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PERSPECTIVE

Transition zones across agricultural field boundaries for integrated landscape research and management of biodiversity and yields

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Abstract

1. Biodiversity conservation and agricultural production have been largely framed as separate goals for landscapes in the discourse on land use. Although there is an increasing tendency to move away from this dichotomy in theory, the tendency is perpetuated by the spatially explicit approaches used in research and management practice.
2. Transition zones (TZ) have previously been defined as areas where two adjacent fields or patches interact, and so they occur abundantly throughout agricultural landscapes. Biodiversity patterns in TZ have been extensively studied, but their relationship to yield patterns and social–ecological dimensions has been largely neglected.
3. Focusing on European, temperate agricultural landscapes, we outline three areas of research and management that together demonstrate how TZ might be used to facilitate an integrated landscape approach: (i) plant and animal species' use and response to boundaries and the resulting effects on yield, for a deeper understanding of how landscape structure shapes quantity and quality of TZ; (ii) local knowledge on field or patch-level management and its interactions with biodiversity and yield in TZ, and (iii) conflict prevention and collaborative management across land-use boundaries.

KEYWORDS
ecotones, field boundaries, functional traits, landscape complexity, land-use conflicts, local knowledge, spillovers

1 | INTRODUCTION

Considerable effort has gone into reconciling biodiversity conservation and agricultural production in science and practice. In science, the dichotomous discourse on land sparing versus land sharing (Fischer et al., 2014; Phalan et al., 2011) developed into a discussion of how to integrate both towards human well-being (Bennett, 2017) and connectivity within landscapes (Grass et al., 2019). In practice, policy encourages farmers to manage their fields or set aside land for biodiversity conservation (e.g. organic farming: Stolze & Lampkin, 2009; ecological focus areas: Pe'er et al., 2017), partially via agri-environment schemes (e.g. Herzon et al., 2018). Nevertheless, biodiversity conservation and agricultural production largely continue to be treated separately, and are largely focused on individual fields and the associated land managers (but see Krämer & Wätzold, 2018; Barghusen et al., 2021), even if this compartmentalized focus has not proven ecologically effective (Pe'er et al., 2020).

The landscape scale is arguably more effective than the field or patch scale for reconciling biodiversity conservation with agricultural production (e.g. Kremen, 2015). It allows us to move beyond thinking about different fields or patches as functioning in isolation, to think about how they and their managers interact via collaborative management practices adapted to site-specific conditions throughout landscapes (Figure 1; Renaud et al., 2018; Wolters et al., 2014). Often described as ecotones or boundaries, transition zones (TZ) are the areas within a landscape in which an influence of the neighbouring field or patch is detectable (see arrows in Figure 1b; for the different definitions of these concepts, see Table 1). Collaborative management could account for the multifaceted interactions between neighbouring fields or patches and their managers. This would mean first improving our understanding of how TZ contribute to biodiversity–yield patterns in agricultural landscapes, which until now has not been addressed sufficiently. As such, we aim to provide an overview of why TZ matter for integrated landscape research and management across several epistemologies. Specifically, we describe three research areas related to understanding TZ for shifting the paradigm from an individual to collaborative approach in studying and managing agricultural landscapes: (i) landscape structure shapes TZ density and type in terms of biodiversity–yield relationships; (ii) land users' knowledge of biodiversity–yield relationships in TZ informs landscape research and management; and (iii) considering TZ effects can prevent land-use conflicts and support collaborative landscape management. In doing so, we focus on TZ which involve agriculture on one or both sides of the boundary, in European agricultural landscapes in temperate climates. With biodiversity, we mean multi-trophic diversity (Sirami et al., 2019).

2 | LANDSCAPE STRUCTURE SHAPES TZ DENSITY AND TYPE IN TERMS OF BIODIVERSITY–YIELD RELATIONSHIPS

Agricultural landscape structure is the result of composition and configuration. Together, these will affect biodiversity–yield relationships in TZ. Landscape composition is how much of each land use exists within an area, and landscape configuration is the spatial pattern of these land uses (Mitchell et al., 2015). Landscape configuration will define TZ density (Haan et al., 2020). For example, decreasing mean field size from 5 to 2.8 ha had a similar effect on biodiversity as increasing semi-natural habitat from 0.5 to 11% within a landscape (Sirami et al., 2019). Consequently, higher TZ density allows species to use resources from diverse fields and patches made up of different land-use systems (Dunning et al., 1992), since spillover from one field or patch into another enhances species' survival despite management-driven disturbance (Gurr et al., 2017). That spillover, however, may depend on landscape composition, which could define the quality of TZ. Landscape composition will determine the ecological contrast between neighbouring land-use systems, describing how strongly they differ from each other (Marja et al., 2019; Table 1), in space and time. Diverse

