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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), and in close collaboration with the FAO Animal Production and Health Division, in response to a request from the Commission at its Sixteenth Regular Session¹ 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 at its current Tenth Session. The content of this document is entirely the responsibility of the authors, and does not necessarily represent the views of the FAO or its Members.

¹ CGRFA-16/17/Report/Rev.1, paragraph 47.

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

Alberto Bernués and Daniel Martin-Collado

Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA). Instituto Agroalimentario de Aragón– IA2 - (CITA-Universidad de Zaragoza), Zaragoza (Spain)

TABLE OF CONTENTS

1	Introduction	4
2	The ecosystem services framework	4
2.1	Ecosystem functions, ecosystem services and human well-being.....	4
2.2	Application of the ecosystem services framework to livestock production and livestock breeds: the socio-agroecosystem approach.....	5
2.3	Ecosystem services and sustainability.....	7
3	Key steps in the valuation of ecosystem services provided by livestock breeds and their associated socio-agroecosystems	8
4	Identification of ecosystem services provided by livestock breeds	8
4.1	Provisioning services.....	9
4.2	Regulating services.....	10
4.3	Cultural services	11
4.4	Biodiversity	13
4.5	Livestock genetic diversity as a provider of multiple ecosystem services	13
5	Valuation of the ecosystem services provided by livestock breeds	15
5.1	Biophysical methods	18
5.2	Sociocultural methods	19
5.3	Economic methods	20
5.4	Mapping and spatial analysis.....	22
5.5	Evaluation of synergies and trade-offs	23
6	Summary	23
	Bibliography.....	24

1 Introduction

This review presents a structured framework for the application of the ecosystem services (ES) concept in agroecosystems and to livestock breeds and the production systems in which they are kept. The intention is to facilitate the 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 agroecosystems.

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 agroecosystems; 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 related to the ES framework and the use of the framework to assess agroecosystems and livestock breeds.

Section 3 outlines a six-step valuation process.

Section 4 presents an inventory of the ES provided by agroecosystems 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 brief conclusions

The material presented is based on a review of peer-reviewed articles that specifically address livestock agroecosystems and the ES they deliver and of reports from national and international institutions that likewise address this topic (see Table A1 in the Appendix to the document). A full list of references is provided in the bibliography.

2 The ecosystem services framework

2.1 *Ecosystem functions, ecosystem services and human well-being*

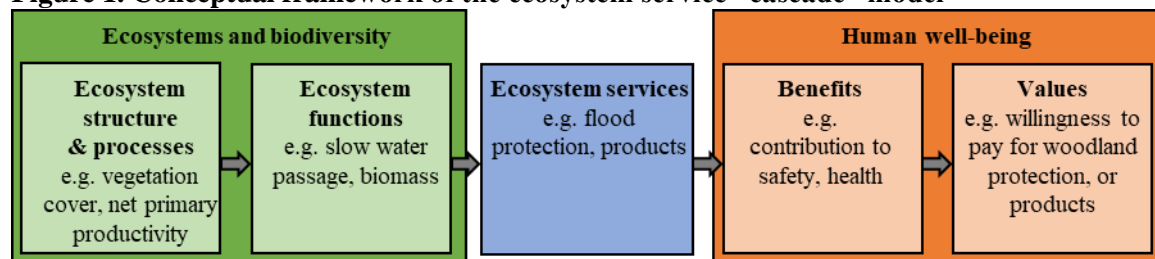
The discussion of ES presented in this review is based on the most widely accepted definition of the term: “Ecosystem services are the direct and indirect contributions of ecosystems to human well-being” (TEEB, 2010).² It is important to distinguish ES from ecosystem functions, defined as the “interactions 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 to clarify 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 from values (i.e. the appreciation of benefits on the part of particular stakeholders or the public at large). The metrics used to measure the “value” of an ES

² 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).

can be biophysical, sociocultural or economic (Section 4). Box 1 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).

Box 1. 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.

Agroecosystem: 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-agroecosystem: 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)

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

When applied to agroecosystems, the conceptual framework outlined above needs to be modified so as to include the key role that livestock production plays in the provision 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 agroecosystems; (ii) livestock farms (or other production units) and breeds; and (iii) society. Following Potschin-Young *et al.* (2018), the framework locates the farm at the “production boundary”, the border between the ecological and the socio-economic system.

