Article (refereed) - postprint

Bardgett, Richard D.; Bullock, James M.; Lavorel, Sandra; Manning, Peter; Schaffner, Urs; Ostle, Nicholas; Chomel, Mathilde; Durigan, Giselda; Fry, Ellen L.; Johnson, David; Lavallee, Jocelyn M.; Le Provost, Gaëtane; Luo, Shan; Png, Kenny; Sankaran, Mahesh; Hou, Xiangyang; Zhou, Huakun; Ma, Li; Ren, Weibo; Li, Xiliang; Ding, Yong; Li, Yuanheng; Shi, Hongxiao. 2021
Combatting global grassland degradation. *Nature Reviews Earth & Environment*, 2 (10). 720-735. https://doi.org/10.1038/s43017-021-00207-2

Combatting global grassland degradation

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Abstract

Grasslands are under severe threat from on-going degradation, undermining their capacity to support biodiversity, ecosystem services, and human wellbeing. Yet grasslands are largely ignored in sustainable development agendas. In this Perspective, we examine the current state of global grasslands and explore the extent and dominant drivers of their degradation. Socio-ecological solutions are needed to combat degradation and promote restoration. Important strategies include: increasing recognition of grasslands in global policy; developing standardised indicators of degradation; using scientific innovation for effective restoration at regional and landscape scales; and enhancing knowledge transfer and data sharing on restoration experiences. Stakeholder needs can be balanced through standardised assessment and shared understanding of the potential ecosystem service trade-offs in degraded and restored grasslands. The integration of these actions into sustainability policy will aid in halting

degradation and enhancing restoration success, and protect the socio-economic, cultural and ecological benefits that grasslands provide.

Table of Contents Summary

Grasslands provide key ecosystem services, but their protection is often ignored in sustainable policy. This Perspective describes grassland degradation and sets out the steps needed to protect these systems and promote their restoration.

[H1] Introduction

Grasslands, comprising open grassland, grassy shrublands and savannas, cover about 40% of the Earth's surface and 69% of Earth's agricultural land area[1-3]. Grasslands serve as an important global reservoir of biodiversity, including many iconic and endemic species, but also provide a wide range of material and non-material benefits to humans. These benefits include a wide range of ecosystem services, such as food production, water supply and regulation, carbon storage and climate mitigation, pollination, and a host of cultural services[1-3]. Despite the importance of grassland, its degradation is widespread and accelerating in many parts of the world[4-6] , with as much as 49% of grassland area globally having been degraded to some extent[5,7,8].

Grassland degradation poses an enormous threat to the hundreds of millions of people who rely on grasslands for food, fuel, fibre and medicinal products, in addition to cultural values[9,10]. The global cost of grassland degradation on livestock production has been estimated at $6.8 billion over the period 2001-2011[11], with the resulting impact on human welfare being particularly severe in regions where most the population is below the poverty line. Grassland degradation also creates major environmental problems, as grasslands play a critical role in biodiversity conservation, climate and water regulation, and global biogeochemical cycles[2,4]. For example, the conversion of tropical grassy biomes to arable cropland poses a threat to biodiversity, given grasslands have vertebrate species richness comparable to forests[12]. The expansion of croplands in United States has caused widespread conversion of prairie grasslands, with considerable cost to wildlife[6]. Moreover, the conversion of grasslands to arable cropland and disturbance through overgrazing, fire and invasive species can lead to substantial soil carbon loss[13].

Because of these problems, grassland degradation represents a major global challenge that must be addressed to achieve the key targets of biodiversity agendas, such as the Aichi Biodiversity Targets of the Convention on Biological Diversity (CBD) and the United Nations

Sustainable Development Goals (SDGs), including restoration and sustainable use of terrestrial ecosystems, hunger and poverty alleviation, and climate change mitigation. Combating degradation is also central to the UN Decade on Ecosystem Restoration (2021-2030), which puts a firm focus on the urgent need for restoration strategies for degraded ecosystems, including grasslands.

There are multiple, co-occurring drivers of grassland degradation, including over-grazing, eutrophication, land conversion to forestry and crops, land abandonment, invasive species, climate extremes and altered fire regimes (Fig. 1). These drivers are also often closely linked to socio-economic drivers, such as spatial expansion of humans, the economics of land use, changes in affluence and dietary preferences, and in land tenure and a lack of enforcement of land use rights[9]. Climate change is further exacerbating grassland degradation, especially through more frequent and intense fires and droughts [8]. Despite the importance of grasslands, there has been little progress in finding solutions to halting and reversing global grassland degradation, which is compromising sustainable development and the ecosystem services grasslands provide.

In this Perspective, we consider the current state of and ecosystems service provided by grasslands (open grassland, grassy shrublands, and savanna). The known extent and dominant causes of grassland degradation are reviewed. We then consider the challenges that grassland restoration efforts face, from societal attitudes to practical efforts, and identify actions that are critical to the development of socio-ecological solutions to combat degradation and promote restoration of global grasslands. We argue that progress can only be made through increasing recognition of grasslands in regional and global policy, developing standardised indicators of degradation and restoration, introducing ecological innovation into restoration, and enhancing knowledge transfer and data sharing regarding restoration experiences.

[H1] Defining grasslands

A key issue in the poor recognition of grassland in policy is a lack of clarity in defining the grassland biome. Indeed, there are many definitions of "grassland" and the boundaries between grasslands and other ecosystems are often poorly delineated, which contributes to variable estimates of their global extent[3]. For example, some definitions of grassland have a relatively high tree cover of 30% before they become classed as forest[14] and in many regions there is no clear delineation of grasslands, forests and their distinct transition zones, which in

Eurasia are called forest-steppes[15]. This Perspective uses the common definition of grasslands as areas dominated by grasses or other graminoids, with a low abundance of trees or shrubs[3,16].

The definition here includes both temperate and tropical grasslands and considers broad grassland types based on a gradient anthropogenic influence, ranging from 'natural grasslands' that are climatically determined with minimal human interference, to 'semi-natural grasslands' that have been shaped by centuries of human activity, and 'intensively managed grasslands' that have been substantially modified for agriculture[3]. As agriculture has become increasingly intensive over the last century, 'intensively managed grasslands' of low plant species diversity now dominate in some parts of the world, characterised by the use of inorganic fertilisers, high stocking densities of productive livestock breeds, and often frequent re-sowing with high-yielding plant varieties. While intensively managed grasslands are valued by some stakeholder groups, here we consider them potentially degraded given that they are fundamentally different from natural and semi-natural grasslands in terms of their biodiversity and the ecosystem services they provide[17].

Natural grasslands are often considered the most important grassland type. They are found in both the tropical (namely as savannas, which are extensive in Africa and South America) and temperate (North American prairies, Eurasian steppes and South American pampas) regions of the world. Their extent is largely climatically determined, occurring where the climate and/or soils cannot support woody plant growth, such as above the tree-line or in drylands. However, climatic factors often interact with natural disturbances, such as by fire or wild herbivores, which constrain growth of woody plants and maintain the grasses and associated low-growing plants[18]. Indeed, changes in the balance of these interacting factors can trigger radical change. For example, the encroachment of native woody plants into natural grasslands is occurring in many parts of Africa (and elsewhere), which is linked to a decline in burned area and herbivore densities along with warmer and wetter climates[19]. In contrast, the Holocene transition from extensive grasslands into the Sahara Desert was likely due to the onset of drier conditions at the end of the African Humid Period[20].

Semi-natural grasslands, also referred to as secondary grasslands[16], have been created by clearing natural vegetation such as forest and by modifying natural grasslands. They are typically 'early successional' systems and would not exist without some human influence[3]. This type of grassland is of particularly high concern for conservation in Europe, due to their importance as reservoirs for biodiversity[21] and their historical role in the landscape[22]. Indeed, semi-natural grasslands have been produced by centuries of human activity, generally by traditional, low-intensity agriculture involving livestock grazing, hay-cutting, and sometimes management with fire, and are often valued for their aesthetics and are related to a sense of identity, place and heritage[22].

The vegetation of both natural and semi-natural grasslands, while typically dominated by grasses and graminoids, can have a large forb component[23]. In terms of species richness, forbs dominate grasslands worldwide, and are often the most species-rich functional group[23]. Natural grasslands are grazed by wild herbivores, but large areas are also used for domestic livestock. As such, meat, dairy and other livestock products, such as wool, comprise the most prominent ecosystem services provided by both natural and semi-natural grasslands. Indeed, the livelihoods and cultures of some traditional pastoralist communities revolve almost entirely around their livestock systems[24], which in turn maintains the diversity of livestock breeds[25]. Natural grasslands also support rich biodiversity, hosting numerous species not found in forests[12,26] and distinct assemblages of native large herbivores and their predators, many of which are threatened by extinction[27]. Many of these species are charismatic and globally recognized, such as bison, wolves, rhinos and lions, and hence provide cultural services, such as ecotourism[28].

It is less acknowledged, however, that both natural and semi-natural grasslands provide other ecosystem services, including holding flood waters, providing clean water, regulating soil erosion, and providing wild food and medicines[10]. These services and their importance vary geographically in relation to local environments and the demands from people[10]. Cultural services include aesthetic value, hunting, heritage values and resources for tourism and recreation, especially where grasslands define the ecology and culture of an area[29].

The role of grasslands in carbon storage is often overlooked, but could contain 30% of the world's soil carbon stock[30], with natural and sparsely grazed grasslands potentially acting as a notable global carbon sink and providing an important climate cooling service[31]. However, there is a global trend of grasslands transitioning towards a net warming effect on climate due to increased greenhouse gas emission associated with higher livestock numbers and management intensification[31]. Natural and sparsely grazed grasslands contain "irrecoverable carbon" that is vulnerable to land use conversion; once lost, this carbon is not recoverable over timescales relevant to climate mitigation[32]. Nevertheless, there is high potential for increasing soil carbon sequestration in grasslands via improved grazing and by arresting grassland conversion and degradation[33].

