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Animal genetic resources diversity and ecosystem services

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ABSTRACT

Animal Genetic Resources (AnGR) are a component of agricultural biodiversity making a large contribution to ecosystem services, resulting from their complex interaction with their respective environments. This review investigates how AnGR diversity, which includes more than 7000 distinct local and 1000 transboundary livestock breeds of around 40 species plus domesticated honeybees and other pollinators, influences, through livestock production systems and practices, the generation of a diversity of provisioning, regulating and maintenance, as well as cultural ecosystem services. The main use of domestic animals is for their provisional services of food production, with a large contribution from commercial breeds in industrial production systems in developed and emerging countries. However, in rural areas of developing countries, local livestock breeds often play a crucial role in food security, nutrition and health. Less intensive systems, located especially in harsh climate conditions, offer more diverse ecosystem services, including important regulating and maintenance services, with indirect use or non-use values, while permitting the use of land not suitable for crop production. Breeds used in such systems have often developed specific adaptive features for those environments. The identification and integration of traits relevant for ecosystem services within breeding programmes represent however a particular challenge, especially in low-input systems. The keepers of the livestock that offer these services are often marginalised and isolated from markets and excluded from decision making processes, however. It is therefore important to recognize the existence and value of these ecosystem services to better understand the trade-offs and synergies associated with their maintenance, and to account for them in policy and legal frameworks at national and international levels including providing appropriate incentives to the communities contributing to the generation of those services.

1. Introduction

Ecosystem services (ESS) are defined as the broad range of benefits that people can obtain from ecosystems. They are a key component of the"Green Economy", an economic system in which material wealth does not increase environmental risk, ecological scarcity or social disparity (McGahey et al., 2014). The balance between exploitation of resources for food and agriculture and conservation of the ecosystems and their services is crucial for achieving the Sustainable Development Goals (SDGs) of the United Nations 2030 Agenda, particularly SDG 2 (End hunger, achieve food security and improved nutrition and promote sustainable agriculture) and SDG 15 (Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss), which aim to enhance the delivery of ESS for all types of environments.

Agriculture is usually considered both a provider and beneficiary of ESS, placing it at the centre of a web formed by interactions among those services (Swinton et al., 2007; Zhang et al., 2007). Agricultural systems and management practices are usually strong determinants of the extent, trade-offs and synergies occurring among ESS (Power, 2010). This holds true for domesticated livestock. Their interaction with ecosystem components and processes is highly complex, but three actions of livestock are particularly important: (i) the conversion of human-inedible feedstuffs and organic waste into useful products; (ii) interaction with their ecosystem through grazing, browsing and trampling, as well as the production of urine and dung; and (iii) their ability to move and respond to temporal and spatial fluctuations in resource availability of ecosystems (FAO, 2014).

Animal genetic resources for food and agriculture (AnGR) constitute a specific element of agricultural biodiversity. They are defined as those animal species that are used, or may be used, for the production of food and agriculture, and the populations within each of them. These

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resources include more than 7000 distinct local (reported in only one country) and 1000 transboundary (reported by several countries) livestock breeds of around 40 species, found around the world (FAO et al., 2015). Some of those breeds can be considered as locally adapted in the sense of they have been in a country for a sufficient time to be genetically adapted to one or more of traditional production systems environments in the country. Domesticated honeybees and other managed pollinators are also considered within the scope of AnGR. The importance of livestock breeds in the context of ESS has however been rarely investigated in an extensive manner (Ovaska and Soini, 2016; Marsoner et al., 2017). The place of AnGR diversity in the ESS framework is also not always clear. Mace et al. (2012) showed that in general biodiversity is included in assessments in very different ways, from a regulator of underpinning ecosystem processes to a final service or good to be delivered by ecosystems. Following the Millennium Ecosystem Assessment MEA (2005) classification, genetic resources have also been considered as a provisioning service/good, supporting service (Zhang et al., 2007) or even as indicators of cultural ESS, given the socio-cultural importance attached to local breeds (Ovaska and Soini, 2016; Marsoner et al., 2017). Genetic resources are also often included in the management practices (Power, 2010), the choice of specific breeds or species largely impacting the production systems, and related ESS. For instance, in “landless” industrial systems, provision of food is much more important compared to other systems. It has been estimated that the contribution of exotic breeds or their crossbreds, mostly raised in industrial systems and especially in developed countries, to pig, egg and chicken meat production in 2005 was more than 80% (FAO, 2014). Many of the ESS from domesticated species rely on a direct connection between production and natural ecosystems, including circumstances where these two cannot be distinguished. These environments are primarily grassland and rangelands, and mixed production systems, where ruminant species and locally adapted breeds tend to be raised (FAO, 2014).

In this study, we investigate to which extent AnGR diversity, in the sense of the variability among individuals, breeds and species within livestock, is associated with ESS delivered by agroecosystems across the world, considering especially grassland, rangelands, and mixed production systems. We first assess how ESS provided by livestock are impacted by the kind of AnGR used, especially regarding potential trade-offs and synergies. The opportunities and constraints regarding the recognition and valuation of those services are also discussed.

2. Ecosystem services provided by animal genetic resources

In order to understand the place of AnGR diversity in the ESS framework, it is first important to review to which extent ESS provided by livestock production systems and practices are impacted by the choices of farmers in term of species, breeds, individuals and their combination, and what are the relevant phenotypic traits behind those choices (Fig. 1, Table 1). We consider the V5.1 Common International Classification of Ecosystem Services (Haines-Young and Potschin, 2017), which split ESS into provisioning, regulating and maintenance, and cultural services.

2.1. Provisioning services

Domestic breeds and species are mostly used for the supply of food, fibre and skins. Animal products are an important part of the human diet, providing, in 2013, 40% and 18% of human global protein and food energy (kcal), globally, with those percentages decreasing to 8% and 22%, respectively in the 47 least developed countries, respectively (FAO, 2018). It has indeed been showed that the consumption of animal products tends to increase with wealth. Yet in poor countries, livestock have even more a crucial role in food security, nutrition and health, especially for children, since animal source foods provide high quality protein and micronutrients (vitamin A, vitamin B12, riboflavin, calcium, iron, zinc, etc.) that are difficult to obtain in adequate quantities from plant-based foods alone (Neumann et al., 2002).

There is a lack of studies assessing the contribution of locally adapted breeds to food security at a global scale. Therefore, the contribution to different ESS can only be assessed indirectly, as specific breeds are often associated with specific production systems. For example international transboundary, highly-selected breeds for the production of a single product (e.g. milk, meat, eggs) are mostly kept in high-input intensive industrial systems, whereas locally adapted breeds provide multiple products in low external input mixed or grassland systems. Different production systems contribute unequally to food production. For example 43% of products from cattle and buffaloes, small ruminants, poultry and pigs come from industrial pig and poultry systems and ruminant feedlots, 34% from intermediate intensity pigs, chicken and mixed ruminant systems, 16% from grazing ruminant systems, and 7% from backyard pig and poultry systems (Mottet et al., 2017).

