Animal 19 (2025) 101515

Contents lists available at ScienceDirect

Animal
The international journal of animal biosciences

Animal board invited review: A biocultural perspective of animal farming systems in Europe

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ARTICLE INFO

Article history:
Received 11 September 2024
Revised 1 April 2025
Accepted 3 April 2025
Available online 15 April 2025

Keywords:
Animal husbandry
Animal Science
Biocultural diversity
Mediterranean
Peatland

ABSTRACT

Europe's landscapes have evolved through the intricate interplay of natural processes and human activities, one of which is animal farming; thus, historically creating biocultural landscapes rich in biological and cultural diversity. However, agricultural intensification has neglected and altered the role of animals within landscapes, and undermines the potential of more extensive animal farming systems to create sustainable landscapes, as an alternative to highly industrialised and high-density animal production, which is responsible for a wide range of environmental trade-offs. We present a biocultural diversity (**BCD**) framework to emphasise the contributions of animal farming systems to landscape sustainability from a social-ecological perspective. By applying a biocultural lens across three European case studies — peatland restoration in Germany, wildfire control in the Mediterranean, and hay milk production in the Alpine region— we demonstrate how animal farming systems can contribute to biodiversity conservation, climate resilience, and cultural values. We discuss the need for evolving scientific approaches using a BCD Framework to shift the perception of animal farming from a threat to a solution for sustainability. Our cases highlight how a biocultural approach allows for a comprehensive evaluation of human-nature relationships, promoting sustainable practices and addressing environmental challenges. Benefits include creating multifunctional landscapes, conserving biodiversity, enhancing genetic diversity, and preserving traditional knowledge and cultural heritage. However, a decline in traditional practices jeopardises these benefits. To unlock the potential of animal farming systems within landscapes in Europe and beyond, we call for more integrated and transdisciplinary approaches in animal sciences. Biocultural-grounded assessments can inform the transformation of animal farming systems towards animal-based solutions for achieving landscape sustainability on a global scale.

Implications

The biocultural diversity framework encourages researchers to assess animal farming systems from a more holistic perspective and explore the contributions of animals to landscape sustainability. As exemplified by three case studies, this approach can help shift the view of animal farming systems from a threat to being reconsidered as a solution (animal-based solution) to global challenges such as climate change, biodiversity loss, and environmental hazards. By integrating biocultural dimensions and engaging with diverse knowledge holders, animal science can contribute to comprehensive management strategies for landscape sustainability in Europe and beyond.

Introduction

Over millennia, Europe's landscapes have evolved through complex interactions between natural processes and human activities, including animal farming (Gaillard et al., 2009). This co-evolution through social-ecological interactions has given rise to biocultural landscapes, i.e. places that are rich in biological and cultural diversity (Baránková and Špulerová, 2023). Such agricultural landscapes are typically managed in low intensity. They provide the resources

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https://doi.org/10.1016/j.animal.2025.101515

and materials for agricultural production, offer habitat heterogeneity that promotes species diversity, provide recreational values, and contribute to the quality of life, among other benefits (Hong et al., 2014; Verschuuren et al., 2014; Assandri et al., 2018). They are often managed by family farmers, traditional livestock keepers, and pastoralists (Agnoletti and Rotherham, 2015).

Yet, during the last century - especially following World War II and substantially driven by the Common Agricultural Policy of the European Union since 1962 - many farming landscapes have been intensified through altered land management practices, land consolidation, enhanced reliance on fossil fuel–driven technologies, and agroindustrial input use with integration into global food markets. While food production to meet the demands of increasingly affluent and growing populations in Europe and globally has thus been increased, this intensification has also placed considerable pressure on natural resources that are necessary to sustain agriculture in the long term. It has also fueled the climate crisis, biodiversity loss, and the biocultural homogenization of farming landscapes (Jongman, 2002; Rozzi et al., 2019; Pardo et al., 2020).

Globalisation and modernisation are major drivers of biocultural diversity loss, fostering biocultural homogenisation—the simultaneous erosion of biological and cultural diversity at local, regional, and global levels (Rozzi et al., 2019). This shift is also evident in animal farming systems, which range from extensive pastoralism and transhumance, to mixed crop-livestock systems that are often rooted in traditional livelihoods and cultural heritage, as well as highly industrialised models largely detached from local distinctiveness and shaped by globalised market economies (Primi et al., 2024).

All these different animal farming systems are deeply embedded in socioeconomic contexts where consumer preferences and production methods are shaped by local, national, and global market dynamics. Meat consumption has shifted dramatically. In ancient societies, it depended on availability and ecological conditions. Today, global meat production has surged due to technological advancements, supply chain efficiencies, and expanding markets (Moran and Blair, 2021). Since the 1960s, consumption has nearly doubled and is expected to rise by 145% by 2050, particularly in emerging economies (Godfray et al., 2018). At the same time, growing awareness of the environmental, ethical, and health implications of meat production has led to shifting dietary choices and the emergence of alternative proteins (Henchion and Zimmermann, 2021). Yet, there is still a lack of consumer awareness of the environmental impacts from meat production in Europe (Sanchez-Sabate and Sabaté, 2019).

The intensification of agriculture in large parts of Europe excludes most of Europe's 75 million bovine animals, 134 million pigs, and 70 million sheep and goats (Eurostat, 2023) from natural spaces, with intensified production replacing traditional animal farming systems integrated into landscapes. As such the integral role of livestock within landscapes has been disrupted. For example, in Germany, about 80% of cattle are kept year-round in barns, and pigs are kept indoors on fully slatted floors, respectively (Destatis, 2021). This trend is evident throughout Europe, particularly in more fertile and accessible regions (MacDonald et al., 2000). For instance, in the Mediterranean, intensification has predominantly taken place in fertile lowlands. This shift has been accompanied by the further extension and eventual abandonment of traditional pastoralist systems in areas with poor soils, leading to a loss of landscape heterogeneity (Delattre et al., 2020).

Although reducing the intensity of animal farming is necessary, extensive farming systems alone cannot fully meet dietary needs and preferences. However, a combination of agroecological farming practices, circularity, shifting diets, and changing consumer demands presents an opportunity to do so (Billen et al., 2021). Historically, European agricultural landscapes comprised a mosaic of diverse land-use systems including animal farming systems, where animals transformed inedible plant mass into high–quality products (Leip et al., 2015). Sheep roamed the hillsides and wood pastures of southern Europe (Pinto-Correia and Vos, 2004), as well as the heath and peat landscapes of northern and central Europe (Webb, 1998). Cattle grazed the mountain pastures of the Alpine countries (Maurer et al., 2006), while pigs foraged in southeastern wetlands and forests (Molnár et al., 2021, Alday et al., 2022). Semi-wild horses wandered through the ancient forests and grasslands of Eastern Europe (Kugler and Broxham, 2014). Nowadays, animal farming systems in Europe are often decoupled from the natural system and depend on external inputs (Watson et al., 2005; Garrett et al., 2020).