Crucially, the production unit (with its associated livestock breeds) is considered an intermediary between the agroecosystem and society or as a “filter” of agroecosystem processes and functions

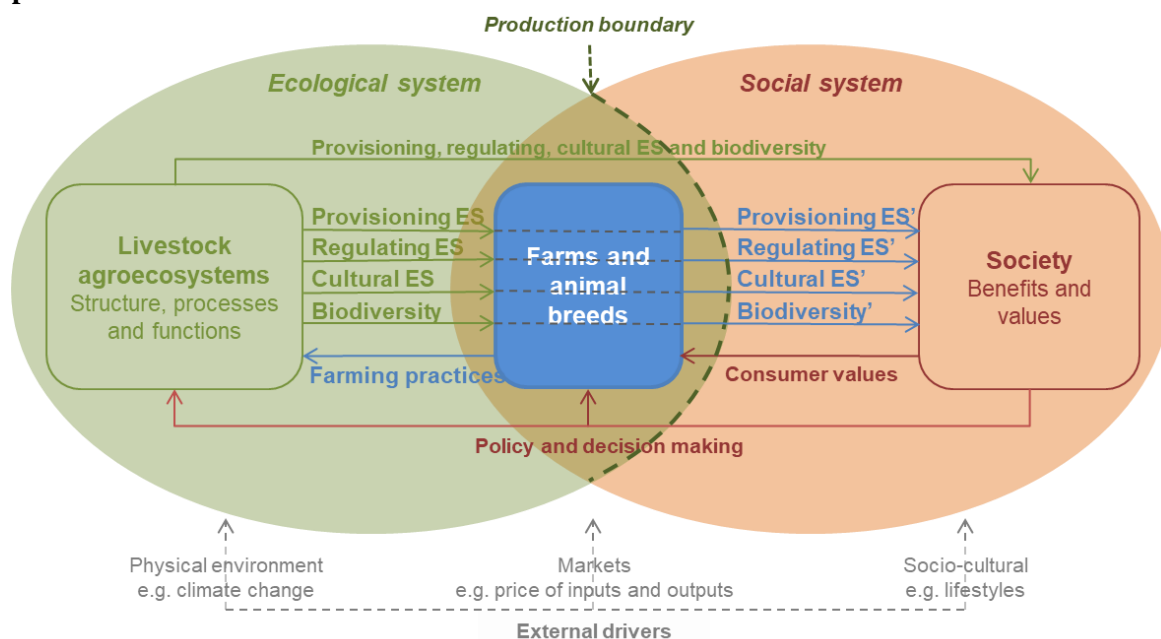
that modifies the flow of ES from the natural world (Bernués *et al.*, 2016a; Plantureux *et al.*, 2016). On the one hand, the farm or production unit benefits from provisioning ES (e.g. forage) and regulating ES (e.g. climate regulation, soil fertility and water availability). On the other, the farmer or livestock keeper implements management regimes and practices (including the choice of breeds) that modify ecosystem structure and functioning.

This 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 agroecosystems. 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).

The goal of the farmer (or other livestock keeper) is usually to optimize the outputs from provisioning services of the farm or production environment, according to his or her own personal needs and desires. Achieving this objective often comes at the expense of a reduction in the delivery of other ES and an increase in negative externalities or ecosystem disservices. Alternatively, farmers may 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 – and the inter-relations between them – are influenced by various driving forces. On the one hand, they are affected by legal frameworks and policies in fields such as nature protection, land management, marketing, and food quality and safety. On the other, external drivers, such as the physical environment (e.g. climate variability), markets for inputs and outputs, and sociocultural factors (e.g. consumer lifestyles and trends), can influence the ways in which agroecosystems, livestock production and society function and relate to each other.

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



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

This review focuses on livestock farms and other livestock production units, and livestock breeds in particular, as filters or modifiers of ES that deliver social benefits (e.g. through the transformation of forage into quality products) and as generators of alternative ES, such as cultural ES linked to educational or heritage values. Animal breeds constitute the entry point.

2.3 Ecosystem services and sustainability

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

1. How, when and where are ES co-produced? There is a need to better understand the effect of human activities, including agricultural practices, on ES, considering cross-scale effects and path-dependence.
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 are they supplied and used.
3. What are the best practices for the governance of ES? There is a need to understand power relations and institutions in order to improve equity and ecosystem stewardship.