[H1] Extent and drivers of degradation

Globally, estimates suggest that as much as 49% of the total grassland[5,7,8] and about half of the natural grassland area has been degraded to some extent[34]. However, specific estimates of the extent of grassland degradation vary greatly. For instance, about 90% of the UK's semi-natural species-rich grasslands have been degraded as result of intensive agriculture and land conversion since the 1940s[17]. Up to 90% of the vast grasslands of the Qinghai-Tibetan Plateau have been degraded due to human activities and climate change[35]. Over 60% of the former grassland area of southern Brazil has been lost to unsuitable management and land use change[36].

A key issue when considering grassland degradation is clarifying what it constitutes, especially since definitions of both grassland and degradation vary. Degradation is broadly defined as a decline in land condition, or more specifically the human-caused processes that drive a persistent decline or loss in biodiversity, ecosystem functions or ecosystem services[34]. Such a broad definition of grassland degradation can help to inform policy and practice about the level of grassland degradation in a certain region. However, pinpointing what degradation constitutes in specific settings can be less clear because it has both ecological and socioeconomic dimensions[37], and different stakeholder groups prioritise different combinations of ecosystems services[38,39]. As such, the definition of grassland degradation can depend upon the stakeholder and needs to be tailored accordingly.

Grassland degradation is defined here from a socio-ecological perspective, where grassland is considered degraded if the supply of multiple ecosystem services falls short of that demanded by grassland stakeholders[40]. In some cases, grassland degradation is apparent to all grassland stakeholders, for instance when overgrazing leads to loss of vegetation, declines in soil organic matter and consequent soil erosion[41], or when natural or semi-natural grassland is converted to another land use. However, in many cases, perceptions of degradation could differ: the increase in plant production but accompanying loss of plant species diversity resulting from fertiliser use might be considered an improvement by pastoralists (due to increased forage production), but degradation by conservationists concerned with biodiversity protection[42]. Hence, defining grassland degradation from a socio-ecological perspective recognises that it alters the supply of multiple ecosystem services from grassland relative to their human demand by different stakeholders[40]. Moreover, a socio-ecological approach provides a framework for guiding the restoration of degraded grasslands as it considers the need to enhance the co-supply of multiple ecosystem services in efforts to meet the needs of all stakeholders[37,40,43].

Although threats to natural and semi-natural grasslands are present globally (Fig. 1), the tropics face particularly acute threats[18], while degradation of European semi-natural grassland has largely slowed[44]. Human activities are the principal drivers of grassland degradation. For example, increased disturbance from over-grazing or a heightened fire frequency has reduced vegetation cover, increasing susceptibility to soil erosion and desertification[45]. Conversely, the cessation of livestock grazing associated with extensive land abandonment of semi-natural grasslands in Europe during the 20th century has led to grassland degradation due to the expansion of scrub[46.] Nutrient enrichment of natural and semi-natural grasslands from fertiliser use and/or atmospheric nitrogen deposition has led to widespread declines in biodiversity and other ecosystem services[17,47]. These impacts are especially notable when combined with the sowing of productive cultivars to support heavy grazing and/or silage production in intensively managed grasslands[3]. The conversion of natural and semi-natural grasslands to other land uses, such as arable farming, built infrastructure and forestry, is also a major driver of grassland degradation worldwide[36,48]. One immediate land use threat is the planting of trees on natural grasslands, ostensibly to meet afforestation targets for climate change mitigaton[49].

Ongoing climate change also poses a threat to all grasslands, as it causes grassland degradation. Projected future climate change will likely combine with human activities to cause increased woody plant encroachment in some areas and desertification in others[50,51]. For example, natural grasslands in the Americas, Australia and Africa are being degraded due to woody plant encroachment, with the major causes thought to be a combination of higher atmospheric CO_2 concentrations, warmer and wetter conditions, and changes in grazing intensity and timing relative to fire, which is key to episodic tree recruitment[52]. Conversely, in many parts of the world, such as Central Asia and Africa, over-grazing combined with more intense and frequent droughts is exacerbating grassland desertification and degradation[53].

[H1] Promoting restoration

A socio-ecological approach is also key to identifying how restoration of degraded grasslands might be achieved[37,43]. Five actions are proposed here that should be deployed to develop effective socio-ecological solutions to the halting the degradation and promoting the restoration of global grasslands.

[H2] Policy recognition of grasslands. National and global policy are needed to recognize the role of grasslands in addressing climate mitigation, food security, biodiversity conservation and poverty alleviation. A major factor contributing to the degradation of grasslands is the lack of representation of grassland in national and international policy. In fact, grasslands are often underappreciated, with the scientific and political focus of global sustainability policy being on ecosystems such as oceans, freshwaters, forests and croplands. Indeed, despite suffering some of the highest rates of degradation of any biome, only 8% of grassland and savanna biomes are protected[54].

The reasons for this neglect of grasslands in sustainability policy are unclear, but it likely relates to historical factors and misconceptions about grasslands. For example, natural grasslands are often erroneously considered to be degraded lands or wastelands, a result of human action, or early successional stages of forest, whereas forests are perceived as more productive, pristine ecosystems that are rich in diversity[18,55]. Moreover, natural grasslands primarily occur in areas where climatic and soil factors only allow for relatively low economic benefits to land users, whereas their economic value for the provision of ecosystem services has only been fully recognised over the last twenty years [56]. Another reason for this bias might be that worldwide, forests were the first lands to be converted to agriculture, which has contributed to greater awareness of the consequences of deforestation for biodiversity and society. In contrast, most natural and semi-natural grasslands continued to be grazed at low densities by wild herbivores and livestock until technological barriers hindering agricultural improvement of grasslands and land conversion were overcome. As such, the consequences of large-scale grassland degradation, which are also less obvious than cutting down trees, are newly appreciated[57].

Although grasslands are recognised in some national policies on environment and sustainability, such as China's Grassland Law, numerous prominent examples exist where they have been ignored. For example, halting and reversing ecosystem degradation is a central goal of the SDGs (Goal 15), the UN Framework Convention on Climate Change (UNFCCC), and the Convention on Biological Diversity (CBD), but there is no explicit mention of grasslands in any of them. The SDG targets also fail to mention grasslands, whereas forests, oceans and coastal ecosystems are repeatedly referenced in targets and indicators. Further, while around half the world's 234 Centres of Plant Diversity—sites of global botanical importance based on endemism and species richness—are contained in grassland regions, they were not mentioned in the Aichi Biodiversity Targets of the CBD. The European Biodiversity Strategy to 2020 also makes little mention of grasslands relative to forests, which feature heavily. Although the EU Common Agricultural Policy (CAP) does aim to protect grasslands, there has been widespread criticism about the effectiveness of the grassland measures for biodiversity conservation in this policy[58].

Pressures on grasslands have also been accentuated through the unforeseen consequences of global and national environmental and socio-economic policies. In particular, natural grasslands are increasingly targeted in carbon sequestration programs that emphasize tree planting, such as REDD+ and China's Grain-to-Green Project, which often leads to their degradation. The Chinese government, for example, has invested heavily in tree planting, with tree coverage of previously non-forested areas increasing at an average rate of 0.15 million hectares per year over the last 25 years[59]. However, there is major concern that tree planting in arid and semi-arid grasslands with water-demanding trees is exacerbating grassland degradation, reducing plant diversity, damaging soils, and increasing water shortages[60-62].

Similarly, large tracts of natural grassland in Brazil have been identified as targets for tree planting, posing a major threat to these ancient and highly diverse ecosystems[26]. An estimated 7.41 million ha of eucalypt and 2.07 million ha of pine plantation already occupy mostly former savannas and grassland, at a rapid rate of 0.4 million ha per year from 2013-2017 (Ref[63]). Indeed, it has been calculated that meeting land restoration and protection targets would increase global tree cover by 4 million km^2, often at the expense of grasslands[64]. Furthermore, models of global forest restoration potential have identified natural grasslands as sites for restoration using tree planting, with potential to contribute to carbon sequestration and climate mitigation[65]. The logic of such proposals for climate mitigation, however, is increasingly been challenged on the basis of their damaging impact on natural grasslands and because their carbon sequestration potential is considered inflated[49,66.]

Evidence is mounting that grasslands can be more resilient carbon sinks than forests[67], and afforestation can cause soil carbon loss[68,69], soil acidification and nutrient-depletion[70], especially when trees are planted in natural grasslands[68], which can make them prone to carbon loss from fires[66]. Large-scale afforestation also leads to changes in surface albedo, given that forests absorb more short-wave radiation than grasslands, thereby creating a warming effect[71]. As such, changes in albedo resulting from afforestation can reduce or even negate benefits of increased carbon capture, potentially leading to a net warming effect of tree planting[71]. Another issue is that policies such as REDD+ focus primarily on carbon sequestration in aboveground tree biomass, while healthy and restored grasslands can store comparable amounts of organic carbon as forests, but mainly belowground[67,72]. Grasslands have also been shown to be more effective than forests in providing soil erosion control and water protection in semi-arid ecosystems[73], and in some situations the conversion of grassland to forest, either through natural regeneration or afforestation, can be highly detrimental to people who depend on grasslands for forage, game habitat, water reserves, and cultural services[66,74,75.]

