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COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

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REVIEW OF METHODS FOR IDENTIFICATION AND VALUATION OF THE ECOSYSTEM SERVICES PROVIDED BY LIVESTOCK BREEDS

Note by the Secretariat

This document has been prepared at the request of the Secretariat of the FAO Commission on Genetic Resources for Food and Agriculture (Commission) by the FAO Animal Production and Health Division, in response to a request from the Commission at its Sixteenth Regular Session[1] for FAO to review methods for identification and valuation of the ecosystem services provided by livestock breeds for consideration by the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture (Working Group) at its Tenth Session.

The Working Group took note of the review,[2] but recommended revision and the addition of material, including concrete examples, that broadened the scope of the document to cover all continents and livestock production systems, socio-ecological systems and categories of breeds and addressed the question of how to scale up data collection from local to national level. It requested the Secretariat to revise the document accordingly, for consideration by the Commission at its current session.[3]

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[1] CGRFA-16/17/Report/Rev.1, paragraph 47.
[2] CGRFA/WG-AnGR-10/17/Inf.5.
[3] CGRFA/17/19/11.1, paragraph 10.

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Methods for identification and valuation of ecosystem services provided by livestock breeds and their production systems

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1 Introduction

This review presents a structured framework for the application of the ecosystem services (ES) concept in agro-ecosystems, specifically to livestock breeds and the production systems in which they are kept. The objective of the review is to summarize the common approaches for identification and valuation of relevant ES and ultimately to inform decision-making processes related to the development, conservation and promotion of the world's livestock breed diversity and associated agro-ecosystems.

The specific objectives of this review are to:

1. define the role of livestock production systems, and livestock breeds in particular, in the delivery of ES;
2. outline the main steps involved in valuing these ES;
3. identify the potential ES provided by livestock breeds and associated agro-ecosystems; and
4. review the main methodologies for identifying and valuing ES in specific socio-economic and biophysical contexts.

The document is structured as follows:
Section 2 presents a general overview of basic concepts and the use of the ES framework to assess agro-ecosystems and livestock breeds.
Section 3 outlines a six-step valuation process.
Section 4 lists and describes the main ES provided by agro-ecosystems and livestock breeds.
Section 5 discusses methods of assessing the importance and value of ES provided by livestock breeds, taking various perspectives (biophysical, sociocultural and economic) into account.
Section 6 provides a brief summary of the review.

The examples presented in the document were drawn from peer-reviewed articles and reports from national and international institutions that specifically address livestock agro-ecosystems and the ES they deliver, as well as references provided by National Coordinators for the Management of Animal Genetic Resources for Food and Agriculture. Due to the small number of studies about ES provided by particular breeds, many examples refer to species or production systems in which locally adapted breeds are raised.

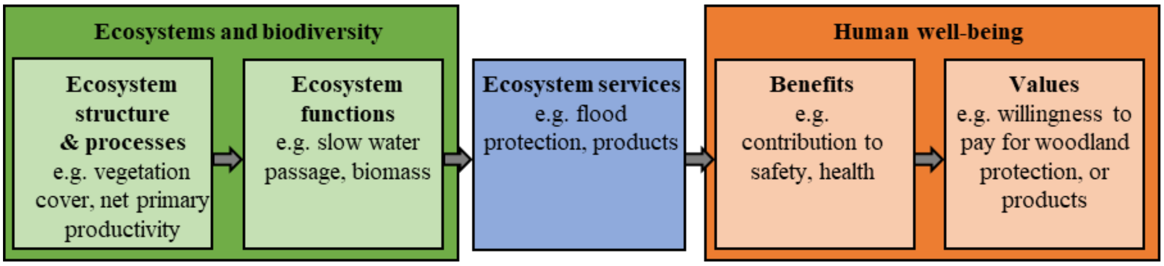
2 The ecosystem services framework

2.1 Ecosystem functions, ecosystem services and human well-being

The discussion of ES presented in this review is based on the most widely accepted definition of the term: "Ecosystem services are the direct and indirect contributions of ecosystems to human well-being"[4] (TEEB, 2010). It is important to distinguish ES from ecosystem functions, defined as the "interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services" (TEEB, 2010).

This review utilizes the "cascade" model proposed by Haines-Young and Potschin (2010) and modified by de Groot (2010), which spans the transition from ecosystem structures and processes, to ecosystem functions, ES, human benefits and human values (Figure 1). As well as elucidating the relationships between people and nature and delineating the functional characteristics of ecosystems and the benefits and values they produce (Potschin-Young *et al.*, 2018), this framework helps avoid double counting of ES and clarifies the spatial distribution of the supply of ES and that of their benefits, which do not necessarily coincide (de Groot *et al.*, 2010). It distinguishes benefits (i.e. the contributions to human well-being) from values (i.e. the appreciation of these benefits on the part of particular stakeholders or the public at large). The metrics used to measure the "value" of an ES can be biophysical, sociocultural or economic (Section 5). Box A presents definitions of key terms used in the review.

Figure 1. Conceptual framework of the ecosystem service "cascade" model



Source: Adapted from Haines-Young and Potschin (2010) and de Groot (2010).

[4] The Millennium Ecosystem Assessment (MA, 2005) formally defined ES as "the benefits that ecosystems provide to people." The Economics of Ecosystems and Biodiversity (TEEB, 2010) adapted this definition as follows: "the direct and indirect contributions of ecosystems to human well-being". The concept had been previously been seminal works by Costanza (1997) and Daily (1997).

Box A – Glossary of terms

Definitions of cascade model components according to (TEEB, 2010)

Ecosystem structure: the biophysical architecture of an ecosystem.

Ecosystem process: any change or reaction that occurs within ecosystems, either physical, chemical or biological.

Ecosystem function: a subset of interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services.

Ecosystem services: the direct and indirect contributions of ecosystems to human well-being.

Benefits: positive change in wellbeing from the fulfilments of needs and wants.

Values: the contribution of an action or object to user-specified goals, objectives or conditions.

Other terms used in the document

Ecosystem: a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (United Nations, 1992). For practical purposes it is important to define the spatial dimensions involved.

Agro-ecosystem: an ecosystem under agricultural management, connected to other ecosystems (OECD, 2001).

Socio-ecological system: an ecosystem and the management of this ecosystem by actors and organizations, and the rules, social norms and conventions underlying this management (MA, 2005).

Socio-agro-ecosystem: a socio-ecological system under agricultural management.

Production boundary: an imaginary boundary where an "ecosystem service" becomes a "good" (or a benefit). For example, the wheat growing in a field is a service while the grain in a market is a good. For non-material ecosystem outputs the "production boundary" is crossed when the output is linked to some kind of relationship that people have with an ecosystem which then changes their well-being in some way (Haines-Young and Potschin, 2016)

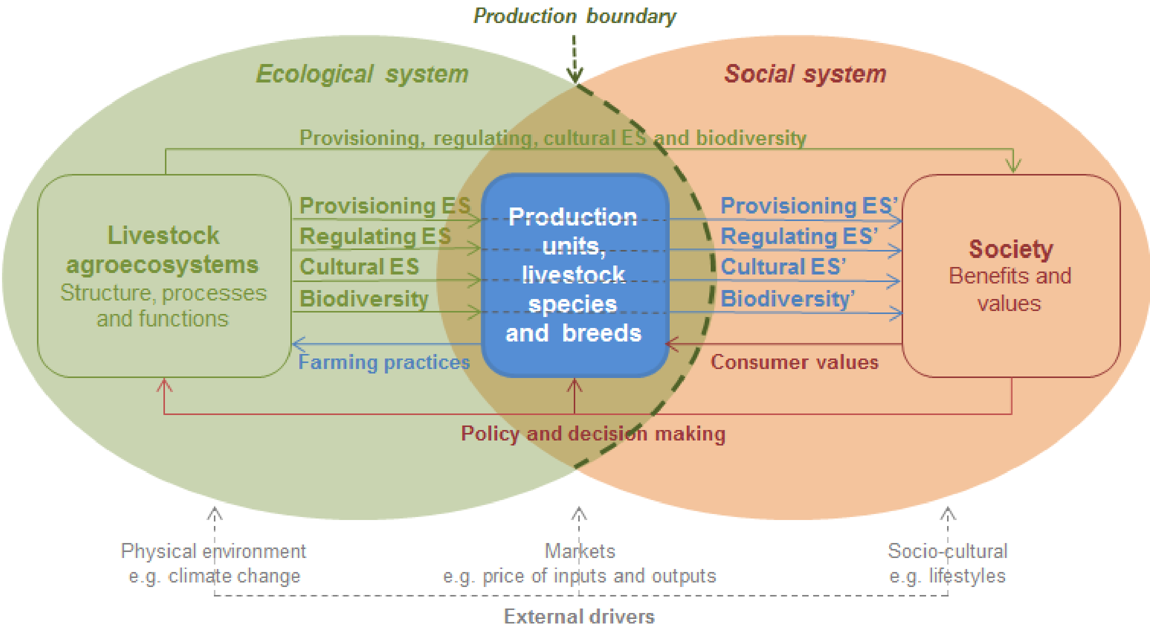
Transhumance: a system of livestock production based on the continual movement of animals over long distances

Transtermitance: a system of livestock production based on the movement of animals over relatively short distances, but nevertheless through varied landscapes (such as those resulting from differences in altitude)

2.2 Application of the ecosystem services framework to livestock production and livestock breeds: the socio-agro-ecosystem approach

When applied to agro-ecosystems, the conceptual framework outlined above needs to be adjusted so as to include the key role that livestock production plays in the delivery of ES to society (Figure 2). The adapted framework allows the ES concept to be applied to livestock production and to livestock breeds in particular. The framework integrates three main components: (i) livestock agro-ecosystems; (ii) livestock farms (or other production units), livestock species and breeds; and (iii) society. Following Potschin-Young *et al.* (2018), the framework locates the farm (or other production unit) at the "production boundary", the border between the ecological and the social system.

Figure 2. The socio-agro-ecosystem: ecosystem services framework applied to livestock production and livestock breeds



Source: Adapted from Bernués *et al.* (2016a).

