Is the ecosystem services concept relevant to capture the multiple benefits from farming systems using livestock biodiversity? A framework proposal

Anne Lauvie, Gisèle Alexandre, Valérie Angeon, Nathalie Couix, Olivia Fontaine, Claire Gaillard, Michel Meuret, Catherine Mougenot, Charles-Henri Moulin, Michel Naves, et al.

Genetic Resources

ORIGINAL ARTICLE

Genetic Resources (2023), 4 (8), 15–28
DOI: 10.46265/genresj.MRBT4299
https://www.genresj.org
ISSN: 2708-3764

Is the ecosystem services concept relevant to capture the multiple benefits from farming systems using livestock biodiversity? A framework proposal

Anne Lauvie [*,a], Gisèle Alexandre [b], Valérie Angeon [c], Nathalie Couix [d], Olivia Fontaine [a], Claire Gaillard [e], Michel Meuret [a], Catherine Mougenot [f], Charles-Henri Moulin [a], Michel Naves [b], Marie-Odile Nozières-Petit [a], Jean-Christophe Paoli [g], Lola Perucho [g], Jean Michel Sorba [g], Emmanuel Tillard [a] and Etienne Verrier [h]

[a] *UMR Systèmes d'élevage méditerranéens et tropicaux (SELMET), INRAE – CIRAD – Institut Agro Montpellier – Univ. Montpellier, 34060 Montpellier cedex 01, Montpellier, France*
[b] *ASSET (Agroécologie, génétique et SystèmeS d'Elevage Tropicaux), INRAE, 97170 Petit-bourg, France*
[c] *UR Ecodéveloppement, INRAE, 84914 Avignon cedex 9, France*
[d] *UMR AGIR, INRAE-Université de Toulouse, 31326 Castanet Tolosan cedex, France*
[e] *AgroSup Dijon, INRAE UMR Territoires, 21079 Dijon Cedex, France*
[f] *Arlon Campus Environnement, Université de Liège, 6700 Arlon, Belgium*
[g] *INRAE Selmet-LRDE, 20250 Corte, France*
[h] *Université Paris-Saclay, AgroParisTech, INRAE UMR GABI, 91120 Palaiseau, France*

Abstract: Local breeds are key components of livestock farming systems. They are part of livestock biodiversity and this diversity has been threatened since the second half of the 20th century by their replacement with animals from specialized breeds. The multiple benefits of farming systems using local breeds – provision of goods, landscape and environmental management, and uses related to cultural and heritage dimensions – have long been recognized and used to argue for their conservation. However, the notion of ecosystem services is rarely used to analyze those benefits. This article presents a qualitative approach to the provision of ecosystem services by farming systems that use livestock biodiversity. Based on diverse case studies of breeds from several species, we propose an analytical framework that accounts for how a service is qualified, who is concerned by the services identified, the role of the breed in the process of service provision, and interactions between services. Finally, the framework considers the links between the provision of services and the management of the breeds. We discuss to what extent the notion of ecosystem services is useful in dealing with the multiple benefits from farming systems using local breeds.

Keywords: Livestock biodiversity, ecosystem services, inductive approach, interdisciplinary, local breeds

Citation: Lauvie, A., Alexandre, G., Angeon, V., Couix, N., Fontaine, O., Gaillard, C., Meuret, M., Mougenot, C., Moulin, C., Naves, M., Nozières-Petit, M., Paoli, J., Perucho, L., Sorba, J. M., Tillard, E., Verrier, E. (2023). Is the ecosystem services concept relevant to capture the multiple benefits from farming systems using livestock biodiversity? A framework proposal. *Genetic Resources* 4 (8), 15–28. doi: 10.46265/genresj.MRBT4299.

Introduction

Livestock biodiversity has been threatened since the second half of the 20^{th} century, as many local breeds have been replaced by a few specialized breeds and hybrids, which, among other traits, have been intensively selected to increase production, and have become mainstream breeds (Audiot, 1995; FAO, 2015). However, local breeds are both a resource for and a product of livestock farming. Globally, FAO (2015) reported

*Corresponding author: Anne Lauvie (anne.lauvie@inrae.fr)

Received: 22.03.2023 | Accepted: 15.06.2023 | Published online: 06.09.2023

a total of 8,774 breeds from 38 domesticated animal species, resulting from long-term livestock farming in diverse territories with different goals. The first challenge for livestock biodiversity faced by stakeholders and the scientific community, is its conservation, mainly focused on breed conservation and within-breed genetic variability management (Hall and Bradley, 1995; Ajmone-Marsan and Consortium GLOBALDIV, 2010). Beyond this conservation challenge, adding value to local breeds has been underlined as a key process for farm animal biodiversity, in particular through the production of quality food products (Verrier *et al*, 2005; Mathias *et al*, 2010; Ligda and Casabianca, 2013). Various authors in the field of local breeds management have stressed that the supply of animal products is associated with other benefits: provision of a high diversity of food and other goods, services related to landscape and environmental management, uses related to cultural and heritage dimensions (Audiot, 1995; Alexandre *et al*, 2002; Gandini and Villa, 2003; Rege and Gibson, 2003; Verrier *et al*, 2005; Berland *et al*, 2006; Fontaine *et al*, 2008; Naves *et al*, 2011; Leroy *et al*, 2018; Hall, 2019). These material and immaterial benefits have been used as one of the arguments to underline the importance of local breeds' conservation (FAO, 2015).

Few authors use ecosystem service approaches to analyze the material and immaterial benefits provided by the raising of local breeds (Hoffmann *et al*, 2014). However, from being a simple metaphor to raise public awareness (Norgaard, 2010; Barnaud *et al*, 2011), since the Millennium Ecosystem Assessment (2005), the ecosystem services concept is being increasingly used (Kull *et al*, 2015; Droste *et al*, 2018). A prolific literature highlights the diversity of ecosystem services produced or used by agricultural ecosystems (Zhang *et al*, 2007) and how it is linked to human practices (Lescourret *et al*, 2015). Up to now, when the ecosystem services approach was applied to livestock biodiversity, it was mainly at a global scale, through the generic inventory of ecosystem services (Leroy *et al*, 2018), or to focus on specific dimensions of them, like the cultural and heritage values of breed diversity in the Alpine area (Marsoner *et al*, 2018).

Hall (2019) hypothesized that the underuse of this framework by stakeholders and the scientific community is partly due to a lack of recognition of livestock biodiversity by the ecosystem services community, and suggested it would be useful and beneficial that linkages be strengthened among several scientific communities. However, Velado-Alonso *et al* (2021) highlighted the interest in considering both cultural and ecological dimensions of the relationships between livestock breeds and ecosystem services.

Moreover, as underlined by Beudou *et al* (2017), the most commonly used ecosystem services approaches are quantitative and, as a consequence, neglect the social dimension of livestock farming systems, while qualitative approaches are relevant to comprehend the complex processes and interrelations underlying the production of ecosystem services (Barnaud *et al*, 2018). Indeed, we can wonder if a qualitative ecosystem service approach could help better understand the dynamics underlying the multiple benefits obtained from farming systems using livestock biodiversity.

The purpose of the present paper is to propose a qualitative approach to ecosystem services provision by different farming systems that exploit livestock diversity. Considering that the ecosystem services notion applies at the ecosystem scale, we do not look here at ecosystem services provided by livestock biodiversity but ecosystem services provided by farming systems using livestock biodiversity (Martin-Collado *et al*, 2019). In this paper, we present a framework for the analysis of ecosystem services provided by farming systems using livestock biodiversity focusing on the processes at play and the interactions supporting them. Then, we discuss to what extent the notion of ecosystem services is appropriate to deal with the multiple benefits obtained from farming systems using livestock biodiversity.