The ES framework needs to be embedded in the wider concept of sustainability, which is unique in its capacity to integrate multiple societal, ecological, economic and governance consequences of development choices. Evaluation of sustainability should include not only a range of indicators, but also different perspectives, spatial-temporal scales and methodological frameworks.

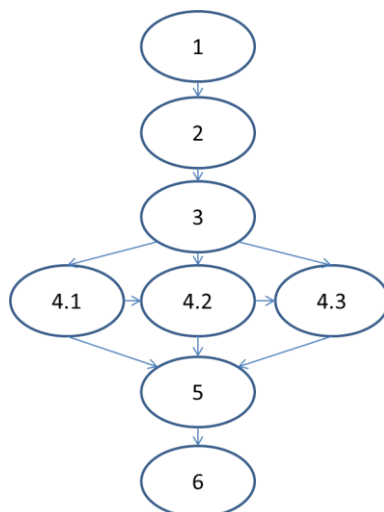
3 Key steps in the valuation of ecosystem services provided by livestock breeds and their associated socio-agroecosystems

The process of valuing the ES provided by livestock breeds and their associated socio-agroecosystems can be divided into the following steps:

1. Definition of the objectives of the ES valuation (e.g. is the objective to value the ES delivered by a particular breed or to value the ES delivered by the socio-agroecosystem in which the breed is located?);
2. Delimitation and characterization of the socio-agroecosystem and its context (farming systems, agricultural practices, physical environment, socio-economic and policy contexts, etc.) and identification of stakeholders;
3. Identification of ES associated with the socio-agroecosystem and the breeds present within it;
4. Valuation of ES;
 - 4.1 Biophysical assessment,
 - 4.2 Sociocultural assessment,
 - 4.3 Economic assessment;
5. Evaluation of trade-offs among ecosystems services; and
6. Support to policy design.

Figure 3 represents the sequence of steps to be followed in a valuation exercise. This should not, however, 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. The steps addressing identification and valuation of ES are the main focus of this review and are described extensively in Sections 4 and 5.

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



4 Identification of ecosystem services provided by livestock breeds

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

The concrete ES provided in each case will depend on the specificities of the socio-agroecosystem considered (e.g. transhumance systems may have different ES from those associated with semi-extensive systems) and the associated livestock breed (e.g. one breed may be associated with added-value products while others may not).

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 provided by livestock breeds are listed in Table 1.

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

CICES code	CICES Class	Descriptions, examples and notes
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. For the specific case of livestock breeds, added-value quality products are a key ES.
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. Other non-livestock products coming from the agroecosystem, for example 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 and urine for energy. Biomass for bioenergy and for use in biorefineries may also be considered as provisioning ES of grazed grasslands (Plantureux <i>et al.</i> , 2016).
1.2.2.1	Animal genetic material collected for the purposes of maintaining or establishing a population	Referred to as genetic pools, genetic resources or genetic diversity. Some studies specifically refer to livestock breeds (Ovaska and Soini, 2016) and wild flower germplasm for restoration/breeding (Plantureux <i>et al.</i> , 2016).
1.2.2.3	Individual genes extracted from organisms for the design and construction of new biological entities	Under this category, Hoffmann <i>et al.</i> (2014) refer generically to biotechnical resources
...	Other provisioning ES	Some authors include the availability of clean water among the provisioning ES contributed by pasture-based livestock systems (Plantureux <i>et al.</i> , 2016). With regard to the provision of food, a particular characteristic of these systems is their ability to use and transform non-human edible resources, an aspect that is sometimes referred to as a specific ES (D'Ottavio <i>et al.</i> , 2017; Hoffmann <i>et al.</i> , 2014; Ovaska and Soini, 2016).

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 they are 22 and 9 different classes of biotic and abiotic regulating ES, respectively. Table 2 lists ES that can be related to livestock breeds and their associated agroecosystems.