Crucially, livestock farms/production units (with their associated livestock species and breeds) are considered an intermediary or link between the agro-ecosystem and society, functioning as a "filter" of agro-ecosystem processes and functions that modifies the flow of ES from the natural world to society (Bernués *et al.*, 2016a; Plantureux *et al.*, 2016). On one hand, the farms or production units benefit from provisioning ES (e.g. forage) and regulating ES (e.g. climate regulation, soil fertility and water availability). Livestock production allows for the delivery of new provisioning ES to society (e.g. meat or milk) while modifying the flow of other ES (e.g. cultural ES provided by landscapes), and biodiversity (e.g. increasing soil biodiversity or domestic animal biodiversity). On the other hand, livestock keepers implement management regimes and practices (including the choice of species and breeds) that modify ecosystem structure and functioning.

The goal of the livestock keeper is usually to optimize the outputs from provisioning services of the production unit according to his or her own personal needs and objectives. Achieving this goal often comes at the expense of a reduction in the delivery of other ES and an increase in negative externalities or ecosystem disservices.[5] Alternatively, livestock keepers may

[5] The negative effects of livestock on the environment, called ecosystem disservices in the ES framework, are not addressed in this study. Livestock can also receive ecosystem disservices from the ecosystems (e.g. parasites) and provides numerous ecosystem disservices (e.g. nutrient runoff, habitat loss, greenhouse gas emissions, etc.) (Zhang *et al.*, 2007), which have been widely covered by the literature. The flow of ES and

simultaneously pursue multiple outcomes, more equitably addressing provisioning and other ES (i.e. multifunctional agriculture). The modification of management regimes and agricultural practices at the farm level to address multiple outcomes will largely depend on public (e.g. agri-environmental schemes) and private (e.g. market prices) economic stimuli, but will also be influenced by availability of labour, farm-continuity prospects and the subjective perceptions and goals of farmers and their families.

The three components listed above – livestock agro-ecosystems, production units, and society, and the interrelations between them – are influenced by various driving forces. For example, external drivers, such as the physical environment (e.g. climate variability), legal and policy frameworks in fields such as nature protection, land management, markets for inputs and outputs as well as marketing, food quality and safety and sociocultural factors (e.g. consumer lifestyles and trends), can influence the ways in which agro-ecosystems, livestock production and society function and relate to each other.

The particularities of livestock production units (i.e. structure and management), livestock species (i.e. different feed sources, associated biodiversity and type of products) and breeds (i.e. variable capacity to produce under specific production systems or associated cultural values), modify in different ways the flow of ES. As mentioned, this review considers livestock farms and breeds as filters or modifiers of the flow of ES from the natural world that deliver social benefits (e.g. through the transformation of forage into quality products).

The review utilizes the concept of social-ecological systems (Ostrom, 2009), which provides a powerful framework within which to analyse the complex and evolving relationships between human activities and agro-ecosystems. Livestock production systems can be considered "adaptive" social-ecological systems in which biophysical and social components continuously and dynamically interact at various spatial, temporal and organizational scales. Accordingly, the conservation of livestock breeds and the ES associated with them cannot be achieved without considering the general evolution of agriculture, the rural population, the food chain and consumption patterns (Figure 2).

2.3 Ecosystem services and sustainability

The ES framework needs to be embedded in the wider concept of sustainability, which should integrate multiple societal, ecological, economic, and governance consequences of development choices. From this perspective, sustainability assessments should include not only a range of indicators for ES and ecosystem disservices, but also different perspectives, spatial-temporal scales and methodological frameworks that complement each other.

The ES concept has become mainstream, but its incorporation into decision-making remains limited to date. Bennett *et al.* (2015) list several research areas that need to be addressed in order to narrow this gap. The following are particularly relevant to the livestock sector:

1. How, when and where are ES co-produced? There is a need to better understand the effect of human activities on ES, considering cross-scale effects and path-dependence. This greater understanding is particularly relevant in the case of agricultural practices and their effects of ES delivery.
2. Who benefits from the provision of ES? There is a need to understand the diversity of stakeholders and social preferences for ES and for where and when ES are supplied and used.

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ecosystem disservices from livestock depend on the agricultural practices and use of on- and off-farm resources (Rodríguez-Ortega *et al.*, 2018).

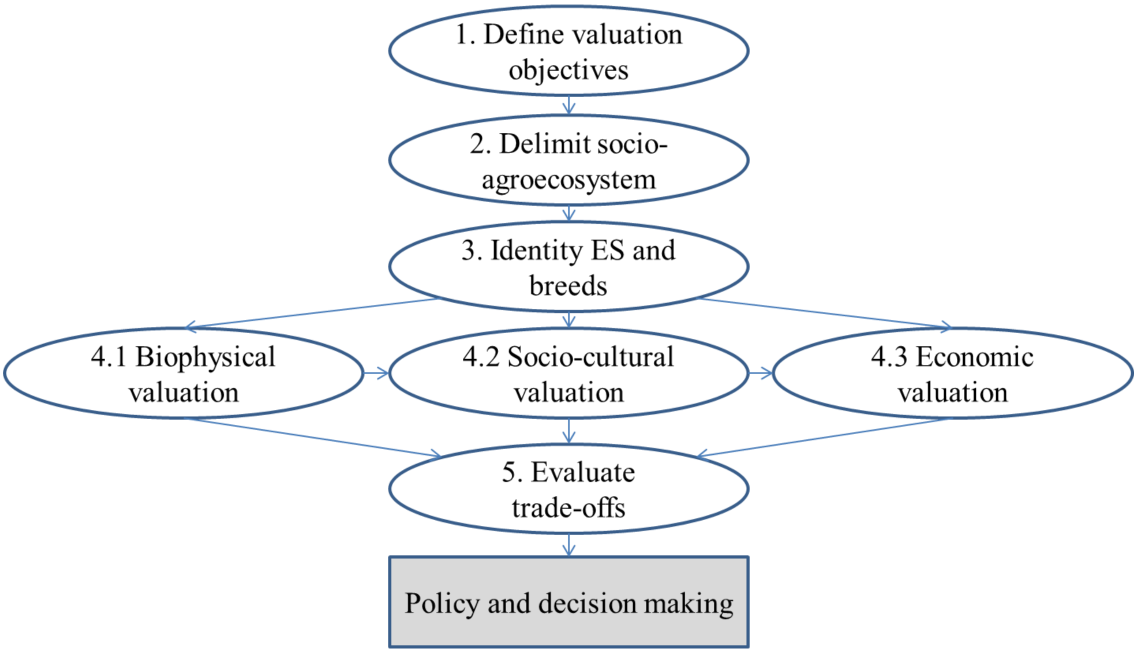
3. What are the best practices for the governance of ES? There is a need to understand power and economic relations, stakeholders and policies in order to improve equity and agro-ecosystem stewardship.

3 Key steps in the valuation of ecosystem services provided by livestock breeds and their associated socio-agro-ecosystems

The process of valuing the ES provided by livestock breeds and their associated socio-agro-ecosystems can be divided into the following steps (Figure 3):

1. Definition of the objectives of the ES valuation;
2. Delimitation and characterization of the socio-agro-ecosystem and its context and identification of key stakeholders;
3. Identification of ES associated with the socio-agro-ecosystem and its livestock species and breeds;
4. Valuation of ES;
   4.1 Biophysical assessment,
   4.2 Sociocultural assessment,
   4.3 Economic assessment;
5. Evaluation of trade-offs among ES; and
6. Support to policy design.

Figure 3. Key steps in the valuation of ecosystem services provided by livestock socio-agro-ecosystems and breeds



This six-step valuation framework should not be considered a rigid chronological sequence, as some steps can be implemented concurrently. It should also be noted that, depending on the objectives of the exercise, some steps may not be necessary. Steps 3 to 5, addressing ES identification and valuation, are the main focus of this review and are described extensively in the following sections 4 and 5.

If the final purpose of the valuation exercise is to improve the conservation of a particular breed and/or the sustainability of the agro-ecosystem in which the breed is integrated, a final stage of policy design and decision making support should be considered in all valuation steps. This is key considering that current agricultural policies and decision making currently ignore or undervalue ES (Bateman *et al.*, 2013).

Step 1. Definition of the objective of ES valuation

The first step in any valuation process, particularly important in ES provided by livestock breeds, is the definition of the objective, which will determine the breadth and depth of the valuation process and the methods to be applied. In this step the (i) objective and (ii) scale of the valuation should be determined.

(i) In the particular case addressed by this review, the objective of the valuation could be the ES delivered by a particular livestock breed (or group of breeds) or the ES delivered by the socio-agro-ecosystem in which the breed is embedded. Depending on the objective, the valuation would focus on different sets of ES. If the interest is a particular livestock breed, the valuation could focus on the ES for which the supply differs substantially from that provided by any other breed. If a given breed is closely associated to a specific livestock production system (or particular geographical location), which would be modified substantially if the breed were substituted, it could be assumed that the ES are provided by the indivisible breed-production system combination.

(ii) The scale of the analysis refers to the particular ES of interest. Many valuation exercises focus on groups of ES (e.g. on all cultural ES provided by a breed) or some specific ES within a group (e.g. landscape as cultural ES, floristic biodiversity, soil fertility as a regulatory ES, or an added value product as a provisioning ES). The evaluation of all ES provided by, for example, a socio-agro-ecosystem requires large effort and resources, and trade-offs among ES normally occur. Therefore, complete valuation of all ES can be difficult and is not usually implemented.

Step 2. Delimitation and characterization of the socio-agro-ecosystem, context and stakeholders

Once the objectives of the valuation are clearly defined, the next step is to delineate the boundaries of the socio-agro-ecosystem to be valuated and to characterize its main ecological and socio-economic units (livestock production system(s) and practices, physical environment, policy context, etc.). The identification of these units permits the analysis of their interactions at the system scale and how they relate to ES delivery. Having a clear picture of the units that form the socio-agro-ecosystem will also facilitate the identification of the key stakeholders, which should be integrated in the valuation process. Martín-López *et al.* (2017) propose a spatial methodology that can be applied to delimit the socio-agro-ecosystem associated with a given breed or group of livestock breeds.

