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Perspective Article

Pitfalls in global grassland restoration challenge restoration programs and the science-policy dialogue

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ABSTRACT

Restoring degraded ecosystems is crucial for human wellbeing and biodiversity conservation. Nowadays, ecological restoration goes far beyond recovering a degraded ecosystem according to a historic reference. Instead, more specific restoration goals are set, following global environmental strategies that are individually highly important, but often conflicting. Furthermore, various pitfalls exist regarding the evaluation of ecosystem degradation and, directly related to this, the question what is the most desirable ecological state of an ecosystem. Ignoring such issues can lead to a failure of restoration projects and do more ecological (and social) harm than good. A crucial aspect in tackling conflicting goals and circumnavigating restoration pitfalls is the considerate choice of the indicators to assess ecosystem degradation and restoration capacity.

In this Perspective, grasslands and rangelands are used exemplarily for ecosystems with globally high restoration demand. I discuss potential restoration pitfalls related to enhancing carbon sequestration, soil fertility, and ecosystem service multifunctionality. For all three goals, strong trade-offs and unwanted side effects exist. For example, while increasing carbon storage and restoring soil fertility are widely acknowledged environmental goals, both can compromise other restoration targets such as grassland biodiversity and further ecosystem services, depending on the specific context. Thus, there are no universally applicable indicators for ecosystem degradation and restoration. Instead, indicator systems have to account not only for strong trade-offs among restoration goals but also for a number of environmental and socio-ecological misconceptions, such as presented for the case of grassland ecosystems.

I argue that one-sided goal setting and an imprudent choice of indicators can misguide the science-policy dialogue and related restoration efforts. To avoid this, restoration programs must integrate holistic assessments of their objectives across spatial scales and with all stakeholders concerned. The associated ecological indicator system for restoration success and program performance must therefore also be based on multidisciplinary and participatory approaches. Restoration and degradation indicators have to further ensure the target ecosystem is correctly and comprehensively identified, and the manifold conflicting land management objectives associated with heterogeneous human societies are taken into account. Researchers can assist this process by by-default considering the socio-ecological context of a restoration target and by identifying trade-offs arising from potential solutions, before these are suggested to the public. Only when all these aspects are considered, restoration projects at the local to global scale will result in long-term sustainable outcomes.

1. Introduction

Boosted by the UN Decade on Ecosystem Restoration 2021–2030 (United Nations Environment Agency, 2019), combatting ecosystem degradation has been emphasized as a key strategy for addressing biodiversity loss and increasing ecosystem services. While in the past, ecological restoration primarily aimed at recovering or re-creating a specific type of ecosystem or species community according to an undegraded (semi-) natural reference, large-scale restoration initiatives nowadays often follow specific restoration goals linked to global environmental strategies such as combatting climate change or improving food security. These goals and related indicator systems for ecosystem degradation and restoration are thus based on globally acknowledged targets such as increasing carbon storage, sustaining soil fertility, and

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enhancing ecosystem multifunctionality (e.g. Gann et al., 2019; Sims et al., 2020; Bardgett et al., 2021). While all these goals are highly desirable, there are strong potential trade-offs, side effects, and normative or cultural misconceptions that must be considered if global ecosystem restoration is to be successful and sustainable. This also challenges the development and application of reliable indicators, as well as their establishment and calibration on a global scale (Muñoz-Rojas, 2018).

In this Perspective, grasslands and rangelands (Fig. 1), which cover about 40% of the terrestrial earth surface and 70% of the global agricultural land area, providing essential services and livelihood to hundreds of millions of people, are used exemplarily for ecosystems of particular restoration concern (Dudley et al., 2020; Bardgett et al., 2021; Buisson et al., 2022). Grassland restoration projects are, however, associated with the risk to run into a number of potential pitfalls that can corrupt restoration outcomes, as will be discussed in the following for i) increasing carbon stocks, ii) restoring soil fertility, and iii) maximizing ecosystem service multifunctionality.

2. Increasing carbon stocks

Increasing ecosystem carbon stocks is the foremost nature-based climate solution (Griscom et al., 2017), with above- and belowground carbon stocks as primary indicators of degradation (Sims et al., 2020). In grassland ecosystems, most organic carbon is not stored above but below the ground (Bai and Cotrufo, 2022). Attempts to maximize aboveground

