Balancing competing grassland ecosystem services requires stakeholder involvement and actions on different spatial scales

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Abstract

Ecosystem services (ES) are highly important for human wellbeing, but many grassland ES show trade-offs that are strengthened by management intensification. For example, high forage production conflicts with many cultural ES as well as the conservation of grassland biodiversity. Balancing these competing services is thus required to ensure that ES supply meets societal demand. This poses the question of how to achieve such a balance in the future. We discuss how involving stakeholders and implementing ES-enhancing actions at landscape, farm, and field scales can contribute to tackling this urgent question. First, multi-stakeholder approaches are required to assess prioritisation of ES to understand societal ES demand, to design multi-functional landscapes, and to motivate farmers to increase insufficiently supplied ES. Second, different actions need to be implemented across spatial scales, with the landscape being crucial to balance ES by spatial targeting of different grassland types. In addition, actions to enhance ES that are in short supply can and must be taken at farm and field scale. Therefore, all three spatial scales should be considered to balance competing grassland ES. Our synthesis provides not only a framework for improved balancing of ES, but also gives applied examples how this can be achieved.

Keywords: agri-environmental policies, ecosystem service trade-offs, land-use intensity, landscape management, multi-stakeholder surveys, synergies

Introduction

Ecosystem services (ES) are defined as the goods and benefits humans derive from all sorts of ecosystems. They are crucially important for human wellbeing, and grasslands have been shown to be critical for ES supply in many regions of the world (Bardgett *et al.*, 2021; Bengtsson *et al.*, 2019; Power, 2010). Generally, ES can be categorised into *provisioning* (e.g., food, forage, fibre), *regulating* (e.g., erosion and stormwater control, carbon storage, habitat, biodiversity) and *cultural* services (e.g., aesthetics, recreation, heritage; Richter *et al.*, 2021). Ecosystem service multi-functionality describes the simultaneous production of many such ES (Allan *et al.*, 2015; Manning *et al.*, 2018). In recent times, the multi-functional role of agriculture in general, and of grasslands in particular, has repeatedly been emphasised by scientific, societal and political initiatives (Hart *et al.*, 2016; Nowack *et al.*, 2022). Nevertheless, many ES of permanent grassland are threatened and decreased by pressures such as land-use change and biodiversity loss (Allan *et al.*, 2015; IPBES, 2019). As a consequence, in Europe, ES supply does currently not match societal ES demand (Bengtsson *et al.*, 2019). One reason for this is different grassland ES competing with each other due to trade-offs, i.e., antagonistic relationships between two or more ES (Franzluebbers and Martin, 2022; Power, 2010). For example, high forage production conflicts with high cultural ES and biodiversity conservation (Figure 1). To match ES demand and supply in the future, such competing services need to be more effectively balanced.

Balancing competing ES, notably provisioning ES versus non-provisioning ES, is complicated. First, many non-provisioning services do not have a market value and are not directly addressed by agricultural policies. Second, different groups of stakeholders hold contrasting demands on ES supply. Indeed, agricultural and nature-conservation stakeholder groups may have different perceptions of 'healthy' versus 'degraded' grasslands in terms of the set of ES that should be delivered (Bardgett *et al*., 2021; Klaus, 2023). Therefore, attempts to balance competing ES have to be based on a broad societal basis, which can only be achieved by involving all relevant stakeholders. These comprise all people or groups affecting or being affected by a change in ES supply (Peter *et al*., 2021).

In this paper, we discuss options to balance competing ES and design multi-functional landscapes, requiring improved understanding of ES trade-offs and societal ES demand. We suggest that closing the gap between ES supply and demand requires targeted management actions at different spatial scales, i.e., landscape, farm and field. These three scales are all important for balancing competing ES due to scale-dependent opportunities and shortcomings. Finally, to enhance ES in short supply and to promote the uptake of these management actions, we argue for both improved collaboration between all involved stakeholders and also for policies that support farmers in producing ES that are in short supply because they do not have a market value.