Materials and methods

Our work is based on empirical research on nine ruminant breeds in six different regions. All the case studies are located in France, including in French overseas territories, Reunion Island (Indian Ocean) and Guadeloupe Island (French West Indies). The locations were chosen to represent diverse (i) biogeographical and climatic conditions, (ii) species, (iii) main uses and (iv) population sizes (Figure 1). We analyzed data and empirical knowledge on those breeds and the associated livestock farming systems, taken from previous or ongoing studies (Table 1).

All the breeds concerned are local except one, the Montbéliarde breed, which is the second most important dairy cattle breed in France. For this breed, we repurposed work carried out in its cradle of origin (located in the east of France, in the Bourgogne Franche Comté Region), which allowed us to have a wide variety of situations on the fourth criterion mentioned above (Gaillard *et al*, 2018).

We developed an inductive approach (Woo *et al*, 2017) based on several working meetings that brought together researchers from different animal sciences, and social and economic sciences (the authors of the present paper). We share a research position that relies on the importance of a qualitative approach, tackling empirical issues to build realistic conceptualizations. We also share a vision of ecosystem services as social constructs: Barnaud *et al* (2018) illustrated that in such a vision, "an open landscape does not 'naturally' or 'intrinsically' provide a cultural ecosystem service but someone, in a given geographical, cultural, and historical context, attributes a specific patrimonial or aesthetic value to such landscape." Indeed, even for the services that result from ecological dynamics, the way humans qualify them as services, recognizing them as such, has a social dimension. Consequently, our aim is not to describe 'objective' ecosystem services and

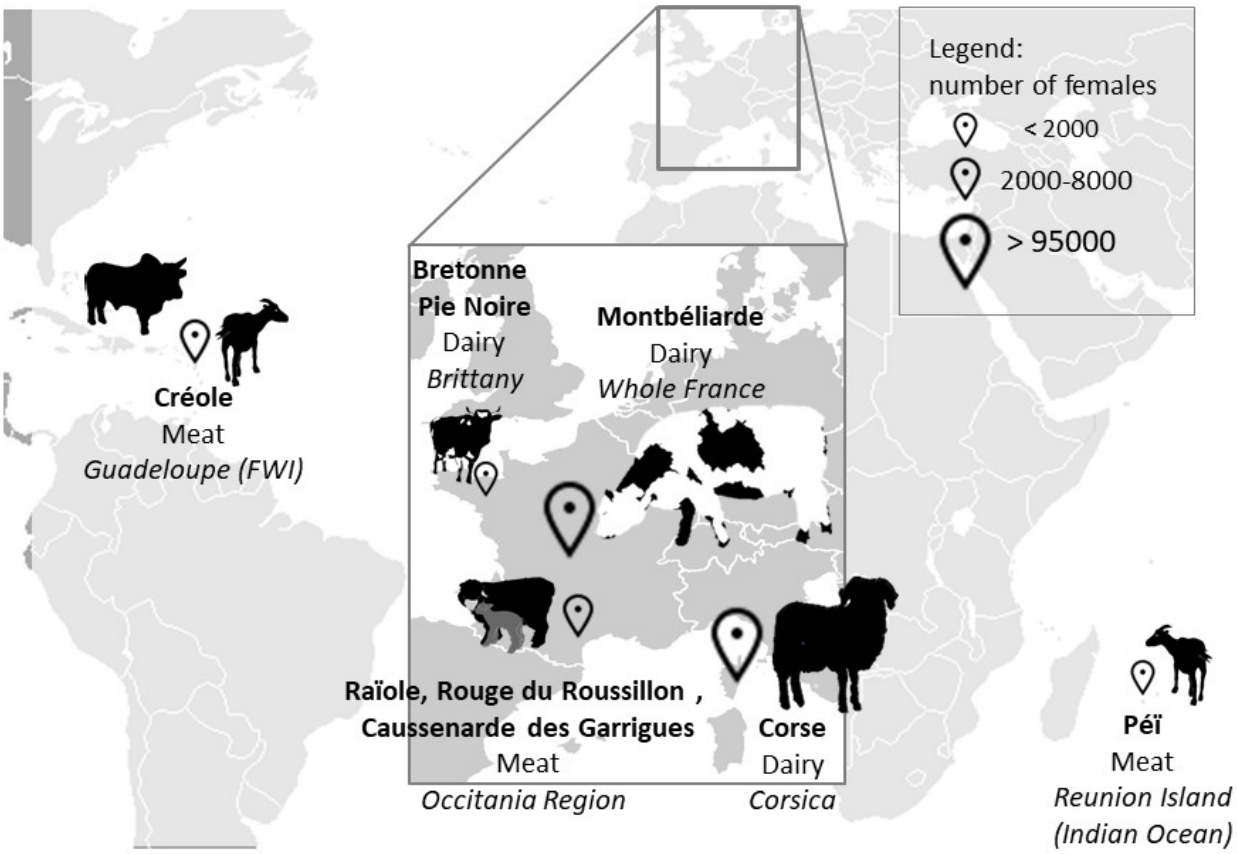

Figure 1. The six regions and the nine breeds analyzed in the present study (source of the population size estimates: INRA (2014)).

Table 1. References associated with the described case studies.

Case study	Species	References
Creole	Cattle and goat	Alexandre *et al* (2002); Gautier and Naves (2011); Naves *et al* (2011); Boval *et al* (2012); Gourdine *et al* (2021)
Bretonne Pie Noir	Cattle	Couix *et al* (2016); Lauvie *et al* (2017)
Peï	Goat	Fontaine *et al* (2008)
Montbéliarde	Cattle	Gaillard *et al* (2018)
Raïole, Caussenarde des Garrigues, Rouge du Roussillon	Sheep	Lauvie *et al* (2017); Nozieres-Petit and Lauvie (2018)
Corse	Sheep	Lauvie *et al* (2017); Perucho *et al* (2020)

quantify or assess them (and such a vision is not adapted to do this kind of assessment). Our aim is rather to take into account services as social constructs: such a vision is adapted to a qualitative and comprehensive approach of complex processes in agroecosystems.

First, we organized three online workshops in 2016, during which we shared our knowledge of the case studies (Table 1 and Figure 1) by presenting (i) their main characteristics, and (ii) the ecosystem services produced by the systems that used the breeds concerned. All the researchers were invited to the online workshops and the attendance ranged from 11 to 12, according to the individual availability for each workshop. The ecosystem services were identified from a researcher's point of view, resulting in an interpretation of what could constitute a service, and to whom.

We organized two 2-day workshops in 2017 during which a transverse analysis resulted in a first analytical grid. Eleven researchers participated in the first and nine in the second workshop. In these workshops, we raised the following questions: i) who were the beneficiaries or potential beneficiaries of the ecosystem services identified, ii) who provided the services and iii) the role of the breed in the process of providing

the service, thanks to available data and expertise. This analysis raised several theoretical and methodological questions reported in the result section.

We organized four online workshops in 2017 and 2018 to complete the iterative development of the framework, identifying loops between knowledge of the case studies, the questions we wanted to ask and the notions and concepts used to tackle these questions in the literature. This iterative collective back and forth between the case studies and the literature provided the background necessary to discuss to what extent the concept of ecosystem services (and associated concepts) was useful to deal with the multiple benefits of systems using livestock biodiversity. The process is summarized in Figure 2.

Results

Services provided by farming systems using livestock biodiversity: our proposed framework

Our transversal approach enabled us to develop a framework to analyze the provision of ecosystem services in farming systems using livestock biodiversity, focusing on the main elements to be taken into account and their interactions. We developed this framework in the form of a list of items to be considered in studies of ecosystem services produced by farming systems using livestock biodiversity. The main themes of the framework are summed up in Figure 3.

We formulated all the items as questions possibly applicable to other situations. The data from our empirical studies did not necessarily enable us to answer all the questions with the same level of detail, but the questions were considered key to understanding the processes for at least one case, even if empirical data to answer them were not available for all the cases.

