfill criteria such as being a member of the relevant breed society and/or participating in approved breeding programs. Some countries fund breed societies or rare breed conservation organizations, again linked to approved breeding programs. The United Kingdom is unique in linking support for breeds to agri-environment schemes; thus support is only provided for grazing animals (Small and Hosking, 2010). Such incentives do not need to be only monetary, for example many hobby breeders take pride in partaking in exhibitions. The changing role of livestock in society, such as social care farming, may also offer opportunities for breed conservation. Several EU-GENRES funded projects stressed the recognition of the breeders’ contribution to breed conservation by society and well-functioning breeding organizations as crucial for conservation (Hiemstra et al., 2010).

Promoting niche market development for products derived from local breeds and adding value to their primary products offer important opportunities to promote conservation objectives (LPP et al., 2010). But even these are not without problems: Kotchen (2003) who interpreted “green products” as impure public goods, with joint production of private and environmental public characteristics, found that increased demand for a green product or improvements in a green product’s technology can have detrimental effects on environmental quality. On the other hand, the discourse on ‘sustainable diets’ and their relation to biodiversity is advancing (FAO, 2010e) and some countries are developing guidelines in this regard.

4. Part two: Country level assessment of breed diversity and economic development

Breed numbers differ widely across countries. Countries have reported on average 70 breeds, with slightly less international than local breeds. However, considering only the economically most important six species, the ratio between international and local breeds reverses (Table 2). While on average, 7.5 breeds per country are at-risk, the range of different risk categories is very wide (Table 3).

Results of the regression models are discussed in terms of positive and negative trends, while the detailed results are presented in Tables 4 and 5.

The share of the poorest population quintile in national consumption or income has a significant relationship with all breed variables at country level, except the share of at-risk breeds in conservation (Table 4). With an increase in the share of very poor people’s consumption, the share of local breeds increases while the share of transboundary breeds declines. With an increase in GNI per capita, the shares of breeds at-risk and extinct-and-at-risk increase while the share of breeds with unknown risk status declines. This is expected, as poorer countries will have rather more local breeds but little records indicating breed population trends.

The share of mountains and hills in a country’s area is a proxy for marginal production systems. As this share increases, the share of transboundary breeds declines and the share of local and not-at-risk breeds increases. With an increase in the share of arable and cropland, the share of transboundary breeds increases and that of local breeds decreases. The different variables on crop and livestock production per capita and per ha were positively correlated with each other (results not shown), possibly due to a higher general agricultural management status. However, they did not have a significant effect on the breed variables.

Low purchasing power, a large share of very poor people’s consumption and higher altitude terrain seem to be favorable for local but impediments for transboundary breeds. This result may indicate that local breeds which are often well adapted to harsh environments are not at-risk in those environments as other breeds cannot compete with them (FAO, 2006b) — or that the poor do not have the capital available to purchase the initial germplasm of other breeds.

<table>
<thead>
<tr>
<th>Breed number per country. Source: FAO, DAD-IS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breed number</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>International (all species)</td>
</tr>
<tr>
<td>International (main species *)</td>
</tr>
<tr>
<td>Regional (all species)</td>
</tr>
<tr>
<td>Regional (main species *)</td>
</tr>
<tr>
<td>Local (all species)</td>
</tr>
<tr>
<td>Local (main species *)</td>
</tr>
<tr>
<td>At-risk</td>
</tr>
<tr>
<td>In conservation</td>
</tr>
</tbody>
</table>

* Cattle, buffalo, sheep, goats, pigs, chicken, and camels.
Taking the share of extinct-and-at-risk breeds as a proxy for past and current threats for the survival of a breed, it appears that economic development may affect the threats to breeds in two directions (Tables 4 and 5).

- The share of extinct-and-at-risk breeds declines with higher employment in agriculture and a higher share of agricultural GDP. Threat levels thus tend to be lower in countries with high consumption shares of poor people and agriculture based economies, low purchasing power and low urban population.