Ecosystem service trade-offs and bundles

Farming for grassland ES is faced with considerable field-scale trade-offs among ES, which need to be considered to deliver the whole set of societally-demanded services (Figure 1). Management intensity is known to play a major role in shaping these trade-offs (Lindborg *et al*., 2022). For example, a key trade-off occurs from fertiliser inputs, which affect biotic and abiotic processes: While high fertilisation intensity promotes plant growth and thus forage production, this at the same time decreases the aesthetic quality and biodiversity of a grassland (Bengtsson *et al*., 2019). In response to the fertilisation-driven differences in resources, communities of plant, animal and microbial taxa change their functional traits related to growth and nutrient capture (i.e., resource economics; Grigulis *et al*., 2013; Neyret *et al*., 2024). While slow-growing species with resource conservative traits dominate in nutrient-poor grasslands, fast growing and competitive species with exploitative traits, such as rapid nutrient uptake, dominate in nutrient-

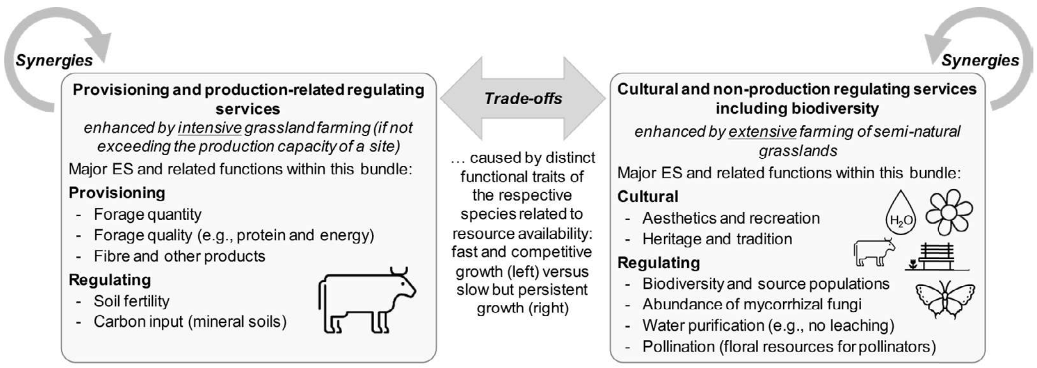

Figure 1. Trade-offs and synergies among ecosystem services (ES) related to intensive, productive versus extensive, semi-natural grasslands, which provide distinct bundles of ES (Lindborg *et al*., 2022). Note that in intensive grasslands (left), many ES depend heavily on anthropogenic inputs (fertiliser, fuel, etc.), which are not considered part of the ES framework (Bethwell *et al*., 2021). Therefore, ES from intensive grasslands need to be considered in contrast to the inputs required. This issue is much less relevant in less intensive and extensive grasslands (right). It is important to note that besides trade-offs between provisioning (intensive) and non- provisioning (extensive) grassland ES, many services primarily supported by extensive semi-natural grasslands are important for sustaining productivity on the landscape scale, e.g., pollination of crops.

rich conditions (Lavorel *et al*., 2011). This management-induced functional distinction of grassland ecosystems results in distinct ES bundles, i.e., ES that occur together in space and time (Saidi and Spray, 2018). For the temperate zone, strong trade-offs between biodiversity and many cultural and regulating ES (first bundle) versus intensive food and forage production (second bundle) have been found (Figure 1). For instance, dry matter production is highest in sown temporary grasslands (leys), but somewhat lower in most intensive permanent grasslands, and lowest in extensive semi-natural grasslands, which constitute the backbone of traditional cultural landscapes and nature conservation (Lindborg *et al*., 2022; Schils *et al*., 2022). This clustering of many ES into a reduced number of ES bundles facilitates land-use decisions by reducing the complexity inherent to the multiple ES provided by grasslands, and it depicts an important tool for communicating ES supply and demand to stakeholders (Saidi and Spray, 2018).

