



Original Articles

Bee diversity in crop fields is influenced by remotely-sensed nesting resources in surrounding permanent grasslands

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ABSTRACT

Landscape heterogeneity is an important driver of biodiversity in agroecosystems. However, the functional heterogeneity of agricultural landscapes, taking into account the different resources that habitat patches can provide to species, has rarely been studied. In this study, we explored the effect of landscape-scale nest availability provided by permanent grasslands on wild bee communities. Wild bees were sampled in 43 cereal fields in south-western France differing in the surrounding proportion of permanent grasslands. Using remote sensing tools, we measured two parameters of grassland structure known to locally influence bee nest density (slope and proportion of sparse vegetation). We found that mean slope of surrounding grasslands was the factor that most positively influenced bee richness, abundance and trait distribution in bee communities. We also found that mean slope of surrounding grasslands had a better predictive power of bee community structure than the proportion of permanent grasslands. Ground-nesting species, species with high dispersal capacities and species with a generalist diet were positively affected by the availability of sloped ground in the surrounding permanent grasslands. Only bee species with specialized flower requirements responded positively to the proportion of sparse vegetation in grasslands. Our results suggest that landscape-scale availability of nesting resources provided by grasslands affects bee communities in agricultural landscapes and can help sustain functionally diverse bee assemblages. Using simple remote sensing tools, this study highlights the importance of considering nesting resources in agricultural landscapes to maintain wild bee diversity in farmlands.

1. Introduction

Wild bees are key providers of pollination services (Garibaldi et al., 2013; Klein et al., 2007) and the conservation of wild bee assemblages in agroecosystems is therefore a critical issue. However, these pollinators are threatened throughout western countries, due to the degradation and loss of habitats (Biesmeijer et al., 2006; Potts et al., 2010). To reverse this decline, new strategies based upon habitat management in agricultural landscapes are needed (Kremen, 2005; Kremen et al., 2007). Permanent grasslands are crucial habitats for bees in agricultural landscapes as they can provide both floral resources and nesting sites (Gámez-Virués et al., 2015; Hopfenmüller et al., 2014; Steffan-Dewenter and Tschamtkke, 1999). Moreover, due to the stability of these resources over time in comparison to annual crops, permanent grasslands can act as a source of bee populations in agricultural landscapes (Hopfenmüller et al., 2014; Steffan-Dewenter et al., 2002; Steffan-Dewenter and Tschamtkke, 1999). However, the quality and quantity of resources provided by permanent grasslands depend on management intensity, soil type and ground topography. Indeed, frequently mown,

grazed or fertilized grasslands often have reduced floral diversity (Blüthgen et al., 2012), which can in turn negatively influence local bee communities (Gámez-Virués et al., 2015). In grasslands, ground structure, such as slopes, ground texture and proportion of bare ground have also been shown to influence local nest density for ground-nesting bees in those habitats (Hopfenmüller et al., 2014; Potts and Willmer, 1997; Potts et al., 2005). A change in the availability of these resources provided by permanent grasslands would therefore have important implications for wild bees visiting crop fields.

Habitat quality is often characterized locally in bee studies but rarely assessed at the landscape scale (Holzschuh et al., 2007; Hopfenmüller et al., 2014; Kim et al., 2006). In the few studies assessing the effect of resource quality at the landscape scale on pollinator diversity, all patches with the same cover type are considered equal in terms of resource quality, using *a priori* knowledge on species habitat preferences (Perović et al., 2015) or flowering plant surveys (Dainese et al., 2017; Scheper et al., 2015). The variability in the quality of a given cover type among landscapes, due to variations in management intensity, topography or vegetation structure is often overlooked

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(Fischer and Lindenmayer, 2006). As the latter parameters are known to locally influence the availability of critical resources used by bees in semi-natural habitats (Albrecht et al., 2007; Gámez-Virués et al., 2015; Hopfenmüller et al., 2014), there is substantial scope for characterizing the landscape-scale changes in the resources provided by permanent grasslands. In particular, as the majority of wild bees encountered in temperate agricultural landscapes are below-ground nesters (65–75% of the total species pool, Carrié et al., 2017; Le Feon et al., 2013; Steffan-Dewenter et al., 2006), the landscape-scale assessment of nesting resources in grasslands could help to better understand how they can sustain the diversity of crop-visiting wild bees (Holzschuh et al., 2007; Morandin et al., 2007; Steffan-Dewenter and Tschardt, 1999).