- Threat levels tend to increase with rising incomes and the related electricity consumption, energy use and CO₂ emissions. However, higher incomes and shares of urban population tend to increase also the share of breeds in conservation programs, and reduce the share of breeds with unknown risk status. In line with this observation, McKinney (2002) argued that the impacts of urbanization on native species are poorly studied, but educating a highly urbanized human population about these impacts can greatly improve species conservation in all ecosystems. This may indicate a curvilinear relationship where societies first lose breeds but, with increasing affluence, increased awareness about their values leads to better breed monitoring, management and conservation programs. The data however did not support this hypothesis.

Care has to be taken in interpreting these results, as regression models assume a linear one-directional relationship between independent and dependent variables whereas some of the independent variables may be correlated with the error term. Also, cause–effect relations over time are difficult to calculate; for example a breed becoming extinct is the consequence of earlier cumulated effects. However, despite the methodological problem of endogeneity and the low resolution of country level data, the analysis confirms the result of the qualitative questionnaire surveys (FAO, 2009c) about the importance of society level economic development drivers for the risk status of breeds. They also confirm the high social impact local breeds have for poor people and marginal regions (Vivanco, 2010). Improved data quality–time series and full information on a wider set of socio-economic indicators and breed populations may allow more comprehensive analyses in the future which could become a component of an early-warning system at country level. The current updating of country breed population data in DAD-IS by the National Coordinators for Animal Genetic Resources is a right step in this direction. With better data, also the societal cost for losing breeds may be assessed; these costs may indicate the payment needed to abate the threats.

### Table 3
Risk status of breeds by country.
Source: FAO, DAD-IS.

<table>
<thead>
<tr>
<th>Breed number</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical</td>
<td>61</td>
<td>7.8</td>
<td>12.6</td>
</tr>
<tr>
<td>Critical-maintained</td>
<td>25</td>
<td>3.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Endangered</td>
<td>85</td>
<td>7.9</td>
<td>12.9</td>
</tr>
<tr>
<td>Endangered-maintained</td>
<td>38</td>
<td>6.6</td>
<td>8.5</td>
</tr>
<tr>
<td>Extinct</td>
<td>73</td>
<td>9.3</td>
<td>18.3</td>
</tr>
<tr>
<td>Not at-risk</td>
<td>140</td>
<td>14.9</td>
<td>38.6</td>
</tr>
<tr>
<td>Unknown risk status</td>
<td>166</td>
<td>16.5</td>
<td>22.1</td>
</tr>
</tbody>
</table>