4 Identification of ecosystem services provided by livestock breeds

The third step of the valuation process is identification of the ES to be evaluated. As explained above, the specific ES provided in each case will depend on the socio-agro-ecosystem considered (e.g. mobile livestock production systems may have different ES from sedentary ones) and the associated livestock breed (e.g. one breed may be associated with added-value products while others may not).The following subsections list and describe the potential ES provided by livestock breeds, species and the associated production systems. Systematic reviews on ES delivered by pasture-based livestock systems can be found in Rodríguez-Ortega *et al.* (2014) for Europe and in Pogue *et al.* (2018) for the Prairie Provinces of Canada.

This review classifies ES into four groups: the three categories used under the Common International Classification of Ecosystem Services (CICES)[6] (i.e. provisioning, regulating and cultural ES), plus biodiversity as a separate category.

4.1 Provisioning services

Provisioning ES are the products obtained from ecosystems (TEEB, 2010). These products are very diverse. For example, CICES recognizes 25 classes of biotic provisioning ES and 17 classes of abiotic provisioning ES. The main provisioning ES specifically delivered by livestock breeds are listed in Table 1.

In general, most provisioning ES from livestock breeds and species have been identified and markets have been established, thus allowing livestock keepers to be compensated for the goods and services to varying degrees. International transboundary breeds, with generally greater production, tend to out-compete local and locally adapted breeds in standard markets for provisioning ES. The products of locally adapted breeds often have distinct characteristics that are preferred by consumers and may thus merit a premium price relative to the same product from a transboundary breed, assuming a marketing system to capture this premium can be established. For example, in northern Viet Nam, pig farmers have realized that customers in Hanoi prefer the meat of purebred pigs of the local Ban breed (Le *et al.*, 2016). The higher price customers are willing to pay for this particular provisioning ES allows the Ban pig to more easily compete with crossbred animals.

4.2 Regulating services

Regulating ES (called regulation and maintenance services in CICES) are the benefits obtained from the regulation of ecosystem processes (TEEB, 2010). Regulating ES categories often constitute public goods: i.e. individuals cannot be excluded from their use and use by one individual does not reduce availability to others. According to CICES, there are 22 and 9 different classes of biotic and abiotic regulating ES, respectively.

Regulating ES are usually not directly linked to specific breeds but to production systems (i.e. pasture based systems or extensive systems). As noted by FAO (2014), the effect of livestock species and stocking densities and of the special and temporal trends of production systems have much larger effect on regulating ES than specific breeds *per se*. Therefore, examples in Table 2 refer mainly to production systems.

[6] https://cices.eu/

Table 1. Main biotic provisioning ecosystem services provided by livestock breeds and their associated agro-ecosystems according to CICES classification and coding

CICES code and class	Description	Examples	
		Livestock breeds	Associated biodiversity
1.1.3.1. Animals reared to provide **nutrition**	Livestock and food products of animal origin (meat, milk, eggs, honey, edible offal), as well as non-animal products from the associated ecosystem.	Added-value quality products linked to livestock breeds (at least 28 European breeds are connected to PDO labelled products (FAO, 2014); or general food products in areas where production is only possible due to some breed characteristics (i.e. Icelandic sheep breeds, Brune de l'Atlas or Yakutian cattle, and trypanosome–tolerant goat, sheep and cattle breeds)	...
1.1.3.2. **Fibres** and **other materials** from reared animals for direct use or processing (excluding genetic materials)	Fibre, wool, hides, skin, manure and urine for fertilizer, medicinal resources and ornamental resources.	Many international transboundary livestock breeds have been intensively selected for one food production trait, often either milk, eggs or meat, thus losing some of their ability to provide other products. However, many locally adapted breeds are still used and selected for supplying other products such as wool , cashmere (e.g. Mongolian goats) or other fibres (e.g. South American camelids and Asian yaks).	Other non-livestock products coming from the agro-ecosystem, such as fuelwood, timber and materials for use in biochemical, industrial and pharmaceutical processes, could also be included in this category (Ovaska and Soini, 2016).
1.1.3.3. Animals reared to provide **energy** (including mechanical)	Animal draught power and manure for energy.	Many breeds of various livestock species have been selected for their draught characteristics. Examples of it are the Canadian horse (Khanshour *et al.*, 2015) or draught buffalos in Asia (Nanda and Nakao, 2003). More examples can be found in Starkey (2010) and (FAO, 2014).	Biomass for bioenergy and for use in biorefineries may also be considered as provisioning ES of grazed grasslands (Plantureux *et al.*, 2016).
1.2.2.1. Animal **genetic material** collected for the purposes of maintaining or establishing a population	Frequently referred to as gene pools, genetic resources or genetic diversity. Some studies specifically refer to livestock breeds (Ovaska and Soini, 2016).	See section 4.4.	Pasture wildflower germplasm for restoration and breeding (Plantureux *et al.*, 2016).
1.2.2.3. **Individual genes** extracted from organisms for the design and construction of new biological entities	Under this category, (FAO, 2014) refer generically to biotechnical resources	See section 4.4.	...

Table 2. Main regulating ecosystem services provided by livestock breeds and their associated agro-ecosystems according to CICES classification and coding

CICES code and class	Description	Livestock breed examples
2.2.1.1. Control of **erosion**	Erosion control or prevention by contributing to the maintenance of land cover or soil structure	Some studies note the role of grassland based and mixed production systems in preventing soil degradation (FAO, 2014; Ovaska and Soini, 2016; D'Ottavio *et al.*, 2017).
2.2.1.2. Buffering and attenuation of **mass movement**	Moderation of extreme events such as avalanches and landsides	Pasture systems in mountain areas, which are usually linked to breeds adapted to harsh environments, control erosion on slopes and prevent snow glide though the maintenance of short grasses (e.g. Newesely *et al.*, 2000).
2.2.1.3. Hydrological cycle and **water flow** regulation (including flood control and coastal protection)	Hydrological cycle and water flow maintenance, and flood protection	Some authors stress the potential role of grazed grasslands in water infiltration, retention of water in soils and flood control (Plantureux *et al.*, 2016; Oteros-Rozas *et al.*, 2014).
2.2.1.4. **Wind** protection	Lack of vegetation, e.g. due to human-caused land use change and overgrazing, exposes the soil to increased oxidation, increases the impact of rain and soil removal by wind	Production systems maintaining vegetation cover have positive effects in reducing soil erosion caused by wind or storms (Ovaska and Soini, 2016). Also tree fences are used to provide wind shelter to pastures, crops and livestock while controlling erosion in soil (e.g. Bird *et al.* (1992)). Tree fences could also have a positive effect on farm biodiversity in fragmented landscapes, as noted by Harvey *et al.* (2004).
2.2.1.5. **Fire** protection	Reduced risk and virulence of forest fires through the effect of animals on vegetation.	Prevention of shrub encroachment through grazing reduces the risk of fires which are especially critical in Mediterranean countries, as mentioned by several authors (i.e. FAO, 2014; Leroy *et al.* 2018a,b). Some countries have programmes to use grazing animals for fire prevention (e.g. Ruiz-Mirazo *et al.*, 2011).
2.2.2.1. **Pollination** (or "gamete dispersal in a marine context)	Sometimes defined as the role of biota in the movement of floral gametes (Oteros-Rozas *et al.*, 2014). This ES may refer to pollination of grassland plants, or wild or cultivated plants in the edges or crop fields close to grasslands, or the maintenance of wild pollinators or honeybees (Plantureux *et al.* (2016).	This ES is mainly related to grazing production systems, which are usually associated to locally adapted livestock breeds. Moderate grazing has been shown to be favourable to bee populations in some ecosystems (e.g. Vulliamy et al., 2006; Lázaro *et al.*, 2016). Hevia *et al.* (2016) observed that drove roads for grazing livestock are reservoirs of wild bee diversity.
2.2.2.2. **Seed** dispersal	Animal movement favours plant colonization due to the transport of seeds in guts and coats.	Livestock breeds linked to transhumance or transtermitance favour seed dispersal, increasing the connectivity potential (Cosyns *et al.*, 2005; D'Ottavio *et al.*, 2017). A negative side of this process can be the distribution of invasive species.

Table 2. (Regulating ecosystem services continued)

CICES code and class	Description	Livestock breed examples
2.2.2.3. Maintaining nursery populations and **habitats** (including gene pool protection)	Some production systems provide habitats suitable for wildlife nursery	Pasture systems can provide suitable places for wild species to live and reproduce (e.g. Gennet *et al.*, 2017). Breeds linked to mountain pasture productions systems contribute to maintaining these semi-natural habitat in areas which not all breeds can survive and function.
2.2.3.1. **Pest** control (including invasive species)	Generically referred to as biological control.	Livestock can have a role in pest regulation (e.g. direct consumption of pests, creation or maintenance of habitats that favour the natural enemies of pests, destruction of pest habitats) and control or eradication of weeds (Martinez Correal, 2007).
2.2.3.2. **Disease** control	Animal and human disease regulation. Generically described as the capacity to destroy the habitats of disease vectors (D'Ottavio *et al.*, 2017).	Grazing livestock can control ticks and the diseases they spread, including zoonoses such as Lyme disease (Richter & Matuschka, 2006). Less intensive production systems, more frequently associated with locally adapted breeds, are theorized to be less prone to propagation and spread of pandemic diseases such as influenza (Wallace and Wallace, 2014).
2.2.4.2. Decomposition and fixing processes and their effect on **soil** quality	These services include the maintenance of soil fertility, waste treatment, waste management, waste recycling and maintenance of soil structure or litter quantity.	This is a key ES of grazing livestock managed under sustainable stocking rates. In Sri Lanka, herders of the Jaffna Local Sheep are paid to graze flocks on rice paddies during the off-season, in compensation for the benefits to soil fertility (Ranathunga and Silva, 2009).
2.2.5.1. Regulation of the chemical condition of **freshwaters** by living processes	Control of nitrate leaching, water purification and increasing the supply of clean water are among the ES generically assigned to grazing livestock, especially when compared to industrialized systems.	Good management (e.g. reduced artificial fertilizer) and appropriate stocking rates are important factors in reducing potential contamination and enhancing the purification capacity of grasslands.
2.2.6.1. Regulation of chemical composition of the **atmosphere** and oceans	This ES is sometimes referred to as air purification, air quality regulation or microclimate regulation (through land cover). Carbon sequestration, carbon storage and greenhouse gas mitigation are more controversial.	The debate on the relationship between grazing livestock, grasslands and the atmosphere is ongoing: see Garnett *et al.* (2017) for a review. Gerber et *al.*, (2013) discusses climate-related issues in detail. The parties of the United Nations Framework Convention on Climate Change adopted The Koronivia Joint Work on Agriculture[7] to address the trade-offs of agriculture and climate change.