Contemporary sustainability discourses focus on transforming the agriculture sector, particularly animal farming systems are highly controversial. The substantial environmental impacts of industrial animal farming systems and their contribution to declining human health have been widely acknowledged (Ilea, 2009, González et al., 2020). For example, 81% of European agricultural emissions come from livestock production, with 39% of these emissions occurring outside Europe due to feed imports, transportation, and land-use change. Additionally, livestock production contributes to around 78% of biodiversity loss in Europe and is responsible for the majority (73%) of nitrogen emissions in the agricultural sector, significantly impacting water quality and ecosystem degradation. Furthermore, livestock farming is a major contributor to air and soil pollution, with ammonia (NH_3) emissions accounting for more than 80% of total agricultural emissions (Leip et al., 2015). Yet, in biocultural landscapes, animal farming systems are not inherently environmentally harmful to ecosystems and societies (Solomon et al., 2023); rather they co-exist. Depending on the type of animal farming, it can also contribute to a sustainable agri-food transition while supporting food security, ecological functions, and livelihoods (Wijerathna-Yapa and Pathirana, 2022; Hayek et al., 2024).

The integration of grazing animals into landscapes is often overlooked or even misconceived for their role and function in enhancing landscape multifunctionality and conserving diverse cultural landscape values that contribute to human well-being (Ingty, 2021; Primi et al., 2024; Fernández-Giménez, 2015). In fact, extensive production systems tend to bring a variety of benefits to people and nature (Dean et al. 2024) and are storehouses of biocultural diversity resources (in particular of knowledge, practices, and values) (Bridgewater and Rotherham, 2019) that are necessary for sustainability transformation. Meat and dairy products provide income sources for farmers and are crucial to ensuring food security - particularly in regions where year-round access to fresh plant-based food is limited or the land is unsuitable for crop production (Smith et al., 2013; FAO, 2018). Furthermore, farming animals can act as transformative agents in landscapes, for instance, supporting the rehabilitation of ecosystems, creating valuable ecological niches (e.g., de Faccio Carvalho et al., 2021; Fraser et al., 2022; Thompson et al., 2023), and providing immaterial values (Leroy et al., 2018a). Traditional extensive animal farming also contributes to the *in situ* conservation of animal genetic resources (most notably, of traditional breeds that are adapted to low-input agricultural environments), which are declining rapidly (Woolliams et al., 2008) yet needed to adapt to new challenging agroecological conditions. Traditional breeds are critical to safeguard practices that can provide essential local knowledge able to foster landscape resilience and sustainability (Leroy et al., 2018b). Furthermore, extensive grazing is often considered more animal welfare-friendly (Hennessy et al., 2020).

Yet, the positive effects of grazing animals depend on the respective biogeographic context and management practices. In regions where large herbivores were originally present, livestock can also be used for trophic rewilding, a landscape restoration

practice where introduced grazers mimic similar functions like displaced animal communities and contribute to ecosystem functionality (Cromsigt et al., 2018).

The crucial role of animals in shaping landscapes is not new to some scholars, particularly in the animal sciences. However, social-ecological perspectives on the interrelationships of humans, livestock, and landscapes and on the role that animal farming systems can play in springboarding transformations towards landscape sustainability are less known. In this Animal board invited review, we argue that advancing social-ecological perspectives in the animal sciences contributes to a more comprehensive understanding of animal farming systems.

We introduce a biocultural diversity (**BCD**) framework as a lens and holistic model that animal scientists can adopt to assess the contribution of animal farming systems to landscape sustainability. Landscape sustainability refers to the capacity of a landscape to provide and maintain land-specific ecosystem services that contribute to human well-being (Wu, 2013). BCD thinking has gained traction in the last ten years in sustainability science, and our review elaborates on three case studies to demonstrate how this framework can be adapted to assess animal farming systems. We illustrate and discuss examples of animal farming systems in Europe that contribute to tackling compounding global crises such as biodiversity loss and climate change, while also examining their impact on the multiple values of landscapes.

Our contribution thus highlights how biocultural-based assessments of animal farming systems can inform the transformation of animal farming systems towards animal-based solutions for achieving landscape sustainability. Not all animal-based approaches contribute to sustainability, and it is crucial to distinguish between different management practices. For example, industrial farming models often exacerbate environmental and social challenges, whereas other systems, under specific conditions, can offer benefits—these are the practices we refer to as animal-based solutions. Given this distinction, while the common narrative focuses on the environmental problems of the dominant model of intensive animal farming, we aim to present a more nuanced perspective on animal farming systems and explore how more extensive farming systems can provide benefits for both nature and society. By providing a structured approach to assessing these systems, the BCD framework helps illustrate how alternative animal farming systems can support sustainability transitions and foster more socially and ecologically integrated farming models.

The authors of this research come from diverse disciplines, including animal science, social-ecological systems science, environmental science, transformational research, and transdisciplinary studies. To conceptualise the paper, we organised several meetings and, after drafting the outline, selected case studies through a collective process of reflection and discussion. The final decision was informed by our co-authors' expertise, previous research, insider knowledge of the case examples, and familiarity with relevant literature and the critical problems the case studies address. Each case study represents a region in Europe where we have in–depth experience, allowing us to apply and demonstrate the BCD framework effectively.

While we acknowledge that animal farming systems are interconnected with both production and consumption dynamics and interact with other subsystems across different spatial scales and economic, ecological, political, and social domains (Darnhofer et al., 2010), our primary focus remains on the production side where animals are integrated at the landscape level.

The biocultural diversity framework

Biocultural diversity has its roots in natural resource management, indigenous studies, and anthropology. It has gained traction within the natural sciences after having been added to the Convention on Biological Diversity in 1992 (Bridgewater and Rotherham, 2019). Often defined as the "diversity of life in all its manifestations – biological, cultural, and linguistic – which are interrelated within a complex social-ecological adaptive system" (Maffi, 2005, p.602), biocultural diversity has evolved more broadly to describe the co-evolution of cultural and biological diversity (Bridgewater and Rotherham, 2019).

The BCD framework stands apart from similar frameworks, such as ecosystem services and nature's contributions to people. The ecosystem service framework considers nature as a provider of provisioning, regulating, supporting, and cultural services that contribute to human well-being. The nature's contributions to the people framework expand the concept of ecosystem services and include material and non-material aspects, recognising the role of local knowledge and diverse values. In this framework, nature is not only seen as a provider of measurable services but also as a source of relational and non-material contributions, including reciprocity between people and nature (Díaz et al., 2018).

