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Homogenizing and diversifying effects of intensive agricultural land-use on plant species beta diversity in Central Europe — A call to adapt our conservation measures

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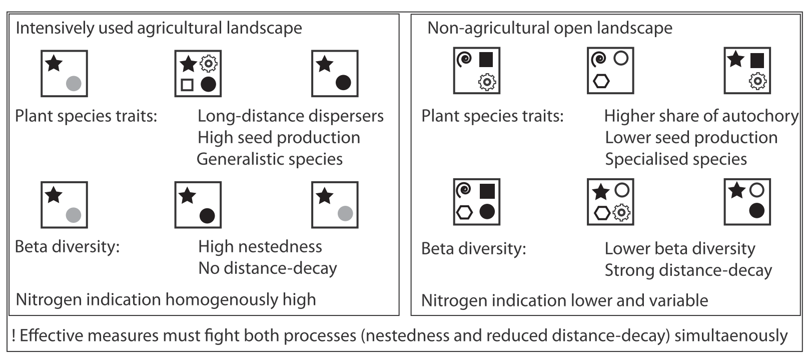
HIGHLIGHTS

- Processes responsible for species loss under intense agriculture are specified.
- Plant species trait filtering lead to species nestedness and loss of distance decay.
- Processes were induced by selection for generalist species and good dispersers.
- N indicator values show eutrophication and homogenization under intense agriculture.
- Action to combat phytodiversity loss must address both processes simultaneously.

GRAPHICAL ABSTRACT



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ABSTRACT

The prevention of biodiversity loss in agricultural landscapes to protect ecosystem stability and functions is of major importance to stabilize overall diversity. Intense agriculture leads to a loss in species richness and homogenization of species pools, but the processes behind are poorly understood due to a lack of systematic case studies: The specific impacts by agriculture in contrast to other land-use creating open habitat are not studied as such landscapes hardly exist in temperate regions.
Applying systematic grids, we compared the plant species distribution at the landscape scale between an active military training areas in Europe and an adjacent rather intensively used agricultural landscape. As the study areas differ mainly in the type of disturbance regime (agricultural vs. non-agricultural), differences in species pattern can be traced back more or less directly to the management. Species trait analyses and multiple measures of beta diversity were applied to differentiate between species similarities between plots, distance-decay, or nestedness.
Contrary to our expectation, overall beta diversity in the agricultural area was not reduced but increased under agricultural. This was probably the result of species nestedness due to fragmentation. The natural process of

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increasing dissimilarity with distance (distance-decay) was suppressed by intense agricultural land-use, generalist and long-distance dispersers gained importance, while rare species lost continuity.
There are two independent processes that need to be addressed separately to halt biodiversity loss in agricultural land. There is a need to conserve semi-natural open habitat patches of diverse size to favor poor dispersers and specialist species. At the same time, we stress the importance of mediating biotic homogenization caused by the decrease of distance-decay: The spread of long-distance dispersers in agricultural fields may be acceptable, however, optimized fertilizer input and erosion control are needed to stop the homogenization of environmental gradients due to nitrogen input into semi-natural habitat.

1. Introduction

Halting biodiversity loss is a central goal of world-wide conservation efforts (Convention on Biological Diversity, 2010) and is incorporated into European legislation within the Biodiversity Strategy to 2020 (European Commission, 2011). Over 45% of the European landscape is under agricultural use creating considerable need to protect species richness in cultural landscapes to halt overall biodiversity loss (Kleijn et al., 2011; Tscharntke et al., 2005). Land-use intensification has been found to be a major driver of the loss of biodiversity (Clavel et al., 2011; Foley, 2005; Sala et al., 2000) and ecosystem functions (Allan et al., 2015; Isbell et al., 2011; Isbell et al., 2013; Isbell et al., 2015; Rader et al., 2014). However, land-use intensification seems necessary to sustain food production for the increasing global human population (Tilman et al., 2011; Tscharntke et al., 2012a). What will a semi-intensively or intensively managed landscape look like if phytodiversity is to be conserved? Under intensive agricultural use, homogenizing effects on functional, taxonomic and genetic diversity occur (Olden et al., 2004) and are accompanied with habitat loss for specialised species (Foley, 2005; Meyer et al., 2013). Due to a lack of systematic studies linking species composition, pattern and trait analyses at the within-landscape scale, there is a large uncertainty regarding the processed responsible for species loss and reductions in diversity.

