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Organic farming supports spatiotemporal stability in species richness of bumblebees and butterflies

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ABSTRACT

The spatiotemporal stability of wild organisms, such as flower-visiting insects, is critical to guarantee high levels of biodiversity in agroecosystems. Whereas the proportion of semi-natural habitats in the landscapes has been shown to stabilize the species richness of flower visitors, the effect of farming intensity has not yet been studied. In this study, we compared the temporal and spatial stability (continuity of species richness in space and time) of two groups of flower-visiting insects (butterflies and bumblebees) between nine conventional and ten organic farms, distributed along a gradient of semi-natural grassland proportion. We surveyed bumblebees, butterflies and local flower cover during the growing season, covering multiple years and several habitat types per farm (cereal fields, temporary grasslands and semi-natural grasslands). At the field scale we found that within-year stability of bumblebee species richness was higher in organic than in conventional temporary grasslands (leys), because of a higher continuity of in-field flower resources. Further analyses showed that late-season flower resources in organic ley fields were critical to maintain a high within-year stability of bumblebee species richness by reducing resource bottlenecks during that period, when most bumblebee colonies produce new queens. The among-year stability of bumblebee species richness was higher in organic than in conventional cereal fields, whereas the within and among-year stability of butterfly species richness was not influenced by farming system. On the farm scale, we found that the spatial stability of butterfly and bumblebee species richness was higher in organic than in conventional farms, but this was not explained by a greater spatial continuity of flower resources. Our study shows that organic farming reduces the spatiotemporal fluctuations in bumblebee and butterfly species richness. In addition, increasing floral resources as such benefits bumblebees and butterflies irrespective of farming system. Organic farming and increasing availability in floral resources therefore contribute to maintaining the within and between-year stability of bumblebees and butterflies in agricultural landscapes.

1. Introduction

Biodiversity in agroecosystems has declined significantly during the last four decades, mainly caused by the intensification of agricultural practices and loss of semi-natural habitats (Biesmeijer et al., 2006; Bommarco et al., 2011; Robinson and Sutherland, 2002; Tilman, 1999). The loss of undisturbed, non-cropped habitats in agricultural landscapes has reduced the availability of shelters, nesting sites and food resources for farmland species (Hendrickx et al., 2007; Tscharntke et al., 2012). The in-field intensification of agriculture can disturb the establishment and persistence of diverse communities by creating large resource-poor areas, disrupting crucial ecological processes such as dispersion or landscape complementation (Henckel et al., 2015; Tscharntke et al., 2012; Vasseur et al., 2013).

These two drivers of biodiversity loss are particularly important for flower-visiting insects such as butterflies and bumblebees, as these two taxa depend to a large extent on flower resources provided by multiple habitats in mosaic landscapes (Ekroos et al., 2016; Gathmann and Tscharntke, 2002; Öckinger and Smith, 2007). In particular, they rely on semi-natural habitats such as permanent grasslands (Hopfenmüller et al., 2014; Öckinger and Smith, 2007; Svensson et al., 2000). Bumblebees and butterflies are interesting to consider because they can utilize spatially scattered resources in agricultural landscapes, altered by landscape structure and agricultural management (Halder et al., 2017; Holzschuh et al., 2016; Jönsson et al., 2015) and they are relatively easy to monitor. However, little is known about how farming intensity and landscape structure independently and jointly affect resource availability and spatiotemporal stability in species richness of

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flower-visiting insects.

Agricultural landscapes are highly dynamic, because of rapid changes in resource availability (crop rotation, seasonal peak of mass flowering crops or weeds) and frequent disturbances due to farm management (pesticide spraying, harvest) (Schellhorn et al., 2015; Vasseur et al., 2013). Therefore, local or periodical shortage of resources can prevent species from completing their life cycle (Schellhorn et al., 2015), endangering the maintenance of diverse flower visitor communities. Hence, the spatiotemporal discontinuity of floral resources is expected to lead to declines or local extinctions of bumblebee and butterfly species and consequently to high temporal fluctuations in their diversity (Garibaldi et al., 2011). As the spatiotemporal stability of insect communities (continuity in their community structure in space and time; Lehman and Tilman, 2000) can be an essential component of the stability of ecosystem functioning (Garibaldi et al., 2011; Klein, 2009; Kremen et al., 2004), there is a need to understand the factors affecting their landscape-scale and long-term persistence.

Increasing the proportion of semi-natural habitats in agricultural landscapes has been shown to enhance spatiotemporal stability of flower visitor species richness at the field scale and along the growing season (Garibaldi et al., 2011). However, it still unknown whether the stability of bumblebee and butterfly species richness, measured at the landscape-scale and among several years, also benefit from a reduction in farming intensity. In general, organic farming benefits biodiversity due to the exclusion of pesticides and inorganic fertilizers (Batáry et al., 2011; Lichtenberg et al., 2017; Tuck et al., 2014) and to lower livestock density (Power et al., 2012). As species-rich communities are predicted to display higher stability over time and space (Loreau et al., 2002; Tilman et al., 2006; Weigelt et al., 2008), organic farming can in turn be expected to increase spatiotemporal stability of flower-visiting insect communities in agricultural landscapes. In particular, organic farming has the potential to reduce resource deprivation that flower-visiting insects face in agricultural landscapes by providing more in-field flowering resources (Holzschuh et al., 2008, 2010). As bumblebees commonly experience a lack of floral resources early and late in the growing season (Rundlöf et al., 2014; Westphal et al., 2009), an outstanding question is to determine whether organic farming could contribute to maintaining the persistence of flower visitors by reducing such resource bottlenecks. Hence, by reducing in-field management intensity, organic farming could enhance the long-term persistence of flower visitor communities in agricultural landscapes.