As animals are fed with crops or on land that could be used to feed humans (Godfray et al., 2010), one important debate about livestock and food security relates to their relatively low efficiency in converting feed into human-edible products (around 10%). However, when species' different abilities to use feeds that are not edible by humans (such as grass or food by-products) are taken into account (considered formerly as a supporting service), some ruminant production systems return more than one unit of human-edible food per unit of human-edible food consumed (Mottet et al., 2017). The same study estimated that livestock currently use 1.26 billion ha of grassland and rangeland that are unsuitable for crops, representing half of the 2.5 billion ha that can be allocated to livestock feed. A significant part of cropland may also be temporarily unavailable for human food production due to crop rotation.

Locally adapted breeds often have characteristic features (for instance salt tolerance) allowing them to survive in harsh conditions and thrive on the poor feed resources of those lands that are unsuitable for crop production (Shabtay, 2015; Leroy et al., 2016a). In more intensive systems, the use of genetic variability within and between breeds is viewed as an important leverage to improve the efficiency with which animal source food is produced (Hayes et al., 2013); the heritability (i.e the proportion of the variance in the trait attributable to genetic variation) of net feed efficiency over 7 species/types was estimated around 0.25 (Pitchford, 2004).

Other provisioning services are crucial in mixed and/or pastoral production systems. In developing countries, a large number of people depend on livestock for agricultural work and transportation, as draught animal power is often the only source of energy for such purposes. FAO (2003) estimated that by 2030, 20% of agricultural areas would still be cultivated using draught animals, recent information on current being unfortunately not available. Certain breeds may be particularly suitable for transport and draught work. In a survey carried out in southern Mali (Traoré et al., 2017), farmers indicated draught power as the most important production objective for keeping cattle. Good traction ability, disease resistance and drought tolerance were reported as the main reasons to prefer N'Dama cattle over the larger Fulani Zebu breed.

Manure and urine are also two important by-products from livestock for use in agricultural production. In 2000, Potter et al. (2010) estimated that manure contributed about 60% of global nutrients for crop fertilization. Dung also continues to be a commonly used fuel for cooking and heating. It was estimated that, in 2005, 668 million people in India were relying on fuelwood and dung for cooking and heating (IEA, 2007).

In the MEA framework (2002) genetic resources have been considered as a provisioning service as such, considering that (agro)ecosystems are providers of genes and genetic information usable for breeding and biotechnology. Over the last decades, genetic selection programmes have indeed been estimated to contribute 50% or more to

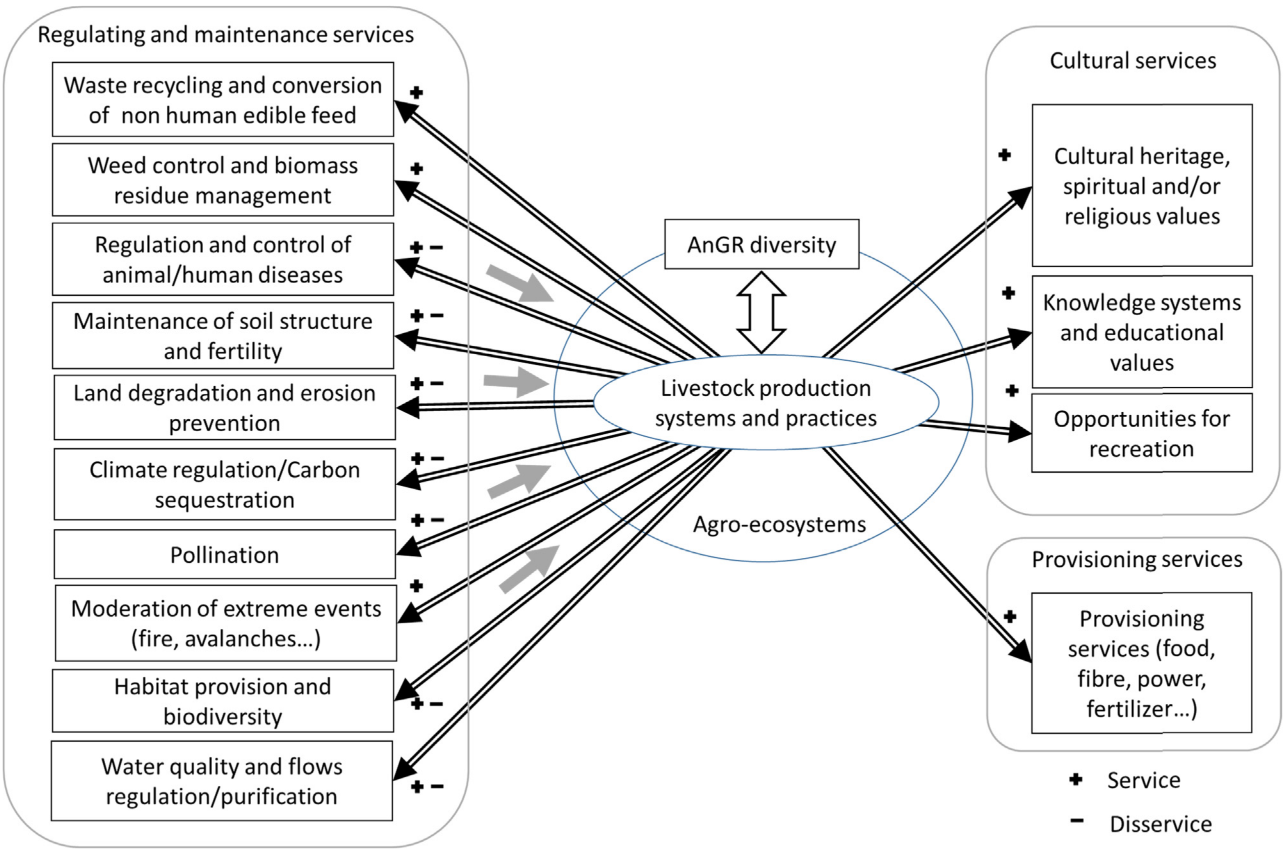

Fig. 1. Impact of AnGR diversity on ecosystem services through livestock production systems and practices.

Table 1
Ecosystem services provided by AnGR.