Considering ecosystem services as a social construct implies the analysis of each ecosystem service identified, including its temporal dynamics, with these questions:

- How is the service formulated or qualified? The formulation or qualification may be plural, depending on from whose point of view the service is considered. It needs to consider dynamics over time and space.
- What processes underlie service provision?
  - Who is concerned?
    - Who are the beneficiaries and/or the people who help provide the service?
    - Who identifies the service as such?
    - Is the service produced intentionally or not (and by whom)?
    - What are the interactions between the people concerned?
  - What is the role of the breed in the process?
    - Is the effect of the breed linked with biological characteristics and the abilities of the animals of the breed (direct or indirect effects)? If so, which abilities are considered to be involved in the provision of services by the different people concerned (several points of view are possible)?
    - Is the effect of the breed linked with other attributes of the breed that are not directly linked to biological characteristics (e.g. local heritage or image)? If so, which attributes are considered to be at play by the different people involved in service provision (several points of view are possible)?
    - Can the breed be considered a marker of the search for innovation/alternatives in farming systems?
    - Does the breed play a catalytic role in relation to collective action to provide a service?
  - What are the interactions with other services?
    - Do other services result from this service? I.e. does the fact that this service is produced enable the provision of other services? (e.g. cascades or bundles of services)
    - Are there any variations in the generic formulation of the service?
    - Do other services – synergies or trade-offs – interact with it?
- To what extent is the service taken into account in the management of the breed?

In the following sections, for the different items in the framework, we present each item and provide details on:

(i) How the transverse analysis of our case studies enabled the identification of the item

(ii) How creating linkages between our cases and the literature helped build the framework and provided insights into the usefulness of the notion of ecosystem services.

We explore which elements from the literature helped us in the analysis of the case studies. The elements presented in those paragraphs result from linkages between empirical data (from case studies) and theoretical contributions (from the literature and the questions raised by our cross-cutting analysis).

Dynamics of production of a diverse range of services

The first step was to identify each service. We first established that systems that use livestock biodiversity are involved in the production of a wide range of ecosystem services. Table 2 summarizes this diversity by giving examples from our case studies. Our aim here was to illustrate the diversity and put it in perspective with a classification frame proposed in ecosystem services literature, but not to make an exhaustive, generic or 'objective' inventory.

Indeed, the temporal (and spatial) dynamics of ecosystem services provision are important in the cases we studied.

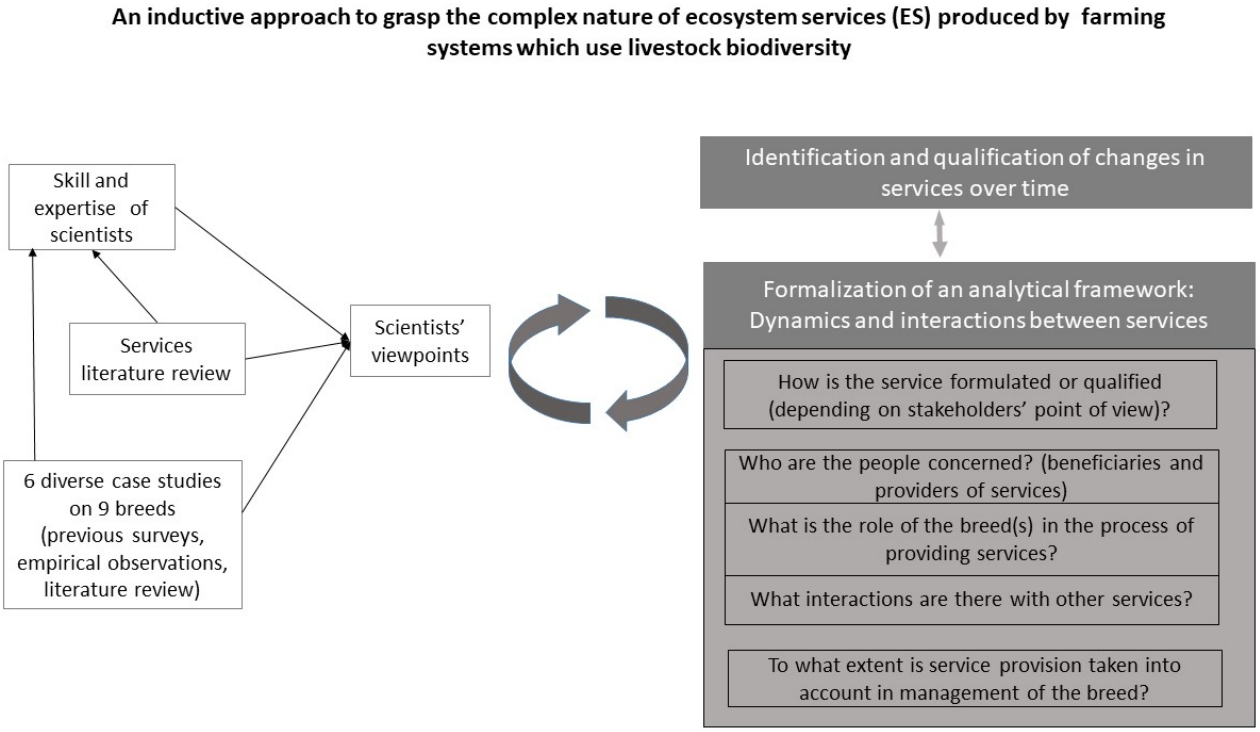

Figure 2. Process used from the six case studies analysis to the building of the framework

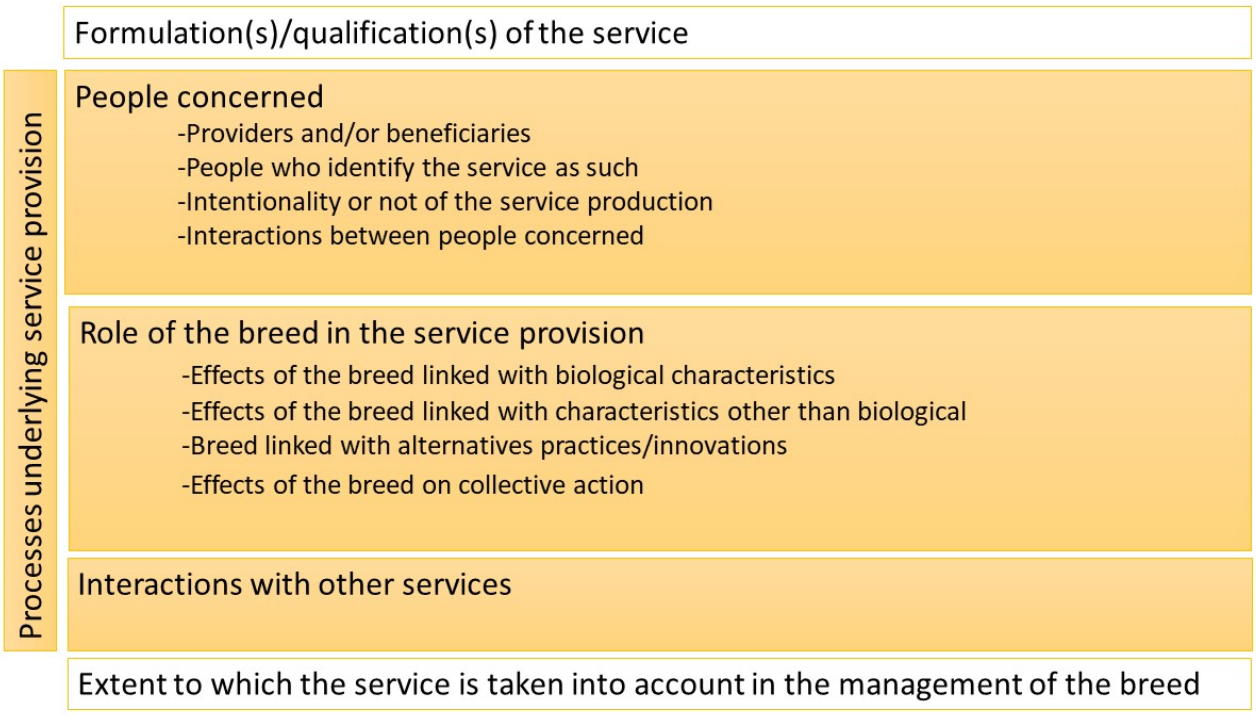

Figure 3. Main themes of the framework

Table 2. The diversity of services identified in the case studies.