The lack of emphasis on grasslands in international and national policies has a long history. Grasslands in India have been historically undervalued in national policies, and still today they are widely considered to be unproductive wastelands of limited value, leaving them vulnerable to land conversion[76,77]. In Brazil, major progress has been made in the conservation of forest ecosystems, but non-forest biomes—including the Cerrado and Pampas grasslands—have been largely neglected, despite being among the most species rich grasslands in the world[78]. Similarly, and despite their ancient origin, Asian savannas have been considered degraded forest since colonial times, which has led to inappropriate management and policies that promote savanna degradation and loss[77,79]. China's grassland law now includes policies to protect healthy and restore degraded grasslands, and progress being made in certain areas[80], but was not incorporated in the Constitution of the People's Republic of China until 1985.

If grasslands are to be valued and managed sustainably, then both global and regional policy must change to recognize the value of grasslands as providers of multiple ecosystem services and hotspots for biodiversity, and to establish targets for their protection and sustainable management. Approaches could comprise specific inclusion of natural and semi-natural grasslands in conservation laws and policies and ensuring conservation policies do not have perverse consequences for grasslands, such as promoting fire suppression or afforestation. New policies to promote and fund appropriate management and restoration of grasslands are also needed, including penalties for degrading activities such as overgrazing.

[H2] Standardised assessment. New approaches are needed to enable standardised assessment of grassland condition globally under different situations. These approaches should assess the severity of grassland degradation and its consequences for biodiversity and ecosystem services and evaluate the success of restoration schemes. Currently, restoration efforts are disjointed across regions and carried out by a wide range of organisations, which often leads to incompatible and inaccessible datasets, and a lack of communication about successful methods[81]. The diversity of grasslands across and within regions, and the many drivers of degradation, mean a fully uniform set of guidelines is impractical. Yet, standardised approaches are needed to underpin effective decision-making.

Progress can be made by defining grassland degradation from a socio-ecological perspective, where the severity of degradation and the relative benefits of different grassland restoration practices can be assessed by combining measures of ecosystem service supply and stakeholder priorities and demands[40]. Such measures can show how alternative restoration options differ in their impacts on ecosystem service supply and in their resulting benefits for different stakeholder groups. We recommend that this goal be achieved via a general five-step approach for standardising the assessment of grassland degradation and restoration (Fig. 2). The results of this approach can also be used to support negotiation over restoration management.

The first step is to assess the demand for, and relative priority of, different ecosystem services by multiple stakeholder groups, for instance via social surveys of many stakeholders, or representative community leaders[38,82] (Fig. 2). It is vital that all major stakeholder groups are represented and the full range of relevant ecosystem services considered, including non-material (cultural) benefits. Otherwise, bad management decisions could result and potential conflict[83]. Moreover, it is important that potential power imbalances among stakeholders are addressed, for instance by strengthening and enforcing land use rights of pastoralists and agro-pastoralists.

Once ecosystem service demand is determined, indicators need to be identified and measured for each of the services (Fig. 2). These should fall into two classes: general indicators, which measure ecosystem services for all stakeholder groups (measured in step two); and specific indicators for services used by a subset of the stakeholder community (measured in step three). The general indicators measured in step two should be inexpensive and easy to measure over large scales, and relate to key regulating functions that underpin all other ecosystem services. Such properties could include the cover and type of vegetation present, aboveground biomass, and soil properties such as organic matter, nutrient content, and pH (Table 1).

While the general indicators proposed above provide broadly comparable information on grassland condition, perceptions of grassland degradation differ between stakeholder groups[84]. Therefore, in addition to general indicators, other variables should be identified locally for these context-specific ecosystem services via stakeholder engagement, and developed according to local conditions (step three). In the French Alps, for example, surveys identified that aesthetic value of mountain grasslands was essential to local farmers and tourists, and related not only to flower diversity, but also to the absence of a build-up of plant litter[85]. As another example, the cover of woody species can be used as an indicator of the vital regulating service of shade provision in East African grasslands[86]. Visually estimable indicators can also be employed in such assessments to ensure both relevance and cost-effectiveness.

In the fourth step, general and specific measures are combined to calculate an integrated index of grassland condition that can be related to local environmental conditions, management factors, global change drivers and restoration management. The creation of such indices can be achieved by adapting approaches developed for measuring the co-delivery of multiple ecosystem services based on stakeholder preferences[40,87], and other participatory multi-criteria analyses of ecosystem services[88]. Both approaches can also be used to weigh the measures included in the calculation of the index, for example by encouraging representatives of different stakeholder groups to assign scores to the ecosystem services considered[86].

In the final step, conclusions from this standardised approach are used to inform management decisions regarding which restoration options should be employed and where. Deciding on which restoration options are employed and where is best resolved in participatory approaches, so that stakeholders share understanding, and conflict is minimised (Fig. 2). The best options for whole communities can be estimated by weighting stakeholder groups equally in a community level metric, or by evaluating which restoration options minimise trade-offs between groups. As a single restoration practice might not benefit all stakeholder groups, the compartmentalisation of the landscape into different restoration options should also be considered (Fig. 2). The approach presented here would not only allow for more detailed examination of grassland condition with regards to local needs, but also a better means of assessing the severity of grassland degradation and restoration success at both local and larger scales (Figures 3 and 4; see Supplementary Material for details on the source of these estimates).

[H2] Shared understanding and trade-offs. When assessing grassland restoration options that best suit different stakeholder groups, there will likely be differences in preferred options (Figs. 3 & 4), which might cause disagreement and conflict. To address these differences, there is a need for shared understanding, based on best knowledge and practice and operational constraints, of the potential for different grassland restoration options to supply different ecosystem services[43,89], which can be quantified using the same tools as described here for assessing degradation. Such an approach could help identify which restoration option might best deliver the needs of all stakeholder groups, thereby supporting resolution of disagreements and conflict.

To illustrate these trade-offs and how they could be resolved, two examples are considered (Figs. 3 and 4). In both, fundamental trade-offs caused by degradation and restoration options prevent the co-supply of all ecosystem services. The first example is taken from permanent agricultural grasslands in Europe (Fig. 3), where extensive management promotes functions related to water and soil carbon storage, which support ecosystem services linked to water and climate regulation. In contrast, intensive management with fertiliser use and high grazing pressures leads to faster rates of nutrient cycling and higher plant productivity, thereby promoting provisioning services[42,90]. However, intensive management also reduces plant and soil biodiversity and causes soil compaction, which diminishes the supply of several ecosystem services demanded by stakeholders, leading to reduced overall benefits to stakeholder groups (Fig. 3)[90]. To reverse these impacts, restoration to high diversity grassland can enhance the supply of multiple ecosystem services, and therefore provides substantial benefits to all stakeholder groups. Despite these benefits, the abandonment of agricultural management altogether, which leads to woody plant encroachment, could be the best option to provide some of the benefits prioritized by national decision makers, namely water quality and climate regulation. Given these various trade-offs, and depending on European or national objectives, and on regional conditions[91], collective choice would likely favour a mosaic of all three grassland types with the restoration of high diversity grassland, accompanied by the segregation of intensive production and climate regulation into specific regions and landscapes[92].

The second example is taken from natural grasslands in arid and semi-arid regions of Eastern Africa (Fig. 4). Here, nomadic pastoralists favour provisioning services of forage production and natural products from grasslands, while charcoal producers derive their livelihoods from native woody vegetation and, increasingly, from invasive woody species such as *Prosopis juliflora*. Because the invasion of *P. juliflora* transforms grasslands into scrubland with bare soil[93], the supply of most ecosystem services demanded by stakeholders is greatly reduced, but fuel wood and charcoal production are promoted[86]. The supply of other services, such as soil carbon storage, is context-dependent; soil conditions are improved when *P. juliflora* invades grasslands degraded by overgrazing and other forms of mismanagement. However, if undegraded grassland is invaded, the supply of these services is reduced[94] and all stakeholders, apart from charcoal producers, lose ecosystem service benefits and so perceive the invasion as degradation. This example also clearly demonstrates that successful restoration depends on stakeholder perspectives as all restoration options benefit the priority services of some groups, while diminishing those of others. These constraints preclude a single win-win-win restoration option. Therefore, regional-scale restoration that establishes a landscape mosaic, including livestock grazing and patches of conserved or abandoned land, is likely to be required for all three stakeholder groups to be satisfied. It should be noted, however, that such a landscape mosaic would require continuous management of *P. juliflora*, otherwise it will re-invade grasslands and conserved land.

Identifying the presence and cause of trade-offs is a first step towards management and policy solutions to grassland degradation. We suggest that the approaches presented here could be combined as a decision support tool in ecosystem management[95]. This tool can be used as part of a 'landscape approach' to management, which emphasises close collaboration and shared understanding between stakeholder groups to identify and mitigate land management conflicts. Depending on context, this approach could allow for the allocation of different restoration options to different sections of the landscape, as in semi-arid grasslands of Eastern Africa (Figure 4), or the identification of win-win options where a single restoration practice might suit multiple stakeholder groups, such as in European grasslands (Figure 3).

These approaches are already considered in existing grassland management approaches, such as the Participatory Rangeland Management (PRM) approach, which has been developed to improve the sustainable management of rangeland resources and their security of access for local rangeland users in arid and semi-arid grasslands[96]. This approach includes a step where stakeholder groups, through extensive meetings, discussions and negotiations, develop a rangeland management agreement that considers the needs of all stakeholder groups involved. This agreement should ultimately become a binding contract document between a representative rangeland management institution and the appropriate government authority. The PRM was initially developed by a consortium including the International Livestock Research Institute in Ethiopia and has been applied in Kenya and Tanzania[97]. A similar approach called Participatory Rangeland Management Planning (PRMP) has been adopted by the International Union for Conservation of Nature (IUCN)[98].