Services	Main production systems	Main species	Examples of relevant traits
Provisioning services			
Food	All	All	Growth, milk yield, fat content
Fibre and/or skins	All	All	Fleece weight
Power	Mixed and pastoral systems in developing countries	Cattle, camelids and equids	Draught power, behaviour
Fertilizer (manure and urine)	Mixed	All	Foraging, feed behaviour, body size
Fuel (manure)	Mixed and pastoral systems in developing countries	All	Body size, feed behaviour
Genetic resources	All	All	Various
Regulating and maintenance services			
Waste recycling of non-human edible feed	All	All	Fibre digestibility
Weed control and biomass residue management	Grazing systems	Especially local ruminant/equids breeds	Grazing behaviour, adaptedness
Regulation and control of animal/human diseases			Disease resistance
Maintenance of soil structure and fertility			Body size
Land degradation and erosion prevention			Body size, walking ability
Water quality and flows regulation/ purification			Body size
Moderation of extreme events			Grazing behaviour, walking ability
Habitat provision and biodiversity			Grazing behaviour, body weight, walking ability, adaptedness
Pollination		Bees and other pollinators and indirectly ruminants	Grazing behaviour, walking ability (ruminants) y
Climate regulation/Carbon sequestration	All	All	Feed efficiency (mitigation), heat stress resistance (adaptation)
Cultural services			
Cultural heritage, spiritual and/or religious values	All	All	Specific morphologic traits
Knowledge systems and educational values	All	All	Grazing behaviour, adaptedness
Opportunities for recreation	All, especially grazing systems	All, especially ruminants	Behaviour, adaptedness

Box 1
Examples of specific traits related to the provision of ecosystem services.

In relation to the diversity of production environment where domestic species are raised, local breeds have developed a wide range of specific phenotypes and traits. They may contribute to various purposes (adaptedness, production, biological model, aesthetics, etc.) and ESS provision.

Specific phenotypes may increase the production and therefore the provision of products, such as meat, milk or wool. For example, the Booroola phenotype,increase the litter size in sheep. Initially identified in an Australian Merino flock, the mutation behind the trait has been then diffused to numerous breeds and countries.

Some other traits relate to the adaptation to specific harsh environments, allowing breed to survive and feed in areas that could not be used otherwise. A diversity of gene variants has been identified in various breeds and species (pig, goat, cattle, yak) adapted to high altitude, their function relating to hypoxia and erythropoiesis for instance.

In terms of regulating services, some specific grazing behaviour related to the preference of breeds, such as the Damascus goat, for diets richer in tannins, may constitute opportunities for the control of shrub encroachment.

Finally, the distinctive morphologies of some breeds may be of cultural importance, and for instance, the bulbous horn of Kuri cattle, function of which is still unclear, is a strong marker of breed identity for their keepers.

Adapted from Leroy et al. (2016a)

the increase of livestock productivity (Havenstein et al., 2003; Shook, 2006). The value of global exports of live animals and bovine semen increased from less than 2 billion to almost 6.5 billion US$ between 2000 and 2012 (FAO et al., 2015). The value of AnGR lies not only in their role for current selection objectives, but also in their potential value for future use, related to the wide diversity of traits, including adaptive ones, that are shared by locally adapted breeds. In that regard, AnGR can also be considered as a public good. In a wide range of production environments, the domesticated breeds have developed a diversity of phenotypes, more or less population-specific, relating to adaptedness, production, aesthetics, or biological interest (Box 1). AnGR diversity is also an important resource for technologies and innovations in relation to the fields of medicine, reproduction, genomics and biology. The use of natural and rare mutations occurring in livestock populations also provide valuable models for improving our knowledge of gene function (Leroy et al., 2016a).

2.2. Regulating and maintenance services

Regulating and maintenance services correspond to the benefit obtained from the regulation of ecosystem processes. In comparison to provisioning services, they are more difficult to quantify and appraise, given their indirect use values or non-use values.

In addition to the above discussion on food security and feed conversion, livestock play a critical role in recycling, especially for crop residues. According to Mottet et al. (2017), nearly 300 million ha of land across the world can be allocated as land used to produce crops by-products and residues which are used to feed livestock. Cut-and-carry forages, cover crops, roadside grasses, hay or silage constitute a source of animal feed of great importance in the mixed and backyard production systems. Local breeds are generally considered to have good capacities to thrive on food waste (Lekule and Kyvsgaard, 2003; Copland and Alders, 2009), and in different experimental studies, indigenous pigs were shown to have higher digestibility of fibrous diets, such as cassava residue or rice bran, compared to commercial pigs (Freire et al., 2003; Len et al., 2009).

Grazing systems, involving more or less direct interaction between domesticated species and their environment, generate a number of regulating and maintenance ESS. Grazing livestock play an important role in weed control and biomass residue management, minimizing the spread of invasive species (FAO, 2014). Livestock may have a role in terms of regulation and control of human and animal diseases, however this aspect is less documented. For instance, low-intensity livestock grazing has been shown to reduce the prevalence of spirochete infection in vector ticks, thus reducing the risk of Lyme disease (Richter and Matushka, 2006).

Livestock grazing plays a significant role in land management (FAO, 2014). Multiple factors have been identified as contributing to deteriorating pastures, water bodies and rangeland areas, including overgrazing, compaction and erosion caused by livestock. On the other hand, several studies have highlighted the positive effects of appropriate grazing practices (e.g. ensuring appropriate livestock density, managing turnover according to phenological state of plants) on plant productivity and biodiversity, fertility, soil's ability to retain water, or protection from erosion (Derner et al., 2014; Petz et al., 2014). Given the importance of some physiological factors such as body size on trampling or nitrogen excretion, the choice of species and breeds is expected to impact the provision of those service and disservices (Smith and Frost, 2000; Rook et al., 2004; Hoogendoorn et al., 2011).

Another group of regulating and maintenance ESS relates to habitat provision, which links the effect of livestock management (mostly grazing) to the biodiversity of the host ecosystem. In such co-evolved landscapes, AnGR may have a strong role in maintaining the life cycle of wild animal and plant species, and maintenance of local genetic diversity. In the absence of grazing activity, grassland ecosystems, such as dry grasslands, heath and meadows are expected to undergo substantial changes, first in terms of vegetation communities, followed by the animal diversity which depends on them (Socher et al., 2013; Arcoverde et al., 2016; Török et al., 2016). There are numerous cases in Europe where, to compensate for abandonment of agriculture, locally adapted breed populations have been deliberately released to maintain habitat (Kugler and Broxham, 2014). In the Keoladeo National Park, India, the ban on grazing by buffalos led to a decrease of Siberian cranes in the park, as these birds were prevented from accessing plant tubers for food, due to uncontrolled growth of water weeds (Lewis, 2003). Also, because livestock can move across space and time, ruminants may have a role in connecting habitats, by transporting seeds in their digestive tracts or attached to their coats and hoofs. In Spain, transhumance roads act as local biodiversity reservoirs and increase potential connectivity at the regional level (Azcárate et al., 2013).