4.3 *Cultural services*

Cultural ES are non-material benefits people obtain from ecosystems though spiritual enrichment, cognitive development, reflection, recreation and aesthetic experience (TEEB, 2010). Like regulating ES, they are often public goods. According to CICES, there are 12 and 5 different classes of biotic and abiotic cultural ES, respectively. Livestock breeds, as a human-made concept (FAO, 2007), have strong links with cultural ES. Interestingly, developing countries report downwards trends of cultural services associated with livestock, whereas developed countries reported an upward trend (FAO, 2015). The focus here is on biotic cultural ES that can be related to livestock breeds and their associated socio-agro-ecosystems (Table 3 and Box C).

[7] Decision 4/CP.23, Koronivia Joint Work on Agriculture: https://unfccc.int/sites/default/files/resource/docs/2017/cop23/eng/11a01.pdf

Table 3. Main biotic cultural ecosystem services provided by livestock breeds and their associated agro-ecosystems according to CICES classification and coding

CICES code and class	Description	Livestock breed examples
3.1.1.1. Characteristics of living systems that enable activities promoting **health, recuperation or enjoyment** through **active** or immersive interactions	This ES class includes recreational and leisure activities and values related to rural, agricultural or eco-tourism.	Livestock are used in recreational activities, such as horseback riding. The Chilote horse from Chile is used in hipotherapy (Escobar and Tadich, 2006; FAO, 2013). De Bruin (2009) explored the use of green care farms for health benefits.
3.1.1.2. Characteristics of living systems that enable activities promoting **health, recuperation or enjoyment** through **passive** or observational interactions	Depending on their precise nature, most of the activities noted under the class above can also be included here.	Oteros-Rozas *et al.* (2014) refer specifically to tranquillity and relaxation associated with the influence of ecosystems on human physical and psychological wellbeing.
3.1.2.1. Characteristics of living systems that enable **scientific investigation** or the creation of **traditional ecological knowledge**	The contributions of ecosystems to scientific discovery, agricultural, social or economic research and local/traditional/indigenous ecological knowledge are widely recognized.	Farmers' knowledge of ES (and the agricultural practices that influence them) are discussed in detail by Lamarque *et al.* (2014) and Bernués *et al.* (2016b). Archaeological studies have used livestock remains to derive new historical knowledge about the human societies that kept them (e.g. Jeong *et al.*, 2018).
3.1.2.2. Characteristics of living systems that enable **education and training**	This category includes education and cognitive development for society at large (e.g. through school visits) and training/ extension services for farmers and technicians.	An increasing number of farms holding local breeds in high nature value areas combine farming and tourism, or have open days for tourists and consumers.
3.1.2.3. Characteristics of living systems that are resonant in terms of **culture or heritage**	This category includes culture, heritage and art values related, for example, to agricultural buildings, gastronomy, handicrafts, fashion, stories, cultural identity, sense of place, lifestyle or livestock keepers' prestige.	Cultural services provided by livestock breeds are usually considered as a part of the cultural heritage. These services are especially high for traditional breeds raised in small farming systems. Examples of this are Madura Cattle in Indonesia (Widi *et al.*, 2013) and Yakutina cattle in Russia (Ovasaka and Soini, 2011), or camelids and guinea pigs in Peru (FAO, 2014). The roles of some livestock breeds as part of their keepers' cultural identity have been reviewed by Ovanska and Soini (2016).
3.1.2.4. Characteristics of living systems that enable **aesthetic experiences**	Aesthetic values associated with livestock agro-ecosystems are mostly related to landscapes and vegetation types. Agro-ecosystems where nature, humans and livestock breeds have co-evolved over long periods of time are usually highly valued.	The singular appearance of some breeds (e.g. Highland cattle in Scotland and Ankole Watusi in Uganda) and the role of other in managing landscapes can also be included in this category. The Borana Conserved Landscape in Ethiopia is an outstanding example of a specific livestock breed (Borana cattle) strongly linked to the maintenance of a cultural landscape.
3.2.1.1. Elements of living systems that have **symbolic meaning**	For example, specifically mention the. These authors also mention the symbolic significance of the conservation of charismatic or iconic habitats used by these breeds.	Examples of the symbolic meaning that livestock breed can play are, for example, the appearance of native breeds as regional or national symbols (Ovaska and Soini, 2016).

Table 3. (Main biotic cultural ecosystem services continued)

CICES code and class	Description	Livestock breed examples
3.2.1.2. Elements of living systems that have **sacred or religious meaning**	This category can include natural features that have spiritual value such as churches along drove roads (Oteros-Rozas *et al.*, 2014).	Livestock breed, especially local breeds with close links to certain human groups, play a role in social practices such as birth and funeral ceremonies, rainmaking ceremonies and spiritual cleansing ceremonies (FAO, 2014).
3.2.1.3. Elements of living systems used for **entertainment or representation**	Described by CICES as "the things in nature used to make films or to write books".	Ovaska and Soini (2016) note the appearance of native breeds in media, arts and literature. Other aspects could include exhibitions, fairs and other cultural events many of which are breed specific.
3.2.2.1. Characteristics or features of living systems that have an **existence value**	Described by CICES as "the things in nature that we think should be conserved".	Some authors have shown, using Total Economic Value (TEV) experiments, that people give a large value to the right of "endangered" livestock breeds of continuing to exists (Martín-Collado *et al.*, 2014; Zander *et al.*, 2013).
3.2.2.2. Characteristics or features of living systems that have an option or **bequest value**	Described by CICES as "the things in nature that we want future generations to enjoy or use".	Ovaska and Soini (2016) refer to the value of Finnish landrace breeds as part of local history and intergenerational thinking. The bequest value of livestock breeds have been shown to be especially relevant in the case of "endangered" breeds in Europe (Martín-Collado *et al.*, 2014; Zander *et al.*, 2013).
Other cultural ES	Many other cultural ES have been attributed to socio-agro-ecosystems in general.	Examples include folklore, poverty alleviation, traditional markets, and connection to land, moral values, nature–culture relations, wisdom, skills maintenance, ancestor worship and human history. See Hanaček and Rodríguez-Labajos (2018) for further information.

Box B – The historical importance of the cow to the Hindu culture

Cattle play a central role in Hindu culture. Cattle worship influences culture, religion and politics. The origins of this adoration are believed to date back to about 5000 years before-present (YBP) to the Hindus Valley Civilization (Lodrick, 2005). The Vedas writings, which were composed by the Aryan people in around 3500 YBP and are considered the original scripture of modern Hinduism, described the importance of cattle in both economic and ritualistic terms. By around 2700 YBP, the cow had evolved from a metaphoric deity to a literally sacred being. During subsequent centuries, concepts from other cultures, such as strict non-violence of Buddhism, became increasingly accepted by traditional Hindus and applied directly to cattle. Krishna, one of the most popular Hindu gods, is frequently represented as a cattle herder. During the second millennium, India was subjected to multiple invasions by outsiders that did not share the same reverence for cattle and this "revolting" behaviour was often used as a motivating factor to unite the local communities (Alavijeh, 2014; Lodrick, 2005). During the most recent 150 years, protection of cattle has become substantial in politics. Mahatma Gandhi established cow-protection agencies (Parel, 1969). The national constitution includes an article recommending that individual Indian State governments establish legal frameworks for cattle improvement and protection. To this day, protection of cattle and restrictions on their slaughter continue to be important and controversial issues.

Read more: Kennedy *et al.*, (2018)

4.4 Biodiversity

Biodiversity at a genetic, species and ecosystem level is complex, with multiple roles in the delivery of many ES services, as a regulator of ecosystem processes, as an ES in itself and as a good with intrinsic value (Mace *et al.*, 2012). Biodiversity is the subject most widely covered in the literature dealing with livestock production systems and the environment (Rodríguez-Ortega *et al.*, 2014). Livestock systems and breeds show both synergies and trade-offs with biodiversity maintenance. Generally speaking, biodiversity is negatively affected by landscape homogenization, whether caused by intensification in favourable agricultural areas or by abandonment of marginal lands. Many wild plant populations have been severely threatened by livestock over-grazing, especially in island ecosystems (Garcillán *et al.*, 2008). Conversely, well-managed agro-ecosystem can booster biodiversity (Diacon-Bolli *et al.*, 2012). Grasslands in mountains and other less-favoured regions around the world are human-made ecosystems that need to be managed if their structural heterogeneity and species diversity is to be maintained (Yuan *et al.*; 2016)[8].

Similar to biodiversity in general, livestock biodiversity has multiple roles in the delivery of ES, in addition to being an ES in itself. For each species, livestock genetic diversity comprises genetic diversity within breeds (i.e. how genetically different the animals within individual breeds are from each other) and within species across breeds (how genetically different the breeds within a species are from each other). The capacity of livestock species to supply a range of ES in a variety of production environments is increased by the presence of a diverse range of breeds, each having its own particular set of genetic and phenotypic characteristics. The genetic characteristics of a given breed can contribute in four ways to its capacity to deliver ES: (i) by conferring specific production and functional features; (ii) by conferring features that help animals cope with specific production environments; (iii) by conferring particular aesthetic features; and (iv) by conferring capacity to adapt to unpredicted future events. These four characteristics are explained in detail below:

i) The genetic differences between breeds lead to variation in their production and functional features, which owing to their straightforward economic importance are usually relatively well characterized (Leroy *et al.*, 2016). This effect can be related to provisioning ES in CICES (code 1.2.2.1). Most production and functional traits are influenced by many genes (i.e. they are “quantitative” or “polygenic” traits in breeding terms), but in some cases they are influenced by the effect of one major gene or directly related to a single mutation. With adequate introgression (for major genes) and breeding programmes (for quantitative traits and major genes) these features can be transferred into other breeds or further improved within the breed (FAO, 2010). Relevant examples include major genes associated with increased production (e.g. the ROA gene in Rasa Aragonesa sheep, which increases ewe prolificacy (Alabart *et al.*, 2016), and the double-muscling mutations (Aiello *et al.*, 2018) found in Belgian Blue cattle and Texel sheep, among other breeds) and quantitative traits linked to performance (e.g. those associated with high milk production in the Holstein cattle breed or high beef production in the Limousin breed). More examples can be found in Leroy *et al.* (2016).

ii) Some features specific to particular breeds give them the ability to cope with harsh environmental conditions such as high altitude (e.g. Tibetan sheep; Wei, *et al.*, 2016), climatic extremes (e.g. Senepol cattle; Olson *et al.*, 2003), high disease or parasite prevalence (e.g. Barbados Black Belly sheep; Aumont *et al.*, 2003) or low feed quality

[8] The Intermediate Disturbance Hypothesis proposes that within a broad range of environmental disturbance levels, species diversity is maximized at an intermediate level of anthropogenic and natural disturbance, because competitively inferior, disturbance-tolerant species and competitively dominant, disturbance-sensitive species coexist when disturbances are neither too rare nor too frequent. With low levels of disturbance, richness is predicted to be low because of competitive exclusion. With high levels of disturbance, richness is predicted to be low, because most species cannot tolerate frequent destructive events. With intermediate levels of disturbance, richness is predicted to be high, because dominant competitors and rapid colonizers are able to coexist.