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

CICES code	CICES Class	Descriptions, examples and notes
2.2.1.1	Control of erosion rates	Erosion control or prevention. Some studies additionally note a role in preventing soil degradation (D'Ottavio <i>et al.</i> , 2017; Hoffmann <i>et al.</i> , 2014; Ovaska and Soini, 2016).
2.2.1.2	Buffering and attenuation of mass movement	Moderation of extreme events such as avalanches (maintenance of short grasses that prevent snow glide) and landside control (control of erosion in hilly areas).
2.2.1.3	Hydrological cycle and water flow regulation (including flood control and coastal protection)	Plantureux <i>et al.</i> (2016) detail the role of grazed grasslands in water infiltration, retention of water in soils and flood control. An example is the regulation of the water cycle through land cover due to evapotranspiration and runoff (Oteros-Rozas <i>et al.</i> , 2014).
2.2.1.4	Wind protection	Ovaska and Soini (2016) mention storm protection through the maintenance of vegetation cover
2.2.1.5	Fire protection	Reduced risk and virulence of forest fires through the effect of animals on vegetation. The prevention of shrub encroachment through grazing is mentioned by Leroy <i>et al.</i> (2018a,b).
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 <i>et al.</i> , 2014). Plantureux <i>et al.</i> (2016) note that 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. Hevia <i>et al.</i> (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. Seed dispersal is related to habitat connectivity (D'Ottavio <i>et al.</i> , 2017; Hoffmann <i>et al.</i> , 2014; Oteros-Rozas <i>et al.</i> , 2014)

CICES code	CICES Class	Descriptions, examples and notes
2.2.2.3	Maintaining nursery populations and habitats (including gene pool protection)	Described by Oteros-Rozas <i>et al.</i> (2014), pastures can provide suitable places for wild species to live and raise their young. The maintenance of open semi-natural habitats in mountain areas and maintenance of the diversity of grassland habitats are a great concern in Europe (Plantureux <i>et al.</i> , 2016).
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.
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 <i>et al.</i> , 2017). Other authors point, for example, to the capacity of livestock to control ticks and the diseases they spread, including zoonoses such as Lyme disease (Hoffmann <i>et al.</i> , 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.
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 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 <i>et al.</i> (2017) for a review.
	Other regulating ES	Ditch maintenance (Oteros-Rozas <i>et al.</i> , 2014), control of flowering onset (Lamarque <i>et al.</i> , 2014) and management of crop residues (Leroy <i>et al.</i> , 2018a,b).

4.3 Cultural services

Cultural ES are the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experience (TEEB, 2010). Like regulating ES, they are frequently public goods. According to CICES, there are 12 and 5

different classes of biotic and abiotic cultural ES, respectively. The focus here is on biotic cultural ES that can be related to livestock breeds and their associated agroecosystems (Table 3).

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

CICES code	CICES Class	Descriptions, examples and notes
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. Ovaska and Soini (2016) refer to the use of care farms for rehabilitation.
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 <i>et al.</i> (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 <i>et al.</i> (2014) and Bernués <i>et al.</i> (2016b).
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.
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.
3.1.2.4	Characteristics of living systems that enable aesthetic experiences	Aesthetic values associated with livestock agroecosystems are mostly related to landscapes and vegetation types. Agroecosystems where nature, humans and livestock breeds have co-evolved over long periods of time are usually highly valued. The appearance of animals and of particular breeds can also be included in this category.
3.2.1.1	Elements of living systems that have symbolic meaning	For example, Ovaska and Soini (2016) specifically mention the appearance of native breeds as regional or national symbols. These authors also mention the symbolic significance of the conservation of charismatic or iconic habitats used by these breeds.
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 <i>et al.</i> , 2014) or that play a role in practices such as birth and funeral ceremonies, rainmaking ceremonies and spiritual cleansing ceremonies (Hoffmann <i>et al.</i> , 2014).

CICES code	CICES Class	Descriptions, examples and notes
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.
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.” Ovaska and Soini (2016) refer to the intrinsic value of the existence of animal breeds.
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 animals as part of history and intergenerational thinking.
...	Other cultural ES	Many other cultural ES have been attributed to agroecosystems in general. Examples include folklore, poverty alleviation, traditional markets, connection to land, moral values, nature–culture relations, wisdom, skills maintenance, ancestor worship and human history. See Hanaček and Rodríguez-Labajos (2018) for further discussion.