### Table 4
Outcomes of regression models for breed shares.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>DF</td>
<td>110</td>
<td>0.2745</td>
<td>&lt;0.0001</td>
<td>-0.1359</td>
<td>0.000010724</td>
<td>0.000081396</td>
<td>-0.00004919</td>
<td>0.00000242</td>
<td>-0.000002712</td>
<td>0.000000495</td>
<td>0.0000004911</td>
<td>0.0000027111</td>
</tr>
<tr>
<td>R-square</td>
<td>0.2740</td>
<td>0.2745</td>
<td>&lt;0.0001</td>
<td>-0.1359</td>
<td>0.000010724</td>
<td>0.000081396</td>
<td>-0.00004919</td>
<td>0.00000242</td>
<td>-0.000002712</td>
<td>0.000000495</td>
<td>0.0000004911</td>
<td>0.0000027111</td>
</tr>
<tr>
<td>Pr-F</td>
<td>0.2740</td>
<td>0.2745</td>
<td>&lt;0.0001</td>
<td>-0.1359</td>
<td>0.000010724</td>
<td>0.000081396</td>
<td>-0.00004919</td>
<td>0.00000242</td>
<td>-0.000002712</td>
<td>0.000000495</td>
<td>0.0000004911</td>
<td>0.0000027111</td>
</tr>
<tr>
<td>Intercept</td>
<td>-0.1359</td>
<td>-0.1359</td>
<td>&lt;0.0001</td>
<td>-0.1359</td>
<td>0.000010724</td>
<td>0.000081396</td>
<td>-0.00004919</td>
<td>0.00000242</td>
<td>-0.000002712</td>
<td>0.000000495</td>
<td>0.0000004911</td>
<td>0.0000027111</td>
</tr>
<tr>
<td>Urban population [% of total population] (2005)</td>
<td>0.000010724</td>
<td>0.000010724</td>
<td>&lt;0.0001</td>
<td>-0.1359</td>
<td>0.000010724</td>
<td>0.000081396</td>
<td>-0.00004919</td>
<td>0.00000242</td>
<td>-0.000002712</td>
<td>0.000000495</td>
<td>0.0000004911</td>
<td>0.0000027111</td>
</tr>
<tr>
<td>Purchase power parity GNI ($/capita) (2008)</td>
<td>0.000081396</td>
<td>0.000081396</td>
<td>&lt;0.0001</td>
<td>-0.1359</td>
<td>0.000010724</td>
<td>0.000081396</td>
<td>-0.00004919</td>
<td>0.00000242</td>
<td>-0.000002712</td>
<td>0.000000495</td>
<td>0.0000004911</td>
<td>0.0000027111</td>
</tr>
<tr>
<td>Share of poorest quintile in national consumption or income (1990–2007)</td>
<td>-0.00004919</td>
<td>-0.00004919</td>
<td>&lt;0.0001</td>
<td>-0.1359</td>
<td>0.000010724</td>
<td>0.000081396</td>
<td>-0.00004919</td>
<td>0.00000242</td>
<td>-0.000002712</td>
<td>0.000000495</td>
<td>0.0000004911</td>
<td>0.0000027111</td>
</tr>
<tr>
<td>Meat-equivalent production per ha agricultural land (kg/ha) (2007)</td>
<td>0.00000242</td>
<td>0.00000242</td>
<td>&lt;0.0001</td>
<td>-0.1359</td>
<td>0.000010724</td>
<td>0.000081396</td>
<td>-0.00004919</td>
<td>0.00000242</td>
<td>-0.000002712</td>
<td>0.000000495</td>
<td>0.0000004911</td>
<td>0.0000027111</td>
</tr>
<tr>
<td>Mean-equivalent production per capita (kg/capita) (2007)</td>
<td>-0.000002712</td>
<td>-0.000002712</td>
<td>&lt;0.0001</td>
<td>-0.1359</td>
<td>0.000010724</td>
<td>0.000081396</td>
<td>-0.00004919</td>
<td>0.00000242</td>
<td>-0.000002712</td>
<td>0.000000495</td>
<td>0.0000004911</td>
<td>0.0000027111</td>
</tr>
<tr>
<td>Mountains and hills (% of total land area) (2007)</td>
<td>0.000000495</td>
<td>0.000000495</td>
<td>&lt;0.0001</td>
<td>-0.1359</td>
<td>0.000010724</td>
<td>0.000081396</td>
<td>-0.00004919</td>
<td>0.00000242</td>
<td>-0.000002712</td>
<td>0.000000495</td>
<td>0.0000004911</td>
<td>0.0000027111</td>
</tr>
<tr>
<td>Lowland and plains (% of total land area) (2007)</td>
<td>0.0000004911</td>
<td>0.0000004911</td>
<td>&lt;0.0001</td>
<td>-0.1359</td>
<td>0.000010724</td>
<td>0.000081396</td>
<td>-0.00004919</td>
<td>0.00000242</td>
<td>-0.000002712</td>
<td>0.000000495</td>
<td>0.0000004911</td>
<td>0.0000027111</td>
</tr>
<tr>
<td>barren and permanent cropped pasture and meadow (ha)</td>
<td>0.0000027111</td>
<td>0.0000027111</td>
<td>&lt;0.0001</td>
<td>-0.1359</td>
<td>0.000010724</td>
<td>0.000081396</td>
<td>-0.00004919</td>
<td>0.00000242</td>
<td>-0.000002712</td>
<td>0.000000495</td>
<td>0.0000004911</td>
<td>0.0000027111</td>
</tr>
<tr>
<td><strong>P &lt; 0.001, * P &lt; 0.01, + P &lt; 0.05, P &gt; 0.1.</strong></td>
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</tbody>
</table>
the World Trade Organization perpetuates the dominance of the international trade regime of provided by breeds. Such under-valuation of ecosystem services for local breeds kept in order to close the mismatch between the private and public interests in breed conservation.

