

Editorial

Landscape-scale management for biodiversity and ecosystem services

1. Introduction

Compelling evidence has accumulated that biodiversity in agricultural landscapes is declining (Dudley & Alexander, 2017; IPBES, 2019). Reversing this trend requires us to transform how we envision and manage agricultural systems (Kleijn et al., 2019; Grass et al., 2019; Tscharnke et al., 2021). While most current efforts focus on modifying practices at the field scale, organisms are also affected by ecological patterns and processes that transcend individual fields and farms. Consequently, effective conservation of biodiversity and related ecosystem services will require addressing practices at the landscape scale as well (Tscharnke et al., 2012, Landis, 2017, Jeanneret et al., 2021).

The key role of heterogeneity at multiple scales for sustaining biodiversity has been recognized for some time (Benton et al., 2003). Today, there is a growing consensus that landscapes harbouring more semi-natural habitats, and smaller fields which increase edge density, are needed to enhance farmland biodiversity (Fahrig et al. 2015; Martin et al., 2019; Sirami et al., 2019; Haan et al., 2021; Estrada-Carmona et al., 2022). Additionally, landscape heterogeneity can be augmented by crop diversification, a broad term that encompasses a wide range of strategies augmenting plant diversity in space and time; from the field to the landscape scale, each yielding specific biodiversity benefits (Bellouin et al., 2021). How these different options can be harnessed and act together to foster biodiversity at landscape scales is still largely undocumented, prompting calls for additional studies quantifying the impact of the spatio-temporal dynamics of landscape-wide farming practices on biodiversity (Grass et al., 2019; Petit et al., 2020; Marrec et al., 2022). This research is a prerequisite to identify the range of options for transforming landscapes for biodiversity.

To be successful, landscape transformation must also consider two additional aspects. The first is whether regional actors find landscape-scale management options to be acceptable (Steingröver et al., 2010, Geertsema et al., 2016). Managing this challenge may require a paradigm shift towards farmer-led solutions (Bohan et al., 2022). The second aspect is the necessity to consider multiple ecosystem services and potential trade-offs between services at

the landscape scale (Raudsepp-Hearne et al., 2010; Spake et al., 2017). These trade-offs occur most notably between biodiversity benefits and agricultural productivity (Tamburini et al., 2020; Sietz et al., 2021).

In this Special Issue, landscape-scale transformation of agricultural management is addressed in 12 original papers. Some of the papers originate from the Landscape 2021 conference ‘*Diversity for Sustainable and Resilient Agriculture*’ held in September 2021, Berlin, Germany which convened scientists from across disciplines with key actors to explore whether and how diversity and diversification can contribute to a more sustainable and resilient agriculture. Many papers in this issue address the specific ecosystem service of natural pest control, an alternative and a possible pathway to reduce pesticide use in future landscapes (Paredes et al., 2021; van der werf and Bianchi, 2022), yet it should be noted that landscape-scale management strategies augmenting pest control services also often deliver other services as well, e.g. pollination (Sutter et al., 2017), water recharge and carbon sequestration (Tamburini et al., 2020).

The focus of the Special Issue is on (i) predicting the biodiversity and ecosystem service outcomes of landscape transformation, (ii) understanding the outcomes of crop diversification, and (ii) restoring and managing off-crop habitats to increase landscape multifunctionality.

2. Predicting the biodiversity and ecosystem service outcomes of landscape transformation

Many of the ecological principles that should guide informed landscape-scale management to optimize biodiversity and ecosystem services are available today (Landis, 2017; Martin et al., 2019; Haan et al., 2021). Evaluating the capacity of current and future landscapes to deliver on biodiversity and ecosystem services remains however challenging. Ecological responses to in-field and landscape management are highly variable because they are species and context-dependent (Karp et al., 2018; Haan et al., 2019). Management strategies should be tailored to specific landscapes and the variability in ecological responses is a major obstacle to our capacity to provide reliable and robust predictions (Alexandridis et al., 2021). On the one hand, generic responses of biodiversity to landscape management may not manifest as expected in a specific landscape setting. On the other hand, ecological models developed in a specific landscape setting are unlikely to be transferable outside the specific cases for which they were developed (Lautenbach et al., 2019).