(for a review, see Leroy *et al.*, 2016). For a given ecosystem, breeds with relevant adaptive characteristics will be better able to deliver ES than will other less-adapted breeds. Adaptation traits can be associated with either simply-inherited or quantitative (polygenic) traits, and can be transferred to other breeds or improved further within breeds. Examples of adaptation traits include the anti-predator behaviour of breeds such as the Old Norwegian sheep, the swimming ability of African Kuri cattle, the trypanosome tolerance of some African sheep and cattle breeds and the adaptedness of the Manchega sheep breed to high temperatures. More examples can be found in Leroy *et al.* (2016).

iii) Aesthetic traits, such as particular coat colours and patterns, horn lengths and shapes, and hair and feather lengths, have been selected for by livestock keepers since animals were first domesticated. This has meant that particular breeds have acquired particular aesthetic features that may not necessarily make a contribution, direct or indirect, to animal production, but rather constitute breed hallmarks. These hallmarks can, however, increase the perceived value of provisioning ES provided by breeds and their associated socio-agro-ecosystems by helping to create a "brand" image for the breeds and their products. Breed aesthetics can also contribute to cultural ES (FAO, 2014; Leroy *et al.*, 2018a,b; Martín-Collado *et al.*, 2014), for example via contributions to regional heritage (e.g. the symbolic value of the Highland cattle in Scotland), aesthetic experiences, symbolic, sacred or religious meaning and existence and bequest values. Many specific breeds play roles in local cultural events, for example the use of steers from the Berrenda beef breed to manage fighting bulls in Spain or the use of Madura cattle for racing in Indonesia (Widi *et al.*, 2014). More examples of cultural ES provided by livestock breeds can be found in FAO (2014).

iv) Genetic diversity increases the capacity to respond to unpredictable future events and to maintain or increase animal performance in a variety of situations, thus reducing risks. This effect can be related to provisioning ES under CICES (code 1.2.2.1), although it relates more closely to the concept of option value under the total economic value (TEV) framework (see Section 5.3), which specifically refers to insurance roles. The vulnerability of the livestock sector to unpredictable future events (mainly associated with disease outbreaks and changes in environmental conditions, for example due to climate change) can be reduced by the genetic diversity of livestock populations.

4.5 Delivery of multiple ecosystem services

In many instances, a given livestock breed or species offers a number of ES across the four categories of ES listed above. All breeds and species of livestock deliver some type of provisioning ES. As the examples in Tables 2 and 3 show, many breeds provide other ES as well. In general, livestock that are managed in pasture-based systems are more likely to provide a wider-range of ES, because such animals interact more with the ecosystem. This tendency is especially true for livestock raised in transhumant production systems, because these systems typically involve multiple agro-ecosystems and movement of animals among them. This movement establishes linkages between various ecosystems. Moreover, many transhumant livestock populations have been associated with their agro-ecosystems and livestock keepers for generations, favouring the co-evolution with the landscape and the development of important cultural ES. A particularly interesting example of ES "multi-tasking" is provided by the Neuquén Creole Goat of Argentina and its agro-ecosystem (Box C - Lanari, 2004).

Box C -Neuquén Creole Goats deliver a wide range of ecosystem services

As the name implies, Neuquén Creole Goat (NCG) are native to the mountainous grasslands of the Neuquén province of Argentina. They provide meat, milk, hides and fibre to their traditional keepers, a distinct community of herders from the region. Their production system is transhumant, allowing the goats to not only convert human-inedible plants into palatable protein and energy, but to perform these tasks in concert with the seasonal changes in quality and availability of vegetation in the diverse local landscapes. The NCG and their agro-ecosystem deliver a number of regulating ES, including landscape maintenance and seed dispersal. Perhaps most importantly, the NCG are of great cultural significance to their keepers, the self-named “Crianceros” of Neuquén. The traditional husbandry of the NCG is a major component of the Crianceros’ cultural identity. The transhumant husbandry system is based on a great deal of traditional knowledge that has been passed on through the generations and supports the maintenance of both the breed and the agro-ecosystem. The movement of flocks across the territory and sharing of common resources allows for more social interaction among herders than would a fully sedentary lifestyle. The Crianceros celebrate their history and lifestyle through various festivals throughout the year, which also attracts tourism to the region, providing entertainment for citizens outside of the local community.

Read more: Lanari (2004)

5 Valuation of the ecosystem services provided by livestock breeds

Once the ES linked to a livestock breed have been identified and its associated socio-agro-ecosystem has been defined, the following step is to measure the ES and assess their value. Broadly speaking, there are four groups of methods for valuing ES, which may be used independently or in concert. The choice of method(s) to use will depend on the objectives of the assessment and the types of ES under consideration (see Section 4):

1. Biophysical methods: mostly used to value provisioning ES, regulating ES and biodiversity.
2. Sociocultural methods: mostly used to value cultural ES, although the perception of stakeholders is important in the valuation of any type of ES.
3. Economic methods: mostly used for provisioning ES (private goods). However, some economic methods can be used to assess other ES and biodiversity (public goods).
4. Spatial analysis and mapping: these techniques are used to locate, analyze and present spatial data about ES and upscale ES delivery to the landscape or regional scale. These approaches can be applied to any type of ES, but may particularly useful for regulating ES.

Valuation of ES aims to consider the full costs and benefits that socio-agro-ecosystem evolution will have for people and nature (Martín-López *et al.*, 2014). Therefore, revealing the value(s) of ES for human well-being requires a variety of tools that embrace the multidimensional character of ES (biophysical, sociocultural and economic). Depending on the objectives of the valuation exercise, one or more methods will need to be used. Therefore, integrated multidisciplinary approaches are recommended (see Box D for an example).

Box D - Holistic valuation of traditional livestock farming in Norway

Livestock agro-ecosystems in fjord and mountain areas in Nordic countries make a minor and decreasing contribution to local economies, which are largely dependent on tourism and other services. However, traditional farming, largely in the form of grazing livestock systems, is essential to the maintenance of the local agricultural landscape, rural heritage and cultural identity, which constitute key assets for the tourism industry.

The municipality of Aurland in southwestern Norway includes two of the country's major tourist attractions, the Nærøyfjord and the Flåmsbana (a scenic railway line). In both places, traditional farming with Norwegian White sheep and Norwegian goat breeds contributes to keeping the landscape open (Image 1) and to other cultural and heritage values, including highly appreciated quality food products. In 2012, there were 56 livestock farms in the municipality.

Image 1. Farm at the Nærøyfjord

Qualitative (sociocultural) and quantitative (biophysical and economic) methods were combined to obtain a holistic evaluation of the societal value of these fjord and mountain agro-ecosystems. The study combined deliberative (interviews with farmers and other local stakeholders) and survey-based stated-preference methods (choice modelling) to achieve two goals: (i) to identify the perceptions of farmers and other local stakeholders regarding the diverse functions of fjord and mountain livestock farming; and (ii) to value these functions in economic terms according to the willingness of the local population (residents of the study area) and the general population (residents of the region where the study area is located) to pay for these functions.

The first step in the study was a sociocultural valuation in which the diverse functions of livestock farming were identified, discussed and rated by farmers and representatives of the tourism industry, governmental agencies and non-profit organizations. The following functions were identified: control of forest growth; maintenance of cultural heritage; continuation of rural life and activity; preservation of soil fertility; maintenance of tourist attractions; conservation of traditional agricultural landscapes; conservation of biodiversity; and production of local high-quality foods. The functions were translated into ecosystem services (ES), following the The Economics of Ecosystems and Biodiversity (TEEB)[9] classification.

The next step was a choice experiment involving representative samples of the local and regional populations. People were asked to choose their preferred level of delivery of selected ES under three policy scenarios representing different combinations of ES delivery (Image 2): the *liberalization* scenario (Policy A - reduction of agri-environmental support); the *targeted support* scenario (Policy B - additional funding to agri-environmental schemes); and the *status quo* scenario (CURRENT policy).