Complex trade-offs might prevent the formulation of simple solutions, and in such situations multi-criteria decision analysis (MCDA) can be used to support deliberation among groups and help steer them towards a compromise where local communities have a voice and multiple perspectives of grassland degradation are accommodated[99,100]. Advanced MCDA approaches also allow for the incorporation of socio-economic factors, such as access rights and ease, and power relationships between stakeholder groups across scales, which will determine the ultimate benefits of ecosystem services to different groups[101]. However, to ensure better outcomes from decision tools such as MCDA it is also important to consider optimal allocation and prioritisation of limiting resources to actions[102], especially since funds for grassland restoration are often limited.

[H2] Knowledge sharing in grassland restoration. Evidence of success or failure of grassland restoration programmes is scant[103,104]. Accordingly, there is a need for standardised and accessible reporting of restoration successes and failures, and ongoing monitoring of grassland restoration programmes and their outcomes in different parts of the world. Restoration knowledge must be shared to achieve this goal, which requires the formation of networks of scientists and practitioners that exchange knowledge on successful, but also unsuccessful, restoration efforts. Examples of platforms that provide information on successes and failures of grassland restoration programmes are beginning to emerge. The Society for Ecological Restoration (SER) launched their Restoration Resource Centre in 2017, an online, publicly accessible platform for exchanging knowledge and experience through ecological restoration projects, publications, and other resources from around the world. The World Overview of Conservation Approaches and Technologies (WOCAT) database provides a format and a platform for knowledge exchange regarding Sustainable Land Management (SLM) technologies and approaches and is recognized as the primary recommended database by UNCCD. The Global Landscape Forum (GLF), led by the Centre for International Forestry Research (CIFOR) and supported by the UN and World Bank, provides a mobile platform for discussions leading to action on sustainable land use, including land restoration.

While grasslands are currently underrepresented within these databases, which are still under development and continually being expanded, they demonstrate the potential for user-driven platforms to provide valuable insight into effective restoration practices in different parts of the world (Box 1 Fig. 1). To be effective, such platforms should include a wide range of restoration programmes, both local and regional, and small and large scale. They should also include less successful programmes and identify why they have not reached their objectives. Moreover, grassland restoration projects should identify clear aims of restoration and an inventory before restoration starts to be able to evaluate restoration success[105]. By comparing case studies, it is possible to understand how the effectiveness of specific restoration methods differ geographically and depending on the degree of degradation and socio-ecological context, the first step towards finding general rules, both social and ecological, for successful restoration. They could also illustrate the successful translation of research into improved restoration and management, which should include the co-creation and co-implementation of technical solutions to grassland restoration, and the political and socio-economic conditions that made them possible.

Case studies reporting technical solutions to grassland degradation at scales of hundreds to thousands of hectares are particularly scarce, especially for developing countries in semi-arid and arid regions of the world. However, previous efforts indicate that grassland restoration is feasible, at least starting from low levels of degradation, and that technical and socio-ecological solutions often need to be combined to achieve long-term management goals (Box 1). For example, steppe grasslands in Inner Mongolia are challenged with a diverse set of stakeholder demands, including the need for environmental services, such as increased soil carbon storage, the local herders' wish to retain traditional livelihoods while increasing their income, and an increasing demand for red meat by the wider population in China and elsewhere[80]. To address these demands of various stakeholder groups, a grassland management system was developed that built on optimizing income from livestock production per unit area, which was achieved by increasing animal growth rates (and thus reaching marketable size earlier) by decreasing livestock numbers by approximately 50%[80]. Thus, the system created a win-win situation by improving local herders' income and enabling the recovery of steppe and associated ecosystem services (Box 1.

In northern Ethiopia, several years of excluding livestock from degraded communal grazing lands led to the recovery of plant species richness, forage and wood production, and soil health, and thus helped to improve the supply of services prioritised by local stakeholders[106,107]. However, the uptake of technical solutions for restoring degraded grasslands depends on socio-economic factors, including reconciliation with traditional land-tenure systems, well-established communication pathways, and supporting institutional settings and policies (Box 1. For example, implementation of sustainable grassland management in Inner Mongolia benefits from efforts of the Chinese government to emphasize sustainable grassland management in agricultural policies[108]. The success of the grazing exclosure programme in northern Ethiopia will depend on successful communication and negotiations between local stakeholder groups and policy, and among local stakeholders to ensure land use enforcement and sharing of management responsibilities and harvesting benefits[109].

[H2] Research innovation: Innovations in environmental research need to be developed and employed to improve the assessment of grassland degradation and provide novel solutions to restoration and sustainable grassland management. At a global and regional scale, developments in remote sensing offer potential to evaluate both the extent and status of grasslands and inform the spatial targeting of large-scale restoration efforts. For example, maps of general degradation indicators, such as primary productivity, standing biomass, soil moisture, phenology, soil organic carbon[110-112], could be combined with spatial information on climate, edaphic and socio-economic data to identify national and global patterns of grassland degradation and pin-point locations where restoration efforts could have the greatest impact. Although current global maps of primary productivity and biomass carbon still need improvement, they offer a means to monitor the dynamics of grassland aboveground biomass and evaluate the degradation of global grasslands[113,114].

There has been a boom in research directed at grassland management for sustainable agroecosystems since the turn of the 21st Century, leading to improved grazing and fertiliser management, and reduced reliance on external inputs, nutrient losses and emissions of greenhouse gases[115]. However, new ecological understanding could also facilitate grassland restoration. For example, new research could enable landscape and regional scale restoration of inter-connected grasslands in regions where semi-natural grassland remnants are fragmented and persist within a matrix of forested or intensive agriculture land uses. Indeed, there is increasing evidence that grassland dynamics and function are enhanced by connectivity that encourages flows of species and biogeochemical processes[116,117]. In theory, such spatial networks have improved resilience to perturbations, such as climate extremes, and the ability to adapt to a changing environment[118]. These emerging concepts on landscape design could also be applied to the restoration of ecological flows of species and processes within landscapes[119,120], and at a practical level, there is already considerable opportunity to trial these approaches in large-scale restoration programmes[121]. Such approaches also require improved understanding of the tele-coupling of different landscape elements, whereby human-induced processes in one area impact on distant areas. For example, pastoralists in arid regions depend on grazing areas along major water bodies, which are also of interest to other stakeholders for crop production or biodiversity conservation[122]. Loss of such grazing areas forces pastoralists to overgraze rain-fed grasslands elsewhere, leading grassland degradation[123].

Another fast-developing area of ecological research that could assist grassland restoration programmes concerns the application of knowledge of aboveground-belowground interactions[124,125]. A wealth of studies show that high grassland plant diversity can enhance multiple ecosystem functions, both above- and belowground, and increase the resistance of plant production to environmental perturbations, such as climate extremes[126-128]; such knowledge could be applied to degraded grassland to restore ecosystem functions and their resilience to environmental change[129,130]. Benefits can also be realised through informed selection of plant species based on functional traits, especially root traits, which has been shown to be an effective way of enhancing grassland multifunctionality[131] and the physical properties of degraded soils[132]. Research points to the potential of soil inoculation and plant translocation from donor sites to enhance the recovery of degraded ecosystems and steer plant community development[133,134]. Further, there is increasing awareness that diversifying livestock promotes plant diversity and grassland multifunctionality[135], especially at moderate levels of grazing[136], and that interventions can facilitate robust multi-trophic interactions in restored ecosystems could benefit restoration[137].

A potential hurdle to the adoption of new research innovation is that the majority of scientific knowledge underpinning grassland restoration comes from studies done at a local scale and in a handful of regions, especially North America, Australasia and Europe. As such, there is a need for new, long-term research to underpin approaches to large-scale restoration of degraded grasslands, especially in Asia, Africa and South America where grassland degradation is widespread[138]. One solution to these geographic gaps might be the use of meta-level analyses[139-140] and data collection using standardised methodology from globally distributed grassland studies such as the Nutrient Network[141] and HerbDivNet[142]. These can help to identify generalisable impacts of biotic and environmental drivers and disturbances, such as grazing and nutrient enrichment, on grassland diversity and function, that could be transferred to regions where data is lacking. However, that large gaps in environmental and management conditions still need to be filled, and the ecological context will affect the specific applicability of any generalisations[143]. At all scales, new technology and practices need to be embedded within socio-ecological approaches to grassland restoration to ensure empowerment of local people and best outcomes for their quality of life.

[H1] Summary and future perspectives

Despite progress in understanding the causes and consequences of grassland degradation, and in developing restoration techniques, there remain many barriers to halting grassland degradation and effective restoration. Here, we have argued that overcoming these barriers requires an integrated socio-ecological approach to grassland degradation and restoration, which not only demands greater recognition of grasslands in global policy, but standardised approaches for assessing grassland degradation and restoration success. It also requires the adoption of innovations in environmental science for detecting grassland degradation and enhancing restoration success, along with enhanced knowledge transfer and data sharing regarding restoration experiences.

Many examples exist of national and international sustainability policies that have ignored grasslands, including the SDGs and CBD. Giving due attention in sustainability policy to grasslands and the ecosystem services they provide, on a par with other biomes such as forests, is therefore essential for the future protection of healthy grasslands and restoration of those that are degraded. The UN Decade on Ecosystem Restoration (2021-2030) and CBD post-2020 global biodiversity framework provides an opportunity to set future targets for the protection, sustainable management and restoration of grasslands, and prevent damaging practices such as the planting of trees in natural grasslands[144]. Put simply, if grasslands are to be managed sustainably, then both global and regional policy must be revised to recognize the value of grasslands for multiple ecosystem services and establish targets for their protection, restoration and sustainable management.