Phytodiversity of a landscape (gamma diversity) is strongly dependent on the extent of change in species composition between different land-use patches (beta diversity) within the landscape (Jurasinski et al., 2009; Tscharntke et al., 2012b; Whittaker, 1972). On the one hand, such dissimilarity in species composition between land-use patches is typically high in heterogeneous landscapes and decreases if the landscape is homogenized and simplified as under intense agricultural use (Benton et al., 2003; Gámez-Virués et al., 2015). On the other hand, dissimilarity in species composition between single land-use patches is also known to increase with rising geographical distance of the samples to each other (distance-decay effects; Nekola and White, 1999; Soininen et al., 2007). Distance-decay of species composition exists because larger similarity of environmental conditions tends to exist in closer vicinity than when located further away, thus affecting species sorting according to their particular niches. Secondly, distance-decay in species composition occurs because species dispersal potential declines considerably with greater distance. This is either due to dispersal barriers like forest patches that limit dispersal or due to neutral processes based on lower propagule pressure at larger distances than in nearby areas (Soininen et al., 2007). Intensive agricultural land-use might affect both factors negatively (reducing both environmental gradients and dispersal limitations) and might, thereby, lead to a decrease in distance-decay as compared to other landscapes. First, environmental gradients may weaken or disappear because intense agricultural land-use creates relatively large patches of homogenously treated land (fertilized, ploughed, treated with pesticides). This homogenization of environmental conditions favors generalist species with a wide physiological amplitude. These are mostly ruderal species that are able to live and reproduce successfully under various environmental conditions (Ekroos et al., 2010) making environmental gradients less important for species sorting processes (Clavel et al., 2011). Secondly, the reduction of dispersal limitations may happen because dispersal barriers like hedges disappear from the intensively used landscape (Benton et al., 2003; Ekroos et al., 2010). Furthermore, intense agricultural disturbance may select for species capable of long-distance dispersal. Species with effective long distance dispersal may quickly re-establish on intensively managed land from distant seed sources after heavy disturbance. In contrast, poor dispersers may suffer from fragmentation under intense agricultural land-use, as they survive only in remaining habitat fragments or disappear altogether (Ekroos et al., 2010; Gámez-Virués et al., 2015). Accordingly, specialist species (with narrow physiological niche width) that have low dispersal capacity – usually rare species - are disappearing from the landscape or suffer from fragmentation while strong dispersers as most generalist species become omnipresent (Henle et al., 2004; Meyer et al., 2013; Ozinga et al., 2005; Schweiger et al., 2005).

The process by which plant communities become more and more similar within larger areas is known as biotic homogenization (Olden and Rooney, 2006), and may be coupled with a decline in ecosystem functions and services (Clavel et al., 2011; Rader et al., 2014; Tscharntke et al., 2012a).

Previous work demonstrated higher similarity of plant communities or biotic homogenization between areas dominated by very strong land-use intensity over large distances across Europe (Dormann et al., 2007). For grasslands, a homogenizing trend, mainly due to high nitrogen input, has been demonstrated over Central Europe (Wesche et al., 2012) and within Switzerland (Bühler and Roth, 2011). However, the homogenizing role of semi-intense or intense agricultural land-use within open landscapes has never been compared with non-agricultural open landscapes. This may be because Central European landscapes tend to be realty affected by agricultural land-use and it is difficult to find adjacent landscapes that differ significantly in their disturbance regime (agricultural versus non-agricultural) but not in other fundamental characteristics.

Some existing studies indirectly approached the problem by sampling land-use intensity gradients (Kleyer, 1999; Meyer et al., 2013). In contrast, the present study directly utilizes the potential provided by one of the largest military training areas in Europe, thus enabling the comparison of adjacent open landscapes with very similar environmental characteristics but entirely differing disturbance regime and history. In addition, our study includes the monitoring of complete plant species identities on 1 ha plots which is larger than the size of typical land-use patches. Though this was very time consuming, it makes our dataset unique, as it allows not only differences between patches, but also landscape sections. Measures of beta diversity are explained according to species trait analyses at the within-landscape scale:

Our objectives are to disentangle processes of biotic homogenization, fragmentation and species distance-decay in similarity under the influence of agricultural land-use. The species trait analyses provide evidence sufficient to analyze if long-distance dispersers, generalists and nitrogen indicators are promoted under agricultural land-use as compared to non-agricultural use (military management coupled with semi-natural disturbances) and how this reflects the spatial patterns of species occurrence in the landscape. The understanding of the processes leading to species sorting and species loss are crucial to evaluate