in order to close the mismatch between the private and public ecosystem services, provided by livestock should be intensi

5. Conclusion

Research on the sustainable use of livestock genetic diversity is difficult because of the scarcity of detailed data for breeds’ status and the drivers affecting it, the multi-level stakeholders involved and the trade-offs between the various social and environmental global public goods concerned. Livestock keepers and breeders as managers of breed diversity aim to improve their livelihoods and well-being, while genetic diversity conservation is a global public good. Literature review, qualitative questionnaire results and country level data analysis all point to a trade-off between livestock genetic diversity conservation and economic development goals. The dichotomy between intensive livestock production systems for food production based on few transboundary breeds and low external input systems where local breeds provide multiple services for the livelihoods of their keepers is fast increasing.

The results seem to indicate that countries that have achieved immediate food security needs and surpassed a certain average income are more likely to invest in breed population monitoring and conservation. Given the rapid global changes, poor countries, like poor livestock keepers, would need incentives to start improved genetic resource management at an earlier stage in economic development. However, unless better ways are found to maximize co-benefits between biodiversity conservation and economic development, the threats for livestock genetic diversity are expected to continue at accelerating rates.

One reason for the mismatch between private and public goods is the non-reflection of the considerable negative environmental externalities of livestock production in the costs of livestock products. Closing this mismatch will therefore require the removal of perverse incentives – which mostly target breeds’ provisioning services – and provide positive incentives for the other ecosystem services they provide. Genetic erosion may be included in the list of externalities not captured by market prices, and innovative ways, either market-based or regulatory, could be explored to reward “providers” and charge “polluters”. Another reason is the current undervaluation of the positive externalities – the non-market products and services provided by breeds. Such under-valuation of ecosystem services perpetuates the dominance of the international trade regime of the World Trade Organization – which focuses on regulating trade in market products – over the CBD which covers a wide range of ecosystem services in addition to market products. Research in the assessment of true environmental costs and valuation of non-market products and services, including ecosystem services, provided by livestock should be intensified in order to close the mismatch between the private and public interests in breed conservation.

Although the analysis indicates that there is little mismatch between private and public goods for local breeds kept in marginal production systems and by poor people who depend directly on the various products and services provided by those breeds, poor livestock keepers are not the ‘natural’ custodians of breed diversity. Conserving breeds and other types of biodiversity has to go hand in hand with securing and improving their livelihoods; this includes value-adding to the breeds’ products. Implementing integrated approaches to rural development, poverty alleviation and the sustainable use and conservation of biodiversity is difficult but potentially highly rewarding. In many cases, small-scale livestock keepers are the targets of poverty alleviation and rural development programs, and they often use areas important for the conservation of wild biodiversity or C-sequestration. Improving possible co-benefits will require participatory planning and policy development approaches that take local knowledge and traditions into account. More research in breed–vegetation–soil interactions is needed. This should include the development of baselines and indicators that would allow monitoring and underpin incentive mechanisms, including payment-for-environmental-services schemes (FAO, 2007c). Only if the value of biodiversity conservation is recognized and accounted for, and livestock keepers conserving at-risk breeds are rewarded by society through both economic and non-economic incentives can biodiversity conservation be in “conformity with provisions of the World Trade Organization and other international agreements” (CBD, 2010a). Further possible trade-offs between genetic diversity conservation and other environmental goals need to be analyzed on a much better database.

Conflict of interest

The Author certifies that there is no conflict of interest regarding the material discussed in the manuscript.

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