4.4 Biodiversity

Biodiversity is a complex phenomenon 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). Generally speaking, biodiversity is negatively affected by landscape homogenization, whether caused by intensification in favourable agricultural areas or by abandonment of marginal lands. Many 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)³

4.5 Livestock genetic diversity as a provider of multiple ecosystem services

Livestock genetic diversity comprises genetic diversity within breeds (i.e. how genetically different the animals within individual breeds are from each other) and across breeds (how genetically different the breeds within a species are from each other). The genetic characteristics of a given breed can contribute in four ways to its capacity to supply 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. The capacity of livestock species to supply a range of ES in a variety of production environments is increased by the presence of a

³ 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.

diverse range of breeds each having its own particular set of genetic and phenotypic characteristics. Several of these characteristics are explained below:

1. 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 traits” in breeding terms), but in some cases they are influenced by the effect of one major gene or directly related to a 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, and the double-muscling mutations 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).
2. Some features specific to particular breeds give them the ability to cope with harsh environmental conditions such as high altitude, climatic extremes, high disease or parasite prevalence or low feed quality (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 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).
3. 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 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-agroecosystems by helping to create a “brand” image for the breeds and their products. Breed aesthetics can also contribute to cultural ES (Hoffmann *et al.*, 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, 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 Hoffmann *et al.* (2014).
4. Genetic diversity increases 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, 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) is reduced by the genetic diversity of livestock populations.

The value (measured in terms of the need to invest in conservation) associated with the genetic diversity 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. There are multiple ways of assessing the value that the genetic resources of specific breeds within a given species provides in terms of the four above-described contributions to the supply of ES. (i) 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. (ii) 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. (iii) 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. (iv) With regard to genetic variability itself, two indicators can be used to assess the potential provision of ES: genetic diversity studies and gene-flow value (live animals or semen doses sold outside the breed's agroecosystem).

5 Valuation of the ecosystem services provided by livestock breeds

Once ES linked to a breed and its associated agroecosystem have been identified, it is necessary to measure them (see Section 6). Broadly speaking, there are four groups of methods of valuing ES. The choice of which method to use will depend on the objectives of the assessment and the types of ES under consideration:

1. Biophysical methods: mostly used to value provisioning ES, regulating ES and biodiversity.
2. Sociocultural methods: mostly used to value cultural ES. However, the perceptions of stakeholders are key in any ES valuation.
3. Economic methods: mostly used for provisioning ES (private goods). However, some methods can be used to assess other ES and biodiversity (public goods).
4. Spatial analysis and mapping: mostly used to value provisioning ES, regulating ES and biodiversity, but can also be used for cultural ES.

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

Box A - Holistic valuation of traditional livestock farming in Norway

Livestock agroecosystems 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 the 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 Nærøfjord

Qualitative (sociocultural) and quantitative (biophysical and economic) methods were combined to obtain a holistic evaluation of the societal value of these fjord and mountain agroecosystems. 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)⁴ 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 *status quo* scenario, the *liberalization* scenario (reduction of agri-environmental support); and the *targeted support* (additional funding to agri-environmental schemes) scenario.