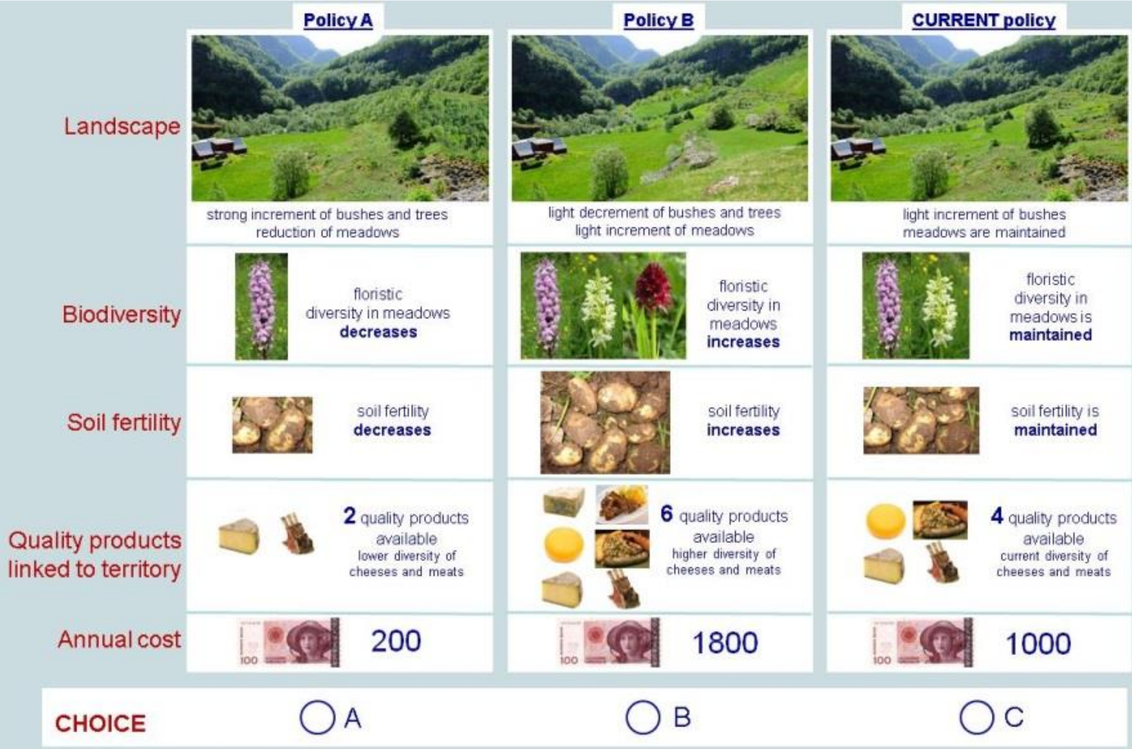


Image 2: Choice experiment design: agricultural landscape, biodiversity, soil fertility, availability of quality products linked to the territory and societal cost vary across policy scenarios

Results of the choice experiment are presented in Image 3. Among the general population, the four ES were assigned similar values in the two study areas, ranging from 22% for biodiversity to 28% for quality products. Local people, however, placed substantially greater emphasis on the value of a more human-influenced agricultural landscape (36%) and to the production of quality local products (34%). With regard to the policies described in Image 2, the liberalization scenario (Policy A) was estimated to result in substantial perceived welfare losses, relative to the current policy. Marginal gains in perceived welfare above the *status quo* were predicted to be low when providing targeted support (Policy B).

The valuation process showed that there was a clear underestimation by the general public of the sociocultural and economic values of the unique ES provided by fjord and mountain agro-ecosystems, relative to the local inhabitants of these areas. This observation implies a need to include consideration of all relevant stakeholders benefiting from ES in sustainability assessments and in policy design.

[9] http://www.teebweb.org/

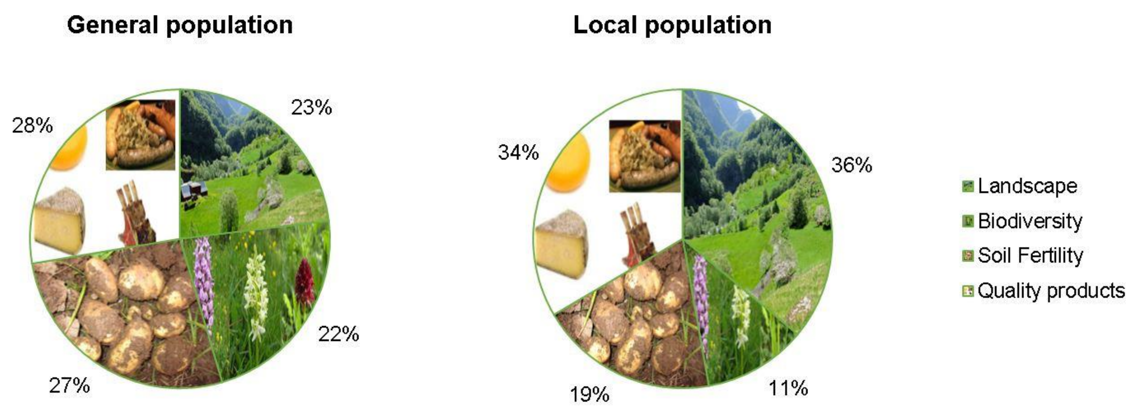


Image 3. Relative importance of each ecosystem service delivered by fjord and mountain agriculture

Read more: Bernués *et al*. (2014); Bernués *et al*. (2015)

5.1 Biophysical methods

Biophysical methods derive values from measurements of the physical costs (e.g. in terms of labour, land area, energy and material inputs) of producing a given good or service (TEEB, 2010). Therefore, biophysical methods use measurable indicators of ES delivery. Because of the diverse nature of ES, methods are also very diverse, ranging from empirical measurement of production yield, species abundance or population size, biomass, net primary production, etc. to sophisticated approaches such as biophysical modelling, ecosystem-service modelling, agent-based modelling or integrated-assessment modelling (Reyers *et al.*, 2010; Harrison *et al.*, 2018). The specific biophysical methods to be used will vary with the specific ES and the metrics (indicators) used to represent them. Indicators should convey relevant information about the ES in a particular location by being intuitive (communicating information about ES clearly and without ambiguity and being easily understood by the general public and policy-makers), sensitive (able to detect changes in ecosystem status) and accepted (adhere to agreed scientific methods and available datasets).

Indicators can be categorized according to the attributes under evaluation as follows:

1. *Diversity* indicators measure and map the diversity of species or other ES; (e.g. species diversity, genetic diversity of breeds or diversity of cultural ES);
2. *Quantity* indicators measure abundance (e.g. population number of a given wild species, visits to plants by pollinators) or production (e.g. net primary production, production of breed-related food products or carbon sequestration);
3. *Condition* indicators reflect changes in the condition or quality of ES (e.g. nutritional content of products, landscape modification and fragmentation or change in fire frequency or intensity); and
4. *Pressure* indicators quantify drivers of change to ES (e.g. land-cover change or variation in stocking rate).

An advantage of biophysical valuation is that the information collected is usually objective and methods can be standardized across studies, agro-ecosystems and countries. The units of measure are typically well-understood and easily interpreted. Biophysical valuation of provisioning ES is rather straightforward, as it is reasonably simple to convey information on the products and services of interest (kg of protein, breed-related food products, number of animals, etc.). However, for regulating ES and biodiversity, valuation studies should explicitly assess the biophysical relationship between livestock (or livestock breeds) and associated agricultural practices and ES. The difficulty of biophysical valuation results from the wide variety of scopes and methodologies that can be used (Rodríguez-Ortega *et al.*, 2014). Also, spatial and temporal scales need to be clearly identified. Box E contains an example of biophysical valuation of ES linked to tropical livestock systems in Latin America.

Box E – Livestock production with high efficiency and biodiversity in tropical agroforestry systems

Agroforestry systems, also called agro-silvopastoral systems, combine pastures with shrubs and trees, sometimes including forages or agricultural crops. Permanent meadows and pastures occupy 27 percent of the land in South America[10] and livestock production is one of the main causes of deforestation in tropical areas. A potential solution to address this problem is the use of sustainable and more efficientproduction methods, with greater on-farm biodiversity, no increase in land occupation and better welfare for animals (Broom *et al.*, 2013; EMBRAPA, 2017).

Broom *et al.* (2013) propose a cattle production system whose characteristics and aims include: (i) using three-level or other multi-level production of edible plants; (ii) managing the soil taking account of worms and other invertebrates and impacts on water retention; (iii) encouraging predators of harmful animals; (iv) minimizing greenhouse gas emissions; (v) improving job satisfaction for livestock keepers and labourers; (vi) enhancing animal health and welfare;(vii) increasing natural biodiversity, including through the use of native shrubs and trees: and (viii) sustainably harvesting timber and other forestry products.

For example, the introduction of *Leucaena leucocephala* (a leguminous shrub native of Yucatán, México) in a pasture-only system in Colombia reduced to zero the need of nitrogen fertilizer while increasing the the biomass by 29 percent. Silvopastoral systems had higher numbers of beneficial insects (e.g. dung beetles) and lower number of insects that transmit diseases (e.g. horn flies and ticks), due to increased predation by larger populations of birds. The presence of shrubs and trees also increased the number of mammals, reptiles and invertebrates.

The adaptation of conventional extensive pastures to intensified silvopastoral systems substantially increased the animal stocking rate and animal weight gain per day and per ha, and reduced the methane emissions per kg of meat and the land area required to produce the same amount of meat per year (from 14.8 ha in the conventional system versus 1.2 ha in the silvo-pastoral system).

Read more: Broom *et al.*, 2013; FAO, 2016; EMBRAPA, 2017

5.2 Sociocultural methods

Sociocultural values of ES can be defined as the importance people, as individuals or groups, assign to ES (Scholte *et al.*, 2015). Values depend on the stakeholders' interests and socio-cultural background and these interests and backgrounds may differ substantially among stakeholders. Therefore, a variety of key stakeholders should be included in the valuation exercise. The determination of values is critical when using the ES conceptual framework, as these values constitute the last step in the ES "cascade" model (Figure 1). A wide variety of sociocultural methods can be used to assess the preferences, needs, values, norms and behaviours of individuals, institutions and organizations with respect to ES (Cowling *et al.*, 2008). They can be grouped into three main types:

1. *Consultative* methods: structured processes of inquiry into people's perceptions and preferences.

[10] FAOSTAT, 2019.

2. *Deliberative* methods: group-based activities that elucidate people's relationships with ecosystems, identify conflicts between stakeholders and identify trade-offs between management strategies, land uses or potential future scenarios.
3. *Observational* approaches: direct observation of people's behaviour (e.g. counting the number of visits to a national park to assess its recreational value) and systematic reviews of scientific and grey literature.

Table 4 lists the most widely used methods for the sociocultural valuation of livestock production and breeds and ES. Christie *et al.* (2012) and Scholte *et al.* (2015) provide more detailed reviews.