The BCD framework adds further value by fostering a deeper, more interconnected understanding of nature and culture, acknowledging the co-production and co-evolution of biological and cultural diversity (Maffi, 2005). It provides an actionable framework for inclusive and just management practices, offering contextually relevant solutions. Additionally, it underscores the synergistic and reinforcing relationships between different dimensions of biodiversity and human society, making it particularly relevant for conservation and sustainability efforts in diverse social-ecological contexts (Gavin et al., 2015; Bridgewater and Rotherham, 2019; Stålhammar and Brink, 2021).

Although inherently embedded within many animal farming systems, preserving biocultural diversity has often been ignored and left out when considering the sustainability of complex land-use systems (Poole, 2018). Understanding and restoring biocultural diversity underpins numerous sustainable development goals simultaneously (Bremer et al., 2018), while holistically informing research and practice to ensure sustainable communities and ecosystems (Buizer et al., 2016). Therefore, the concept is set up to intuitively and comprehensively study animal farming and its trajectories towards sustainability.

Elands et al. (2019) provide a conceptual framework arguing that biological and cultural diversity do not need to be differentiated, but should rather be studied collectively. It outlines multiple dimensions of biocultural diversity across three dimensions – materialised, lived, and stewardship – as starting points from which changes within one dimension simultaneously influence the assemblage of the other two dimensions (Elands et al. 2019). By applying this framework to our case examples, we understand that "Stewardship of biocultural diversity" is the conscious and active production of biocultural diversity through individual and group engagement. For example, people organise themselves to manage and promote biodiversity or to decide to include animal welfare within animal farming assessments, or to create policies and protection measures for biodiversity. Knowledge creation and the passing on of knowledge also belong here. The "lived biocultural diversity" entails perceived and experienced characteristics through everyday practices; these are moderated by norms, values, traditions, knowledge, and aesthetic perceptions. Lived biocultural diversity most often concerns management decisions and practices as well as other landscape-user daily experiences. Lived biocultural diversity includes the relations people have with animals and landscapes, cultural heritage and aesthetic perceptions and preferences for a landscape (e.g., appreciation of odour, sound). Finally, "materialized biocultural diversity" describes the tangible outcomes of processes, for example, genetic diversity or animal-based products.

Understanding animal farming at a system level involves acknowledging all the three dimensions of biocultural diversity. Due to its intuitive and interdisciplinary nature, the biocultural diversity framework offers animal sciences the opportunity to understand systems from a social-ecological perspective.

Applying the adapted biocultural diversity framework: three case examples

The first case example explores how animal farming systems support wetland restoration projects, with an emphasis on peatland restoration in Germany. Specifically, we exemplify how local knowledge and traditions are interlinked with peatland restoration (Stewardship of BCD), the cultural values related to animal farming systems in peatlands (Lived BCD), and the multiple material benefits (Materialised BCD).

The second case example focuses on the contribution of animal farming systems to mitigating wildfires in the Mediterranean. Here, we focus on stakeholders and policy tools for sustainable landscape management (Stewardship of BCD), cultural aspects such as local traditions and landscape aesthetics (Lived BCD), and on the biomass impacts (Materialised BCD).

The third case example explores the relationship between animal farming systems and the biocultural diversity of hay milk production in the Alpine Mountain region of Austria and Germany, part of a Globally Important Agricultural Heritage System and registered under the Protected Designation of Origin (**PDO**) certification system in Germany. We emphasise the role of certification for protecting hay milk (Stewardship of BCD), the inherent values and scenic landscapes of the animal farming systems (Lived BCD), and the importance of local food products within the tourism sector (Materialised BCD) (Fig. 1).

Animal farming systems and wetland restoration and conservation

Wetlands, including peatlands, have been significantly degraded in Europe over the past centuries. Restoring these ecosystems is essential, as they are core nature-based solutions for combating climate change and enhancing biodiversity (Parish et al., 2008), while allowing for multifunctional landscapes. At the European Union level, there is political commitment to enhance efforts for peatland restoration and conservation as part of a strategic approach to address climate change. This dedication is demonstrated through programmes such as the National Peatland Protection Strategy in Germany and the financial support provided by the EU Common Agricultural Policy. Currently, rewetting (peat)lands is a top priority for mitigating climate change in German agricultural policy (BMU, 2022). Animal farming systems can play a vital role in the rehabilitation of degraded wetlands (Biró et al., 2020) while maintaining the provision of food and materials and contributing to non-material benefits (Fig. 2).

Stewardship of biocultural diversity

Wetland livestock keepers and pastoralists are important stewards of biocultural diversity, actively archiving knowledge. They hold essential local ecological knowledge for peatland and wetland restoration. Knowledge on specific extensive grazing practices can support sustainable peatland management by directly influencing carbon emissions through appropriate grazing intensity (Worrall and Clay, 2012) and enhancing biodiversity (Pearce-Higgins and Grant, 2006; Littlewood et al., 2010). Moreover, pastoralists' and livestock keepers' knowledge allows for the employment of effective techniques to manage their rangelands and livestock. Knowledge specific to a landscape, such as pasture composition, water resources, livestock nutritional knowledge, or stocking rates, and knowledge of when and how to conduct controlled burnings (Seid et al., 2016), is essential for promoting synergies that foster sustainability within landscapes. For example, in Polish wetlands, livestock keepers understand the suitability of different landscape zones for their livestock and have profound knowledge about local plant species, particularly regarding their grazing and mowing value (Sucholas et al., 2022). Such local practices and knowledge about animal keeping and grazing in wetlands and peatlands are necessary for the sustainable management and restoration of these ecosystems.