Understanding ecosystem service demand to design multi-functional landscapes

Improved understanding and joint consideration of ES demand, production (supply), and flow to society is needed to adequately balance ES (Neyret *et al*., 2023). However, societal ES demand is difficult to assess and studies on the related socio-cultural dynamics are scarce (Peter, 2020). Currently, ES demand is best approximated via the prioritisation of ES by stakeholders, putting quantitative weightings to each ES. This requires comprehensive surveys of relevant stakeholder groups and their perceptions and values (Horcea-Miclu *et al*., 2016). To move towards standardised analyses of inherently different ES, multi-criteria evaluation approaches of the benefits delivered by ES can be adopted (Manning *et al*., 2018). Such interdisciplinary and participatory approaches also help understanding the gap between perceptions of ES across stakeholder groups, including the scientific community and the general public. Based on such surveys, the socio-cultural factors and worldviews shaping ES demand and supply can be understood (Peter *et al*., 2021).

Although many grassland ES might not be sufficiently recognized by society, studies on the prioritisation of ES by stakeholders and the perception of citizens found almost all ES to be relevant when people were directly asked about them. Yet, significant differences were found between individuals depending on factors such as profession, education, socio-cultural context, age, and geographic location (e.g., Klaus *et al*., 2022; Lamarque *et al*., 2011; Peter *et al*., 2021; van den Pol-van Dasselaar *et al*., 2014). This highlights the complexity of interactions between culturally-defined worldviews and ES priorities of different groups. Contrasting stakeholder views also relate to short versus long-term gains and local versus global considerations, such as local disadvantage versus global benefit linked to a management decision. Previous studies found agriculture to mainly prioritise provisioning ES, while tourism tends to focus on cultural ES such as leisure activities and biodiversity (Peter *et al*., 2021). In addition, Peter *et al*. (2021) identified so-called 'worldview types', which describe the link between prioritising certain ES and a specific socio-cultural worldview. Stakeholder groups, in which an individualistic and rather conservative worldview dominates, put greater value on provisioning ES and perceive nature as constant but unpredictable. In contrast, stakeholder groups that are more oriented towards the common good mainly prefer cultural ES and perceive nature as suffering from biodiversity loss (Peter *et al*., 2021).

With data on ES demand/prioritisation and supply, it is possible to calculate the ES multi-functionality of landscapes, i.e., supply relative to human demand (Manning *et al*., 2018), and to model land-use scenarios that create an 'optimal' landscape with highest distribution equity, i.e., the equitable access of multiple stakeholder groups to ES supply (Neyret *et al*., 2023). The latter study revealed that the current state of land use (i.e., proportions of different types of grassland, forest, and arable land) in three regions in Germany were almost optimal, potentially because these landscapes have been culturally shaped for centuries and are thus already well adapted to the diverse interests of society. Yet, the identification of scenarios for the equal fulfilment of all interests resulted in a minimal increase in forest area and an extensification of some grasslands leading to a slight improvement towards the optimal distribution equity compared to the current situation (Neyret *et al.*, 2023). Results from such studies that make use of data on ES supply and demand can help to guide landscape-scale management towards balancing ES (Cong *et al.*, 2014). A landscape being close to the priorities of society does however not mean its composition does not change over time, as land-use decisions are usually taken by few stakeholder groups driven by agricultural policies and markets.

Targeted action for balancing ecosystem services: the landscape scale

As the processes causing ES trade-offs cannot be resolved only at field scale, larger spatial scales such as the farm and landscape are needed to balance competing ES. The landscape is the level of organisation integrating the different aspects and components of ES production, ranging from ecological processes over agricultural practices to social structures and interactions, linking ES (co-)producers and beneficiaries (Vialatte *et al.*, 2019). Indeed, the landscape offers the opportunity to combine different types of grasslands (and further ecosystems types), which all deliver different bundles of ES (Figure 1). Many ES are provided and/or maintained by multiple ecosystems at the same time, due to positive and negative spill-over effects and spatial interrelations between landscapes elements (Le Provost *et al.*, 2023). Thus, only at the landscape scale it is possible to account for the effects of surrounding land uses, driven by spatial arrangement and connectivity of landscape elements (Fahrig *et al.*, 2011; Gebhardt *et al.*, 2023). Balancing ES at the landscape scale is faced by the challenge of variation in space and time, as ES result from processes at multiple spatial and temporal levels.