⁴ <http://www.teebweb.org/>
















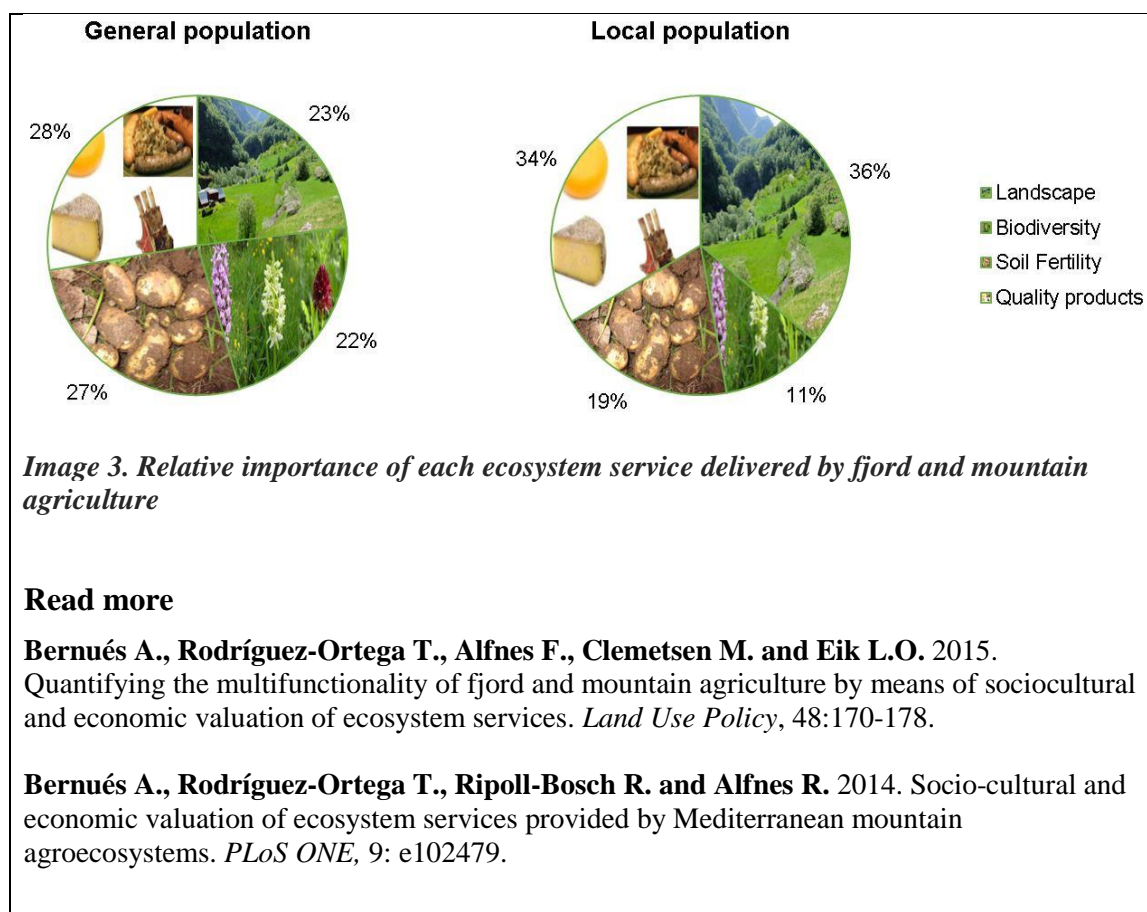
	Policy A	Policy B	CURRENT policy
Landscape	 strong increment of bushes and trees reduction of meadows	 light decrement of bushes and trees light increment of meadows	 light increment of bushes meadows are maintained
Biodiversity	 floristic diversity in meadows decreases	 floristic diversity in meadows increases	 floristic diversity in meadows is maintained
Soil fertility	 soil fertility decreases	 soil fertility increases	 soil fertility is maintained
Quality products linked to territory	 2 quality products available lower diversity of cheeses and meats	 6 quality products available higher diversity of cheeses and meats	 4 quality products available current diversity of cheeses and meats
Annual cost	 200	 1800	 1000
CHOICE	<input type="radio"/> A	<input type="radio"/> B	<input type="radio"/> C

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. In Norway, the most important ES was the preservation of soil fertility, as agricultural land is very scarce. However, the other three ES were assigned similar values in the two study areas. In Norway, the general population considered the production of quality products, the conservation of agricultural landscapes and the conservation of biodiversity to be of similar importance. Local people, however, placed greater emphasis on the value of a more human-influenced agricultural landscape and to the production of quality local products.

The valuation process showed that there is a clear underestimation by the general public of the sociocultural and economic values of ES provided by fjord and mountain agroecosystems. It is therefore essential to include consideration of these ES in sustainability assessments and in policy design. The study authors also argue that the welfare loss linked to the further abandonment of livestock farming and the associated environmental degradation is very large in these areas, which constitute clear examples of high nature value farmland and thus have the greatest biodiversity indexes in Europe. It is therefore necessary to measure the biophysical, sociocultural and monetary value of ecosystem services provided by grazing livestock agroecosystems and livestock breeds and to compensate farmers in an equitable way for the delivery of public goods.



5.1 Biophysical methods

According to TEEB (2010), a biophysical method derives 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. Biophysical methods use measurable indicators. Because of the diverse nature of ES, methods for biophysical quantification can be very diverse, ranging from empirical measurement of production, abundance or 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 or diversity of cultural ES).
2. *Quantity* indicators: measure abundance or productivity (e.g. net primary production or carbon sequestration).
3. *Condition* indicators: reflect changes in the condition or quality of ES (e.g. landscape fragmentation or change in fire frequency or intensity).
4. *Pressure* indicators: quantify drivers of change of ES (e.g. land-cover change or stocking rate).