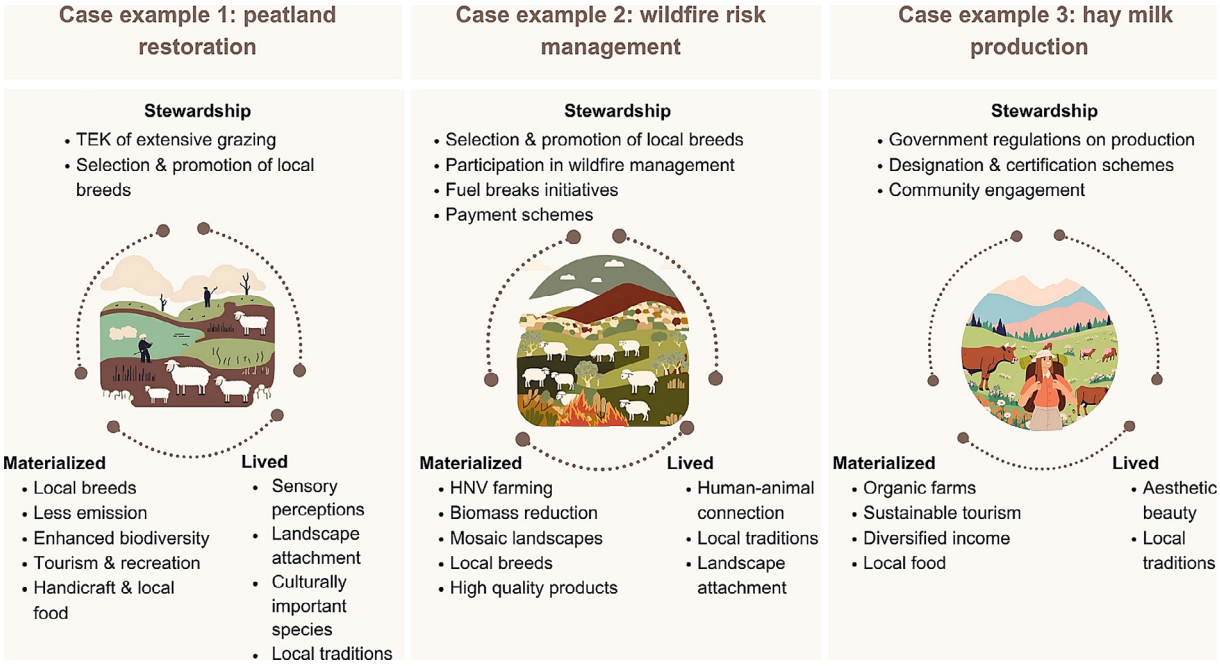

Fig. 1. Application of the biocultural diversity framework for the three case examples. Extensive grazing supports peatland restoration (case example 1) and helps reduce wildfire risks (case example 2), and Alpine cattle farming produces high-quality hay milk, valued both within and beyond the production region (case example 3). (TEK = traditional ecological knowledge; HNV = high nature value farming).

Fig. 2. A flock of sheep keeps the landscape open in the Diepholzer Mire Region in northwestern Germany. (Photo taken by: C. Heindorf).

Another aspect of biocultural diversity stewardship in wetlands related to animal farming systems is the selection, conservation, and promotion of breeds adapted to harsh wetland conditions. A notable example is the "Weisse Hornlose Moorschnucke," a small, lightweight, and robust sheep breed from Northwestern Germany that has grazed the lower mires since the 14th century. This breed is well-adapted to the low feed quality of peatland vegetation (Erasmus et al., 2017). However, the Weisse Hornlose Moorschnucke is currently under threat and while it was widespread in the 1930s, it has become nearly extinct. Conservation efforts were undertaken by only one dedicated shepherd committed to preserving this breed. Currently, the Weisse Hornlose Moorschnucke is classified as a highly endangered livestock (BLE, 2023) and registered as a geographical food product (i.e. geographical indication). The meat of the Moorschnucke is distinct because of the social-ecological landscape within which it is reared (Erasmus et al., 2017).

Lived biocultural diversity

Animal farming systems in wetland restoration contribute to the immaterial values and cultural connections people have with the ecosystem. For example, grazing animals used in wetland restoration, such as in peatlands, create landscape features that enhance people's sense of place, form part of the cultural heritage, and strengthen the bond between people and landscapes. In the case of peatlands in Northwestern Germany, sheep shape the landscape in ways that foster deep attachment. The open landscape character is a key feature appreciated by those living and working in the peatlands. Grasslands and restored peatlands, alongside conserved areas with minimal human intervention, are highly valued landscape features. Sheep are considered important living components of the landscape, contributing to its aesthetic appeal and fostering a connection for both residents and visitors, while creating pleasurable moments while visiting and working (Heindorf et al., 2024). Their presence can create habitats for associated biodiversity, including culturally important bird species like cranes and lapwings (Hart et al., 2002). These animals promoted by extensive grazing create multisensory visitor experiences and contribute to human well-being (Heindorf et al., 2024).

Traditional sheep breeds hold cultural significance and foster community engagement through festivals and activities related to these farming systems. One example is the promotion of social-creative practices like the tradition of spinning clubs where mainly women meet to make handicrafts out of the wool from local sheep. Another regional tradition is the "Moorschnuckenessen," where people gather to consume locally produced meat from the Moorschnucke breed (Heindorf et al., 2024). Specifically, the distinct food products (Erasmus et al., 2017) and food culture that arise from animal farming is a continuum between stewardship (e.g., registration as PDO), lived (e.g., food culture and eating experience) and materialised food product components (e.g., breed and feed). However, traditions around these animal systems have become scarce. As lived BCD wains, so will knowledge generation and materialised outcomes necessary for ensuring sustainable animal farming systems in the future.

Materialised biocultural diversity

Animal farming systems in wetlands contribute significantly to materialised BCD. Grazing in these environments requires specific livestock species and breeds that are well-adapted to wetland conditions. By promoting extensive wetland grazing, these practices support *in situ* conservation of endangered livestock breeds such as the Moorschnucke, Coburg Fuchsschaf, and Bentheimer Schaf (BLE, 2023). These breeds are essential for maintaining the landscape mosaic and heterogeneity, which in turn supports associated species (Hart et al., 2002). Many landscape-specific livestock breeds have become rare, and conservation and restoration grazing offers unique animal genetics and food products (Erasmus et al., 2017). This presents a valuable opportunity for preserving rare and traditional breeds, many of which evolved alongside habitats now recognised for their conservation value. Besides livestock, herding dogs used for extensive herding (e.g., the Harzer Fuchs) are another highly endangered breed associated with this animal farming system (BLE, 2023).

Peatlands have been highlighted as key sources in conserving biodiversity among both animal and plant communities (Minayeva et al., 2017). Beyond conserving the cultural landscape and associated species which hold a specific value for local people and land managers, wetland restoration also creates a potential for tourism and outdoor activities. Bird watchers, for example, are drawn to wetlands for their diversity of species. Furthermore, these systems offer opportunities to produce meat, wool, and other products, directly generating income for livestock keepers and shepherds. These products often represent the culinary and artisanal uniqueness and richness of a region as indicated by the product's unique meat quality (Erasmus et al., 2017). Sheep keep the landscape open and avoid draining peat soils due to upcoming vegetation. By supporting the restoration and conservation of wetlands, these animals, if kept extensively, also help reduce carbon emissions compared to intensive grazing or agricultural crop production on drained soils (Skiba et al., 2013; Liu et al., 2023).

Animal-farming systems and wildfire management in the Mediterranean region

The landscapes of the Mediterranean provide unique examples of the co-evolution of human, animal, and environmental interactions (Farina, 2000). However, many Mediterranean landscapes are facing degradation due to several factors such as urbanisation, land conversion, and the transition to commercial agriculture, as well as land abandonment (Hearn et al., 2024). Further, heatwaves and prolonged droughts, as a consequence of the climate crisis, have massively affected the Mediterranean basin, with increased frequency and intensity of wildfires (Ruffault et al., 2020).