There is hope in some initiatives, though. The Worldwide Fund for Nature launched a 'Global Grassland & Savannah Dialogue Platform' in 2020, with the aim to "develop consensus around human and biological importance of these ecosystems". The UN Decade on Ecosystem Restoration (2021-2030) has added 'grasslands, shrubland and savannahs' to their set of focal ecosystems. Furthermore, while the Aichi targets of the CBD largely ignored grasslands, and the draft of its post-2020 framework lacks specificity, the most recent synthesis of the proposals of the parties includes mentions of grasslands (albeit other ecosystems such as forest and wetlands are discussed more frequently).

Whilst we demonstrate how our five-step approach can be applied using specific case studies, future research is needed to test this approach in different contexts and at local and larger scales. Research is also needed to better understand different societal perceptions of grasslands and the reasons why they have been neglected in sustainability policy, to develop and test promising new ways of assessing grassland degradation and restoration, and to harness ecological knowledge for restoration success. This aim will require ambitious, interdisciplinary national and international research programmes of the kind that could be facilitated by major research and innovation schemes targeted at achieving Sustainable Development Goals. We hope the approach we present provides a basis for such future research aimed at the assessment of grassland degradation and restoration in the context of stakeholder needs.

The actions we raise for developing effective socio-ecological solutions to the degradation and restoration of global grasslands are not exhaustive and many challenges remain. Nevertheless, we hope that they provide a guide to future research and policy needs for halting grassland degradation and achieving restoration success. We also hope that they serve to raise awareness of the plight of global grasslands and the need for urgent action to halt grassland degradation and enhance restoration success, thereby conserving the many socio-economic, cultural and ecological benefits that grasslands provide.

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Acknowledgements

R.D.B and N.O. acknowledge support from BBSRC in the form of a Global Challenge Research Fund Impact Acceleration Account Award (GCRF-IAA) (BB/GCRF-IAA/14) and a GCRF Foundation Award (BB/P022987/1) “Restoring soil function and resilience to degraded grasslands”, and the N8 via an AgriFood Programme pump priming grant. U.S. acknowledges support from the Swiss Programme for Research on Global Issues for Development (r4d) “Woody invasive alien species in East Africa: Assessing and mitigating their negative impact on ecosystem services and rural livelihood” (Grant Number: 400440_152085) and core financial support from CABI and its member countries (see http://www.cabi.org/about-cabi/who-we-work-with/key-donors/).

Author contributions

R.D.B. conceived the idea and gained funding with input from N.O. R.D.B wrote the paper with significant input from J.M.B, P.M., U.S. and S.L. G.L.P and P.M. designed the figures. All authors contributed to the development of ideas and writing of the paper.

Competing interests

The authors declare no competing interests.

Peer review information

Nature Reviews Earth & Environment thanks [Referee#1 name], [Referee#2 name] and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.

Publisher's note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Table 1. Common ecosystem services of grasslands and indicators of associated ecosystem structure and function parameters

Ecosystem services	**Ecosystem structure / function**	**Common indicators**	**Scale and means of measurement**
Forage production (quantity)	Annual aboveground biomass production	Net primary productivity (NPP) Aboveground biomass	NDVI (remote sensing) at a landscape scale Direct harvesting at a local scale
Forage production (quality)	Protein content and digestibility	Leaf N content Presence of species of nutritional importance	Remote sensing at a landscape scale Direct measures at a local scale
Forage reliability	Interannual variation in aboveground biomass production	NPP Species composition	Remote sensing at a landscape scale
Other grassland products (medicinal, food, hunting)	Species of particular interest	Species presence and/or abundance	Field survey at a local scale
Biofuels	Woody species of interest Grass species of particular interest (including flammable or high yielding species)	Cover or biomass of species of interest	Direct field measures or remote sensing
Species of cultural value	Presence of species of cultural interest	Species presence	Local direct measures and records Regional surveys
Aesthetic value	Plant community composition and phenology	Flower and flower colour, and presence of 'unattractive' species Flowering phenology	Direct surveys Species list and external databases for phenology
Biodiversity conservation value	Plant and animal (vertebrate and invertebrate) species	Presence and abundance of species of conservation value	Global Biodiversity Information Facility (GBIF) and national monitoring schemes

			at larger scales Direct surveys at a local scale
Regulation of invasive exotics and other undesired species	Invasive exotic species Species of negative pastoral or cultural value	Presence and abundance of undesired species	GBIF and national monitoring schemes at a larger scale Direct surveys at a local scale
Global climate regulation	Carbon stocks and carbon cycling processes	Soil respiration and carbon stocks Woody species biomass and vegetation carbon stocks Litter mass and depth	Remote sensing for aboveground stocks Soil sampling and interpolation for belowground carbon stocks and fluxes
Maintenance of soil fertility	Nutrient stocks and nutrient cycling processes	Soil nutrient and carbon content Litter mass Soil enzyme activities	Soil sampling and interpolation to required scales
Maintenance of soil stability and regulation of erosion	Soil stability in the root profile Erosive flows	Evidence for erosion, bare ground cover and soil organic matter (SOM), and measures of soil loss and erosive flows Soil aggregate stability, bulk density, and water holding capacity Plant rooting profile	Field observations or remote sensing to detect erosion Direct sampling and measurement of multiple indicators
Regulation of hydrological flows	Soil water retention and flows	Soil texture and bulk density, and SOM content Soil electrical and hydraulic conductivity)	Direct survey and interpolation Rapid assessment methods

Regulation of water quality	Retention and transformation of pollutants in soil	Soil properties including texture, pH, CEC, salinity and water table depth SOM content and available water capacity. Nutrient and pollutant concentrations in freshwater bodies	Direct sampling of soil and water

Figure legends

Figure 1. Degraded grasslands. The extent of degraded grasslands worldwide with examples of paired non-degraded (left) and degraded (right) grasslands. Grassland classification follows the UN FAO Land Cover Classification System (LCCS) (data downloaded at https://lcviewer.vito.be/2015 [145] with tundra ecosystems excluded). Degradation is measured as greenness changes, as measured by rain use efficiency (RUE) adjusted Sum Normalized Differential Vegetation Index (NDVI) between (1981-2015)[146] with regions showing a reduction in greenness of 0.01 being classed as degraded. Therefore, much degradation involving vegetation change is not shown. Degradation is caused by many factors, including overgrazing, fertilization, tree planting, and invasive species. Image credits: United States (L. Brudvig), United Kingdom (L. Hulmes), India (S.K. Chengappa), and Australia (S. Prober). Map © Copernicus Service Information year of publication [2015]

Figure 2. Standardised assessment of grassland degradation and restoration. Included are the steps required to assess grassland condition and select restoration options. These include the assessment of demand for different ecosystem services by stakeholders (step 1) and identification of universal (step 2) and specific (step 3) ecosystem service, the evaluation of grassland restoration and identification of restoration options (step 4), and the shared selection and implementation of restoration strategy (step 5). The relationship between this approach

and the other strategies described in this Perspective are shown on the side panel. For specific and quantitative examples of steps 1 and 4, see Figures 3 and 4. For steps 2 and 3, which relate to identifying indicators, see Table 1.

Figure 3. **Assessing ecosystem service trade-offs in degraded and restored European grasslands.** Steps 1 and 4 from Figure 2 are shown in greater detail so that the quantitative methods can be demonstrated. In this system, degradation caused by intensive agriculture reduces plant and soil biodiversity and causes soil compaction. This degradation diminishes the supply (SD) of ecosystem services demanded (D, represented for each group as D followed by a number) by stakeholders, resulting in a low multifunctionality (MF) for all stakeholder groups (D x SD). Restoration to high diversity grassland (SR1: Conservation) enhances the supply of multiple ecosystem services, though only moderately for fodder production and climate regulation through carbon storage. Thus, it provides the greatest multifunctionality to all stakeholder groups among restoration options. Restored high diversity grassland also provides the best option for priority ecosystem services (PR) for conservationists (see the D1 x SR1 circle), and for local farmers given their demand for organically-maintained soil fertility and cultural identity (D2 x SR2), which could compensate for lower fodder production than intensive grassland (as in SR2: Livestock grazing). However, abandonment of agricultural management (SR3: Abandoned grassland) could be seen as favourable by some national decision makers due to their prioritization of water quality and climate regulation (D3 x SR3 circle). All MF and PR scores are scaled between zero and one to provide a comparable metric and check marks (+, ++) indicate the restoration option with the highest MF or PR.

Figure 4. Assessing ecosystem service trade-offs in degraded and restored grasslands in arid and semi-arid Eastern Africa. Steps 1 and 4 from Figure 2 are shown in greater detail so that the quantitative methods can be demonstrated. In these regions, invasion of alien woody plants such as *Prosopis juliflora* transforms grasslands into scrubland with bare soil. While the supply (SD) of most ecosystem services (ES) demanded (D) by stakeholders is greatly reduced by this invasion, fuel wood and charcoal production are promoted (as in D2). The supply of other services, such as soil carbon storage, is context-dependent; if grassland previously degraded by overgrazing and other forms of mismanagement is invaded, then soil conditions

are improved. However, if healthy grassland is invaded, the supply of these services is reduced. All stakeholders, apart from charcoal producers, lose ecosystem service benefits (D2 x SD) if undegraded grasslands are invaded by *P. juliflora*, and so perceive it as degradation. Restoration options have differing impacts on stakeholder groups. Sustainable livestock grazing (SR2) requires fencing off or access restriction but promotes ES supply more than conservation (SR1) and supports the greatest multifunctionality (MF) from the perspective of all the considered groups. Abandonment does not restore the supply of any ES and even incurs ES losses (SR3), because *P. juliflora* consumes substantial amounts of groundwater. However, considering economic priorities towards only the priority ES (PR) of fodder for pastoralists, wood products for charcoal producers and ecotourism for tourists would lead these stakeholders to respectively favour livestock production, abandonment or conservation as best restoration options (highest respective PR scores). All MF and PR scores are scaled between zero and one to provide a comparable metric and check marks (+, ++) indicate the restoration option with the highest MF or PR.