Services identified	Examples given in the case studies
Food products (main products of the systems studied, diversity of meat and dairy products mainly subject to market valuation but can also be subject to non-market valuation)	Without geographical indication, sold through direct sales or through intermediaries, like the meat and dairy products from the Bretonne Pie Noir Protected Designation of Origin (PDO) products like Comté cheese made from the milk of cows belonging to the Montbéliarde or Simmental breeds and the Brocciu whey cheese in Corsica, which can only be made from Corsican sheep and goat milk
Inedible products	Wool from the Raïole breed Skins of goats in Guadeloupe Manure used to fertilize the soil (e.g. by Caussenarde des Garrigues, Raiole and Rouge du Roussillon or Creole cattle in Guadeloupe)
Maintenance of some specificities of the farming systems	The sheep breeds Raiole, Rouge du Roussillon and Caussenarde des Garrigues are associated with pastoral systems in the region concerned, and are reputed for their ability to adapt to those systems
Services linked to the management of habitats or the preservation of associated landscapes	Wildfire prevention (particularly in the Mediterranean region) Birds nesting open areas (recorded in typical Guadeloupean savannahs grazed by tethered Creole cattle (Zoom-Guadeloupe, 2012))
Use of animals from the systems for religious rites	In Réunion and Guadeloupe islands, goats are commonly used for Hindu sacrifices. A diversity of phenotypes are sought. Peï and Créole goats contribute to this diversity, more often in Guadeloupe than in La Réunion, along with other goats from various breeds and crossbred animals.
Educational use	In several cases, farmers have allowed farm visits by schoolchildren
Contribution to heritage and cultures	This dimension can be recognized through the associated landscape, e.g. the pastoral landscapes in the Causses and Cevennes area, which are designated UNESCO world heritage sites Local breed animals, with their specific phenotypic attributes (e.g. colour, horns) also contribute to the aesthetics of the landscape and its original identity, and thus serve as an image vector for agro-tourism Through an informal pathway, they may simply be part of the cultural patrimony, like the Creole society in Reunion Island or Guadeloupe.
Contribution of farming systems to the global dynamics of the territories (by helping maintain an agricultural activity and/or to the image of the territory concerned).	A cow from the Bretonne Pie Noir breed was named 'star cow' at the 2017 Paris agricultural fair, and the Pays de Redon where the cow originated benefited from this event being reported in the press.

For example, the use of Créole cattle in Guadeloupe in oxen drawing (bœufs tirants) contests, has played a role in conserving the breed, thanks to the success of this cultural event. However, the increasing success has led to a modification in the rules to include categories of larger animals, shorten the distance to be covered, and no longer place the yoke directly on the horns. These changes have increased the inclusion of exotic breeds with greater muscle development (Limousin, Charolais, Blonde d'Aquitaine) than that of the local breed. The cultural service is thus developing, but the link between the service and the local breed is dwindling.

A second example of temporal and spatial dynamics of ecosystem services is the Montbéliarde cattle breed in the Comté cheese territory (a protected designation of origin (PDO) cheese). The milk is collected and processed by small-scale processors (called fruitières in French) distributed throughout the territory. This organization and the related livestock farming systems are associated with the production of a specific landscape, which can be considered a service. However, we identified changes in farm structure with an increase in the size of the herds. This trend is due to the increasing demand for Comté cheese (and a readiness to make the most of the attractive price of the milk for Comté), the pleasure involved in raising high-yielding dairy cows, as well as the desire to reorganize labour. The tendency to graze the herd on land close to the farm homestead rather than on more distant pastures (more typical of the Jura landscape), as well as to increase the size and homogeneity of the plant covers used in pastures, has also led to changes in the landscape (Gaillard *et al*, 2018).

We compared data gathered from the case studies with data in the literature, which provided benchmarks for the identification of ecosystem services. The well-known categories suggested by the Millennium Ecosystem Assessment (2005) or the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2018) make it possible to distinguish provisioning, regulation and maintenance, cultural, and support services. Identification of services can be facilitated by using such a classification. We used the provisioning, support and regulation and cultural categories to describe the services in our cases, which helped ensure we covered a wide range of services. However, as we will see hereafter, the services we identified were not always easy to classify into a single category. Moreover, the view of ecosystem services as social constructs (Barnaud *et al*, 2018) underlines the fact that they are not intrinsic properties of ecosystems, and that the classification of specific services provided at a given time by an ecosystem may not still be relevant when a dynamic approach is used.

How can services be qualified and classified?

After the first step of identification of services, the first item of the framework is: How can the services be formulated or qualified?

Our analysis of case studies raised the question of how to qualify (and classify) the services. By using the word qualify we mean describe and attribute one or several qualities to a service by naming it/them. The main products of systems using the breeds concerned are food products. However, systems that produce traditional food products, can be considered to provide both a provisioning service and a cultural service. Indeed, the food products concerned often have a cultural dimension, which can be recognized, for instance, through a PDO. Similarly, a pasture system that has shaped a typical landscape can be considered both as a regulation and a cultural service, like the Causses and the Cévennes, where the pastoral landscapes are UNESCO designated world heritage sites. Many services produced by farming systems using local breeds have a cultural dimension.

Ovaska and Soini (2016) noted the overlapping of ecosystem services categories and for instance, Díaz *et al* (2018), underlined the importance of recognizing "the central and pervasive role that culture plays" in the production of nature's contributions to humans, as well as the importance of applying a context-specific perspective. Increasing research in this field has enabled the development of multiple approaches that might be complementary (Peterson *et al*, 2018) to qualify and classify ecosystem services. Following Barnaud *et al* (2018), we consider ecosystem services as "subjective perceptions, socially situated and constructed". The points of view of the people involved in the situation studied should be taken into account when qualifying and classifying ecosystem services.

People concerned by the production of services

The first question regarding the second item of the framework, is: Who is concerned?

Our analysis of the case studies confirmed the diversity of actors involved in the systems using the breeds concerned and in the processes linked to the provision of ecosystem services. For instance, the range of livestock keepers involved in the use of the Bretonne Pie Noir cattle breed includes both hobby breeders and professional breeders, and both dairy and meat herds (Couix *et al*, 2016). Other stakeholders include researchers, consumers, environmental management associations and restaurant owners. Interactions among actors influence the provision of ecosystem services by systems using the breed.

In several ecosystem services that we identified, the same actors, particularly farmers, can be both beneficiaries and providers. For instance, some farmers who raise Bretonne Pie Noir cattle use areas of ecological

interest, like wetlands, as feed resources for their cattle. The farmers thus participate in the production of the management service of those areas through grazing, and at the same time, profit from the vegetation in the areas to feed their herds.

The ecosystem functions are translated into services when they are used, consumed or enjoyed by humans (Fisher *et al*, 2009). This makes ecosystem services beneficiary-dependent (different individuals or collectives benefit from different services (Díaz et al., 2018)). In the framework they proposed for the analysis of social interdependencies underlying ecosystem services dynamics, Barnaud *et al* (2018) identified two other categories of actors together with beneficiaries: providers, and possibly intermediaries between beneficiaries and providers. To grasp the complexity of the actors involved, we suggest adding a step before qualifying actors as a beneficiary, provider or intermediary: identifying what we call the 'people concerned'. The aim of this step is to ensure different levels of concern are included. The people concerned can then be qualified as beneficiaries, producers, intermediaries or, in some cases, may belong to more than one category. Identifying the people concerned is a step in the process of tracing actors who play a direct role in the processes underlying the provision of services and helps grasp the multiple perceptions, values and practices associated with such services (Dendoncker *et al*, 2018; Teixeira *et al*, 2018).