Several options exist for balancing competing ES on the landscape scale. In heterogeneous landscapes, the biophysical conditions of some areas are usually better suited for a certain type of land use, making spatial targeting a relevant option to improve landscape-scale ES supply and multi-functionality (Franzluebbers and Martin, 2022). Improved spatial targeting of agricultural practices and policies, such as agri-environmental schemes, has the potential to increase the supply of several ES and minimise trade-offs. Therefore, local ES production targets need to be set according to the biophysical conditions best supporting these ES (Assis *et al.*, 2023).

Related to the former, collective contracts and incentives can foster collaborative agri-environmental management through innovative schemes that operate at the landscape scale (Prager, 2015). Shifting restrictions such as the proportion of semi-natural habitat required by greening regulations from the farm to the landscape scale and enhancing cooperation among farms can thus enhance spatial targeting, increase positive spill-overs between ecosystem types, support habitat for higher biodiversity, and ultimately lead to higher landscape multi-functionality (Engel, 2016). Collaborations among farmers should affect the distribution and/or area of land uses across the landscape and also the connectivity between them, leading to a more efficient landscape-scale ES supply. Cooperation between farmers can further enhance circularity and sustainability, which in turn leads to increases in ES at landscape scale (Andersson *et al.*, 2005). Various types of landscape-scale collaboration among farms and farmers are possible, such as the exchange of materials (e.g., hay and manure) and shared investments (Prager, 2015).

Despite the widely-acknowledged relevance of the landscape for ES, policy tools to set management targets and stimulate cooperation on the landscape scale are still widely absent (Cong *et al.*, 2014). Examples of existing landscape-scale multi-stakeholder instruments include the Swiss habitat network areas ('connectivity projects'), a collective agri-environmental scheme in which different land users need to cooperate to create links between fields with existing biodiversity-focussed schemes and/or nature conservation areas (FOEN, 2017). Such collective approaches in implementing but ideally also designing agri-environmental schemes are relevant landscape-scale approaches to balance ES. For example, in the *Dutch model* collectives are intermediaries between governmental decision-makers and farmers and involved in the management of landscapes and habitats, often using specific agri-environmental schemes

(Prager, 2015). To efficiently balance ES, more such instruments are needed to enable landscape-scale decision-making. Yet, approaches that 'manage the landscape like a big farm' might also depict a (cultural) challenge for land owners and users.

Due to land competition for different grassland types, balancing ES also translates into increasing the effectiveness of ES production. A higher effectiveness per area can release pressure on land and opens up possibilities to additionally manage for those ES that are in short supply. Therefore, higher effectiveness in producing one ES should not result in increased production of the given ES, but in enhancing another, undersupplied ES. This might, for instance, require conversion of intensive to extensive grassland or vice versa. A higher efficiency can be achieved by, for example, overcoming degradation by weed infestation in intensive grasslands and the ecological restoration of species-poor extensive grasslands, which do not reach their potential for biodiversity conservation and cultural ES (Bullock *et al*., 2021; Freitag *et al*., 2021). While the landscape scale offers many opportunities to increase one ES without reductions in another, competing ES, this can also lead to spatial inequality in ES supply. Thus, action also needs to be taken on smaller scales, i.e., farm and field.

Targeted action for balancing ecosystem services: the farm scale

The farm is the key unit of agricultural ES production driven by farming systems and production aims (in social and economic terms). Effectively balancing ES has to involve activities at the farm, where non-provisioning ES must find a balance with farmer's profits. Because of this, farm-scale intensification threatens several ES not only from extensive but also intensive permanent grassland (Pilgrim *et al*., 2010). Since the 1980s, in several European countries, maize for silage production and (mixed) grass and leguminous leys have widely replaced permanent grasslands in lowland areas (Lanza *et al*., 2021). In mountain areas, traditional small-scale farms that once reared locally-adapted ruminant breeds, fed with on-farm forages from permanent pastures, have introduced high-producing dairy breeds and high energy rations based on purchased concentrates (Sturaro *et al*., 2013). This also led to the loss of ES associated with the abandonment of less suitable mountain pastures, which could be used with the traditional breeds (Pauler *et al*., 2022).