Box 1 | Case studies of successful grassland restoration.

[bH1] Ethiopia (Tigray & Amhara region)
Ref[147-148]

[bH2] Restoration - Needs and Actions
[b1] Drivers of degradation: overgrazing
[b1] People's needs: fodder, wood and water
[b1] Restoration goal: promote soil fertility, herbaceous layer and tree growth, increase water retention
[b1] Actions: time series of area exclosures (5-20 years) protected by community bylaws and /or hired guards.

[bH2] Outcomes (+/-)
[b1] 2 to 3-fold increase in plant species richness, compared to areas outside exclosures
[b1] 2 to 3-fold increase in vegetation cover
[b1] Increased soil nitrogen, available phosphorus and cation exchange capacity
[b1] Erosion and flood perceived to be highly reduced and soil moisture increased
[b1] Improved provision of fodder for stall-fed livestock

[b1] No published information on the economic benefits for local livelihoods.

[bH2] Opportunities and challenges

[b1] Opportunities: government- and NGO-provided incentives including food for work and payments for the protection of exclosures

[b1] Challenges: government has stopped paying incentives in some areas; membership to exclosures and distribution of benefits unclear; decision processes and forms of collaboration need clarification; limited participation by women in decision processes.

[bH1] Brazil (Cerrado Region)

Refs [134,149]

[bH2] Restoration - Needs and Actions

[b1] Drivers of degradation: pine plantations (afforestation) and invasions

[b1] People's needs: water

[b1] Restoration goal: recovery of herbaceous layer; increase habitat for grassland fauna threatened by land conversion and woody encroachment

[b1] Actions: cutting pines, prescribed burns, transplanting native grasses, controlling re-invasion by pines and exotic grasses

[bH2] Outcomes (+/-)

[b1] Within two years, recovery of 70% the ground cover and 55% plant species relative to reference ecosystem.

[b1] 65 plant species recorded after two years

[b1] Increase of grassland area in the protected area by 5%

[b1] Rise in the water table in a cleared watershed

[b1] Economic benefits not expected nor quantified

[bH2] Opportunities and challenges

[b1] Opportunities: eradication of pines mandatory in protected areas; companies obliged to mitigate environmental damage by carrying out restoration work experiments provide scientific support for the practices applied

[b1] Challenges: tendency for woody encroachment and re-invasion by pines from the neighbourhood; fire management would be an important tool but there are legal constraints in restored ecosystems; invasion by exotic grasses is a permanent threat.

[bH1] China (Inner Mongolia)

Ref [80,150,151,152,153,154]

[bH2] Restoration - Needs and Actions

[b1] Drivers of degradation: overgrazing

[b1] People's needs: increased revenue from livestock

[b1] Restoration goal: mutually beneficial outcome for environmental health and household income

[b1] Actions: reduced stocking rates since 2004; optimization of management practices (such as the increased use of feed supplement in winter and spring, and retaining the most productive animals) to increase efficiency.

[bH2] Outcomes (+/-)

[b1] Reduction in stocking rate increased aboveground and below-ground biomass, species diversity, C sequestration and storage, and net sustainable livestock carrying capacities of desert grassland in China

[b1] Light and moderate grazing led to greater ecosystem stability

[b1] Low stocking rate, reducing number of old animals and other optimization practices increased net household income and alleviated grazing pressure.

[bH2] Opportunities and challenges

[b1] adoption of policies for poverty alleviation and grassland restoration, including environmental payment schemes, hiring of supervisors to protect grassland ecosystems, or funding of warm sheds; adoption of an energy-balance/market-based approach to reduce livestock numbers; increased demand for meat in China

[b1] Challenges: uptake of practices of reducing animal numbers and optimizing livestock management by pastoralists.

[bH1] China (Qinghai Tibetan Plateau)

Ref[155-158]

[bH2] Restoration - Needs and Actions

[b1] Drivers of degradation: human disturbance (overgrazing, excessive exploitation), climate change, rodent damage as secondary cause

[b1] People's needs: reasonable income, sustainable grassland management, water conservation

[b1] Restoration goal: promote herbaceous layer; restore soil health; reduce area of 'black soil' degraded grassland

[b1] Actions: planting artificial or semi-artificial grasslands; reducing grazing pressure; establishing protected areas.

[bH2] Outcomes (+/-)

[b1] Continued degradation in grassland has initially been stopped

[b1] In a 17-year chronosequence, grassland restoration increased plant biodiversity and vegetation cover; soil total nitrogen sequestration improved by 25%–40%

[b1] Water supply capacity of watersheds has increased

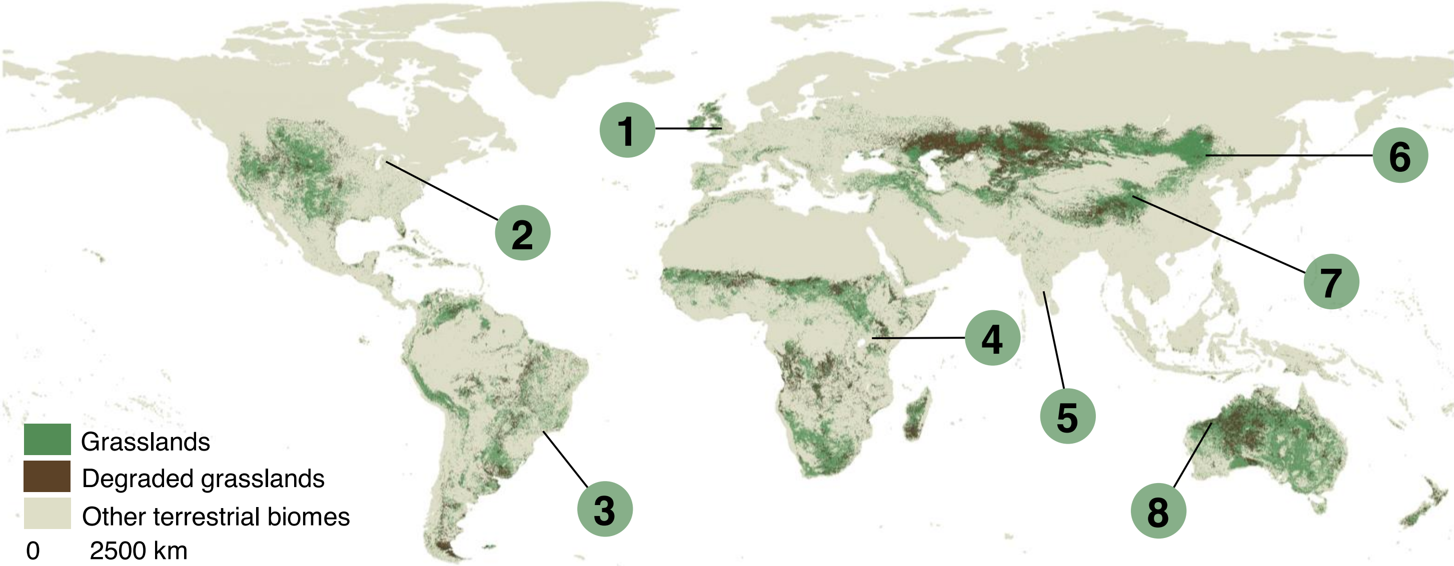
[b1] No significant change in economic profit along restoration chronosequence

[bH2] Opportunities and challenges

[b1] Opportunities: increased awareness that grassland degradation is not only a threat to pastoral livelihoods, but also to ecological stability of the region and to people living in other regions implementation of environmental payment schemes; government provided funding for an ecological conservation and restoration project in the Three-River Source Region

[b1] Challenges: could affect livelihoods because it restricts access to grazing areas; change in grazing system can require high input costs (stalls, new feed sources); collaboration among farmers, local officials and extension workers required for technology transfer and policy implementation.

Global grassland degradation



1

United Kingdom

Ploughing, reseeding and fertilisation has transformed species-rich chalk grasslands into 'improved' grasslands with higher fertility, lower species richness and lower levels of many cultural ecosystem services.

2

United States

Reseeding and fertilisation of tallgrass prairie has transformed species-rich prairie grasslands with a mixture of native C3 and C4 grasses, sedges and forbs, to species-poor grassland dominated by Eurasian C3 grasses.

3

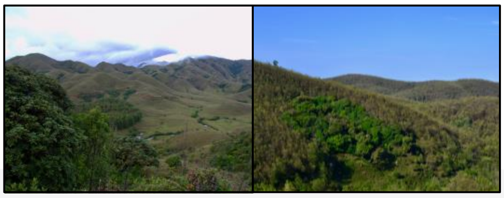
Brazil

Soil tillage and fertilisation for cultivation of Cerrado grasslands destroy underground plant structures and soil aggregates, severely lowering resilience of these ancient and highly diverse ecosystems.

4

Kenya

Decades of overgrazing by cattle and sheep of lowland grassland in Kenya has caused excessive soil erosion, and loss of biodiversity and ecosystem services.



5

India

Invasion by exotic woody species, primarily *Acacia Mearnsii*, poses a major threat to ancient shola-grassland mosaics in the upper reaches of the Nilgiri Biosphere Reserve, Western Ghats.