Some of the ecosystem services produced at the scale of the human-driven farming system are produced intentionally, e.g.edible and inedible goods. However, this is not necessarily the case for all ecosystem services. The provision of cultural services, for instance, may sometimes be considered involuntary, as they are inherited from a long history of co-evolution of the breeds, their environment and the human practices involved in the farming system. It is not always easy to determine whether a service is provided intentionally or not, especially when several dimensions of ecosystem services production are interconnected. However, the distinction proposed by Aznar *et al* (2007) may be useful to deal with the general question of whether or not ecosystem services are produced intentionally. Based on the economy of services, this author defines provisioned services as services provided by agriculture which lead a farmer to maintain or change support and/or contribute technical or human capacities. These provisioned services are supplied by the farmer intentionally and are co-built by the farmer and the beneficiaries/applicant. Aznar *et al* (2007) distinguished them from service externalities that are supplied without the intention of the supplier and from service functions which refer to services supplied to humans by nature.

The role of the breed in service production: not only biological characteristics are at play

The second question regarding the second item in the framework, is: What is the role of the breed?

The provision of ecosystem services may be directly linked to specific abilities of the animals of the breeds involved. In Creole cattle, for instance, a signature of selection has been identified in the genomic region that can be linked to the strength and the shape of the horns, directly inherited from their use as draught animals (Naves *et al*, 2011). Resistance to specific sanitary problems, such as internal parasites in Creole goats, or to ticks and associated infectious diseases in Creole cattle, also help provide some ecosystem services (Naves *et al*, 2011). The integrated management of these diseases enabled by the use of resistant animals reduces the need for treatment, in turn reducing the quantity of chemical residues in edible products, but also in animal dung, which may be useful in agroecological or organic production systems.

However, the animals' specific abilities are not sufficient to describe all the characteristics of the breeds that can play a role in the provision of ecosystem services. The Raiole, Caussenarde des Garrigues and Rouge du Roussillon breeds, for instance, show that breeds also play a role in gathering together a group of farmers who exchange breeding animals, technical knowledge or projects to add value to products (Nozieres-Petit and Lauvie, 2018).

The appropriate scale to identify the provision of ecosystem services is the ecosystem (or the farming system as far as farming activity is concerned); as a consequence, the breed is one of the elements in the system that can contribute to their provision (Martin-Collado *et al*, 2019).

Relevant concepts in the literature to better identify the role of the breed are not specifically related to the notion of ecosystem services. The most relevant concepts to identify the role of the animals' specific abilities are two concepts from animal sciences: the concept of animal abilities and the concept of animal performances. Those concepts are used to describe specific biological characteristics of animals that are useful in livestock farming (directly linked with food production, like milk yield, or indirectly linked with food production, like the walking ability of animals, which is useful in pastoral systems).

A global term, often used for local breeds, covering their functional abilities, and not only their productive feature, is the hardiness of animals. Hardiness covers a wide range of abilities which depend on the situation and the point of view, as described by Hubert (2011). Being hardy means being not very demanding and therefore enabling the herd to survive even in harsh conditions (Poussard *et al*, 2016). The hardiness of a breed is difficult to measure and even to define precisely, as it covers a set of different animal functions interacting with the environment. Moreover, these

functions are more difficult to evaluate than productive traits (e.g. milk yield, protein content, daily gain, etc.). But such abilities are highly valued in non-intensive farming systems and can be directly linked with the provision of ecosystem services (Naves *et al*, 2011; Marshall *et al*, 2016). They generally result from long-term breeding and from natural selection of the animals in specific environments, and are now being increasingly elucidated thanks to recent genomics technologies (Amills *et al*, 2017). For example, a complex trait such as the adaptation to climatic stress or the ability to walk is very useful in pastoral management, and some specific physical attributes useful in such conditions are present in local breeds (for example, short hair, dark hooves or a hump in cattle) (Naves *et al*, 2011; Flori *et al*, 2012).

However, these concepts from animal sciences are not sufficient to describe other dimensions that are not biological but that may also be involved in the provision of ecosystem services, for instance, the ability to trigger collective action. As a consequence, we propose to use the term 'breed attributes' to cover characteristics of breeds that are both biotechnical (abilities and performances) and sociotechnical. In this definition, both the 'ability to exploit native vegetation in pastoral systems' and the 'ability to trigger a collective action' could be considered as complementary breed attributes and combined in underlying processes to produce a set of ecosystem services.

Relations between services

The third question regarding the second item of the framework is: 'What are the interactions with other services?'

Our case studies also underline the fact that diverse ecosystem services are interrelated. For instance, in the case of Raïole, Caussenarde des Garrigues and Rouge du Roussillon breeds, we identified interactions among ecosystem services: some services result from others, like the contribution to wildfire prevention that results from the animals' capacity to graze local resources. Some services are divisions of others: 'participate in education' is a subset of the service 'the social role of livestock farming'. Several ecosystem services are produced jointly in similar farming systems (Nozieres-Petit and Lauvie, 2018). For instance, farms using the Corsican sheep breed produce milk, processed into cheeses and whey cheese (on farm or in industrial dairy plants); and they also help maintain the pastured vegetal resource, thus indirectly helping shape the landscape and preventing wildfires. Creole cattle raised for meat production and manure provision are tethered in natural savannahs, sustaining small-scale family farms, while shaping the typical hilly landscapes of Guadeloupe (mornes). Direct provisional services can be reinvested through the loop of cultural service since they enhance gastronomy, with dishes like goat curry in Guadeloupe, or can provide raw material for the production of musical instruments. The use of goats in Hindu sacrificial rites in Guadeloupe or in Reunion Island illustrates a case of service (with a cultural and religious dimension) that over time has enhanced the development of the entire goat meat sector (service provision).

'Bundles of services' is a useful notion in the literature to jointly consider a diverse range of services produced in similar farming systems, and it can help tackle synergies and trade-offs between services (Cord *et al*, 2017; Dumont *et al*, 2019).

Links between services and management of the breeds

The last item in the framework is: What are the links with the management of the breed?

We found examples in the case studies in which the intentional production of a new service engendered changes in the collective management of the breed. For instance, for the Raïole breed, the farmers developed collective marketing of the wool, and during the sale of rams organized by the breeders' association, they provided information to farmers about the wool quality of rams sold, so that they could consider it in their choice of a breeding animal (Lauvie *et al*, 2017).

Biodiversity and ecosystem services are often closely linked. For instance, Mace *et al* (2012) underlined how biodiversity generally plays a key role in ecosystem services provision, as a regulator of underpinning ecosystem processes, as a final ecosystem service, and as a good subject for valuation. This link between services and management of the breed feeds the question of the links between services and biodiversity dynamics. Indeed, collective management of the breed is an important lever of livestock biodiversity dynamics: through the collective choice of selection criteria that influence the direction of breed management, but also through collective promotion actions that can have an impact on the number of animals, for instance.

Discussion

In this paper, we used several case studies to explore the question of the multiple benefits of farming systems that use livestock biodiversity and developed a framework to address the processes underling the ecosystems services provided by them.