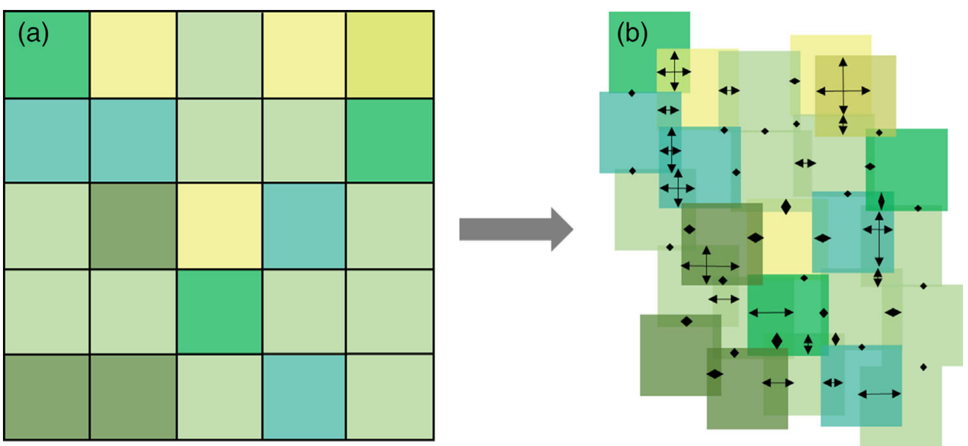

FIGURE 1 Paradigm shift from (a) conceptualizing biodiversity conservation and yield production as compartmentalized, distinct units in agricultural landscapes that are treated individually, to (b) conceptualizing biodiversity patterns and yield production as overlapping and interacting between land uses throughout an agricultural landscape (visualized in the figure with arrows or diamonds where land uses interact). The interactions will differ depending on land-use type. Original figure by M. Kernecker

TABLE 1 Terminology related but not limited to transition zones. See more extensive summaries in Ferro and Morrone (2014), Hufkens et al. (2009), Schmidt et al. (2017), and Yarrow and Marín (2007)

Term	Description	References
Transition zone	• An area characterized by an active and passive exchange of matter, energy and information where biotic patches overlap; • Spatio-temporal variable entity with functional and structural gradients in between adjacent patches; • An area of biotic overlap created by ecological changes that allow the mixture of taxa belonging to different biotic components.	Ferro and Morrone (2014); Schmidt et al. (2017); Yarrow and Marín (2007)
Ecotone	• A zone of transition between adjacent ecological systems; • Area with a set of characteristics defined by space and time scales and the strength of the interactions between adjacent ecological systems; • A transition between two or more diverse communities	Hufkens et al. (2009); Odum and Barrett (1971)
Boundary	• A transition zone between landscape units (e.g. ecosystems, land cover or land uses). • A gradient whose steepness is defined by the contrast between the adjoining systems • A zone between contrasting habitat patches that delimits the spatial heterogeneity of the landscape.	Cadenasso et al. (2003); Marshall and Moonen (2002); Metzger and Muller (1996); Strayer et al. (2003)

land-use systems provide refuges and complimentary food sources due to the asynchronous phenology of vegetation, crops, or management (Vasseur et al., 2013), defining which species use each land-use system and how they in turn might affect agricultural yields across landscapes (Schellhorn et al., 2015). For example, parasitoids were found to first benefit from the increasing proportion of intensively managed fields and then spilled-over into wild plants in adjacent patches (Gladbach et al., 2011) and carabids moved between crop and non-crop areas depending on season (Markó et al., 2017). Moreover, ecological contrast in terms of temporal asynchronicity can stabilize yields (Egli et al., 2020). Therefore, we need to better understand the mechanisms of how landscape structure controls the relative effect of TZ density and quality on biodiversity and yields.

Understanding patterns of biodiversity in TZ means understanding how species respond to landscape structure. The prominent assumption is that the diversity of microhabitats in TZ is higher than in adjacent fields or patches, since there are overlaps of specialist and generalist species, and spillover of specialist species between fields and patches (Berges et al., 2013; Odum & Berrett, 1971; Ries et al., 2004). But how species respond to resource availability and spill over in space and time between land-use systems depends on their traits (de Bello et al., 2010), including body size (e.g. Gallé et al., 2019) and dispersal ability (e.g. Martin et al., 2019). Identifying how species among trophic levels or taxon move around and respond to TZ is an important step towards understanding how species shape the area TZ take in relation to fields or patches.