The farm scale offers interesting options for balancing ES and enhancing ES multi-functionality, for example, by targeting different ES on different fields of the farm (Duru *et al*., 2014; White *et al*., 2019; Figure 1). By cultivating different grassland types, some intensively and others extensively managed, it seems possible to better reconcile production and biodiversity conservation objectives on a farm than by applying a uniform management of intermediate intensity. Indeed, the intermediate intensity level over-proportionally reduces both the digestible energy yield (compared with intensive management; Nemecek *et al*., 2011) and the biodiversity conservation value (compared with extensive management; Gossner *et al*., 2016). Thus, heterogeneity of grassland management at farm scale, in space and time, can be beneficial for biodiversity and other ES without harming overall productivity (Sabatier *et al*., 2015). For example, Ravetto Enri *et al*. (2017) show a rotational grazing system that excluded a plot from grazing for two months during the main flowering period, achieving enhanced flower resources for pollinators without penalising farm-scale production. Diversifying grassland types at farm scale can also strengthen the socio-economic resilience of farms (Dumont *et al*., 2022). Similarly, the importance of a diversity of grassland types on a farm has been suggested for enhanced climatic resilience (Plantureux *et al*., 2022), because climatic variation differently impacts distinct grassland types and their ES bundles.

While balancing the supply of a range of ES requires grasslands within a farm to be managed in different ways and with different intensity levels, there are limits to farm diversification (Dumont *et al*., 2022). Biggs *et al*. (2012) suggest that the growing complexity of increasingly diversified farms can lead, after a certain diversification threshold, to the system becoming too complex for adequate management, thereby reducing its capacity to adapt. As yet, such thresholds remain to be quantified. Further research is therefore necessary to determine what level of diversification of grassland types and farm management is the best solution for increasing farm-scale ES multi-functionality while avoiding the system becoming too complex.

Further farm-scale measures to support ES that are in short supply include digital farming and technical innovations. Examples are fertilisation innovations, which result in both a higher effectiveness per unit nitrogen applied (and related financial inputs) as well as better protection of ES provided by neighbouring semi-natural fields (Morizet-Davis *et al.*, 2023). Moreover, changes in farming systems by, for example, reconsidering breed selection, breeding aims and lifespan of animals can further create opportunities for enhancing specific ES, for example by releasing economic pressure via a more cost-efficient feeding strategy based on self-produced grass (Franzluebbers and Martin, 2022). (Re-)introducing grazing management can not only help to reduce feed-food conflicts but also increases cultural ES (Dumont *et al.*, 2022), and thus overall ES multi-functionality. Yet, depending on the field-scale effects of such measures, it has to be ensured that increasing one ES does not trade-off with another.

Targeted action for balancing ecosystem services: the field scale

Agricultural management practices are key to reduce trade-offs and increase synergies among ES (Power, 2010), and the field is the one place for many such management decisions. Balancing ES can therefore involve a multitude of field-scale management adaptations, usually linked to creating and/or maintaining favourable habitats for important taxa, overcoming degradation, and improving biogeochemical cycles such as the spatial distribution of key resources. Improvements in the field-scale supply of ES have been shown to cascade up to positive effects on larger-scale ES, emphasizing the importance of multi-scale strategies for enhancing ES (Bullock *et al.*, 2021; Figure 2). Measures to enhance ES of a field are often specific for a grassland type, such as (mainly grazed) pastures versus (mainly mown) meadows and fertilised, improved versus unfertilised, extensive grasslands.

In pastures, ES production is strongly affected by trade-offs in ecosystem function driven by stocking rate, such as maximisation of herbage use by animals (carbon offtake) versus carbon returns to soil. Similarly, improved forage quality to reduce emissions of enteric methane conflicts with the decomposability of herbage to increase mean residence time of soil organic carbon (Vertès *et al.*, 2019). Moreover, differences in the spatial distribution of feeding activities and nutrient return (excreta) promote spatial and temporal uncoupling of nutrient cycles in pastures. To improve this, stocking rates and grazing season can be adjusted in line with pedoclimatic conditions, the spatial dispersion of shade and watering points can be improved to encourage more uniform use of the field by the herd, and external dietary supplements that exacerbate plant-soil asynchrony might be restricted (Fontaine *et al.*, 2023).