Fig. 1. Aspects of grassland degradation – or not? Pictures (a) and (b) address the two opposite sides of poor soil fertility, a typical indicator for ecosystem degradation. While (a) shows severe soil degradation and erosion in the Icelandic grassy tundra as a result of historic unsustainable use, i.e., overgrazing (Eddudóttir et al, 2020), in (b) the area within the dashed lines was purposely "degraded" by removing the fertile topsoil to restore a species-rich grassland that requires very nutrient-poor conditions (Switzerland). Nature and soil conservation agencies have thus very different views on such rather drastic restoration measures (Resch et al., 2019). Pictures (c) and (d) show intensively managed agricultural grasslands in Switzerland and Germany, respectively, which can be viewed "potentially degraded" due to generally low biodiversity and multifunctionality (Bardgett et al., 2021). However, such productive grasslands are important for reducing the feed versus fork conflict as they support the production of animal products on non-arable land. While the grassland in (c) was created using a targeted species mixture that aims at partly replacing fertilizer input by symbiotic nitrogen fixation by legumes, a measure of sustainable intensification (Suter et al., 2021), the grassland in (d) shows severe signs of degradation, i.e., the dominance of the native weed *Rumex obtusifolius* (Klötzli et al., 2023), leading to both low biodiversity and low agricultural yield. Picture (e) addresses the normative and cultural dimension of what is viewed as desirable versus degradation: an intensively managed, resource-consuming and species-poor ornamental grassland in an urban environment in Switzerland. Since the UN Decade on Ecosystem Restoration explicitly includes urban environments, ecological restoration has highlighted several alternative (restorative) solutions for such situations, e.g., a species-rich urban meadows as shown in (f) (Switzerland; Klaus and Kiehl, 2021). Such a change in perspective also affects the choice of the indicator to examine the state of an urban greenspace, i.e., biodiversity aspects versus clean and orderly appearance (Fischer et al., 2020).

carbon stocks will thus unavoidably lead to afforestation and facilitate the loss of valuable natural and semi-natural grasslands and their unique ecosystem services (Wang et al., 2020; Buisson et al., 2022). Neglecting such harmful side effects of (forest) restoration activities on the livelihood of local farmers has been shown to particularly threaten the success of restoration projects (Löfqvist et al., 2023).

To, on the other hand, enhance soil organic carbon in grasslands, fertilization and sowing of productive legume and grass species have been shown to effectively increase carbon sequestration after degradation (Bai and Cotrufo, 2022). Yet, both treatments will also change plant community composition and diversity (Wang et al., 2020). In case of fertilization as a restoration tool, and depending on its intensity and frequency, greenhouse gas emissions, the risk of nutrient leaching, and changes in belowground species communities depict further environmental trade-offs that must be considered (Birkhofer et al., 2022; Schils et al., 2022). Achieving this indicator for successful ecosystem restoration can thus easily conflict with other key indicators for ecosystem health and environmental protection. Particularly in connection with carbon storage, a range of misconceptions regarding climate effects of grassland afforestation (Bardgett et al., 2021) and a simplistic focus on maximizing above- and potentially also belowground carbon storage threaten other major targets of ecosystem restoration, which highlights the need to a-priori consider possible side effects of suggested restoration approaches.

3. Restoring soil fertility

Healthy and productive soils are essential to world nutrition (Lal, 2009) and soil quality indicators are critical tools for restoration programs (Muñoz-Rojas, 2018; Fig. 1a). Restoring degraded grassland soils and increasing soil fertility will thus result in a win–win situation with food production and potentially support the recovery of local biodiversity (Bardgett et al., 2021). Yet, nutrient impoverished, “degraded” soils be can also harbor highly valuable ecosystems (Fig. 1b). For instance, for centuries certain natural and semi-natural grasslands have been shaped by biomass and nutrient removal without fertilizer application. This resulted in nutrient impoverished habitats of outstanding nature value such as sand or chalk grasslands and grassland-heathland complexes that contain highly specialized rare species (e.g. Veen et al., 2009). The importance of nutrient-poor soils for these endangered grassland ecosystems is mirrored in restoration approaches that actively reduce soil fertility (Fig. 1b), sometimes involving the complete removal of the fertile topsoil (Kiehl et al., 2010). This restoration approach strongly contrasts the large global extent of heavily degraded grassland and rangeland soils (Bai and Cotrufo, 2022; Maestre et al., 2022). In addition, reducing soil fertility can also be desirable when managing invasive species or as a consequence of changing from resource-intensive irrigated agriculture to more sustainable dryland agriculture (Sims et al., 2020). Therefore, nutrient depletion is an important aspect but not a universal indicator for the need to fight soil and ecosystem degradation. To avoid unintended consequences such as the loss of specialized rare species (Wang et al., 2020), measures to increase soil fertility must consider the local historical and ecological context.

4. Maximizing ecosystem multifunctionality

Grasslands and rangelands provide many important ecosystem services, of which food production represents only one (Maestre et al., 2022; Schils et al., 2022). A recently introduced indicator to assess ecosystem degradation is the number of ecosystem services simultaneously provided, i.e., ecosystem multifunctionality. Current multifunctionality is compared to the demands and priorities of local stakeholders to identify potential discrepancies (Bardgett et al., 2021). This multifunctionality approach accounts for the numerous supporting, regulating and cultural services of grassland ecosystems (Schils et al., 2022), and addresses but not dissolves trade-offs among different services at the field scale. While this approach certainly holds its strength, especially when closely tight to representative stakeholders, focusing on increasing as many services as possible can underestimate the relevance of services that exhibit particularly strong trade-offs, such as intensive food production. For example, productive agricultural grasslands are poor in biodiversity but crucial for the supply with sustainable meat and dairy products (Fig. 1c). While ecologists argue these intensively managed grasslands are generally potentially degraded due to low multifunctionality and biodiversity (Bardgett et al., 2021), a food systems perspective strongly underlines the importance of intensive grasslands to reduce the feed versus fork conflict by strengthening the production of high-quality roughage for livestock on non-arable land while decreasing the production of feed from arable land (Karlsson et al., 2021). This example shows that goal setting in restoration initiatives must account for feedbacks such as food system responses across spatial scales, to internalize land competition as well as food production and consumption, and to avoid externalization of environmental impacts such as by the global feed and food trade. Restoration goals at one place should never risks degradation at another. Therefore, even local indicator systems need to be thought globally.