The abiotic interactions (e.g. light, moisture) between neighbouring fields or patches contribute to the effect that landscape structure has on habitats and yields. For example, cereals grown in TZ adjacent to forest could benefit from lower temperatures and evapotranspiration in dry years (Schmidt et al., 2019), while these microclimatic effects have typically explained crop yield losses (Esterka, 2008). However, yield loss depends on which land-use systems interact. In winter wheat fields, yield loss differed on whether the neighbouring land use was a forest, hedgerow or another crop field. Maximum yields could be reached 17.8 m from forest borders and hedgerows, and 6.9 m from the boundary shared with an identically managed wheat field (Raatz et al., 2019). Future studies should build on these findings and explore how landscape structure defines the density and types of TZ, and the resulting synergistic effects of microclimatic dynamics and species' populations and movement on yields.

3 | LAND USERS' KNOWLEDGE OF BIODIVERSITY–YIELD RELATIONSHIPS IN TZ INFORMS LANDSCAPE RESEARCH AND MANAGEMENT

Landscape structure can be significantly shaped by land-use practices. The practices land users implement influence the TZ connecting their field or patch to the neighbouring one via spillovers (e.g. chemical drift, prey, pollinators, wildlife, seedbank) (Figure 2). Moreover, field size can be controlled with hedgerows or maintaining other landscape elements. Farmers' knowledge of their fields and surrounding agricultural landscape can highlight the interactions between practice, biodiversity and yields that they account for with their management decisions. Therefore, it is a priority to understand how land users' knowledge of the relationship between habitats, species and yield in TZ is applied to practice. For example, land-users' knowledge of grassland plants (Winter et al., 2011), soils (Barrera-Bassols & Zinck, 2003), landscapes (Kernecker et al., 2017) and landscape change (Bürgi et al., 2007) can be used in their management decisions. Furthermore, land users' relationships with each other could allow them to use their biodiversity knowledge for collaborative practices (Nilsson et al., 2019). Incorporating land users' ecological and social knowledge for landscape research and management is particularly relevant since land ownership and management generally have stringent socially constructed boundaries, but biodiversity–yield patterns in TZ go beyond them (e.g. Fazey et al.,