Biophysical valuation of provisioning ES is rather straightforward, as it is easy to convey information on the products and services of interest (kg of protein, number of animals, etc.). For regulating ES and biodiversity, most valuation studies do not explicitly assess the biophysical relationship between livestock and associated agricultural practices and ES, or if they do, the

scope differs widely, methodologies are not standardized and spatial and temporal scales are often not identified (Rodríguez-Ortega *et al.*, 2014).

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). Their measurement is important, as values constitute the last step in the ES “cascade” model depicted in 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.
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 (Table 4). 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	Oteros-Rozas <i>et al.</i> (2014) valued the ecosystem services associated with a drove road using a questionnaire distributed to local residents and visitors.
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 <i>et al.</i> (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.

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	Bernués <i>et al.</i> (2016b) organized five focus groups with farmers and non-farmers to discuss relationships between livestock farming and the environment in terms of ES, as well as agricultural practices that influence these ES and other sustainability issues relevant to the participants.
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	Rodríguez-Ortega <i>et al.</i> (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 agroecosystems.
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 <i>et al.</i> (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.

Most economic assessments follow the taxonomy established by the total economic value (TEV) framework (Pearce and Pretty, 1993), based on the distinction between use and non-use values (Table 6).

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).
Example	Kirton <i>et al.</i> (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 <i>et al.</i> (2014) determined 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 <i>et al.</i> (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.

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: methodologies for determining the appropriateness of animal genetic resources conservation programme costs; methodologies for determining the actual economic importance of the breed; and methodologies for priority setting in breeding programmes.

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

	TEV component	Definition	ES category	Valuation techniques
Less difficult to estimate	-----Use values-----			
	Direct use value	Actual use of a resource		
	<i>Extractive</i>	Consumptive use (e.g. milk)	Provisioning	Direct market analysis Production function analysis
	<i>Non-extractive</i>	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-----			
More difficult to estimate	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

ES, in line with the definition of the term “ecosystem” itself, are associated with specific areas. Thus, any valuation exercise needs to map the specific area(s) where the ES under consideration are provided and enjoyed. In the case of a livestock breed, determining the boundaries of the area providing the ES will require identification and definition of the socio-agroecosystem with which it is associated (see Figure 2). 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 geographical patterns of ES provision.

The first step is to define the physical extent of the agroecosystem 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 production systems or in areas with different environmental conditions (e.g. mountains and valleys) or where there are differences in other factors that affect the ES provision. In such cases, it is necessary to define more than one socio-agroecosystem for the breed. The number of socio-agroecosystems per breed and their geographical sizes and locations will depend on the particularities of each case. Once the extent of the socio-agroecosystem(s) has been defined, there are three main types of spatial approach that can be used to investigate the ES provided by the breed (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-agroecosystem but by some specific parts. For example, cultural ES related to touristic activities may be linked to

towns where these activities occur. It may also be that only some livestock keepers raise the breed.

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 farms 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 *Evaluation of synergies and trade-offs*

Agroecosystems 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). Provision of one ES may affect the provision 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 (regulation and maintenance ES) and enhance the aesthetic value of the landscape (cultural ES) (Bernués *et al.*, 2014).

In most cases there are trade-offs, i.e. the provision 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. Managing such trade-offs is a key challenge in agroecosystem 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 the following four study 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.

6 Summary

The process of identification and valuation of ES provided by livestock breeds must consider three components: agroecosystems, breeds and their production environments, and society; whereby the breeds production systems modify (i.e. either increasing or decreasing) the ES and their value as the flow from nature to society. Four types of ES were considered in this review: provisioning, regulating and cultural services, plus biodiversity. Biodiversity includes both natural biodiversity and the genetic diversity of the livestock themselves and differences among livestock breeds naturally impact substantially this latter category. Four different types of valuation methods were discussed: biophysical, sociocultural, economic methods and approached

involving spatial analysis and mapping. Each method varies in its applicability to the various classes of ES. Because a given breed and its typical production system provides multiple ES of different types, multiple 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 agroecosystem management.

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