In relation to differences in anatomy, physiology and grazing behaviour, livestock species or combinations of species largely differ in their impact on grassland biodiversity (Rook et al., 2004). The breed effect appears less obvious in that context, even if Celaya et al. (2010) showed that local Spanish Celtiberic goats had a more positive impact toward the maintenance of semi-natural grasslands through better control of excessive shrub encroachment than did commercial Cashmere goats.

Pollination is a service provided by different species. 75% of food crops and nearly 90% of wild flowering plants are dependent on pollinators for their reproduction (IPBES, 2016). In Europe it is estimated that 70% of pollination is provided by managed honey bee populations

(Schulp et al., 2014). 5–8% of global crop production (for an annual market value of 235–577 US$ billions) is directly attributable to pollination (IPBES, 2016). There are clear links between grazing management and richness of functional diversity of the pollinator communities (Hopwood et al., 2015; Orford et al., 2016). Therefore, the choice of livestock species or combination of species affecting the diversity of grassland plant and habitat heterogeneity, as stated above, it may also impact, positively or negatively, the levels of pollination services.

The livestock sector is considered to account for a substantial share of global greenhouse gas emissions (considered as a disservice), with large differences in emission contribution depending on species and production systems (FAO et al., 2013). Climate regulation is, however, another service that can be obtained through proper mitigation practices. Using the global livestock assessment model (GLEAM), it has been estimated that around 0.41 gigatonnes CO_2-eq of carbon could be sequestered per year over a 20-year period through improvement of grazing management practices (forage digestibility, grazing practice, husbandry including potentially genetic improvement in residual feed intake and animal health) (FAO et al., 2013).

AnGR diversity offers options to deal with the challenges related to the future impacts of climate change on agroecosystems, in terms of temperature, feed and water availability, or extreme event and zoonotic diseases outbreaks. Once characterized, genes and phenotypes of interest (tolerance to heat stress and diseases, adaptive capacities, etc.) can be introduced to other populations as needs and environments change. For instance, the slick hair haplotype, conferring to cattle a short and sleek hair coat which was initially shared by Senepol cattle and a few criollo breeds, was transferred in the 1990s into a Holstein subpopulation, improving the thermotolerance of the animals (Dikmen et al., 2014).

Finally, through their direct interactions with environment, AnGR may have an important role in preventing extreme events such as drought and flood, but also avalanche and landslide control, and risk of wildfire related to bush encroachment (Franzluebbers et al., 2012; Ruiz-Mirazo and Robles, 2012). Such extreme events are more likely to occur in arid and/or mountainous areas, where ecosystem services such as landslide and fire control are probably more efficiently provided by local breeds which are commonly more robust and adapted to these ecosystems (Kugler and Broxham, 2014; FAO, 2014).

2.3. Cultural services

AnGR play an important cultural role that goes beyond the livestock keepers themselves. The non-material benefits are quite complex to quantify and appraise in comparison to provisioning services. On the other hand, cultural services are often recognized as the most important services provided by livestock breed and species, especially in grazing areas (Leroy et al., 2018).

Local populations of domesticated animals often constitute cultural heritage, representing spiritual and/or religious values. In numerous communities, livestock have a diversity of roles such as being a measure of wealth, subjects of art, a linkage among communities through animal exchanges, or as part of religious ceremonies. In Northern Italy, the three Valdostana cattle breeds are part of important folkloric festivals, the most distinguished cows wearing locally handmade bells (Gandini and Villa, 2003). In Indonesia, Widi et al. (2014) showed that Madura cattle used in local cultural events (bull racing and cow conformation contests) were valued 2–3.5 times higher than cattle not participating in those events.

Continuous management of local AnGR over centuries has also led to the development of substantial traditional knowledge, such as on how the production systems are managed and regulated. This knowledge is threatened by social changes such as sedentarization of pastoral communities. An interesting case showing the connection between traditional knowledge and genetic resources is the production strategy of WoDaaBe herders in Niger (Krätli, 2008), who move their animals in order to feed on fodder plants in their most nutritional stage of development. The WoDaaBe strategy appears to rely on the specific aptitude to walk and grazing behaviour of their Bororo Zebu compared to other local cattle breeds (Azawak), those traits being fully taken into in the selection of breeding animals, and cattle lineages being memorized by herders over periods close to 20 years.

Through the unique phenotypes that have been developed through traditional farming (e.g., coat colours, horn shapes), as well as the cultural values previously described, livestock can be considered as part of the natural heritage, encompassing not only the associated landscape which they have contributed to shape, but also recreational values behind it. Local production systems, breeds and products can be linked with tourism (Ligda and Casabianca, 2013), as seen in the Alpine areas in Europe (Delattre and Dobremez, 2004), pastoral rangelands of the Mara in Kenya (Bedelian, 2014), and in the Pantanal wetland in Brasil (Pinto de Abreu et al., 2010). Development of high grade products, linking of traditional practices and breeds to special foods (such as protected designations of origin (PDO) or geographical indications (PGI)) can also increase farming profitability (FAO et al., 2015).

Local livestock breeds are often viewed as custodians of local traditions and identity in the agroecosystems of their area of origin (Gandini and Villa, 2003). In Finland, Ovaska and Soini (2016) found that ESS provided by locally adapted breeds were perceived as similar to those provided by other breeds, with however particular emphasis on genetic resources and cultural ecosystem services. Given their importance in the provision of ESS, Marsoner et al. (2017) recently suggested to use the diversity of livestock breeds within a given area as an indicator for cultural ecosystem services. Those authors highlighted however that as cultural value may differ considerably depending on the breeds (Gandini and Villa, 2003), such an indicator would only estimate potential cultural services of livestock breeds.

2.4. ESS synergies, trade-offs and use of AnGR

When considering livestock production systems, numerous synergies and trade-offs in terms of ESS services provided by livestock have been described from farm to global scale (Herrero et al., 2009; Bernués et al., 2011; Petz et al., 2014; Rodríguez-Ortega et al., 2014), with trade-offs occurring frequently between provisioning and other services. To achieve sustainable increases in production it has been suggested to better integrate crop and livestock systems, taking advantage of crop rotation to feed livestock, achieving better regulation of biogeochemical cycles and fluxes, diversifying landscape mosaic, and improving socio-economic flexibility of systems (Lemaire et al., 2014). Different approaches have been developed to assess different ESS, quantify their interaction and design optimal solutions (Rodríguez-Ortega et al., 2014).