Despite wildfires being an intrinsic agent of landscape change in Mediterranean-type forest ecosystems, large wildfires are relatively new in the recent history of the northern Mediterranean basin (Pausas et al., 2008). Land abandonment and rural exodus in southern European countries since the mid-20th century have led to spontaneous forest expansion in former marginal agricultural and pasture lands (Cervera et al., 2019; Infante-Amate et al., 2022). As a result, the traditional rural mosaic is disappearing, leading to high biomass content and continuity. Landscape

changes towards homogenisation create favourable conditions for the spread of wildfires (Ascoli et al., 2023; Kelly et al., 2020; Moreira et al., 2011), resulting in reduced fire regulation and fire protection service (Sil et al., 2019). Promoting agro-pastoral activities is increasingly advocated (Moreira and Pe'er, 2018; Varela et al., 2020) as having positive side effects to reduce fire hazard and improve landscape fire regulation capacity (Pulido et al., 2023; Spadoni et al., 2023) (Fig. 3).

Stewardship of biocultural diversity

Human activities such as cultivation, wood harvesting, and grazing have played a crucial role in creating and sustaining landscape heterogeneity in the Mediterranean. These practices have been integral to preserving the cultural landscape and its associated ecological benefits, for example preventing the encroachment of woody vegetation and creating valuable habitats for local biodiversity (Bugalho et al., 2011). Experiences from shepherds in the Mediterranean show that this profession involves adapting to the natural world, learning how to survive in harsh environments, and acquiring knowledge that goes beyond that of agribusiness (Otero et al., 2013; Oteros-Rozas et al., 2013). The adaptation of shepherds and animal keepers requires both tradition and innovation to meet future challenges of social-ecological systems (Otero et al., 2013; Fernández-Giménez, 2015).

Changes in land use have had several impacts on animal farming systems and their contribution to the landscape sustainability of the Mediterranean. For example, land abandonment in Spain coincides with livestock diversity hotspots (Velado-Alonso et al., 2020), where the reduction of land-based livestock systems is increasing the landscape's vulnerability to wildfires. Despite the major role played by humans (Hall, 2004), the distribution of livestock agrobiodiversity is significantly associated with environmental factors. However, the strength of these associations has decreased in contemporary distributions due to increasing anthropic pressures, relaxing breed-environment interactions, and changing the nature of these relationships (Velado-Alonso et al., 2020).

While likely a minority, many shepherds continue to prefer their local breeds over more productive and commercial breeds (Gandini et al., 2012; Fernández-Giménez, 2015). These shepherds act as important agents in sustaining local pasture culture and identity, as well as conserving local breeds (Hall, 2004; Fernández-Giménez, 2015). Besides personal motivation, financial instruments that support the active management of landscapes by promoting traditional breeds and maintaining their adaptive ability to local and challenging environments are essential (Sponenberg et al., 2018). Some initiatives in southern Europe are integrating extensive livestock grazing to reduce biomass and increase the resilience of Mediterranean landscapes to wildfires. One example is the Andalusian network of grazed fuel breaks, the so-called RAPCA program. Currently, RAPCA collaborates with 220 local shepherds, whose managed flocks help keep biomass levels low across nearly 6 000 ha of fuel breaks in public forests, ensuring compliance with fire prevention standards (Varela et al., 2018). In Extremadura, Spain, farmers are highly motivated to reduce wildfire risk and integrate sheep and cattle into their agroforestry systems (Wolpert et al., 2022). Fire flock initiatives give them a collective voice and more social visibility on the importance of their work as demonstrated in Catalonia, Spain (Nuss-Girona et al., 2022). Incorporating pastoralism into fire prevention contributes to the transition towards a paradigm in which fire prevention is a matter of collective action, generating substantial changes towards resilient ecosystems with the active participation of local actors (Tedim et al., 2020).

Fig. 3. A shepherd and his flock of goats in Andalusia working on wildfire risk mitigation services (Photo taken by: E. Varela).

Lived biocultural diversity

Lived biocultural diversity is expressed through the culture and traditions intertwined within farming practices that maintain traditional Mediterranean mosaic landscapes. Not only do local stakeholders prefer tended landscapes with traditional farming mosaics (Frei et al., 2020), such as the silvopastoral systems in the Mediterranean region, but also from an aesthetic viewpoint, these traditional landscapes stand in contrast to unmanaged forests emerging from land abandonment (Frei et al., 2024). The disappearance of open landscapes is often perceived critically from an aesthetic and cultural viewpoint (Fernández-Giménez, 2015; Frei et al., 2020).

Changes in Mediterranean landscapes, along with a declining number of livestock, have also resulted in changes to traditional human activities (Otero et al., 2013, Fernández-Giménez, 2015). Nonetheless, shepherds in the Mediterranean show a deep connection with their livestock and their motivation and identity as shepherds. Local breeds are of high social importance (Gandini et al., 2012, Fernández-Giménez, 2015). Human and animal connections can be profound, with individual sheep and special breeds considered irreplaceable (Fernández-Giménez, 2015).

Further, pastoralism and transhumance (i.e. annually practised seasonal movement of herds) are deeply embedded in the culture and traditions of Mediterranean countries and are part of their cultural heritage (Manzano-Baena and Salguero-Herrera, 2018). The transhumance festival in Spain each year is one of the biggest cultural events on transhumance, and across the country, more than 40 festivals are organised yearly or biennially. Besides, transhumance is also considered a UNESCO World Heritage practice, recognised for its cultural significance, including in regions like Andalusia in Spain (Myers, 2024).

Materialised biocultural diversity

Adequately managed herds practising targeted biomass reduction can contribute to wildfire risk mitigation (Riedel et al., 2013; Robles Cruz et al., 2008) while reducing the high costs of mechanical treatments (Varela et al., 2018). Further reduction of grazing to avoid shrub encroachment is not recommended, highlighting the necessity of integrating livestock into the Mediterranean agroecosystem (Riedel et al., 2013).

Extensive livestock farming systems, beyond their potential contribution to wildfire prevention, are the principal form of management of high nature value farmland in Europe (Beaufoy and Cooper, 2008), i.e., farming systems with high biodiversity values that result from human activities on the territory (Lomba et al., 2023). Most of them relate to mosaic landscapes, whose existence

depends on pastoral activity (Plieninger et al., 2021). Particularly in high nature value pastures and marginal lands, livestock play key roles by maintaining semi-natural ecosystems in conditions that favour important species, habitats, and ecological interactions (Hall, 2019). Pastures in the Mediterranean agroecosystems in Italy, for example, are enriching farmland species richness, while woodland, similar to urban areas, leads to a decline in farmland birds (Campedelli et al., 2018). Continuation of such practices also contributes to the conservation of livestock genetic diversity. The diverse landscapes of the Mediterranean have fostered significant animal genetic diversity, resulting in a large number of unique breeds. This region's variety of breeds is proportionally greater than that found globally. For instance, 97 cattle breeds in the Mediterranean accounted for 12% of all cattle breeds worldwide (Nardone, 1996). Besides products such as wool (e.g., Merino wool in Spain), leather, and meat, the milk is often transformed into local high-quality natural products such as Pecorino, Manchego, and Serra de Estrela cheese, among others (Boyazoglu and Hatziminaoglou, 2002).