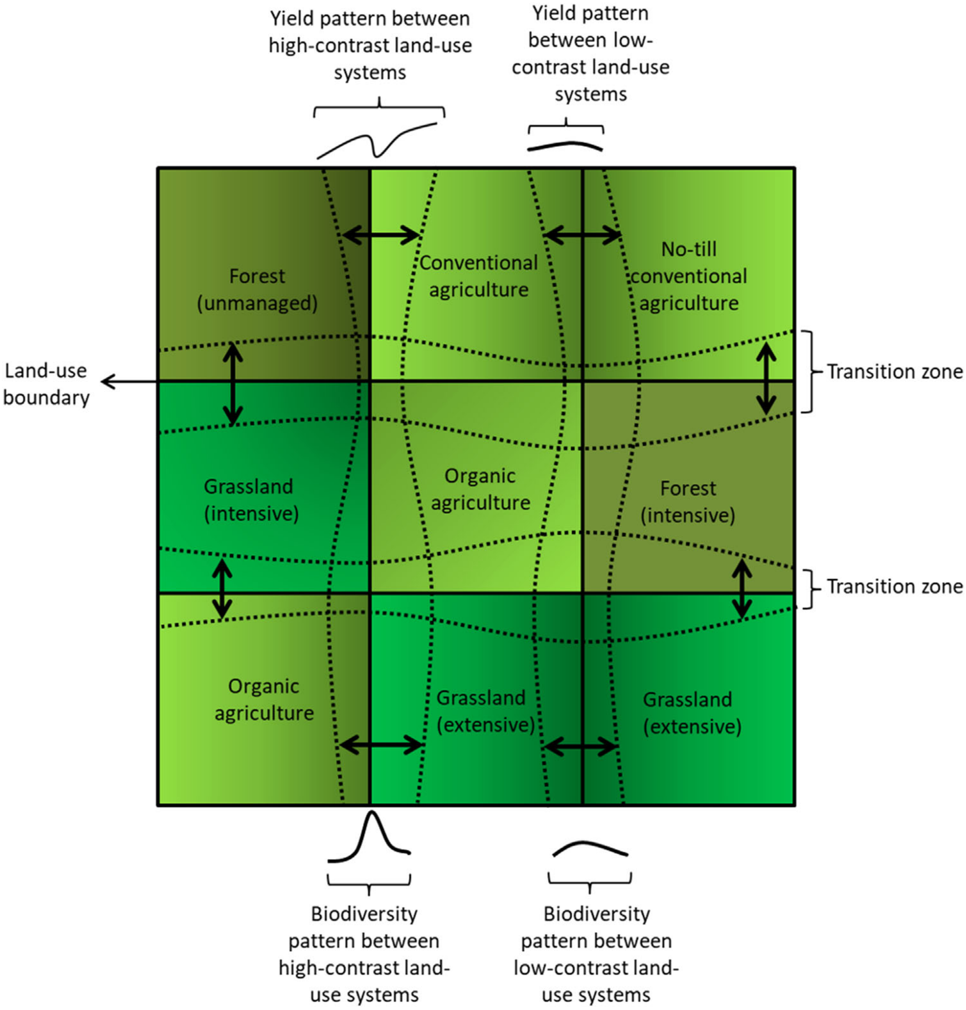

FIGURE 2 Simplified conceptualization of land-use interactions via transition zones (TZ) in an agricultural landscape. Each square represents a land-use system (field, patch), and the dotted lines represent the extent of TZ, within which varying gradients of biodiversity and yield exist, depending on the land-use systems interacting. Original figure by M. Kernecker

2013). If biodiversity and yield spillovers in TZ were clearer for both land users and scientists, opportunities for mutual benefits between land users would become more apparent—particularly by using transdisciplinary research processes (e.g. Mauser et al., 2013).

4 | CONSIDERING TZ EFFECTS CAN PREVENT LAND-USE CONFLICTS AND SUPPORT COLLABORATIVE LANDSCAPE MANAGEMENT

If land users and scientists recognize how TZ can be used to manage landscapes for biodiversity and yield synergies, conflicts between neighbouring land-use systems might be prevented. Most studies regarding land-use conflicts in agricultural landscapes are concerned with agricultural and non-agricultural land uses competing for the same land (e.g. Gottero, 2019), and not necessarily with TZ (but see Bethwell et al., 2017). However, TZ are likely to attract conflicts as they usually involve neighbouring land users with diverging interests (Figure 2; Dahrendorf, 1959). Negative spillovers (e.g. pesticide drift) in TZ can highlight incompatible goals of land users. The land user affected by the spillover will have an interest in changing the neighbouring land use, while the land user causing the spillover has an interest in maintaining the status quo. Since conflicts essentially arise because of perceived uneven trade-offs resulting from certain land uses (e.g. Peltonen & Sairinen, 2010), knowledge about TZ effects may objectify conflicts. Furthermore, considering TZ prior to a land-use change in a field or patch could prevent potential conflicts with land users of neighbouring fields or patches. Therefore, conflicts can serve as indicators for detecting negative TZ effects and inefficient interactions between land-use systems and power imbalances within an agricultural landscape (Mann & Jeanneaux, 2009).

Existing conflicts can undermine joint TZ research and management efforts, and therefore may need to be considered for effective collaboration to harmonize different land users' interests (e.g., Koontz & Newig, 2014). Collaborative landscape research and management takes into account ecological, economic and social considerations of diverse land users, while creating a space for knowledge exchange and learning. Consequently, new ideas for synergies to biodiversity conservation and yield production in TZ can be promoted by strengthening actors' relationships and resource sharing across land-use boundaries (Zscheischler et al., 2019). Some ideas include adapting land use and management to TZ, by planting grass (Pywell et al., 2015) or flower strips (Albrecht et al., 2020), or co-designing other practices for mitigating the use of inputs. While there are many case studies on collective actions for natural common pool resources (Ostrom et al., 1990), studies of collaborative management in TZ are lacking. Additionally, descriptions on how to initiate and build up new collaborations across TZ are uncommon. Transdisciplinary research could explore how collaborative landscape approaches can be designed to promote socio-ecological synergies that favour biodiversity and yields and minimize unintended conflicts in TZ.

5 | CONCLUSION

In this perspective, we provide a transdisciplinary lens for studying social–ecological interactions in TZ that shape biodiversity and yield outcomes in landscapes. We outline three broad research areas related to TZ that can contribute to integrated landscape approaches in science and practice. We touch upon several directions for future work: (i) disentangling the mechanisms of how landscape structure controls the relative effect of TZ density and quality on biodiversity and yields; (ii) delineating species and trait-specific TZ areas; (iii) quantifying yield losses or gains in TZ linked to biodiversity and microclimate; (iv) including land-users' knowledge of TZ and their management in research; (v) identifying what conflicts between neighbouring land-use systems can tell us about biodiversity–yield relationships in TZ and (vi) creating examples of how collaborative, transdisciplinary landscape research and management in TZ may or may not work for biodiversity–yield synergies. In sum, this may create an integrative approach to thinking about and managing agricultural landscapes.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

MK conceived the idea of the manuscript, designed methodology and led the writing of the manuscript. All authors contributed to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

This manuscript does not include any data.

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