In AnGR, both at individual and breed levels, antagonistic genetic correlations may exist between traits of interest, for instance between production traits (e.g., growth, milk, egg production) and functional ones (e.g., longevity, resistance to heat stress, health and reproductive ability) (FAO et al., 2015). In practice, providing the right genotype for a specific environment requires first to identify and rank the most relevant traits, which is usually done in conventional breeding programs by deriving economic values of traits with bio-economic models taking into account correlations among traits (Nielsen et al., 2011). Alternative methods exist that simply consider farmer preferences (Wurzinger et al., 2006). In the context of the ESS framework, the main challenges at the within-breed level are related to (i) the limited experience in implementation of sustainable breeding programmes in low-input production systems, (ii) the difficulty to develop some of the selection criteria relevant for ESS services (e.g., adaptedness, grazing behaviour), especially in relation to the integration of genotype × environment interactions in the prediction of breeding values (Tixier-Boichard et al., 2015), and (iii) the inclusion of non-economic traits into breeding goals (Nielsen et al., 2011). In extensive systems, the recording of performance for the traits of interest and the environmental conditions, which is a prerequisite for the estimate of breeding values, faces various limitations, such as the difficulty to have standardized production environments, or logistical issues (e.g., access to animals, time required, data management, capacites). To that extent, Mueller et al. (2015) have suggested that simple recording schemes taking information of immediate value to the communities (e.g., vaccinations, exhibitions, seasonal herd movements, culling and access to market auctions/sales) were likely to be more sustainable. Considering this last issue, ESS multi-dimensional assessment approaches (Martín-López et al., 2014) are expected to be helpful to integrate economic and non-economic traits into decision-making processes, considering both trade-offs and synergies among services, and correlations among traits.

From the above discussion, we may conclude that the importance of AnGR diversity in the agricultural ESS framework goes much beyond the sole role of provisioning ESS. Through a diversity of traits that are more or less specific to some individuals, breeds and species (Table 1), AnGR are an important determinator of many ESS. This process occurs in general through the livestock production system and practices which in turn determine the species and breeds used within a given agroecosystem (Fig. 1). Greater understanding of the synergies and trade-offs among ESS may allow the identification of traits, and therefore specific individuals or populations, which could constitute levers to maintain a broad range of ESS.

3. Opportunities and constraints for the recognition and valuation of the role of AnGR diversity in ESS provision

As described above, AnGR diversity is related to a wide range of ESS, the maintenance of which is essential to the livelihood and well-being of many communities. Indeed, policy decisions designed to maximize the benefits of livestock have tended to favour the most productive, intensively selected breeds in terms of marketable commodities, whereas non-market values associated with local populations have often been ignored (Martin-Collado et al., 2014). The question on how to ensure that ESS are continuously delivered, especially non-provisioning ESS, is a key challenge. Livestock smallholders, and especially pastoralists, are among the main providers, and beneficiaries, of ESS. They often suffer, however, from poverty, lack of education and general marginalisation, and their access to resources is increasingly difficult (McGahey et al., 2014). Farmers are generally well aware of ESS, their interaction and relationships with agricultural practices (Bernués et al., 2016), and various studies (Marshall et al., 2016; Traoré et al., 2017) have shown that livestock keepers include in their criteria to select breeding animals traits that are directly related to a wide range of ESS (draught power, adaptation, manure, ceremonial practices). Yet, in developing countries, the lack of participation of farmers in the decision decision-making process of livestock improvement programmes has often led to the failure of those programmes, as “improved” animals actually do not fulfil farmer expectations and perform poorly due to a lack of adaptation to harsh conditions of the actual production environment (Wollny, 2003; Leroy et al., 2016b). To that extent, community based breeding programmes (Mueller et al., 2015) may constitute a better opportunity to consider, in a participative manner, incorporating ESS in breeding objectives.

In a survey considering 120 case studies collected from 47 countries on the role of AnGR in providing ESS (FAO, 2014), 70.1% and 67.3% of respondents named economic incentives and recognition of ESS by policymakers, respectively, as opportunities for ensuring that ESS are recognized and utilized. Policies, social issues and research were also frequently named as opportunities or constraints for the management of ESS (Fig. 2). Several approaches have been developed to quantify the benefits from non-provisioning services and determine their value for livestock keepers, as well as for the whole society. A diversity of Market-Based Instruments (MBIs) have been developed as tools for improving access to and delivery of environmental outcomes, through carbon trading schemes, biodiversity offsets, or Payments for ESS (PES) (Gómez-Baggethun and Muradian, 2015). The recognition of ESS and their inclusion into policy and legal frameworks constitute an important issue to ensure their sustainable provision. Such legal frameworks may deal with direct support to the provision of ESS services, management of trade-offs, land management policies adapted to the pastoral systems and related ESS, connection of farmers and pastoralists to markets and the development of certification schemes to increase added-value of livestock products from systems providing ESS (organic, grass-fed and similar labels), or support to research, capacity building and education. In relation to climate change issues, it has been suggested that policies should encourage adoption of more flexible and resilient systems, and make rangeland use less rigid (Barnes et al., 2012). Some of these policies may deal directly with the conservation of AnGR. In the European Union, livestock keepers are encouraged to conserve at-risk local breeds through agri-environment payments. According to country reports for the Second State of the World for AnGR, 52 out of 128 countries indicated the provision of incentives for sustaining at-risk breeds (FAO et al., 2015). Also, 33% of the countries indicated addressing the provision of regulating services through specific policies, plans or strategies. According to several countries, the implementation of those measures has led to diversification of production, as well as increases in the productivity and the economic viability of local breed populations.

4. Discussion and conclusion

The diversity of ESS provided by breeds and species are critical for food security, sustainable livelihoods and resilience, especially in the perspective of climate change. A majority of regulating, habitat and cultural ESS of livestock are provided by locally adapted breeds that are kept in harsh environments, where livestock keepers' livelihoods depend largely on the continuous provision of those ESS. These production systems, despite a low apparent productivity, rely largely on non-edible feeds, thus achieving remarkable conversion efficiency. At the same time, locally adapted breeds often have unique adaptive abilities to cope with diseases, extreme events and climate constraints. Small-scale livestock keepers and pastoralists who keep those animals are often resource poor and marginalised, isolated from markets and excluded from decision making processes, which is putting the long-term survival of their unique production systems at stake. As underlined by McGahey et al. (2014), the recognition of the diverse livestock sector as integral to the Green Economy may allow AnGR and their keepers and guardians to increase their resilience and provide this diversity of ESS in a sustainable manner.