One of our aims was to discuss the extent to which the notion of ecosystem services is useful to deal with these multiple benefits. Services are indeed increasingly taken into account in livestock farming research (Rodríguez-Ortega *et al*, 2014; Alexandre *et al*, 2014; Ryschawy *et al*, 2017; Dumont *et al*, 2019). Steger *et al* (2018) argue that the diversity of definitions and approaches in ecosystem services research has prevented it from being structured by a single discipline, and maintained it as a boundary object. Choosing the ecosystem services notion as an entry point of our analysis did not provide us with a turnkey approach, but rather gave us room to include different visions (and notions) of animal scientists, social scientists

and economists in our analysis. Some of the concepts associated with ecosystem services in the literature appeared to be relevant to our empirical findings in case studies (e.g. the bundle of services) or fed our reflection on the processes underlying the provision of services (e.g. the beneficiaries). However, we also considered other concepts, not related to the ecosystem services literature, which were useful in our analysis, like the concept of animal abilities used in animal sciences. Choosing the notion of ecosystem services as an entry point also favoured a systemic analysis. Indeed, such a view is central to our communities as the farming system is a key notion, particularly for the livestock farming systems community (Dedieu *et al*, 2008). The meeting point of systemic views in several scientific communities is the agroecosystem. However, the view on agroecosystem might favour complementary foci depending on the communities, which could enrich each other. To go further, it would indeed be interesting to broaden our already multidisciplinary vision by including the points of view of ecological scientists in our framework.

Other notions or theoretical frameworks could also be adapted to tackle the question of the multiple benefits obtained by farming systems which use domestic animal biodiversity and are complementary to the ecosystem services approach. The notion of multi-functionality, for instance, is equally constructed and situated (Barnaud and Couix, 2020), and makes it possible to consider the different functions of farming activities. Huang *et al* (2015) reported the proximity of the scientific communities that use multifunctionality and ecosystem services concepts when dealing with agriculture. However, the entry point of the approach is agricultural activity whereas the entry point of the ecosystem services notion is the ecosystem. Huang *et al* (2015) pointed out that the two approaches would benefit from being integrated, and Barnaud and Couix (2020) associated them by using an ecosystem services lens to answer a multifunctionality question. The framework proposed by Díaz et al. (2018) is another relevant framework for our purpose. Díaz et al. argued that the "Nature's Contribution to People" (NCP), the core concept of this framework, is a concept which makes it possible to go beyond some of the limits of the ecosystem services concept, in particular to respond to criticisms regarding the lack of social and humanities sciences involved. This framework indeed emphasizes the importance of the cultural context in understanding NCP, which our case studies highlight. Díaz and her colleagues' proposal led to a broad debate on the real novelty of the concept compared to ecosystem services (Braat, 2018; Faith, 2018; Peterson *et al*, 2018). Without going further in this debate, we note that the use of the word 'nature' (instead of 'ecosystem') as the subject of the contribution, and the people only as the beneficiaries, can question the importance of human action in the production of several of these services. As noted by Peterson *et al* (2018): "a focus on 'nature,' therefore de-emphasizes the ecosystems that are home to and provide the necessities of life to most of the world's population". In our case, the services are clearly co-produced by humans and animals in farming systems and talking about them as NCP may seem counterproductive.

The framework we propose in this paper is the first step in identifying and understanding the services provided by farming systems using livestock biodiversity. This framework could however be put to the test and enriched by applying it to other cases. Steps to enrich it could be to include the points of view, values and practices of the different stakeholders involved. Answers to the questions proposed in the framework can consequently include a diversity of points of view. The interest of the framework is not to provide an irrevocable single answer to each question, but rather contribute to better understanding the processes underlying services production, in their complexity. However, this framework cannot be used for a quantitative assessment of the dynamics of livestock biodiversity or the values of services. The framework can contribute to better understanding the link between livestock biodiversity dynamics and the provision of services in the farming systems concerned. Indeed, from a perspective of livestock biodiversity management and conservation, one of the scientific challenges is to understand the issues underlying the management dynamics of each breed, the corresponding management objectives, and their translation into practices, at both individual and collective levels. This will be a key step in understanding whether or not the provision of services production is at stake for the people concerned. In our framework, we gathered important items to be taken into consideration to analyze the dynamics of services produced as social constructs and to understand the underlying processes. Such an approach implies including a diversity of biotechnical and sociotechnical dimensions, and accounting for their interactions and their dynamics in multiple services over time. The notion of 'breed attributes' actually helps explain how livestock biodiversity contributes to the provision of ecosystem services. We propose this notion to describe not only the biological but also the sociotechnical characteristics of breeds. Our aim is not to objectify the role of a given breed in providing a given ecosystem service (Martin-Collado *et al*, 2019). As ecosystem services are seen as constructs and breeds are seen as dynamics (and not categories with static properties), our aim is rather to question whether accounting for the wide range of productions (including the different services) of farming systems using local breeds would enable a better understanding of the overall dynamics of livestock biodiversity conservation and management .

To conclude, if the ecosystem services notion can help include different visions and develop a multidisciplinary approach, it is not the only notion that can be used to tackle the question of the multiple benefits of farming systems using local breeds. Understanding the

processes underlying service production requires going even further in developing interdisciplinary approaches.

Acknowledgments

The authors have a special thought for their late colleague Claire Gaillard, with whom they had the pleasure to work in this study, and who left us too soon. This work was conducted in the frame of the SECOYA project, funded by the INRA Metaprogram ECOSERV.

Conflict of interest statement

The authors declare no conflict of interest.

Author contributions

Anne Lauvie: Study conception and design, data collection, analysis and interpretation of results, draft manuscript preparation and manuscript revision. Claire Gaillard: Study conception and design, data collection, analysis and interpretation of results. Gisèle Alexandre, Valérie Angeon, Nathalie Couix, Olivia Fontaine, Michel Meuret, Catherine Mougenot, Charles-Henri Moulin, Michel Naves, Marie-Odile Nozières-Petit, Jean-Christophe Paoli, Lola Perucho, Jean Michel Sorba, Emmanuel Tillard, Etienne Verrier: Study conception and design, data collection, analysis and interpretation of results and manuscript revision.

References

Ajmone-Marsan, P. and Consortium GLOBALDIV (2010). A global view of livestock biodiversity and conservation - GLOBALDIV. *Animal Genetics* 41(s1), 1–5. doi: https://doi.org/10.1111/j.1365-2052.2010.02036.x

Alexandre, G., De Beauville, S. A., Bienville, Y., and Shitalou, E. (2002). La Chèvre multifonctionnelle dans la société antillaise. *Ethnozootechnie* 70, 35–52.

Alexandre, G., Fanchone, A., Ozier-Lafontaine, H., and Diman, J. L. (2014). Sustainable Agriculture Reviews 14: Agroecology and Global Change, ed. H, O.-L. and M, L.-J. (Cham: Springer International Publishing), 83-115.

Amills, M., Capote, J., and Tosser-Klopp, G. (2017). Goat domestication and breeding: a jigsaw of historical, biological and molecular data with missing pieces. *Animal Genetics* 48(6), 631–644. doi: https://doi.org/10.1111/age.12598

Audiot, A. (1995). Races d'hier pour l'élevage de demain (Paris, France: INRA Editions).

Aznar, O., Guérin, M., and Perrier-Cornet, P. (2007). Agriculture de services, services environnementaux et politiques publiques: éléments d'analyse économique. *Revue d'Économie Régionale & Urbaine* 4, 573–587. doi: https://doi.org/10.3917/reru.074.0573

Barnaud, C., Antona, M., and Marzin, J. (2011). Vers une mise en débat des incertitudes associées à la notion de service écosystémique. *Vertigo* 11. doi: https://doi.org/10.4000/vertigo.10905

Barnaud, C., Corbera, E., Muradian, R., Salliou, N., Sirami, C., Vialatte, A., Choisis, J. P., Dendoncker, N., Mathevet, R., Moreau, C., Reyes-García, V., Boada, M., Deconchat, M., Cibien, C., Garnier, S., Maneja, R., and Antona, M. (2018). Ecosystem services, social interdependencies, and collective action: a conceptual framework. *Ecology and Society* 23(1). doi: https://doi.org/10.5751/ES-09848-230115

Barnaud, C. and Couix, N. (2020). The multifunctionality of mountain farming: Social constructions and local negotiations behind an apparent consensus. *Journal of Rural Studies* 73, 34–45. doi: https://doi.org/10.1016/j.jrurstud.2019.11.012

Berland, F., Signoret, F., and Roche, B. (2006). Conserver et valoriser la race bovine Maraîchine et les prairies naturelles de marais. *Les Actes du BRG* 6, 485–494.