Traditional and regional animal products in the Alpine mountain region

Traditional animal cheese production systems are often linked to certain regions, food cultures, geography, topography, biophysical characteristics, and landscape management practices (Tamburini et al. 2020). Especially in areas with less favourable agricultural conditions, those traditional systems had and still have a higher chance of being maintained (Agnoletti and Santoro, 2022), compared to other traditional animal farming systems. After a decline in alpine pastures from the 1950s to the 1970s, the number of pastures in the alpine area is relatively stable today. However, the viability of pasture farming depends on regional factors such as area accessibility, availability of trained personnel, attractiveness of the area for tourism, and the economic benefit of practising pasture farming overall (Wanner et al., 2021). Some strategies to generate an acceptable income from traditional animal production systems include certifying production processes, labelling products, or designating production areas. In Austria and Germany combined, there are currently around 7 000 farmers producing milk according to the standards of the quality label called "hay milk", and a further 70 companies which focus on the processing of hay milk into other dairy products. While at the European level, hay milk production represents less than 3% of the milk produced, the share of hay milk amounts to 15% in Austria (ARGE Heumilch, 2024). There are currently seven cheese types registered as geographical indications in Austria, and four of them in Germany (European Commission, 2024). Among those products, the traditional production process and the regionality of the product are emphasised, presenting it as a regional specialty and highlighting the influence of the soil and other environmental conditions on the final product (García-Martín et al., 2022). The example of hay milk production in the Alpine mountains illustrates the relationship between traditional animal-based production systems and biocultural diversity.

Stewardship of biocultural diversity

The maintenance of traditional management practices in the Alpine region requires substantial community engagement to promote local products, foster collaboration, and create niche markets for their products. The effort to register milk and cheese products for their regionality and natural characteristics can be seen as a form of engagement of producer groups with local traditions.

In the German-speaking alpine region (mainly Austria), the prevalent term "hay milk" is controlled by authorities and can be used on milk products for which cows were fed only with fresh grass and hay. In 2023, traditional hay milk farming in the Austrian Alpine Arc was designated as a Globally Important Agricultural Heritage System (ARGE Heumilch, 2024). Thereby, hay milk production was protected as well as the local biocultural knowledge of the animal farming system.

In southern Germany, four types of cheese from the Allgäu region are certified as PDO, with similar requirements regarding milk production compared to hay milk. The PDO label also guarantees a complete regionality of the product (e.g., all steps of production must take place within Allgäu). In both cases, the identification of producer groups, retailers, and consumers with the products explains the motivation to sustain production systems that need extra effort (Zerbe 2022).

Local tradition of transhumance is practised with cattle grazing along the main ridge of the Alps, the lakeland region, and the foothills; landscape use is determined by season (Fig. 4). Managing and caring for the landscape requires deep local farming knowledge, generational and lifelong dedication, and strong social and cultural bonds to the place and its people, who cooperate to protect and promote local systems (Wezel et al., 2016).

Lived biocultural diversity

When looking into the reasons why producers and consumers support traditional and regional milk products, it appears that traditionally managed alpine pastures are mainly valued for their aesthetic beauty (Schirpke et al., 2016). The region's reputation is largely based on the scenery of flower-rich meadows in the alpine landscape, where forests would dominate without agricultural practices. Maintaining open landscape characteristics can be seen as a side effect of producing hay milk or labelled cheese, but producers perceive an inherent value in preserving the landscape as it is, while labels or certifications are tools that make those traditional practices more economically viable (Flinzberger et al., 2024). For protection purposes, the focus is on keeping the entire setting of local knowledge active by embodying its biocultural diversity in materialised characteristics. For instance, cheese products link traditional cattle farming with the landscape featuring mountains and valleys, production methods, customs, and various recipes (Wezel and Weizenegger, 2016).

Further, many cultural practices surround animal farming systems in the Alpine mountain region, such as the "Almabtrieb," which attracts thousands of tourists each year. This event occurs around the end of September when cows are moved from their summer pastures in the mountains to their winter stables in the valleys (DAV, 2024).

Fig. 4. Summer cattle grazing in the Alpine mountains (Photo taken by: L. Flinzberger).

Materialised biocultural diversity

Pasture-based milk production in the alpine mountain region is characterised by practices that contribute to its materialised benefits while preserving cultural landscapes. Local processes include managing grazing areas with a diversity of traditional farming methods, as well as practising organic agriculture (Wezel et al., 2017), producing high-quality dairy products used in distinct local recipes, and developing a sustainability-focused tourism sector (Wezel and Weizenegger, 2016). Cattle grazing, often with local breeds, keeps alpine meadows and permanent grasslands clear of forest succession, thereby increasing biodiversity (Lomba et al., 2020) and enhancing the landscape's aesthetic appeal. This allows regional producers to diversify income through sustainable tourism (Schirpke et al., 2016). Additionally, milk and cheese products, integral to regional food culture and traditional recipes, help maintain local identity and traditions while securing income for farmers (Wezel and Weizenegger, 2016). This contributes to the region's touristic attractiveness (Wezel et al., 2021).

Discussion

By applying a biocultural diversity lens, our three case examples highlight the multidimensional aspects of biocultural diversity in understanding animal farming systems. Despite differences in cultural and environmental settings, these cases share many benefits that promote sustainability beyond mere productivity.

We provided examples of how animal farming systems can foster sustainable landscapes that contribute to human well-being and help mitigate climate change, such as in the case of peatland restoration in Germany, or reduce the impact of environmental hazards, such as forest fires in the Mediterranean. They all contribute to the conservation of biodiversity associated with cultural landscapes, enhance the genetic diversity of animals used in production, and preserve the knowledge surrounding these systems, which is crucial for building sustainable landscapes for the future.

Beyond their importance for climate resilience and biodiversity, animal farming systems can provide alternative income opportunities as highlighted by the case of hay milk and can contribute to the immaterial values of landscapes. These values include enhancing cultural identity, social cohesion, and the bond between landscapes, animals, and people, as well as improving landscape aesthetics (Fig. 1).

However, all three examples experience a trend in decreasing traditional animal farming practices in the near future. This decline could have significant consequences for the sustainability of landscapes, biodiversity conservation, and the cultural and economic benefits these systems provide.