6

Inner Mongolia, China

Planting of pine trees in semi-arid grasslands can reduce plant diversity, damages soils, and increase water shortages.

7

Qinghai-Tibetan Plateau, China

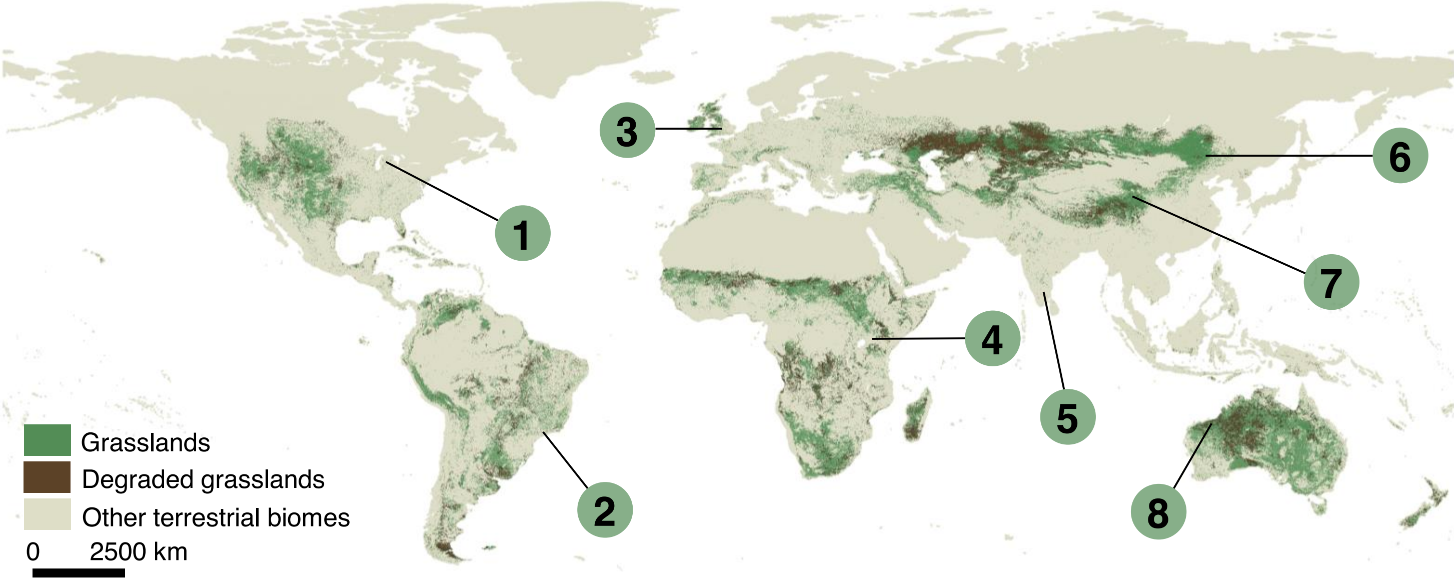
Extensive overgrazing and the increase in rodent population have caused widespread degradation of alpine grasslands, causing soil erosion and loss of biodiversity and ecosystem services.

8

Australia

In many parts of Australia, livestock grazing can quickly break down *Themeda* swards and promote invasion by exotic species.

Global grassland degradation



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United States

Reseeding and fertilisation of tallgrass prairie has transformed species-rich prairie grasslands with a mixture of native C3 and C4 grasses, sedges and forbs, to species-poor grassland dominated by Eurasian C3 grasses.

2

Brazil

Cultivation and abandonment of Cerrado grasslands poses a major threat to these ancient and highly diverse ecosystems.

3

United Kingdom

Ploughing, reseeding and fertilisation has transformed species-rich chalk grasslands into 'improved' grasslands with higher fertility, lower species richness and lower levels of many cultural ecosystem services.

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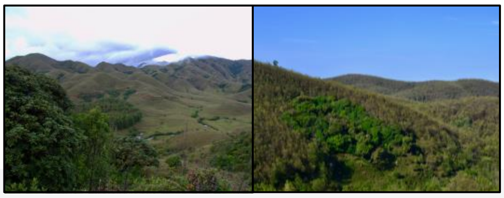