There are still important gaps in identification and provision of ESS linked to AnGR. Rodríguez-Ortega et al. (2014) noted that limited knowledge of the relationships among ESS makes it difficult to predict trade-offs and synergies and identify how to minimise or enhance them. Therefore, there is a need for research integrating livestock production, other academic disciplines (such as agronomy, sociology, and economics) and traditional knowledge to achieve social transformation and paradigm shift in policymaking. Besides the identification and recognition of livestock ESS services, there is a need to quantify to which extent AnGR diversity may contribute to those services, considering both geographical (from farm to global level) and genetic (within and between breeds and species) scales. As underlined by Tixier-Boichard et al. (2015), integrating traits relevant for ESS within breeding programmes represent a particular challenge, especially in low-input systems.

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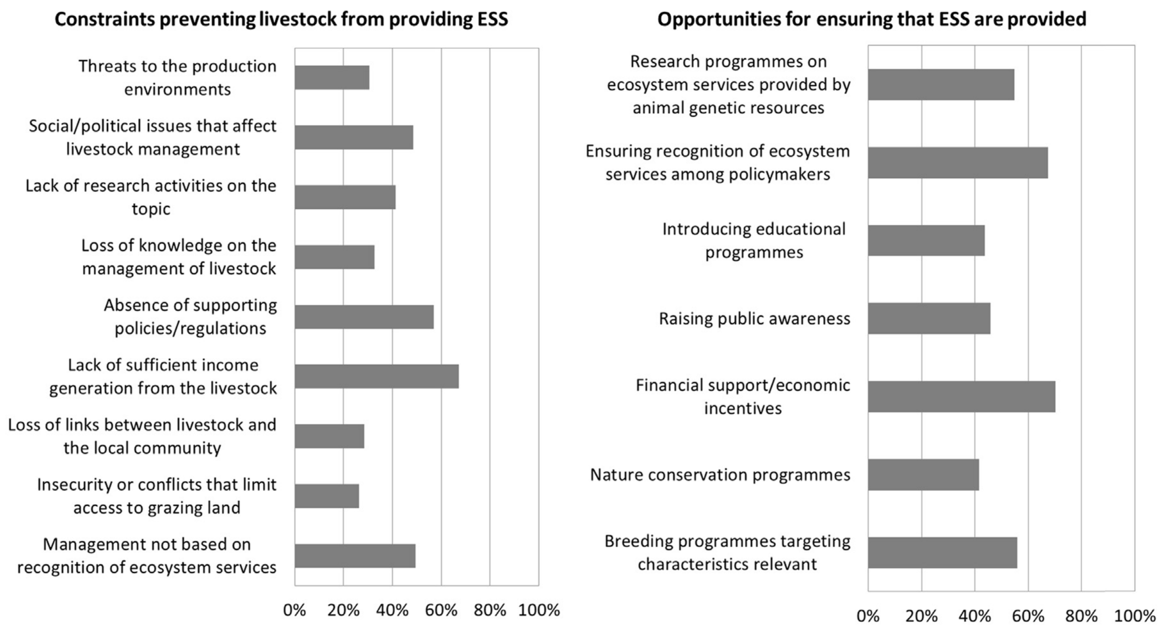

Fig. 2. Reported constraints and opportunities for the provision of ecosystem services by AnGR in grassland (adapted from FAO, 2014).

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Conflicts of interest

None.

References

Arcoverde, G.B., Andersen, A.N., Setterfield, S.A., 2016. Is livestock grazing compatible with biodiversity conservation? Impacts on savanna ant communities in the Australian seasonal tropics. Biodivers. Conserv. 4, 883–897.

Azcárate, F.M., Robleño, I., Seoane, J., Manzano, P., Peco, B., 2013. Drove roads as local biodiversity reservoirs: effects on landscape pattern and plant communities in a Mediterranean region. Appl. Veg. Sci. 16, 480–490.

Barnes, J., MacGregor, J., Alberts, M., 2012. Expected climate change impacts on land and natural resource use in Namibia: exploring economically efficient responses. Pastoralism 2, 2–22.

Bedelian, C.E., 2014. Conservation, Tourism And Pastoral Livelihoods: Wildlife Conservancies in the Maasai Mara, Kenya (Doctoral dissertation). University College London, London.

Bernués, A., Ruiz, R., Olaizola, A., Villalba, D., Casasús, I., 2011. Sustainability of pasture-based livestock farming systems in the European Mediterranean context: synergies and trade-offs. Livest. Sci. 139, 44–57.

Bernués, A., Tello-García, E., Rodríguez-Ortega, T., Ripoll-Bosch, R., Casasús, I., 2016. Agricultural practices, ecosystem services and sustainability in High Nature Value farmland: unraveling the perceptions of farmers and nonfarmers. Land Use Policy 59, 130–142.

Celaya, R., Jáuregui, B.M., Rosa García, R., Benavides, R., García, U., Osoro, K., 2010. Changes in heathland vegetation under goat grazing: effects of breed and stocking rate. Appl. Veg. Sci. 13, 125–134.

Copland, J.W., Alders, R.G., 2009. The comparative advantages of village or smallholder poultry in rural development. In: Village Chickens, Poverty Alleviation and the Sustainable Control of Newcastle Disease, ACIAR Proceedings, 131, pp. 11–14.

Delattre, F., Dobremez, L., 2004. Simulations of scenario for the reinforcement of the multi-functionality of farms in an Alpine region. Fourrages 177, 79–92.

Derner, J.D., Augustine, D.J., Kachergis, E., 2014. Cattle as Ecosystem Engineers: New Grazing Management Enhances Rangeland Biodiversity. Natural Resource Science and Management in the West, Western Confluence, pp. 10–13.

Dikmen, S., Khan, F.A., Huson, H.J., Sonstegard, T.S., Moss, J.I., Dahl, G.E., Hansen, P.J., 2014. The SLICK locus derived from Senepol cattle confers thermotolerance to intensively-managed lactating Holstein cows. J. Dairy Sci. 97, 5508–5520.

FAO, 2003. World Agriculture: Towards 2015/2030. In: Bruinsma, J. (Ed.), An FAO Perspective. FAO, Rome and Earthscan, London.

FAO, 2013. In: Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., Tempio, G. (Eds.), Tackling Climate Change through Livestock – A Global Assessment of Emissions and Mitigation Opportunities. FAO, Rome.

FAO, 2014. Ecosystem Services Provided by Livestock Species and Breeds, with Special Consideration to the Contributions of Small-scale Livestock Keepers and Pastoralist. Background Study Paper 66. FAO Commission on Genetic Resources for Food and Agriculture Assessments, Rome.