In the following, we discuss why a biocultural lens is essential for evaluating the sustainability of animal farming systems and landscapes. We also highlight the need of transforming scientific approaches required to address complex social-ecological challenges and the importance of incorporating biocultural diversity perspectives into animal-based solutions for sustainable landscapes (Fig. 5).

Our work primarily focuses on the production side and the landscape level, where animals are embedded within sociocultural and ecological contexts. Yet, we acknowledge that the dynamics of these systems cannot be fully understood in isolation. Any biocultural appraisal of production-side dynamics will inherently intersect with interconnected consumption-side dynamics and subsystems, including economic and political institutions such as trade agreements and environmental policies (Darnhofer et al., 2010). Future research could explore these intersections at greater depths, for example, how consumption patterns influence the transformation of animal farming systems over time.

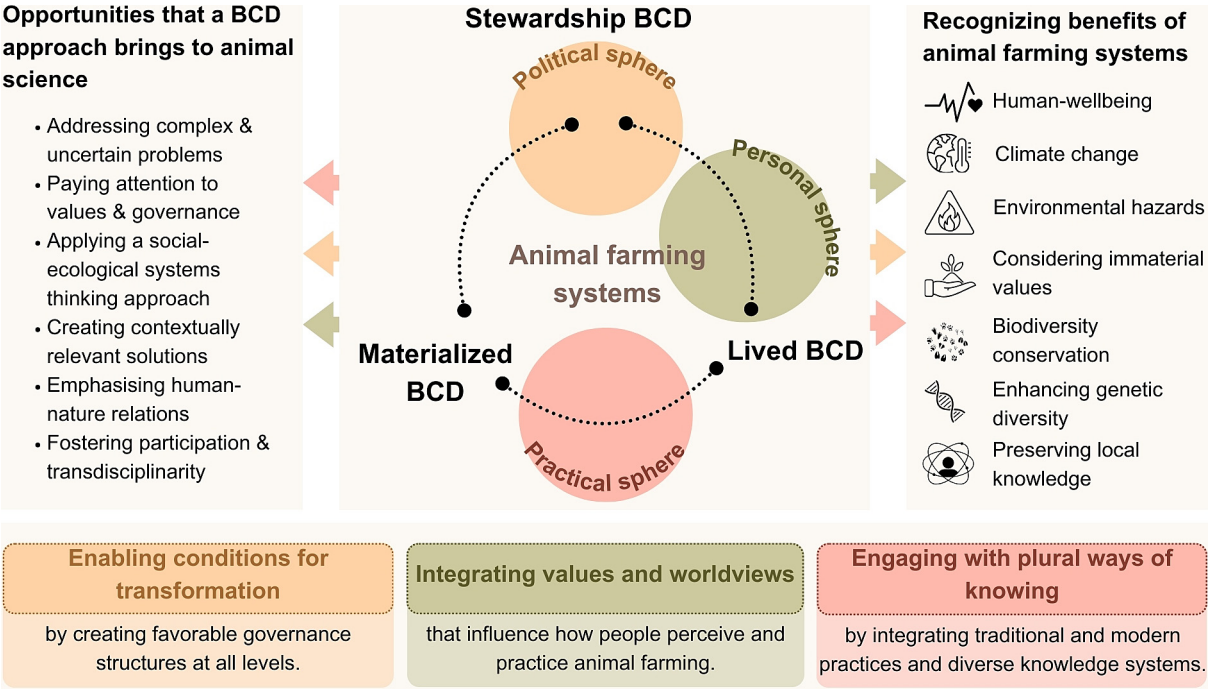

Fig. 5. The biocultural diversity (BCD) lens offers valuable insights for assessing animal farming systems, highlighting opportunities for animal science (left box) and showcasing the systems' multiple benefits (right box). The framework may intersect with three spheres of transformation (central box) and underscores the need for actions that foster landscape sustainability and the transformation of animal farming systems (lower box).

The need for transforming animal science approaches

The transformation of animal farming systems towards sustainability is a complex and contested challenge. To transform the way of dealing with complex sustainability challenges in animal farming systems, we suggest changing the lens from a productionist animal science focus to a broader consideration of biocultural systems. This approach integrates the biological and cultural dimensions of landscapes, emphasising the importance of human-nature relations in creating sustainable animal farming systems. It is a change that entails transforming our view by engaging with transdisciplinarity (Max-Neef, 2005). Transdisciplinarity generates science based on considering what exists (disciplinary knowledge, e.g., zoology) and what we are capable of doing with the disciplinary knowledge we have (technical knowledge; e.g., animal husbandry). It also engages with what we want to do (governance, planning, rules and legal knowledge) to finally address how we should do what we want to do (purposive knowledge; e.g., which values, whose ethics, knowledge) (Hadorn et al., 2006).

Indeed, the transformation of animal farming systems also needs new approaches and frameworks to assess sustainability that include all the data, knowledge, and evidence from a diversity of scientists and non-scientists, working collaboratively together. In this sense, the framework presented here, if applied to transform animal farming systems, allows for assessing and acting at three key spheres for transformation (O'Brien, 2018). Although linking each sphere of transformation to the dimensions of BCD is not straightforward—due to overlapping components and interdependencies within each framework—it can help us reflect on how BCD perspectives contribute to more sustainable landscapes and to identify key levers for transforming animal farming:

The (1) personal sphere of transformation includes plural values, worldviews, and cultural paradigms that influence how people perceive, define, and practice animal farming, such as using local breeds and fostering bonds between shepherds, farmers, animals, and landscapes. This relates mainly to the stewardship and lived biocultural diversity illustrated by the three case studies. Values, worldviews, and relationships are powerful levers for shifting behaviour and must be more effectively addressed. For instance, farmers' adoption and application of sustainable practices depends on their dominating mindsets, which can motivate them to conserve and implement more sustainable approaches (Cayre et al., 2018; Swart et al., 2023).

The (2) political sphere encompasses EU and national policies, governance, and decision processes that facilitate or constrain practical responses, such as the level of bureaucracy for obtaining subsidies and forming supportive networks. Here is a strong link to the stewardship of biocultural diversity. For example, creating enabling governance structures such as favourable legislation and administration can support transitioning to more sustainable animal farming systems (Guerrero Lara et al., 2019).

The (3) practical sphere involves specific actions, interventions, and strategies that directly contribute to desired outcomes, such as producing local animal-based products like cheese, which is mainly associated with the material and lived biocultural diversity (Fig. 5). Promoting traditional sustainable practices and the knowledge supporting them, and integrating traditional and modern practices could significantly contribute to the sustainable transformation of animal farming systems (Guerrero Lara et al., 2019). One example is combining mountain grazing with virtual fencing (Svensson et al., 2023).