5. Indicator systems suffering from cultural bias

Even the best goal and the perfect indicator to supervise its achievement are worthless and potentially threatening ecosystem health if the study system isn’t accurately recognized. This important aspect, which is not as trivial as it might appear, highlights the case and context dependency as well as the spatially-restricted applicability of indicator systems. Several examples show that misconceptions in the nature of an ecosystem, in our case a natural grassland or savanna ecosystem that is misidentified as original forest area, can lead to “perverse results” of global restoration projects (Veldman et al., 2015a; Bond et al., 2019; Dudley et al., 2020). The question whether the below- or the aboveground carbon stock is the primary place to stimulate carbon capture, and hence the indicator for such a restoration project, is the crucial difference between targeting grassland or forest ecosystem restoration (Veldman et al., 2015a). A cultural bias towards forests and the associated preference for aboveground rather than belowground carbon storage is one major reason for the global focus on tree planting programs (Veldman et al., 2015b; Temperton et al., 2019). This is just one example of how not only the environmental but also the societal setting and normative aspects affect and potentially undermine restoration goals and the correct use of indicators for ecosystem degradation and restoration (see also Fig. 1e). Thus, developing indicators for restoration programs inherently means reflecting on the ecological and societal context in which the indicators will be used, and requires pointing out the boundaries of the respective indicator system.

6. Sustainable goal setting and indicators for restoration projects

The abovementioned trade-offs and pitfalls demonstrate that mono-disciplinary indicators for global ecosystem degradation and overly specific goals for ecosystem restoration are likely to fail in identifying sustainable solutions. Yet, these concerns should not prevent us from strong action to counteract ecosystem degradation. Multidisciplinary assessments and a holistic understanding of the respective local context can avoid misconceptions such as *false negatives* in assessing degradation, for instance problematizing low soil fertility and potential carbon debts in unproductive high-nature-value grasslands, as well as *false positives* in monitoring restoration when, for example, reaching global but compromising local targets (Sims et al., 2020).

Because combatting ecosystem degradation is highly multifaceted, sectoral boundaries such as of nature conservation or agriculture must be overcome by ensuring multidisciplinary decision-making processes. This has major implications for the choice of indicators, as they can be ideologically tinged if not based on participatory approaches and holistic assessments. Here, multi-stakeholder workshops to define objectives of ecosystem restoration (e.g., Gann et al., 2019; Bardgett et al., 2021) depict a key step in defining sustainable restoration and land management goals. To result in long-term stable and positive outcomes, this process needs cautious moderation of the various local to international interests and must consider potential social and environmental side effects. To achieve this, large-scale restoration projects need to tackle inevitable trade-offs among restoration goals by creating sustainable, heterogeneous, and multifunctional landscapes, based on inclusive and participatory goal setting processes (Löfqvist et al., 2023). The final negotiation of restoration goals and land use priorities must therefore employ broad stakeholder and societal involvement.

Finding suitable indicators for the complex outcomes of large-scale restoration projects can be particularly challenging, especially if (slow) changes in environmental as well as societal and cultural aspects are to be assessed with (few) cost-efficient indicators (Dale and Beyeler, 2001). At this, we have to keep in mind that due to the societal dimension of restoration initiatives, the complexity of ecological systems and the normative aspect in assessing ecosystem services as well as ecological quality, an indicator system cannot be based solely on scientific criteria but depicts an interface between science and policy (Turnhout et al., 2007).

7. What science can do

Researchers can support socially and environmentally sustainable restoration initiatives by increasing the knowledge base on side effects and trade-offs, and by conducting comprehensive, multidisciplinary assessments of restoration approaches and indicator systems before suggesting them. In addition, the lack of universally applicable, easy-to-use indicators for ecosystem degradation and restoration needs to be acknowledged. The immanent trade-off between easy use and low price versus accuracy of most indicators (Dale and Beyeler, 2001; Richter et al., 2021) appears to be of particular relevance at a time when scientific assessments for overcoming the global environmental crisis peak. If already the calibration of global soil quality indicators appears to be challenging, although this being a well-researched domain (Muñoz-Rojas, 2018), policy suggestions based on global mappings using self-made, barely quality-checked indicators appear highly problematic (Meyer and Pebesma, 2022, and references therein). Thus, to avoid the multiple potential pitfalls in global restoration initiatives, already at the stage of indicator development and testing, the recent and historic environmental and socio-ecological context, the contrasting demands of the diverse stakeholders concerned, and the boundaries of the validity of an indicator system need to be considered.

CRediT authorship contribution statement

Valentin H. Klaus: Conceptualization, Visualization, Writing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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