The aim of this study was to explore the influence of farming intensity (organic vs. conventional farming) on the spatial (landscape-scale) and temporal (among-year and within-year) stability of bumblebee and butterfly species richness, while controlling for effects caused by landscape context. In particular, we explored if increased spatiotemporal stability of bumblebee and butterfly species richness could be explained by increased spatiotemporal continuity of flower resources. We tested the following hypotheses: (1) organic farms increase the spatiotemporal stability of flower resources, bumblebee and butterfly species richness compared with conventional farms; (2) the higher spatiotemporal stability in bumblebee and butterfly species richness in organic farms can be explained by higher spatiotemporal continuity of flower resources; and (3) early and late-season flower resources are more abundant in organic farms, which contributes to maintaining high flower-visitor species richness during those critical periods.

2. Materials and methods

2.1. Site selection and biodiversity sampling

The study was conducted during 2015–2017 in Scania, in southern Sweden (Fig. 1). This region is dominated by agricultural landscapes, but with large variations in terms of structural complexity (semi-natural grasslands, forests) and farming intensity within a relatively small region (Persson et al., 2010). The majority of the land is covered by arable crops (mean = 45%) and by grasslands (mean = 20%) with relatively large fields (mean = 12 ha), with low tree cover (forests, hedgerows), especially in the southwest part of the region (Persson et al., 2010).

Based on land use data obtained from the Integrated Administrative and Control System database (IACS, Blockdatabasen), 19 farms (10 organic, 9 conventional) were selected along a gradient of percentage of semi-natural grasslands within a radius of 1 km around the farm center (Fig. 1).

Surveys were conducted during 2015–2017 for butterflies and flower resources, and during 2016–2017 for bumblebees. Sampling periods were between 20th May to 7th August in 2015, 13th May to 14th August in 2016 and 18th May to 24th August in 2017. On each farm, three habitat types were sampled, consisting of a cereal field, a ley field (rotational, sown and improved temporary grassland, usually mown but sometimes grazed) and a semi-natural grassland (c.f. Hodgson et al., 2010). These three habitat types represent the major land use in farms as well as a major land-use intensity gradient in the region (Persson et al., 2010). The three habitat types were sampled five times within each growing season. Due to crop rotation, some cereal and ley fields changed location among years within the sampled farms. Each survey round was separated by approximately two weeks. In each site (i.e. habitat type) per farm, flower and insect surveys were conducted on two transects of 100 m (one along the border of the habitat and one within the habitat). The transects were placed as far away from neighboring mass-flowering crops as possible, since they might influence local abundance of flower visitors (Holzschuh et al., 2016). Transects were placed in the most flower-rich parts of the site to maximize sample size in each site. Each transect was surveyed only under sufficiently good weather conditions during warm ($\geq +15\,^{\circ}\mathrm{C}$) and sunny days, when wind speed did not exceed 4 on the Beaufort Scale. Transects were surveyed by slowly walking along them during 10 min. Bumblebee and butterfly individuals were recorded in a 2 m-sector along the transect (1 m on both sides of the observer, 200 m^2 transect) and were identified to species levels on the field. We treated *Bombus lucorum* (*s.l.*) and *Bombus terrestris* as one species because they are often impossible to identify in the field. Flowering plants were surveyed along the same transects, but within a 1 m-sector (0.5 m on both sides of the observer, 100 m^2 transect) and were identified to species level. Total flower cover was recorded using a cover scale accounting for the percentage cover of flower corollas per ground surface area (1: < 2%; 2: < 6%; 3: < 10%; 4: < 20%; 5: < 25%; 6: > 25%). In the border and inside of each sites, an additional free transect walk was conducted for an extra 5 min to record extra individuals of bumblebees and butterflies. For this study we only considered the transects situated within the three habitat types.

2.2. Landscape variables

Around each sampling site, the proportion of semi-natural grasslands was calculated using the IACS database, within a buffer of 1 km radius centered on the centroid of the sampling site. To analyze the effect of landscape context on the spatial stability of floral resources and flower-visitor species richness, landscape context in each farm was quantified by averaging the proportion of semi-natural grasslands over the three sites. Similarly, to analyze the effect of landscape context on the long-term temporal stability of flower and flower-visitor species richness, landscape context around each habitat type (cereal, ley and semi-natural grassland) was quantified by averaging the proportion of semi-natural grasslands over the three years. The proportion of semi-natural grasslands around the sampling sites ranged from 1% to 18% and was not associated with farming system (Kruskal-Wallis $\chi = 0.69$, $P = 0.40$).