In this issue, [Perennes et al. \(2023\)](#) present a hierarchical modelling approach to predict the spatial overlap between pest pressure (demand) and natural enemy abundance (supply) and its application in Northern Germany. The model combines species distribution models fitted at both regional and landscape scales. [Bonato et al. \(2023\)](#) specifically address the trade-offs between generality and realism in predictions of natural pest control and show that the application of a generic model in different European landscapes provide predictions that do not correlate well with field measurements. They conclude that to be operational, predictive models of pest control should be tailored to specific landscape contexts and organisms, and be trained with landscape specific field measurements of pest control. [Petit et al. \(2023\)](#) show how Landscape Monitoring Networks (LMN) enable the combination of long-term monitoring, scenario building with stakeholders, and predictive modeling, thus enabling model training. They illustrate with the French LMN on biodiversity and pest control services how the LMN approach can deliver ecological and social understanding along a gradient from place-based to generic knowledge but also bridge the gap between theory and practice and facilitate implementation of landscape-scale management strategies. A key issue when engaging in prospective assessments of landscape transformation is understanding the needs and wants of varying stakeholders - and potential conflicts in their visions. In interviews with a diverse array of stakeholders, [Young et al. \(2023\)](#) found commonalities and differences in their visions for future landscapes that form the basis for finding common ground and alleviating potential conflicts.

3. Understanding the outcomes of crop diversification

In recent years, there has been increasing focus on the potential benefits that could stem from the diversification of cropland itself (Kremen & Miles, 2012). Most studies have focused on the biodiversity benefits of (crop) plant diversification at the field scale (Bellouin et al., 2021; Tamburini et al., 2020). The biodiversity consequences of landscape-scale diversification are less well documented, although it can be expected that increasing the heterogeneity of crop types, through a decrease in field size and the use of more diverse crop types, will promote biodiversity (Sirami et al., 2019; Tscharnke et al., 2021). Nevertheless, the spatial distribution of farming practices and its temporal dynamics across the landscape has been less explored (Marrec et al., 2022). The impact of the landscape-scale expansion of agroecological practices on biodiversity and ES also remains largely unknown, or restricted to the case of organic farming (Petit et al, 2020).

In this issue, [Schaak et al. \(2023\)](#) studied changes in crop species and functional diversity in Sweden from 2001-2018, finding that both crop and functional diversity declined during this period, while crop species diversity also initially declined, it has rebounded in recent years. Farm size, soils, production practices and climatic conditions all influenced diversity metrics. For example, the uptake of organic practices was associated with decreased crop diversity but increased functional diversity. The effects of crop diversity on taxa delivering pest control services were also investigated. [Tortosa et al. \(2023\)](#) show that bat species richness and activity was higher in landscapes with higher crop diversity, specifically the coexistence of annual and perennial crops. Impacts on pest abundance and damage in the crops were variable, decreasing with bat species richness and foraging activity in perennial but not in annual crops. [Raderschall et al. \(2023\)](#) explored the effects of crop diversity on in-field richness and abundance of spiders, rove beetles and carabid beetles in Sweden. They show that carabid richness and the abundance of granivorous carabids benefited from legacies of crop diversity, and were higher when crop diversity in the previous year was high. [Cusser et al. \(2023\)](#) show that conservation tillage practices improve pollination services and net return in cotton crops with economic benefits accruing to both adopters and non-adopters in the landscape. However, even with full adoption they predict that pollination limitations would still occur suggesting a role for additional pollinator enhancement practices.

4. Restoring and managing off-crop habitats to enhance landscape multifunctionality

Given the drastic decline of semi-natural habitats in most agricultural landscapes, re-installing or restoring non-crop habitats around farmland has been considered as a major lever to reverse the current loss of biodiversity, although the lack of planning at the landscape scale is thought to have limited the efficacy of local measures (Kleijn et al. 2006). Linear features around cropland can provide plant resources to many taxa (Yvoz et al. 2021) and deliver multiple services, such as pest control in adjacent fields (Holland et al. 2016).

In this issue, [Garcia et al. \(2023\)](#) show that conserving or restoring semi-natural habitats at the farm-scale enhances birds that consume insect pests of strawberries, and thus deliver an important pest control service in organic strawberry farms in California. [Wesemeyer et al. \(2023\)](#) mobilize multi-objective optimization to attempt solving trade-offs between crop production and farmland bird conservation. They show that increasing the proportion of woody features and reducing field sizes can be an effective strategy to increase avian farmland

biodiversity with little impact on potential net agricultural returns, but that there is spatial variation as to where this would be most effective. [Castellano et al. \(2023\)](#) analyzed the benefits of the restoration of degraded riparian forests in two Spanish landscapes. They found that restored forests could deliver substantial amounts of provisioning and regulating services, and that, if planned where abiotic factors were favorable, restored forests could complement the ES provided by mature riparian forests.

5. Conclusion

Collectively, the papers in this special issue point to the opportunities and challenges of managing landscapes for multiple benefits. Augmenting heterogeneity generally benefits biodiversity and ecosystem services, however, an emerging consensus is that successful landscape design and management are likely to be highly context-dependent and critically require the guidance of stakeholders. Continued innovation in both scientific research and methods for engaging stakeholders as full partners in landscape design are needed for continued success.

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