Beudou, J., Martin, G., and Ryschawy, J. (2017). Cultural and territorial vitality services play a key role in livestock agroecological transition in France. *Agron. Sustain. Dev* 37(36). doi: https://doi.org/10.1007/s13593-017-0436-8

Boval, M., Coppry, O., Naves, M., and Alexandre, G. (2012). L'élevage traditionnel, une source et un support pour l'innovation agro-écologique : la pratique du piquet aux Antilles. *Courrier de l'Environnement de l'INRA* 62, 87–97.

Braat, L. C. (2018). Five reasons why the Science publication "Assessing nature's contributions to people" (Diaz et al. 2018) would not have been accepted in Ecosystem Services. *Ecosystem Services* 30, A1–A2. doi: https://doi.org/10.1016/j.ecoser.2018.02.002

Cord, A. F., Bartkowski, B., Beckmann, M., Dittrich, A., Hermans-Neumann, K., Kaim, A., Lienhoop, N., Locher-Krause, K., Priess, J., Schröter-Schlaack, C., Schwarz, N., Seppelt, R., Strauch, M., Václavík, T., and Volk, M. (2017). Towards systematic analyses of ecosystem service trade-offs and synergies: Main concepts, methods and the road ahead. *Ecosystem Services* 28(C), 264–272. doi: https://doi.org/10.1016/j.ecoser.2017.07.012

Couix, N., Gaillard, C., Lauvie, A., Mugnier, S., and Verrier, E. (2016). Des races localement adaptées et adoptées, une condition de la durabilité des activités d'élevage. *Cahiers d'Agriculture* 25(6), 650009. doi: http://dx.doi.org/650010.651051/cagri/2016052

Dedieu, B., Faverdin, P., Dourmad, J. Y., and Gibon, A. (2008). Systèmes d'élevage, un concept pour raisonner les transformations de l'élevage. *INRA Prod Anim* 21(1), 45–58. doi: https://doi.org/10.20870/productions-animales.2008.21.1.3374

Dendoncker, N., Boeraeve, F., Crouzat, E., Dufrêne, M., König, A., and Barnaud, C. (2018). How can integrated valuation of ecosystem services help understanding and steering agroecological transitions? *Ecology and Society* 23(1). doi: https://doi.org/10.5751/ES-09843-230112

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R. T., Molnár, Z., Hill, R., Chan, K. M. A.,

Baste, I. A., Brauman, K. A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P. W., Van Oudenhoven, A. P. E., Van Der Plaat, F., Schröter, M., Lavorel, S., Aumeeruddy-Thomas, Y., Bukvareva, E., Davies, K., Demissew, S., Erpul, G., Failler, P., Guerra, C. A., Hewitt, C. L., Keune, H., Lindley, S., and Shirayama, Y. (2018). Assessing nature's contributions to people. *Science* 359(6373), 270–272. doi: https://doi.org/10.1126/science.aap8826

Droste, N., Amato, D., and Goddard, J. J. (2018). Where communities intermingle, diversity grows - The evolution of topics in ecosystem service research. *PLOS ONE* 13, (9):e0204749. doi: https://doi.org/10.1371/journal.pone.0204749

Dumont, B., Ryschawy, J., Duru, M., Benoit, M., Chatellier, V., Delaby, L., Donnars, C., Dupraz, P., Lemauviel-Lavenant, S., Méda, B., Vollet, D., and Sabatier, R. (2019). Review: Associations among goods, impacts and ecosystem services provided by livestock farming. *Animal* 13(8), 1773–1784. doi: https://doi.org/10.1017/S1751731118002586

Faith, D. P. (2018). Avoiding paradigm drifts in IPBES: reconciling "nature's contributions to people",biodiversity, and ecosystem services. *Ecology and Society* 23(2). doi: https://doi.org/10.5751/ES-10195-230240

FAO (2015). The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture, ed. Scherf, B. D. and Pilling, D. (Rome: FAO Commission on Genetic Resources for Food and Agriculture Assessments). url: https://www.fao.org/3/i4787e/i4787e.pdf.

Fisher, B., Turner, R. K., and Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological Economics* 68(3), 643–653. doi: https://doi.org/10.1016/j.ecolecon.2008.09.014

Flori, L., Gonzatti, M. I., Thevenon, S., Chantal, I., Pinto, J., Berthier, D., Aso, P. M., and Gautier, M. (2012). A Quasi-Exclusive European Ancestry in the Senepol Tropical Cattle Breed Highlights the Importance of the slick Locus in Tropical Adaptation. *PLOS ONE* 7(5), e36133. doi: https://doi.org/10.1371/journal.pone.0036133

Fontaine, O., Niobé, D., Shitalou, E., Fontaine, D., and Choisis, J. P. (2008). Hindouisme et sacrifice de boucs à l'Île de la Réunion. *Ethnozootechnie* 85, 101–110.

Gaillard, C., Mougenot, C., and Petit, S. (2018). Le fromage de Comté dans l'ère du temps. Succès et tensions. . *Temporalités, Revue de sciences sociales et humaines* 28. doi: https://doi.org/10.4000/temporalites.5377

Gandini, G. C. and Villa, E. (2003). Analysis of the cultural value of local livestock breeds: a methodology. *J. Anim. Breed. Genet* 120, 1–11. doi: https://doi.org/10.1046/j.1439-0388.2003.00365.x

Gautier, M. and Naves, M. (2011). Footprints of selection in the ancestral admixture of a New World Creole cattle breed. *Molecular Ecology* 20, 3128–3143. doi: https://doi.org/10.1111/j.1365-294X.2011.05163.x

Gourdine, J. L., Fourcot, A., Lefloch, C., Naves, M., and Alexandre, G. (2021). Assessment of ecosystem services provided by livestock agroecosystems in the tropics: a case study of tropical island environment of Guadeloupe. *Tropical Animal Health and Production* 53, 435–435. doi: https://doi.org/10.1007/s11250-021-02880-3

Haines-Young, R. and Potschin, M. B. (2018). Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure. url: https://cices.eu/resources/.

Hall, S. J. G. (2019). Livestock biodiversity as interface between people, landscapes and nature. *People and Nature* 1(3), 284–290. doi: https://doi.org/10.1002/pan3.23

Hall, S. J. G. and Bradley, D. G. (1995). Conserving livestock breed biodiversity. *Trends in Ecology & Evolution* 10(7), 267–270. doi: https://doi.org/10.1016/0169-5347(95)90005-5

Hoffmann, I., From, T., and Boerma, D. (2014). Ecosystem services provided by livestock species and breeds, with special consideration to the contributions of small-scale livestock keepers and pastoralists. url: https://www.fao.org/3/at598e/at598e.pdf.

Huang, J., Tichit, M., Poulot, M., Darly, S., Li, S., Petit, C., and Aubry, C. (2015). Comparative review of multifunctionality and ecosystem services in sustainable agriculture. *Journal of Environmental Management* 149, 138–147. doi: http://dx.doi.org/10.1016/j.jenvman.2014.10.020

Hubert, B. (2011). La rusticité: l'animal, la race, le système d'élevage? Pastum Hors Série (Association Franc
Cardère éditeur).

INRA (2014). Races animales françaises menacées d'abandon pour l'agriculture. url: https://agriculture.gouv.fr/sites/default/files/races_menacees_rapport_methodologique.pdf.