FAO, 2015. In: Scherf, B., Pilling, D. (Eds.), The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture. FAO Commission on Genetic Resources for Food and Agriculture Assessments. FAO, Rome, Italy.

FAO, 2018. FAOSTAT OnlineDatabase (available at) 〈http://faostat.fao.org/〉 (Accessed on 19 January 2018).

Franzluebbers, A.J., Stuedemann, J.A., Franklin, D.H., 2012. Water Infiltration and Surface-soil Structural Properties as Influenced by Animal Traffic in the Southern Piedmont USA. Renew. Agr. Food Syst. 27. pp. 256–265.

Freire, J.P.B., Dias, R.I.M., Cunha, L.F., Aumaitre, A., 2003. The effect of genotype and dietary fibre level on the caecal bacterial enzyme activity of young piglets: digestive consequences. Anim. Feed Sci. Technol. 106, 119–130.

Gandini, G.C., Villa, E., 2003. Analysis of the cultural value of local livestock breeds: a methodology. J. Anim. Breed. Genet. 120, 1–11.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Toulmin, C., 2010. Food security: the challenge of feeding 9 billion people. Science 327, 812–818.

Gómez-Baggethun, E., Muradian, R., 2015. In markets we trust? Setting the boundaries of market-based instruments in ecosystem services governance. Ecol. Econ. 117, 217–224.

Haines-Young, R., Potschin, M., 2017. Common International Classification of Ecosystem Services (CICES) V5.1. Centre for Environmental Management, University of Nottingham, Nottingham.

Havenstein, G.B., Ferket, P.R.M., Qureshi, A., 2003. Growth, livability, and feed conversion of 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets. Poult. Sci. 82, 1500–1508.

Hayes, B.J., Lewin, H.A., Goddard, M.E., 2013. The future of livestock breeding: genomic selection for efficiency, reduced emissions intensity, and adaptation. Trends Genet. 29, 206–214.

Herrero, M., Thornton, P.K., Gerber, P., Reid, R.S., 2009. Livestock, livelihoods and the environment: understanding the trade-offs. Curr. Opin. Environ. Sustain. 1, 11–120.

Hoogendoorn, C.J., Betteridge, K., Ledgard, S.F., Costall, D.A., Park, Z.A., Theobald, P.W., 2011. Nitrogen leaching from sheep-, cattle-and deer-grazed pastures in the Lake Taupo catchment in New Zealand. Anim. Prod. Sci. 51, 416–425.

Hopwood, J., Hoffman, B., Lee-Mäder, E., Charlap, A., Preston, R., Mozumder, K., Fleury, S., 2015. Literature Review: Pollinator Habitat Enhancement and Best Management Practices in Highway Rights-of-way. Federal Highway Administration, Washington DC.

International Energy Agency (IEA), 2007. World Energy Outlook 2007 – Special Report - Focus on Energy Poverty. International Energy Agency, Paris.

IPBES, 2016. Summary for policymakers of the assessment report of the Intergovernmental Science-policy platform on biodiversity and ecosystem services on pollinators, pollination and food production. Secr. Intergov. Sci.-Policy Platf. Biodivers. Ecosyst. Serv (Bonn).

Krätli, S., 2008. Cattle breeding, complexity and mobility in a structurally unpredictable environment: the WoDaaBe herders of Niger. Nomad. People 12, 11–41.

Kugler, W., Broxham, E., 2014. The Ecological Value of Feral Livestock Populations in Europe. Overview, situation and development of a network for management wild livestock populations, Final Report. SAVE-Project, St. Gallen, Switzerland.

Lekule, F.P., Kyvsgaard, N.C., 2003. Improving pig husbandry in tropical resource-poor communities and its potential to reduce risk of porcine cysticercosis. Acta Trop. 87, 111–117.

Lemaire, G., Franzluebbers, A., de Faccio Carvalho, P.C., Dedieu, B., 2014. Integrated crop–livestock systems: strategies to achieve synergy between agricultural production and environmental quality. Agric. Ecosyst. Environ. 190, 4–8.

Len, N.T., Ngoc, T.B., Ogle, B., Lindberg, J.E., 2009. Ileal and total tract digestibility in local (Mong Cai) and exotic (Landrace× Yorkshire) piglets fed low and high-fibre diets, with or without enzyme supplementation. Livest. Sci. 126, 73–79.

Leroy, G., Besbes, B., Boettcher, P., Hoffmann, I., Capitan, A., Baumung, R., 2016a. Rare phenotypes in domestic animals: unique resources for multiple applications. Anim. Genet. 47, 141–153.

Leroy, G., Baumung, R., Boettcher, P., Scherf, B., Hoffmann, I., 2016b. Sustainability of crossbreeding in developing countries; definitely not like crossing a meadow. Animal 10, 262–273.

Leroy, G., Hoffmann, I., Form, T., Hiemstra, S.J., Gandini, G., 2018. Perception of livestock ecosystem services in grazing areas inside and outside Europe. Animal (accepted).

Lewis, M., 2003. Cattle and conservation in Bharatpur. A case study in conservation and advocacy. Conserv. Soc. 1, 1–21.

Ligda, C., Casabianca, F., 2013. Adding value to local breeds: challenges, strategies and key factors. Anim. Gen. Res. 53, 107–116.

Mace, G.M., Norris, K., Fitter, A.H., 2012. Biodiversity and ecosystem services: a multilayered relationship. Trends Ecol. Evol. 27, 19–26.

Marshall, K., Mtimet, N., Wanyoike, F., Ndiwa, N., Ghebremariam, H., Mugunieri, L., Costagli, R., 2016. Traditional livestock breeding practices of men and women Somali pastoralists: trait preferences and selection of breeding animals. J. Anim. Breed. Genet. 133, 534–547.

Marsoner, T., Vigl, L.E., Manck, F., Jaritz, G., Tappeiner, U., Tasser, E., 2017. Indigenous livestock breeds as indicators for cultural ecosystem services: a spatial analysis within the Alpine Space. Ecol. Indic. http://dx.doi.org/10.1016/j.ecolind.2017.06.046.

Martin-Collado, D., Diaz, C., Drucker, A.G., Carabaño, M.J., Zander, K.K., 2014. Determination of non-market values to inform conservation strategies for the threatened Alistana–Sanabresa cattle breed. Animal 8, 1373–1381.

Martín-López, B., Gómez-Baggethun, E., García-Llorente, M., Montes, C., 2014. Trade-offs across value-domains in ecosystem services assessment. Ecol. Indic. 37, 220–228.

McGahey, D., Davies, J., Hagelberg, N., Ouedraogo, R., 2014. Pastoralism and the Green Economy – A Natural Nexus? IUCN and UNEP, Nairobi.