Table 4. Overview of sociocultural evaluation methods (continues on next)

Questionnaires	Questionnaires are the most frequently used method of obtaining information for systematic description, prediction or explanation. They can be implemented face-to-face, by phone, by mail or via the internet. Depending on the nature of the research, they can be fully structured, semi-structured or non-structured.
Advantages	Provide large amounts of qualitative and quantitative information that can be analysed statistically and results that can be extrapolated.
Limitations	Highly demanding in terms of resources (personnel, time or economic). Need for standardization and careful formulation of questions. Little flexibility.
Example	Al-Tabini *et al.*, (2012) used a questionnaire to obtain information about how historical changes in pastoralism practices has affected the ecosystem services associated with livestock production in the Badia región of Jordan.
In-depth interviews	Interviews (normally non-structured or semi-structured) can be used to gain a deeper understanding of particular individuals' preferences and values.
Advantages	Interactive approach allows for greater flexibility. Respondents can explain in detail the associations they perceive or the reasons for their preferences, for example with respect to intangible cultural ES.
Limitations	Results cannot be extrapolated. The analysis of results entails transcription and coding. Of limited use for exploring quantitative information.
Example	Bernués *et al.*(2015) arranged semi-structured interviews with 16 local business representatives, governmental agencies and non-profit organizations to collect opinions on relationships between farming and the environment in fjord and mountain animal agriculture.

Table 4 sociocultural evaluation methods (continued)

Focus groups	Qualitative, open, non-directive method that involves group discussion on a given topic(s).
Advantages	Provide in-depth understanding of the views of a limited number of individuals that can illuminate contrasting opinions or shared values. Allow reflection and deliberation and hence the greater comprehension of values.
Limitations	Require trained facilitators. Require careful organization and recruitment of participants. Biases associated with dominant and insecure participants need to be controlled for. Transcription and content analysis are often required.
Example	Sinare *et al.* (2016) used focus groups at various stages in a recent study to assess the ecosystem services associated with livestock raising communities in Burkina Faso.
Delphi method	Iterative consultation with experts or "informed" individuals who contribute information or judgements until a degree of convergence is obtained.
Advantages	Low cost and easy implementation. Applicable to situations where data availability is low. Interviewees understand technical issues and jargon. Participants can reconsider their responses based on others' rankings.
Limitations	Requires careful selection of participants. Continuous commitment of participants is required over successive (minimum of two) rounds. Discussion is not possible. Editing and phrasing of questions are important.
Example	Mukherjee *et al.* (2015) described the Delphi Method and and assessed its application and utility for study of ecology and biological conservation. Rodríguez-Ortega *et al.* (unpublished data) used a two-round Delphi study applied to researchers and technicians/managers to quantify the importance of 36 agricultural practices for five ES in two Mediterranean grazing agro-ecosystems.
Participatory approaches	Field tools originally developed for use in developing countries with the aim of promoting local knowledge and enabling local people to make their own appraisals, analyses and plans: include participatory rural appraisal, participatory action research, participatory scenario planning and participatory mapping.
Advantages	Applicable to situations where data availability is low. Can provide useful insights that can be followed up using other techniques. Provide opportunities to embed valuation in local decision-making and action.
Limitations	Require careful planning and substantial amounts of time. Require awareness of power dynamics among participants. Communication with heterogeneous groups can be difficult.
Example	Pereira *et al.* (2005) used participatory rural appraisal and other methods to assess the linkages between human well-being and ES at the local level as perceived by the community.

5.3 Economic methods

Economic valuation is the process of expressing the value of particular goods or services in a particular context in monetary terms. Monetary valuation of ES remains a controversial issue. Many ES constitute public or non-material goods that are incommensurable, and therefore estimating a price for them can be regarded as the commodification of nature (Gómez-Baggethun and Ruiz-Pérez, 2011). A more pragmatic view defends economic valuation as a tool for change on the grounds that it can help make evident "invisible" flows from nature to the economy

(TEEB, 2010). Economic valuation techniques are normally classified into the following categories: market based; revealed preference; stated preference; and value transfer (Table 5). All can be used to analyse various ES.

Table 5. Overview of economic (monetary) valuation methods

Market-based	Based on current markets: examples include market analysis, cost methods, and production-function methods.
Advantages	Figures for prices, costs or quantities are easy to obtain, and reflect real preferences or costs to individuals.
Limitations	Can only be applied where markets exist (provisioning ES). Markets are sometimes distorted (e.g. by subsidies) and often do not take externalities into account.
Example	Kirton *et al.* (1995) compared quantity and quality traits in different sheep breeds used to produce lamb for export.
Revealed-preference	Estimates values from human behavioural changes or choices in real markets: examples include hedonic pricing and travel-cost methods.
Advantages	Based on actual observed behaviour.
Limitations	Normally restricted to measurement of use values. Data-intensive. Technical assumptions need to be made as to the relationship between the ES and the surrogate market good.
Example	Pouta and Ovaskainen (2006) used the travel-cost method to measure the value of recreation and nature tourism in agricultural landscapes.
Stated-preference	Estimates values according to human preferences in hypothetical markets: examples include contingent valuation, choice modelling and deliberative monetary valuation
Advantages	Can capture use and non-use values and hence all ES.
Limitations	Potential bias in responses. Complex and resource-intensive analytical methods. Hypothetical nature of the market (stated vs. real behaviour).
Example	Martín-Collado *et al.* (2014) assessed the total economic value of an endangered cattle breed using a choice experiment.
Value transfer	Infers the value of an ecosystem or ecosystem service from previous estimation at another study site.
Advantages	Easy to implement. Can be applied to all other valuation approaches.
Limitations	Difficulties in transferring values (generalization errors): challenges associated with differences in spatial scale and differences in values associated with ecosystem characteristics and social, cultural, economic and political context.
Example	Baskaran *et al.* (2010) used benefit transfer to translate the value of ES provided by vineyards from one production area in New Zealand to another.

Note: for further information see, for example, Pascual *et al.* (2010), Christie (2012) and other specialized publications.

Most economic assessments of environmental goods and services follow the Total Economic Value (TEV) concept (Pearce and Pretty, 1993), based on the distinction between use and non-use values. The TEV framework can be translated into the ES framework by linking TEV components with ES categories (Table 6).

Table 6. Components of the total economic value (TEV) and related ecosystem services

	TEV component	Definition	ES category	Valuation techniques
	---***Use values***---			
More	Direct use value	Actual use of a resource		

	Extractive	Consumptive use (e.g. milk)	Provisioning	Direct market analysis Production function analysis
	Non-extractive	Non-consumptive use (e.g. recreation)	Cultural	Travel-cost method Hedonic pricing Contingent valuation Choice experiment
	Indirect use value	Benefits supported by a resource rather than obtained by using it (e.g. fire prevention)	Regulating	Avoided or replacement costs Contingent valuation Choice experiment
	Option value	Option to use a resource in the future	All	Contingent valuation Choice experiment
	---------------------------------------***Non-use values***---------------------------------------			
	Bequest and altruistic value	Value of being able to pass a resource on to future generations or others in the current generation	All	Contingent valuation Choice experiment
	Existence value	Value of simply knowing the resource exists	Cultural	Contingent valuation Choice experiment

Source: Adapted from Rodríguez-Ortega *et al.* (2014).

5.4 Mapping and spatial analysis

Ecosystem services, in line with the definition of the term "ecosystem" itself, are associated with specific geographical locations. One of the first steps of a ES valuation exercise is the delimitation of the boundaries of the socio-agro-ecosystem liked to the livestock breed (s) under consideration (section 3.2.). In some cases, one might be interested in mapping ES delivery as initial steps of further spatial analyses. In such a case, the mapping of ES should consider both the supply and the demand sides of the ES. Thanks to the development of geographical information systems (GIS), freely available digital cartography, satellite images and associated databases, mapping and spatial analysis can now be undertaken relatively easily. GIS is the best tool to help visualize temporal and spatial patterns of ES delivery.

The first step is to define the physical extent of the socio-agro-ecosystem in which the breed is located, for instance by identifying the farms (or other locations) where it is kept (e.g. Marsoner *et al.*, 2017). However, a breed will often be raised in a variety of socio-agro-ecosystems (e.g. transhumant or vertically integrated systems) or under a variety of production systems (e.g. semi-extensive systems in valleys or fully extensive systems in mountains) which will affect the flow of ES differently. In such cases, it is necessary to define more than one socio-agro-ecosystem for the breed. The number of socio-agro-ecosystems per breed and their geographical sizes and locations will depend on the particularities of each case.

Once the extent of the socio-agro-ecosystem(s) has been mapped, there are three main types of spatial approach that can be used to investigate the ES delivered by livestock breeds (adapted from Nemec *et al.*, 2013):

1. Analysis of the past or current (static) spatial distribution of ES in the landscape. Note that in some cases ES are not provided by the whole socio-agro-ecosystem but by some specific parts. For example, cultural ES related to touristic activities may be restricted to specific parts of a landscape, such as to specific municipalities where these activities occur. It may also be that only some livestock keepers raise a given breed which provides breed-specific ES.

2. Dynamic modelling of changes in ES provision caused by changes in livestock numbers and breed distribution. This involves determining changes in the distribution of the breed and in the number of animals or the number of production units keeping the breed that may lead to variation in the value of the ES provided.

3. Development of models and approaches that emphasize social preferences and priorities for ES management, for example biodiversity conservation.

5.5 Livestock genetic diversity

The value associated with the genetic distinctiveness of a breed can be described as having two components: (i) how different it is from other breeds and (ii) how scarce it is. In general, the more genetically different a given breed is from other breeds, the greater its value. Likewise, the smaller the number of animals within a breed the higher its value for distinctiveness (although it may decrease its value for within-breed diversity).

There are four general approaches to assess the value of the genetic resources of specific breeds:

1. The specific production and functional features of a given breed can be assessed according to the difference between its average trait values and the average values of other available breeds.

2. The value of specific adaptive features will depend on how unique they are and how useful they are in helping other breeds to adapt to harsh environments.

3. The value of aesthetic characteristics can be assessed, for example, by considering roles such as the use of the respective breeds in attracting tourists (e.g. via leaflets, videos, etc.), the branding of breed products (use of breed pictures on labels and marketing of added-value products) and the links between breeds and cultural activities such as religious ceremonies or festivities.

4. With regard to genetic variability itself, two indicators can be used to assess the potential delivery of ES: genetic diversity studies (i.e. based on population size and structure, pedigrees or molecular genetic information) and gene-flow value (live animals or semen doses sold outside the breed's agro-ecosystem). Effective population size (Wright, 1931) is a commonly used parameter to measure the amount of genetic variation within a breed. Boettcher *et al*., (2010) have reviewed methods of prioritizing breeds based on molecular markers. The recent advancements in genomics have led to more tools and opportunities to assess the relative value of breeds in terms of both their within-breed variation and genetic distinctiveness and to identify the genetic basis for unique and valuable traits (Bruford *et al*., 2015).