Kull, C., De Sartre, X. A., and Castro, M. (2015). The political ecology of ecosystem services. *Geoforum* 61. doi: https://doi.org/10.1016/j.geoforum.2015.03.004

Lauvie, A., Alexandre, G., Couix, N., Markey, L., Meuret, M., Nozières-Petit, M. O., Perucho, L., and Sorba, J. M. (2017). Comment les diverses formes de valorisation des races locales interagissent avec leur conservation. *Ethnozootechnie* 103, 7–12.

Leroy, G., Baumung, R., Boettcher, P., Besbes, B., From, T., and Hoffmann, I. (2018). Animal genetic resources diversity and ecosystem services. *Global Food Security* 17, 84–91. doi: https://doi.org/10.1016/j.gfs.2018.04.003

Lescourret, F., Magda, D., Richard, G., Adam-Blondon, A. F., Bardy, M., Baudry, J., Doussan, I., Dumont, B., Lefèvre, F., Litrico, I., Martin-Clouaire, R., Montuelle, B., Pellerin, S., Plantegenest, M., Tancoigne, E., Thomas, A., Guyomard, H., and Soussana, J. F. (2015). A social-ecological approach to managing multiple agro-ecosystem services. *Current Opinion in*

Environmental Sustainability 14(0), 68–75. doi: http://dx.doi.org/10.1016/j.cosust.2015.04.001

Ligda, C. and Casabianca, F. (2013). Adding value to local breeds: challenges, strategies and key factors. *Animal Genetic Resources* 53, 107–116.

Mace, G. M., Norris, K., and Fitter, A. H. (2012). Biodiversity and ecosystem services: a multilayered relationship. *Trends in Ecology & Evolution* 27(1), 19–26. doi: https://doi.org/10.1016/j.tree.2011.08.006

Marshall, K., Mtimet, N., Wanyoike, F., Ndiwa, N., Ghebremariam, H., Mugunieri, L., and Costagli, R. (2016). Traditional livestock breeding practices of men and women Somali pastoralists: trait preferences and selection of breeding animals. *Journal of Animal Breeding and Genetics* 133(6), 534–547. doi: https://doi.org/10.1111/jbg.12223

Marsoner, T., Vigl, L. E., Manck, F., Jaritz, G., Tappeiner, U., and Tasser, E. (2018). Indigenous livestock breeds as indicators for cultural ecosystem services: A spatial analysis within the Alpine Space. *Ecological Indicators* 94, 55–63. doi: https://doi.org/10.1016/j.ecolind.2017.06.046

Martin-Collado, D., Boettcher, P., and Bernués, A. (2019). Opinion paper: livestock agroecosystems provide ecosystem services but not their components - the case of species and breeds. *Animal* 13, 1–3. doi: https://doi.org/10.1017/S1751731119001277

Mathias, E., Mundy, P., and Koehler-Rollefson, I. (2010). Marketing products from local livestock breeds: an analysis of eight cases. *Animal Genetic Resources* 47, 59–71.

Millennium Ecosystem Assessment (2005). Ecosystems and human well-being: synthesis (Washington, DC: Island Press). url: https://www.millenniumassessment.org/documents/document.356.aspx.pdf.

Naves, M., Alexandre, G., Mahieu, M., Gourdine, J. L., and Mandonnet, N. (2011). Les races animales locales: bases du développement innovant et durable de l'élevage aux Antilles. *Innovations Agronomiques* 16, 193–205.

Norgaard, R. B. (2010). Ecosystem services: From eye-opening metaphor to complexity blinder. *Ecological Economics* 69, 1219–1227. doi: https://doi.org/10.1016/j.ecolecon.2009.11.009

Nozieres-Petit, M. O. and Lauvie, A. (2018). Diversité des contributions des systèmes d'élevage de races locales. Les points de vue des éleveurs de trois races ovines méditerranéennes. *Cah Agric* 27, 65003. doi: https://doi.org/10.1051/cagri/2018039

Ovaska, U. and Soini, K. (2016). Native Breeds as Providers of Ecosystem Services:The Stakeholders' Perspective. *TRACE finnish journal for human-animal studies* 2, 28–51.

Perucho, L., Paoli, J. C., Ligda, C., Moulin, C. H., Hadjigeorgiou, I., and Lauvie, A. (2020). Diversity of breeding practices is linked to the use of collective tools for the genetic management of the Corsican sheep breed. *Italian Journal of Animal Science* 19, 158–172. doi: https://doi.org/10.1080/1828051X.2020.1713027

Peterson, G. D., Ková, Z. V. H., Meacham, M., Queiroz, C., Jiménez-Aceituno, A., Kuiper, J. J., Malmborg, K., Sitas, N., and Bennett, E. M. (2018). Welcoming different perspectives in IPBES: Nature's contributions to people and Ecosystem services. *Ecology and Society* 23. doi: https://doi.org/10.5751/ES-10134-230139

Poussard, A., Ribere, C., Bonnelle, R., Couix, N., and Labatut, J. (2016). Rusticité des races: Définition. Dictionnaire d'Agroecologie. url: https://dicoagroecologie.fr/encyclopedie/rusticite-des-races/.

Rege, J. E. O. and Gibson, J. P. (2003). Animal genetic resources and economic development: issues in relation to economic valuation. *Ecological economics* 45, 319–330. doi: https://doi.org/10.1016/S0921-8009(03)00087-9

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

Ryschawy, J., Disenhaus, C., Bertrand, S., Allaire, G., Aznar, O., Plantureux, S., Josien, E., Guinot, C., Lasseur, J., Perrot, C., Tchakerian, E., Aubert, C., and Tichit, M. (2017). Assessing multiple goods and services derived from livestock farming on a nation-wide gradient. *Animal* 1-12. doi: https://doi.org/10.1017/s1751731117000829

Steger, C., Hirsch, S., Evers, C., Branoff, B., Petrova, M., Nielsen-Pincus, M., Wardropper, C., and Van Riper, C. J. (2018). Ecosystem Services as Boundary Objects for Transdisciplinary Collaboration. *Ecological Economics* 143, 153–160. doi: https://doi.org/10.1016/j.ecolecon.2017.07.016

Teixeira, H. M., Vermue, A. J., Cardoso, I. M., Claros, M. P., and Bianchi, F. J. J. A. (2018). Farmers show complex and contrasting perceptions on ecosystem services and their management. *Ecosystem Services* 33, 44–58. doi: https://doi.org/10.1016/j.ecoser.2018.08.006

Velado-Alonso, E., Gómez-Sal, A., Bernués, A., and Martín-Collado, D. (2021). Disentangling the Multidimensional Relationship between Livestock Breeds and Ecosystem Services. *Animals* 11, (9):2548. doi: https://doi.org/10.3390/ani11092548

Verrier, E., Tixier-Boichard, M., Bernigaud, R., and Naves, M. (2005). Conservation and value of local livestock breeds: usefulness of niche products and/or adaptation to specific environments. *Animal Genetic Resources* 36, 21–31. doi: https://doi.org/10.1017/S1014233900005538

Woo, S. E., O'Boyle, E. H., and Spector, P. E. (2017). Best practices in developing, conducting, and evaluating inductive research. *Human Resource Management Review* 27(2), 255–264. doi: https://doi.org/10.1016/j.hrmr.2016.08.004

Zhang, W., Ricketts, T. H., Kremen, C., Carney, K., and Swinton, S. M. (2007). Ecosystem services and dis-services to agriculture. *Ecological Economics* 64(2), 253–260. doi: https://doi.org/10.1016/j.ecolecon.2007.02.024

Zoom-Guadeloupe (2012). Bois Jolan. url: http://zoom-guadeloupe.fr/component/content/article?d4dad6935f632ac35975e3001dc7bbe8=a9597d0cde95aa2b7dedeee2f2dd7eca&showall=1&id=42.