Biological Conservation 218 (2018) 247–253

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Relationships between multiple biodiversity components and ecosystem services along a landscape complexity gradient

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ARTICLE INFO

Keywords:
Biodiversity loss
Landscape complexity
Multidiversity
Multifunctionality
Synergies
Trade-offs

ABSTRACT

The assessment of effects of anthropogenic disturbance on biodiversity (BD) and ecosystem services (ES) and their relationships are key priorities of the Intergovernmental Panel for Biodiversity and Ecosystem Services. Agricultural landscapes and their associated BD provide multiple ES and it is crucial to understand how relationships between ES and BD components change along gradients of landscape complexity. In this study, we related eight ES potentials to the species richness of five invertebrate, vertebrate and plant taxonomic groups in cereal farming systems. The landscape complexity gradient ranged from areas dominated by annually tilled arable land to areas with high proportions of unfertilized, non-rotational pastures and uncultivated field borders. We show that after accounting for landscape complexity relationships between yield and bird richness or biological control became more positive, but relationships between bird richness and biological control became less positive. The relationship between bird and plant richness turned from positive to negative. Multidiversity (overall biodiversity), was positively related to landscape complexity, whereas multifunctionality (overall ES provision), was not significantly related to either one of these. Our results suggest that multidiversity can be promoted by increasing landscape complexity; however; we found no support for a simultaneous increase of several individual ES, BD components or multifunctionality. These results challenge the assumption that biodiversity-friendly landscape management will always simultaneously promote multiple ES in agricultural landscapes. Future studies need to verify this pattern by using multi-year data, larger sets of ES and BD components and a study design that is appropriate to address larger spatial scales and relationships in several regions.

1. Introduction

A major aim of the Intergovernmental Panel for Biodiversity and Ecosystem Services (IPBES) is the assessment of biodiversity, the provisioning of ecosystem services, and the relationships between them. Agricultural fields cover more than one third of the global land area (FAOSTAT, 2015), harbour high levels of biodiversity (Macdonald and Feber, 2015) and provide important benefits to human societies ("ecosystem services" hereafter ES, Power, 2010). Several synergistic relationships between ES or between ES and BD have previously been documented (for review see Bennett et al., 2009, Huang et al., 2015, Lee and Lautenbach, 2016). However, trade-offs between ES may

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https://doi.org/10.1016/j.biocon.2017.12.027
Received 8 August 2017; Received in revised form 30 November 2017; Accepted 22 December 2017

generally be more common than such synergies (Howe et al., 2014). The relationships between ES or BD components could change along landscape gradients (Turkelboom et al., 2015), but this context dependency has only recently received attention (Cordingley et al., 2016; Tomscha and Gergel, 2016).

The ongoing loss of biodiversity due to agricultural intensification (Allan et al., 2014; Tsiafouli et al., 2015) is often associated with a decline in ES delivery (Cardinale et al., 2012; Naeem et al., 2012) and the maintenance of high BD and ES supply has been highlighted as a priority for future conservation projects (Cimon-Morin et al., 2013). The most comprehensive evidence for such relationships between single ES and BD components is based on meta-analyses (Cardinale et al., 2006; Balvanera et al., 2006; Howe et al., 2014; Lefcheck et al., 2015). Empirical studies that address the relationships between multi-taxon biodiversity (hereafter multidiversity) and the simultaneous provision of multiple ES (hereafter multifunctionality) in a land-use context are rare (Allan et al., 2015; Jing et al., 2015). Such studies, however, are crucial to understand if multidiversity and multifunctionality can be managed simultaneously (Duncan et al., 2015). Drivers of multidiversity and multifunctionality can be assessed by using indices that combine the diversity of multiple taxonomic groups and a range of individual ecosystem functions or services. Using these approaches, it has been shown that local land-use change affects multifunctionality (Allan et al., 2015) and multidiversity (Allan et al., 2014), but simultaneous effects of landscape changes on multidiversity and multifunctionality are not known.

Agricultural land-use and associated landscape changes affect both the diversity of biotic communities and the provision of ES (Tscharntke et al., 2005). In particular, landscape management that aims for structurally complex agricultural landscapes, for example by promoting high proportions of semi-natural habitats, enhances the species richness of several taxonomic groups (Duru et al., 2015) which in turn may benefit a range of ES (Tscharntke et al., 2005, but see Kleijn et al., 2015). Given the known effects of landscape complexity on individual ES or BD components, it is likely that landscape changes also alter the relationship between multiple ES and biodiversity (Cordingley et al., 2016). However, studies that relate multidiversity and multifunctionality in a land-use context are rare (Lefcheck et al., 2015). To our knowledge, there is only a single study that has related multidiversity and multifunctionality to local, plot-level land-use intensity. Allan et al. (2015) demonstrated that local land-use intensification affected grassland multifunctionality negatively, both by directly reducing levels of ecosystem functions and indirectly via species losses. This knowledge gap may be of particular importance in agricultural landscapes, as recent emphasize is given on the need to re-design these areas to simultaneously promote biodiversity and related ecosystem services (Landis, 2017).