In the case of mown grasslands, multi-species swards with an optimal abundance of legumes are generally considered to be facilitators of multiple ES. Therefore, the transition from monocultures and simple grass-clover swards to more complex multi-species mixtures is associated with gains in multi-functionality (Suter *et al.*, 2021) and a higher resilience to climatic variability (Lüscher *et al.*, 2022). As for pastures, uncut refuges can support pollinator and general insect diversity.

In extensive grasslands, nature-based solutions can be used to achieve higher supply on the same area, potentially leading to win-win situations (Bullock *et al.*, 2021). For example, the ecological restoration of species-poor unfertilised grasslands, which suffer from a depleted species pool and dispersal limitation, can increase biodiversity conservation and aesthetic quality (e.g., Freitag *et al.*, 2021). In all types of grasslands, rewetting of organic soils during the whole year or at least the winter season, when no management actions are undertaken, helps to sustain remaining peat and improves the carbon balance of the fields (Renou-Wilson *et al.*, 2016). Agroforestry, precision agriculture, and changing from mineral to organic fertilisation can further help to enhance carbon storage (e.g., Van Vooren *et al.*, 2018). These examples show that several management practices can promote field-scale ES multi-functionality by increasing specific ES without reducing another, competing ES. However, the uptake of such measures is often slow if not stimulated by incentive schemes and other policy measures.

Stimulating the production of non-provisioning ES

At present, concerted actions for increasing and balancing non-provisioning grassland ES are hindered by a number of issues: (i) political prioritisation of food production and security over non-provisioning ES, (ii) lack of understanding of (co-)benefits of ES on human well-being, including agricultural aspects such as farm resilience, (iii) lack of specific ES-targeted policies and incentives, (iv) difficulties to accurately measure, value and monitor many ES with broadly-accepted indicators, (v) missing practical information on how ES-enhancing management can be implemented, and (vi) lack of broad stakeholder involvement and motivation (e.g., Lindborg *et al.*, 2022; Pacual *et al.*, 2023; Stokes *et al.*, 2023; Tindale *et al.*, 2023). As highlighted by the last issue, involving farmers is crucial to increase their motivation for taking enforced efforts to enhance the ES multi-functionality of their land (Mehring *et al.*, 2023).

Participatory approaches to co-design sustainable social-ecological systems together with all relevant stakeholders are promising, but they require a suitable infrastructure for a broad-scale implementation. This infrastructure still needs to be established in most contexts (Berthet *et al.*, 2019). To further facilitate farming for multiple ES, detailed information on how management practices change ES and their trade-offs, and how ES are also beneficial for producers, and must be available and translatable into implementation (Stokes *et al.*, 2023). Thus, exchange and cooperation between all stakeholder groups from 'policy-making to field management' are essential to stimulate balancing competing ES.

The need to address ES production with agricultural policies is strengthened by mismatches between ES producers and beneficiaries. These can operate on local scales, with farmers producing public non-provisioning goods for the whole local society, but also on larger spatial scales when, for example, global climate services are derived from local carbon sequestration (Hein *et al.*, 2006). As farming for multi-functionality can only happen on a robust economic basis, and because market and policy constraints drive grassland farmers towards focussing on production (Lindborg *et al.*, 2022), new and improved policy tools and incentives, such as payments for ES, seem unavoidable to enhance non-provisioning ES (Engel, 2016). Integrating stakeholder priorities in the design of such payment schemes might considerably help to increase both societal and farmer acceptance of the measures (Tindale *et al.*, 2023).

Improving ES assessments holds considerable potential to better understand the full picture of the ES production by different grassland systems, such as organic versus conventional farming and high-input versus low-input systems. Many assessments do not consider that grassland ES are usually co-produced by biotic and abiotic properties and processes as well as anthropogenic inputs such as labour and materials. Yet, these inputs are not considered part of the natural capital that originally produces ES, and they are methodologically difficult to measure (Bethwell *et al.*, 2021). Where such agricultural inputs are overlooked, there is a clear risk of bias. As management intensity is a main driver of most grassland ES, improved ES assessments considering the required agricultural inputs and related externalities are likely to promote extensive, low-input grassland system that exhibit high ES supply at low environmental costs (Schils *et al.*, 2022). Considering agricultural inputs can therefore be seen as an important step towards balancing ES, also in view of economic and environmental costs.