Opportunities for sustainable landscapes through a biocultural lens

While mainstream scientific approaches usually aim at generating universal, generalisable knowledge claims (Fazey et al., 2018; Sundrum, 2024), a biocultural approach encourages the consideration of animal farming within broader social-ecological systems, allowing for a more comprehensive and nuanced assessment of challenges and opportunities (Hanspach et al., 2020). For example, our Mediterranean case study highlighted the potential of animal farming systems to mitigate wildfire disasters while synergistically providing co-benefits such as local products and enhanced biodiversity. Such an approach allows for the identification of contextually relevant practices and solutions potentially available from diverse animal husbandry systems developed and tested over centuries in different landscapes (Plieninger et al. 2023). In addition, the biocultural approach draws attention to plural values, including immaterial values such as human-animal relationships in case of the shepherds in the Mediterranean, governance and institutions in shaping animal farming systems and landscape sustainability. This may also involve governance structures that facilitate the participation of diverse stakeholders, as for example the Andalusian network of grazed fuel breaks, in decision-making processes, thus shaping their livelihoods and capacities to manage animal farming systems in times of uncertainty (Scoones et al., 2023).

In addition to approaches focused on compiling and evaluating evidence to optimise management practices, transformative science requires overcoming knowledge fragmentation, better integrating research and practice, and embracing creativity and innovation in research processes (Fazey et al. 2018; Gould 2023). A biocultural perspective promotes a system thinking approach that helps address the increasing knowledge fragmentation and reductionism associated with the differentiation of disciplines and expertise (Sundrum, 2024). Moreover, comprehensively integrating animal sciences within traditional systems may facilitate to overcome linear knowledge transfer models where researchers are conceived as the only "knowledge producers" while practitioners are constrained to "knowledge users" (Bertuol-Garcia et al., 2018) (Fig. 5).

The integration of different types of knowledge such as "knowing that" (empirical knowledge of facts) and "knowing how" (skills and abilities to do something) would advance animal science by fostering collaboration and social learning between different actors. For example, "knowing that" unsustainable livestock farming practices account for an important proportion of greenhouse gas emissions has received a lot of attention in animal and sustainability sciences (Moran and Wall, 2011). However, "knowing how" to effectively design systems to reduce carbon emissions and contribute to ecosystem restoration would benefit from engaging with local knowledge from pastoralists and cattle rangers, as illustrated by the local knowledge of shepherds (e.g., about type of pastures, water availability, seasonality) supporting the restoration of peatlands and preventing wildfires in the Mediterranean.

Applying the biocultural diversity framework to the study of animal farming systems

Despite existing research on biocultural mapping (e.g., Dobrovodská et al., 2019; Hanspach et al., 2020), studies rarely assess the three BCD components holistically (we have only found one example so far: Gonçalves et al., 2021). As the BCD framework and its operationalisation are still in their early stages, we offer some general suggestions to inspire researchers in animal science and other fields to apply and further refine this approach in their own work. To operationalise the biocultural diversity framework for sustainability assessments in animal farming contexts, we propose the following steps and questions:

Defining the animal farming system and its social-ecological context

A comprehensive understanding of the targeted farming system requires considering its ecological, cultural, and economic dimensions. Key guiding questions include:

- What are the system's ecological conditions (e.g., vegetation types, land use, biodiversity) and limits of assessment?
- Who are the key knowledge holders (e.g., land managers, men, women), practitioners (e.g., local farmer organisations, NGOs) and decision-makers (e.g., community leaders, local governments)?
- What is the farming system's production purpose, and how is it integrated into local, regional, and global economies?
- How has the animal farming system been shaped by local history and cultural traditions over time?

Mapping biocultural components

Identifying the biocultural elements within these systems involves assessing their lived, material, and stewardship dimensions. Key questions include:

- What contributions does the animal farming system provide or influence, and to whom? What are the biocultural salient co-produced features (e.g., associated landscape aesthetic elements, culturally important plants and animals) in the landscape?
- Which human–animal and human–human relationships, cultural traditions and values, formal and informal norms, and knowledge systems are associated with the animal farming system?, and how do they influence its practices and sustainability?
- What are the products and material contributions that the animal farming system provides to the quality of life of practitioners and other stakeholders in the landscape?

Selecting appropriate methods for assessment

Advancing biocultural approaches requires creative, transdisciplinary, and context-specific mixed-methods research designs that integrate diverse knowledge systems. Possible methods include:

- Quantitative methods (e.g., species inventories, land-use analysis).
- Qualitative and participatory approaches (e.g., plural valuation methods, stakeholder workshops, ethnographic research).
- Creation of knowledge exchange platforms (e.g., digital or physical spaces for collaboration and mutual learning)
- Promote co-creation processes, including arts-based methods, to explore worldviews, interrelationships, and power dynamics.

(see also, Leavy, 2020; Biggs et al., 2021; Torralba et al., 2022).

Conclusion

In this review, we advocate for using a BCD framework to assess animal farming systems in Europe and beyond in order to explore their role for landscape sustainability. Such an approach may shift the view of animal farming systems from a threat to being reconsidered as a potential solution to global challenges such as climate change, biodiversity loss, and environmental hazards. Our European cases highlighted the importance of animal farming systems in supporting biodiversity associated with cultural landscapes, enhancing the genetic diversity of animals used in production, and preserving the knowledge surrounding these systems. An ongoing trend of abandoning traditional animal farming practices could have significant consequences for the sustainability of landscapes, biodiversity conservation, and the cultural and economic benefits these systems can provide—not only in Europe but also in other regions where similar trends occur.

Transformational scientific approaches are needed to promote animal farming systems as part of the solution and address complex social-ecological challenges of agricultural landscapes where nature and society can benefit from integrating extensive animal farming. We consider it crucial to include biocultural diversity perspectives, including local knowledge and diverse stakeholder perspectives, into animal-based solutions for sustainable landscapes. We call for a more transdisciplinary approach in animal sciences that integrates biological and cultural dimensions, engages diverse knowledge holders, and addresses challenges across various spheres (personal, political, practical).

By applying a biocultural lens, animal farming systems can be assessed more holistically and contribute to fostering integrated management strategies that preserve biodiversity, mitigate climate change, reduce environmental hazards, and contribute to cultural landscape values.

Ethics approval

This review did not involve study participants, access-controlled data, sensitive information or personal data. Therefore, no Ethical Approval was required.

Data and model availability statement

The literature list supporting the findings of this study is managed in Zotero (https://www.zotero.org/) but has not been deposited in an official repository. It is available upon request from the corresponding author.

Declaration of Generative AI and AI-assisted technologies in the writing process

No text-generating AI was used. AI-assisted technologies such as Grammarly.com were used to check grammar and orthography.

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Declaration of interest

The authors have no conflicts of interest to declare that are relevant to the content of this review.

Acknowledgements

We thank the editor(s) and reviewers for their comments and feedback.

Financial support statement

No financial support was required.

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