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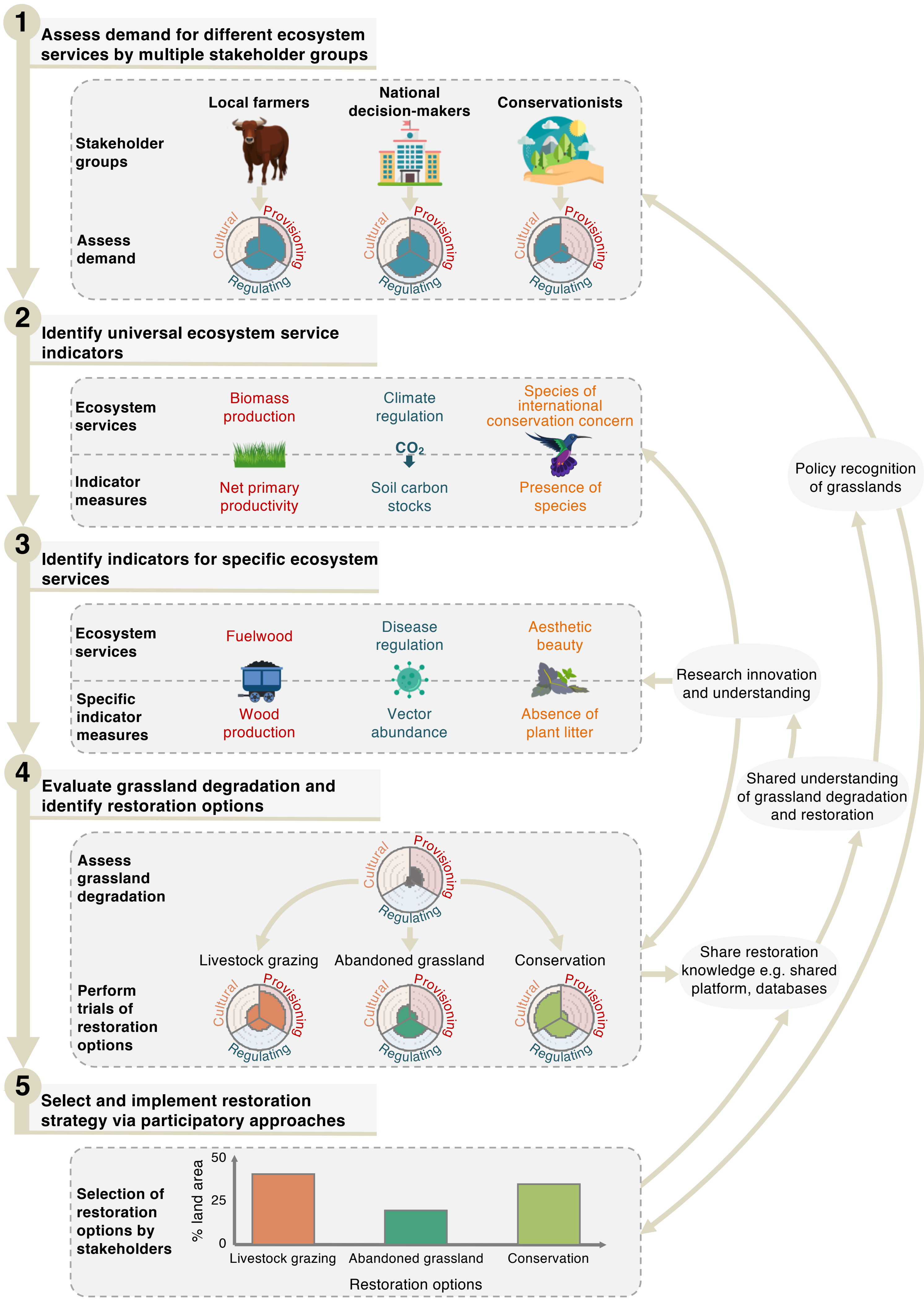
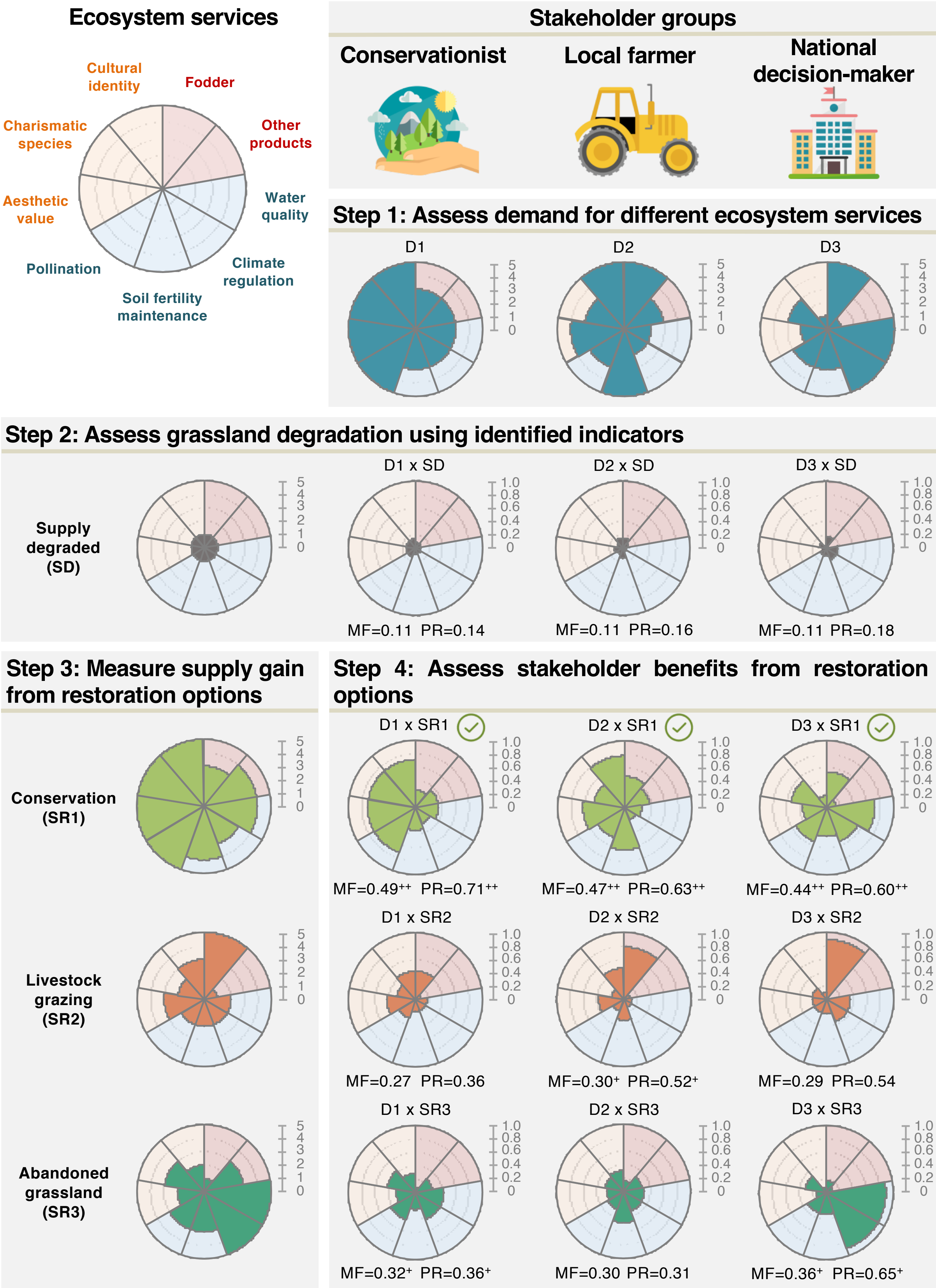
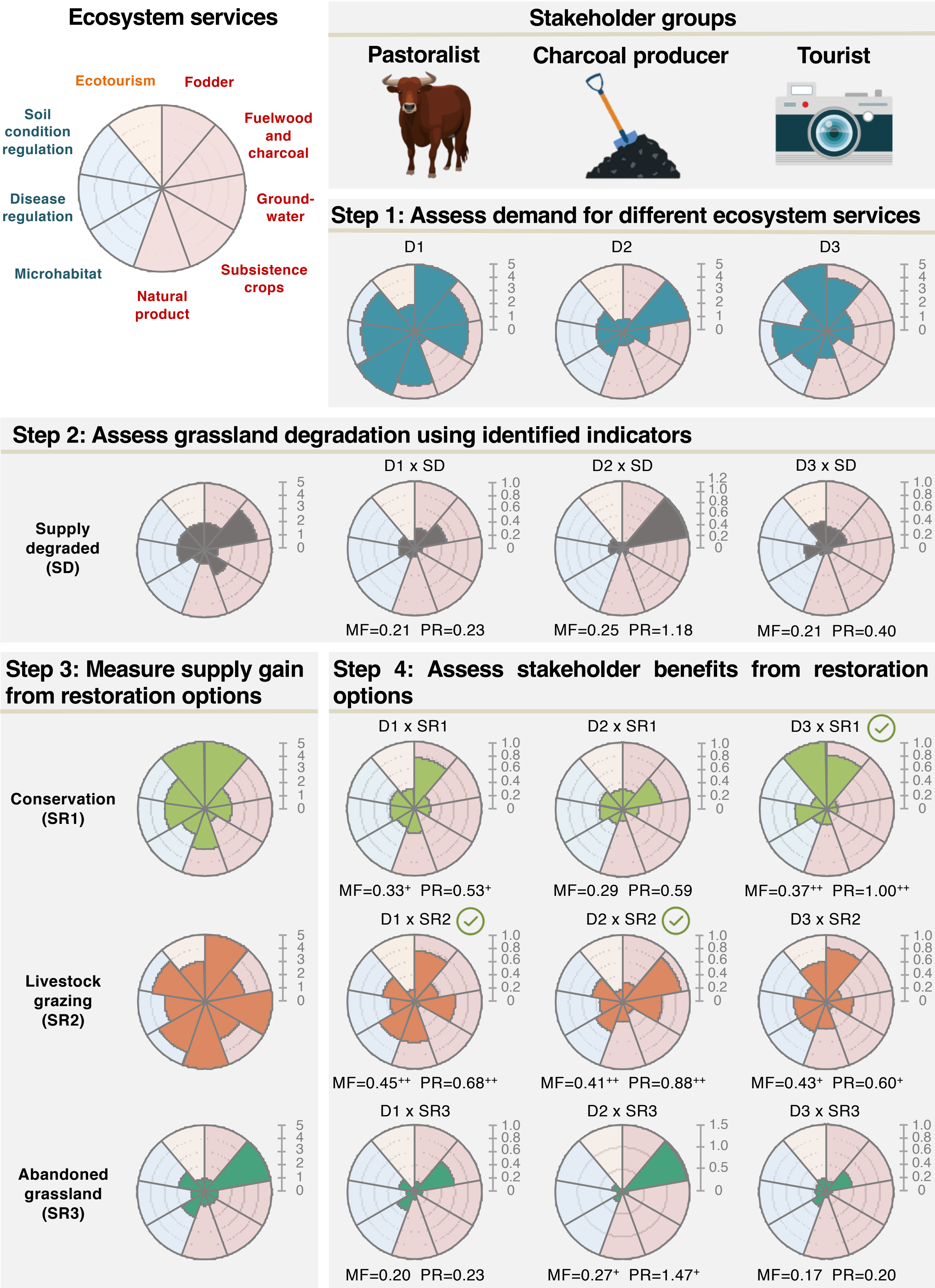

1
Assess demand for different ecosystem services by multiple stakeholder groups
Local farmers
National decision-makers
Conservationists
Stakeholder groups
Assess demand
Provisioning
Cultural
Regulating
2
Identify universal ecosystem service indicators
Ecosystem services
Biomass production
Climate regulation
Species of international conservation concern
CO_2
Indicator measures
Net primary productivity
Soil carbon stocks
Presence of species
3
Identify indicators for specific ecosystem services
Ecosystem services
Fuelwood
Disease regulation
Aesthetic beauty
Specific indicator measures
Wood production
Vector abundance
Absence of plant litter
4
Evaluate grassland degradation and identify restoration options
Assess grassland degradation
Livestock grazing
Abandoned grassland
Conservation
Perform trials of restoration options
5
Select and implement restoration strategy via participatory approaches
Selection of restoration options by stakeholders
% land area
50
25
0
Livestock grazing
Abandoned grassland
Conservation
Restoration options
Policy recognition of grasslands
Research innovation and understanding
Shared understanding of grassland degradation and restoration
Share restoration knowledge e.g. shared platform, databases



Ecosystem services
Cultural identity
Fodder
Charismatic species
Other products
Aesthetic value
Water quality
Pollination
Climate regulation
Soil fertility maintenance
Stakeholder groups
Conservationist
Local farmer
National decision-maker
Step 1: Assess demand for different ecosystem services
D1
D2
D3
Step 2: Assess grassland degradation using identified indicators
Supply degraded (SD)
D1 x SD
D2 x SD
D3 x SD
MF=0.11 PR=0.14
MF=0.11 PR=0.16
MF=0.11 PR=0.18
Step 3: Measure supply gain from restoration options
Conservation (SR1)
Livestock grazing (SR2)
Abandoned grassland (SR3)
Step 4: Assess stakeholder benefits from restoration options
D1 x SR1
D2 x SR1
D3 x SR1
MF=0.49++ PR=0.71++
MF=0.47++ PR=0.63++
MF=0.44++ PR=0.60++
D1 x SR2
D2 x SR2
D3 x SR2
MF=0.27 PR=0.36
MF=0.30+ PR=0.52+
MF=0.29 PR=0.54
D1 x SR3
D2 x SR3
D3 x SR3
MF=0.32+ PR=0.36+
MF=0.30 PR=0.31
MF=0.36+ PR=0.65+


Ecosystem services
Ecotourism
Fodder
Fuelwood and charcoal
Ground-water
Subsistence crops
Natural product
Microhabitat
Disease regulation
Soil condition regulation
Stakeholder groups
Pastoralist
Charcoal producer
Tourist
Step 1: Assess demand for different ecosystem services
D1
D2
D3
Step 2: Assess grassland degradation using identified indicators
Supply degraded (SD)
D1 x SD
D2 x SD
D3 x SD
MF=0.21 PR=0.23
MF=0.25 PR=1.18
MF=0.21 PR=0.40
Step 3: Measure supply gain from restoration options
Conservation (SR1)
Livestock grazing (SR2)
Abandoned grassland (SR3)
Step 4: Assess stakeholder benefits from restoration options
D1 x SR1
D2 x SR1
D3 x SR1
MF=0.33+ PR=0.53+
MF=0.29 PR=0.59
MF=0.37++ PR=1.00++
D1 x SR2
D2 x SR2
D3 x SR2
MF=0.45++ PR=0.68++
MF=0.41++ PR=0.88++
MF=0.43+ PR=0.60+
D1 x SR3
D2 x SR3
D3 x SR3
MF=0.20 PR=0.23
MF=0.27+ PR=1.47+
MF=0.17 PR=0.20