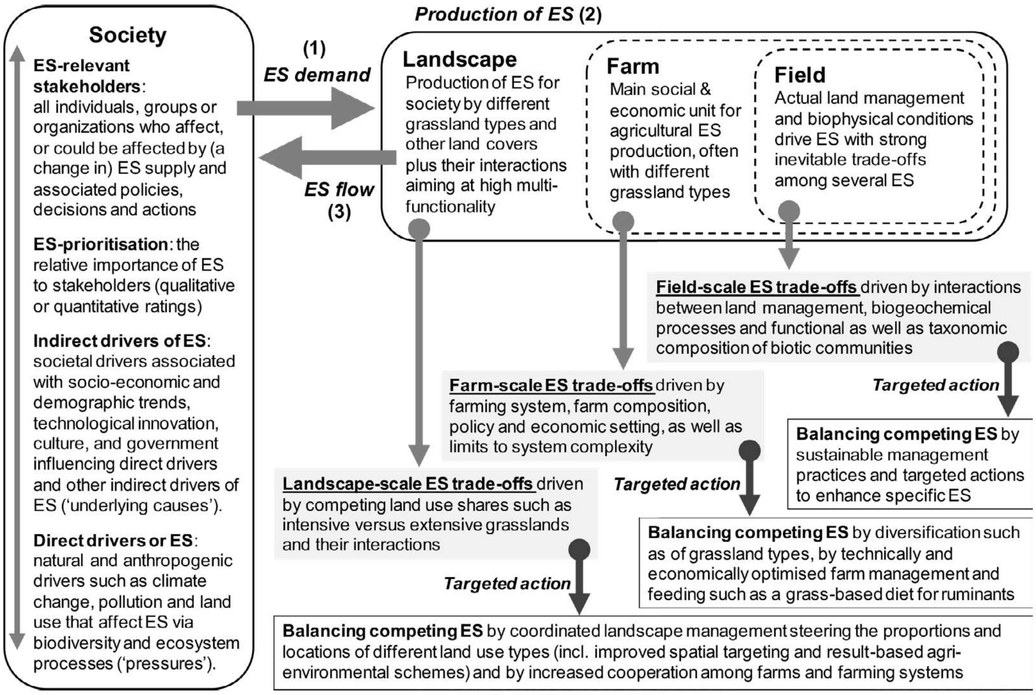

Figure 2. Synthesis figure showing grassland ecosystem services (ES) are (1) demanded by society, with (2) ES production across different spatial scales leading to (3) ES flow to society. The three spatial scales highlighted in this work are *field*, *farm* and *landscape*, which are all relevant for the production of ES due to their agricultural relevance and different mechanisms causing trade-offs among ES. Therefore, targeted action to balance ES can and must be taken on all these scales. Definitions of stakeholder groups, ES prioritisation and indirect as well as direct ES drivers according to the IPBES framework (IPBES, 2019) and Peter *et al*. (2022).

To bridge the gap between ES demand and supply in the future, we suggest focusing on (i) improved policy-making and a co-design of agri-environmental measures by stakeholder involvement, (ii) stimulation of formalised and institutionalised landscape-scale cooperation among farms and among stakeholder groups, (iii) refinement of practical actions and restorative measures across all spatial scales, and (iv) informing farmers about the relevance and the options to adjust farm and field management to enhance ES that are in short supply (Figure 2). Almost all these points require an inter-disciplinary dialogue with stakeholders to set broadly-accepted land-use targets and to co-design respective policies. This involvement is particularly relevant for a system change, as scientific facts alone will not lead to changes in behaviour, while group dialogue and debate including emotions and embracing multiple perspectives may yield much more positive outcomes (Toomey, 2013).

Conclusions

Our considerations underline that the future of balancing ES is *multi*: multi-functionality can only be achieved if multiple stakeholders are intensely involved and multiple spatial scales are targeted with multiple measures. Although we present only a selection of practical approaches to balance competing ES across field, farm and landscape scales (Figure 2), we highlight that a multitude of options exists to reduce trade-offs between ES and bring ES supply and demand closer together. We suggest that all these actions need to be embedded in an improved policy setting, which enables farmers to farm together for grassland multi-functionality.

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