In general, the value of these four aspects can be assessed using different methodologies which are explained in detail in the in Sections 5.1 to 5.4. For example, sociocultural methods would usually be used to determine the aesthetic value of a breed, whereas economic methods may be used to estimate the value of production or functional traits.

Outside the framework of ES, it is worth mentioning the paper by Drucker *et al.* (2001), who reviewed methods for economic valuation of animal genetic resources, classifying them as follows on the basis of their practical purpose: i) methodologies for determining the appropriateness of animal genetic resources conservation programme costs; ii) methodologies for determining the actual economic importance of the breed; and iii) methodologies for priority setting in breeding and conservation programmes. The FAO Guidelines on *In vivo* conservation on animal genetic resources (FAO, 2013) include extensive discussion on estimation of genetic variability within a livestock breed and on prioritizing breeds for conservation. The same approaches may be used to determine the relative value of breeds in terms of their genetic diversity and other ES.

5.6 Combining valuation methods and upscaling approaches

As mentioned previously, the interaction between livestock and the natural environment is manifold, involving various types of ES and back-and-forth exchanges, whereby livestock are both a user and producer of ES. Various approaches for identification and valuation of ES are more appropriate for specific categories of ES. Therefore, in a given study of livestock and ES, multiple approaches for identification and valuation may be applied. Box F summarizes a study undertaken in South Africa to evaluate the ES utilized and produced by livestock producers in a biodiversity-rich area of the country.

As a general rule, ES valuation is location specific. Many ecological and socio-economic factors combine in a unique way to determine the importance of the ES and their respective values. Therefore, comparing the value of ES between places or aggregating location-derived values to larger scales becomes problematic. For economic valuation, benefit transfer methods aim at transposing the monetary estimates across locations, adjusting for differences in ecological and economic contexts, however there are some sources of uncertainty that question the validity of transferred values. More information on benefit (or value) transfer can be obtained from Pascual *et al.* (2010).

Box F - Applying various approaches to study the ecosystem services associated with livestock production in the Bokkeveld plateau in South Africa

The Bokkeveld plateau is a semi-arid rangeland area in western South Africa. It's one of the most biodiverse areas on the country, encompassing several distinct vegetation biomes, including two biodiversity hotspots according to Conservation International (http://www.conservation.org/hotspots). The landscape evolved with the presence of transhumant pastoralism and collective management over hundreds of years. Herds of cattle and sheep were moved across various vegetation biomes in response to seasonal changes in weather and water and pasture availability. During the most-recent centuries, however, land-tenure practices have led to dominance of private ownership and in some case changes in land-use from grazing to crop production. Nevertheless, the private holdings include many ranges that are large enough to allow for and justify seasonal movement of animals. A study was undertaken to evaluate these farmers' perceptions of the ES available from this ecosystem and to understand how these perceptions influenced the management of their livestock and, in turn, the ES provided by the livestock.

To identify the ES supplied by livestock (mostly provisioning ES) and learn more about how ES from the different biomes were utilized by livestock, sociocultural methods were used. Livestock keepers from the Bokkeveld plateau were interviewed and asked about issues including farming history, identification of ES, livestock and crop management, perceived ecological costs and benefits, and vegetation management practices. Sheep were the dominant livestock reported and included locally developed (Dorper) and adapted (South African Mutton Merino) breeds. Fibre production was considered the primary provisioning ES, but these breeds are dual-purpose, producing also meat. In addition, most of the farmers practiced ecotourism to supplement their incomes through cultural ES. Pasture was the primary ES derived from the landscapes and grazing was managed with the multiple objectives of increased livestock productivity, landscape maintenance and avoidance of ecosystem disservices (e.g. poisonous plants during some seasons in some of the vegetation biomes.

Biophysical methods were used to measure the ES from the landscape. Six vegetation biomes were classified. Within each of these, sampling plots were created and several characteristics were measured within each plot. Plant diversity was measured by counting the different types of plants. Productivity was measured by harvesting the plant material and weighing the dry matter. Plant nutrient composition was measured by analysing the collected material for content of nitrogen, phosphorus and potassium and several trace minerals. Phenology was evaluated by repeatedly monitoring the plants and recording the various stages of growth over time. The presence of toxic plants was also noted.

The study confirmed that the grazing practices of livestock keepers tend to follow historical practices, but that these practices correspond with variations in the ES from the rangeland that were observed through the biophysical analyses, thus confirming the validity of the traditional knowledge. In general, livestock keepers with less capacity to move their herds were more likely to supplement their incomes with other farming and non-farm activities.

Read more: O'Farrell *et al.*, (2007)

In some circumstances, however, a common group of ES may be more or less universally provided by a general-type of livestock production system within a country. When countries are large however, scaling-up activities for identifying, valuing and acting to safeguard these ES may be challenging. In such situations, innovative approaches to achieve outreach from national to sub-national levels must be sought. Countries may be able to benefit from existing networks and infrastructure to help ensure that ES associated with livestock production can be properly identified and valued and that management interventions can be undertaken to ensure that these ES are maintained. Box G has an example from Canada.

Box G - Farmer associations facilitate government programmes to maintain rare wildlife species in Canadian agro-ecosystems

Canada is a large country with expansive areas of grassland and a wide range of animals that inhabit these areas. Not surprisingly, beef production is commonly practiced, owing to the previously mentioned provisioning ES of ruminants being able to turn human-inedible plants into highly nutritious and financially valuable meat. Because vast grasslands have evolved in the presence of large wild herbivores (e.g. bison and antelope) and grazing of domestic livestock has been practiced for hundreds of years, the cattle and their agro-ecosystems, including wildlife species, have co-evolved and in most cases share a mutual beneficial relationship when grazing is managed properly. In Canada, various species of wild animals native to pastures and other grassland ecosystems have become at risk extinction due to land use changes, including the cessation of traditional grazing. To combat this problem, the Government of Canada, through its Environment and Climate Change ministry, has recently introduced the Species at Risk Partnerships on Agricultural Lands (SARPAL) programme. The SARPAL programme has identified particular grassland wildlife species at risk of extinction and areas of the country where these animals are found. The SARPAL programme supports livestock herders to ensure that they continue good-grazing practices that maintain the habitat for the endangered wildlife species. Such habitat maintenance is an example of a regulating ES (Table 2 – CICES code 2.2.2.3), as well as a contribution to biodiversity. In order to scale-up this programme to cover the entire country, the Government of Canada is partnering with local organizations. In many of the target locations, these local organizations are provincial “Cattlemen’s” associations. These farmer organizations assist the livestock keepers in applying for the programme and ensuring that the required grazing practices are undertaken.
The direct targets of the SARPAL programme are the wildlife species, rather than livestock breeds. Nevertheless, this programme is indirectly supporting the maintenance of locally-adapted Canadian livestock, inasmuch as these are the animal genetic resources that are usually present and providing the required regulating ES in the targeted agro-ecosystems. In addition, in some provinces, the cattlemen’s associations are developing branded products associated with participation in the SARPAL programme, thus adding value to the provisional ES associated with the locally adapted breeds.

Read more: https://www.canadiangeographic.ca/article/how-cattle-ranching-can-help-preserve-species-risk-canadas-grasslands

5.7 Evaluation of synergies and trade-offs

Agro-ecosystems provide multiple ES (ES bundles) simultaneously. Due to the complex inter-relations between these various ES and the different interests and backgrounds of stakeholders, valuation has to account for potential trade-offs and synergies (Rodríguez-Ortega *et al.*, 2014). Delivery of one ES may affect the delivery of others; likewise, several ES may respond to common drivers (Raudsepp-Hearne *et al.*, 2010).

Synergies can occur when multiple ES are enhanced at the same time. For example, local livestock breeds that are better adapted to using grasslands in the EU Nature 2000 network are recorded as having the highest positive impact on special protection areas due to the contribution they make to the maintenance of open habitats, structural diversity and ecosystem functions (Ziv *et al.*, 2017). This helps to increase bird diversity, but the breeds also supply specific quality products (provisioning ES), contribute to the prevention of wildfires by controlling scrub encroachment (regulating ES) and enhance the aesthetic value of the landscape (cultural ES) (Bernués *et al.*, 2014).

Although synergies sometimes appear, in most cases there also are trade-offs, i.e. the delivery of one ES leads to a decrease in the provision of another ES. Typically, increasing the supply of provisioning ES leads to trade-offs with regulating and cultural ES. A typical example are international transboundary breeds, which usually deliver higher provisioning ES than local breeds, but this specialization has generally led to the reduction of delivering regulating ES (e.g. fire prevention) and many cultural ES. Managing such trade-offs is a key challenge in socio-agro-ecosystem management.

Cord *et al.* (2017) reviewed the main approaches to the analysis of ES relationships and described typical research questions, concepts, methods and limitations for four objectives:

1. identification and description of ES co-occurrences, in particular of those ES that are positively and negatively associated;
2. identification of drivers or pressures that shape ES relationships and their underlying mechanisms;
3. exploration of the biophysical constraints and limitations of landscapes and limitations to their multifunctionality, often using optimization approaches; and
4. supporting agri-environmental planning, management and policy decisions.

These research questions can also be applied to the ES delivered by livestock breeds and species and their associated production systems.

6 Summary

The process of identification and valuation of ES provided by livestock breeds must consider three components: livestock breeds themselves, the farming systems where they are raised, and the socio-agro-ecosystem in which they are embedded. Livestock breeds and their production systems modify (i.e. either increasing or decreasing) the ES and their value as the flow from nature to society. This review considers four types of ES: Provisioning, Regulating and Cultural services, plus Biodiversity. Biodiversity includes both natural biodiversity and livestock biodiversity, which comprises genetic diversity within and across breeds. Four different types of methods are discussed: biophysical, sociocultural and economic valuation methods, and ES mapping and spatial analysis. Each method varies in its applicability to the various classes of ES. Because a given breed and its typical production system deliver multiple ES of different types, several methods may need to be applied and aggregation of the various values obtained will need to consider the trade-offs among the types of ES. Managing such trade-offs is a key challenge in socio-agro-ecosystems management.

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