Here we relate eight ES potentials (“potential” defined as the ability of landscapes to deliver an ES) spread across supporting, regulating, cultural and provisioning ES (Millennium Ecosystem Assessment, 2005) and the diversity of five taxonomic groups (641 plant, vertebrate and invertebrate species) to each other before and after accounting for a landscape complexity gradient in agricultural landscapes in southern Sweden. The gradient describes landscapes that range from areas dominated by annually tilled arable land to areas with high proportions of unfertilized, non-rotational pastures and uncultivated field borders. To address the role of landscape complexity, we first compared pairwise relationships between all ES potentials and BD components before and after accounting for the landscape complexity gradient. We hypothesized that pairwise correlations between ES potentials and BD components are generally driven by shared relationships to landscape complexity instead of correlations between landscape complexity and very few individual ES potentials or BD components (H1: pairwise relationships). We further hypothesized that individual BD components and ES potentials are consistently related to each other across all landscapes (H2: bundles). We thereafter related indices of multifunctionality and multidiversity to each other and to landscape complexity. Here, we hypothesized that multidiversity is positively related to landscape complexity, but that multifunctionality shows a weaker relationship to landscape complexity due to ES potentials that are negatively or not related to biodiversity (H3: multi-diversity and functionality). Ultimately, we expect to gain a better understanding of the modulating effect of landscape complexity on the relationship between multiple BD components and ES potentials in agricultural landscapes. This knowledge will contribute to the development of improved strategies that simultaneously promote subsets of ES and BD components via landscape management.

2. Methods

2.1. Study sites

Ecosystem service potentials (Table 1a) and biodiversity components (Table 1b) were quantified within 1 km radius landscapes centred around 33 conventional cereal farms in the province of Scania, southern Sweden during spring and summer 2011. This scale was chosen to facilitate the selection of study landscapes along a pre-defined landscape complexity gradient in the study design (see next section) and because several of the studied organism groups are known to respond to landscape characteristics at a 1 km scale (e.g. beetles & spiders: Rusch et al., 2014, plants: Rader et al., 2014). The scale of heterogeneity is however related to the mobility of organisms (see for example Fig. 4.1 in Smith et al., 2014) and our results therefore need to be interpreted given the choice of a single scale to assess landscape complexity. This study used landscapes with farms that cultivated spring barley (*Hordeum vulgare* L.) as it was possible to find this crop across a large gradient of landscape complexity. Several ES potentials in this study are relevant in barley fields (e.g. biological control or nutrient storage), whereas other ES potentials act at larger spatial scales (e.g. the provision of hunting opportunities). Some taxonomic groups and ES potentials were therefore studied within a focal spring barley field in each landscape (field scale, Table 1) whereas others were studied in replicated locations within the 1 km radius around the field (farm scale, Table 1). Ecosystem service potentials provide proxy values for the provision of eight ES linked to supporting (soil organic carbon, total nitrogen and plant-available phosphorous), regulating (pollination and biological control), cultural (hunting and conservation potential) and provisioning (yield) ES (Table 1). Taxonomic groups included invertebrates (80 spider, 137 beetle and 30 hoverfly species), vertebrates (95 bird species) and plants (309 species) that reflect major trophic groups (predators, herbivores, autotrophs). Details for each method to quantify ES potentials and BD components are provided in Table 1 and Appendix S1 in Supporting information.

2.2. Landscape complexity

Areas in the study region were characterized by a landscape complexity gradient ranging from homogeneous areas dominated by large arable fields to a heterogeneous mixture of land uses typically including semi-natural grasslands and small fields and thus a larger area of field borders. Landscape complexity was defined based on the amount of semi-natural pastures (permanent, unfertilized grasslands) and field borders in the landscape. Since these variables are highly correlated in the study region (Persson et al., 2010), they were combined into a composite variable expressed on a reference scale of the amount of these land uses in the whole study region. The reference scale encompasses 80% of all landscapes in the productive farming region of Scania (all landscapes with > 40% farmland) and was used to select study landscapes that captured the full range of landscape complexity within this constraint. It was defined as the first axis (PC1) of a principal component analysis (PCA) on the proportion of pasture (square-root transformed) and the areal proportion of field borders (width of