Millennium Ecosystem Assessment (MEA), 2005. Ecosystems and Human Well-being: Biodiversity Synthesis. Island Press, Washington D.C.

Mottet, A., de Haan, C., Falucci, A., Tempio, G., Opio, C., Gerber, P., 2017. Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. Glob. Food Sec. http://dx.doi.org/10.1016/j.gfs.2017.01.001.

Mueller, J.P., Rischkowsky, B., Haile, A., Philipsson, J., Mwai, O., Besbes, B., Sölkner, J., 2015. Community-based livestock breeding programmes: essentials and examples. J. Anim. Breed. Genet. 132 (2), 155–168.

Neumann, C., Harris, D.M., Rogers, L.M., 2002. Contribution of animal source foods in improving diet quality and function in children in the developing world. Nutr. Res. 22, 193–220.

Nielsen, H.M., Olesen, I., Navrud, S., Kolstad, K., Amer, P., 2011. How to consider the value of farm animals in breeding goals. A review of current status and future challenges. J. Agric. Environ. Ethics 24, 309–330.

Orford, K.A., Murray, P.J., Vaughan, I.P., Memmott, J., 2016. Modest enhancements to conventional grassland diversity improve the provision of pollination services. J. Appl. Ecol. 53, 906–915.

Ovaska, U., Soini, K., 2016. Native breeds as providers of ecosystem services: the stakeholders' perspective. trace. Finn. J. Hum. Anim. Stud. 2.

Petz, K., Alkemade, R., Bakkenes, M., Schulp, C.J., van der Velde, M., Leemans, R., 2014. Mapping and modelling trade-offs and synergies between grazing intensity and ecosystem services in rangelands using global-scale datasets and models. Glob. Environ. Chang. 29, 223–234.

Pinto de Abreu, U.G., McManus, C., Santos, S.A., 2010. Cattle ranching, conservation and transhumance in the Brazilian Pantanal. Pastoralism 1, 100–114.

Pitchford, W.S., 2004. Genetic improvement of feed efficiency of beef cattle: what lessons can be learnt from other species? Agric. Aust. J. Exp. Agric. 44, 371–382.

Potter, P., Ramankutty, N., Bennett, E.M., Donner, S.D., 2010. Characterizing the spatial patterns of global fertilizer application and manure production. Earth Interact. 14, 1–22. http://dx.doi.org/10.1175/2009EI288.1.

Power, A.G., 2010. Ecosystem services and agriculture: tradeoffs and synergies. Philos. Trans. R Soc. Lond. B Biol. Sci. 365, 2959–2971.

Richter, D., Matushka, F.R., 2006. Modulatory effect of cattle on risk for lyme disease. Emerg. Infect. Dis. 12, 1919–1923.

Rodríguez-Ortega, T., Oteros-Rozas, E., Ripoll-Bosch, R., Tichit, M., Martín-López, B., Bernués, A., 2014. Applying the ecosystem services framework to pasture-based livestock farming systems in Europe. Animal 8, 1361–1372. http://dx.doi.org/10.1017/S1751731114000421.

Rook, A.J., Dumont, B., Isselstein, J., Osoro, K., WalliesDeVries, M.F., Parente, G., Mills, J., 2004. Matching type of livestock to desired biodiversity outcomes in pastures – a review. Biol. Conserv. 119, 137–150.

Ruiz-Mirazo, J., Robles, A.B., 2012. Impact of targeted sheep grazing on herbage and holm oak saplings in a silvopastoral wildfire prevention system in south-eastern Spain. Agrofor. Syst. 86, 477–491.

Schulp, C.J.E., Lautenbach, S., Verburg, P.H., 2014. Quantifying and mapping ecosystem services: demand and supply of pollination in the European Union. Ecol. Indic. 36, 131–141. http://dx.doi.org/10.1016/j.ecolind.2013.07.014.

Shabtay, A., 2015. Adaptive traits of indigenous cattle breeds: the Mediterranean Baladi as a case study. Meat Sci. 109, 27–39.

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

Smith, K.A., Frost, J.P., 2000. Nitrogen excretion by farm livestock with respect to land spreading requirements and controlling nitrogen losses to ground and surface waters. Part 1: cattle and sheep. Bioresour. Technol. 71, 173–181.

Socher, S.A., Prati, D., Boch, S., Müller, J., Baumbach, H., Gockel, S., Kalko, E.K., 2013. Interacting effects of fertilization, mowing and grazing on plant species diversity of 1500 grasslands in Germany differ between regions. Basic Appl. Ecol. 14, 126–136.

Swinton, S.M., Lupi, F., Robertson, G.P., Hamilton, S.K., 2007. Ecosystem services and agriculture: cultivating agricultural ecosystems for diverse benefits. Ecol. Econ. 64, 245–252.

Tixier-Boichard, M., Verrier, E., Rognon, X., Zerjal, T., 2015. Farm animal genetic and genomic resources from an agroecological perspective. Front. Genet. 6, 153.

Török, P., Valkó, O., Deák, B., Kelemen, A., Tóth, E., Tóthmérész, B., 2016. Managing for species composition or diversity? Pastoral and free grazing systems in alkali steppes. Agric. Ecosyst. Environ. 234, 23–30.

Traoré, S.A., Markemann, A., Reiber, C., Piepho, H.P., Zárate, A.V., 2017. Production objectives, trait and breed preferences of farmers keeping N'Dama, Fulani Zebu and crossbred cattle and implications for breeding programs. Animal 11, 687–695.

Widi, T.S.M., Udo, H.M.J., Oldenbroek, K., Budisatria, I.G.S., Baliarti, E., van der Zijpp, A.J., 2014. Unique cultural values of Madura cattle: is cross-breeding a threat? Anim. Genet. Res. 54, 141–152.

Wollny, C.B., 2003. The need to conserve farm animal genetic resources in Africa: should policy makers be concerned? Ecol. Econ. 45, 341–351.

Wurzinger, M., Ndumu, D., Baumung, R., Drucker, A.G., Okeyo, A.M., Semambo, D.K., Sölkner, J., 2006. Assessing stated preferences through the use of choice experiments: Valuing (re)production versus aesthetics in the breeding goals of Ugandan Ankole cattle breeders. In: Proceedings 8th World Cong. Genet. Appl. Livest. Prod. 13–18 Aug 2006, Belo Horizonte, Brazil. CD-ROM: 31_439-608.pdf. pp. 4.

Zhang, W., Ricketts, T.H., Kremen, C., Carney, K., Swinton, S.M., 2007. Ecosystem services and dis-services to agriculture. Ecol. Econ. 64, 253–260.