However, the assessment of habitat quality over large spatial areas, by field surveys or farmer interviews, is a time-consuming task. Remote sensing is a promising solution to have access to this information over broad geographic areas (Galbraith et al., 2015; Kerr and Ostrovsky, 2003). For example, remotely-sensed habitat diversity in agricultural landscapes, based on vegetation structure, was shown to effectively predict butterfly species richness (Kerr et al., 2001) and bird diversity (Sheeren et al., 2014). However, the ecological application of remote sensing is only possible when an *a priori* knowledge of species habitat requirements is available. In the case of wild bees, steep slopes and areas of bare ground can influence nest densities of below-ground nesters (Potts et al., 2005; Sardiñas and Kremen, 2014). Indeed, bare ground facilitates nest excavation for these species (Potts et al., 2010) and steep slopes can increase solar radiation on exposed slopes compared to flat ground (Hopfenmüller et al., 2014; Potts and Willmer, 1997; Sardiñas and Kremen, 2014). As these two types of ground configuration are easily detected using remote sensing (Kerr and Ostrovsky, 2003), such tools could be used to detect the occurrence of potential nesting sites for bee species over broad areas.

In this study, we first aimed to determine whether the availability of remotely-sensed nesting sites in surrounding permanent grasslands could explain changes in the local diversity of wild bees captured in crop fields. A second objective was to determine whether the two indices of landscape-scale nesting resources in permanent grasslands were better proxies of farmland bee diversity than the proportion of permanent grasslands. We expected that: i) the landscape-scale availability of nesting sites in grasslands (proportion of bare ground and sloped ground) could better explain variations in wild bee diversity than the total proportion of permanent grasslands; ii) the effect of nesting site availability on wild bees would depend on species traits. We indeed expected that below-ground nesters and low dispersing species with specialized flower requirements would be more affected by nesting resource availability than other species.

2. Materials and methods

2.1. Study site and sampling design

This study was conducted in south-western France (Fig. 1a), in the Vallées et Coteaux de Gascogne, which is part of the Long Term Socio-Ecological Research site PYGAR (Pyrénées-Garonne). This hilly region (250–400 m a.s.l.) covers 220 km² (43°17'N, 0°54'E) and is characterized by a mosaic of small woodlands, grasslands and crop fields. The region is dominated by mixed crop-livestock farming systems where permanent grasslands tend to be located on steep slopes and annual crop fields (winter cereals, oilseed rape, maize and sunflower) in the valleys (Choisis et al., 2010). The climate is sub-Atlantic with slight Mediterranean influences (mean annual temperature, 12.5 °C; mean annual precipitation, 750 mm).

Within the studied region, we selected 43 cereal fields (28 in 2013 and 15 in 2014, consisting of wheat and barley fields, Fig. 1b) differing in the proportion of semi-natural habitats within a 500-m buffer centered on the field border. Sites were selected to cover independent gradients of proportions of woodland and permanent grassland, which

are the main semi-natural habitats in the study region. Preselection of sampling sites was based on French agricultural land cover data (for permanent grasslands, Registre Parcellaire Graphique, RPG) and woodland cover data (BD TOPO®, IGN). As the sampling sites were from another sampling procedure, most of the sampling sites were paired and sites from a pair were at least 200 m apart. Each field (hereafter sampling site) was located near a field border that had a grassy margin, at least 100 m from a woodland edge or built area (Fig. 1c). In each sampling site, we established four sampling points: two in the field border, 0.5 m inside the field and 25 m apart from each other, and two in the field interior, 25 m inside the field and parallel to the first sampling points (Fig. 1c). We sampled bees with six pan traps per sampling site (three traps in the border and inside the fields, consisting of colored plastic cups, 15 cm diameter, 7 cm height) placed at the top of four poles (one pole per sampling point), one or two traps per pole. We used three colors of pan traps (white, yellow and blue UV color paint, SparVar® Germany). Traps were 2/3 filled with water, with a small amount of soap (Teepol® Multipurpose detergent) to break surface tension. The poles were designed such that the height was adjustable to the crop canopy (10–120 cm). The traps were placed during two periods of 3 or 4 days (from 22 April to 24 May and from 27 May to 21 June in 2013, and from 17 April to 12 May and from 22 May to 16 June in 2014). Wild bee individuals (solitary and social species) were identified at species level. We excluded honeybees (*Apis mellifera*) from the analyses because the abundance of this managed species is likely to be related to beekeeping rather than a direct effect of landscape context. We also excluded cleptoparasitic bees due to their low abundance in the traps (5 individuals). The number of individuals and the number of species determined for each sampling site represented the sum of all traps (border and interior sampling points) from the two sampling periods conducted in that site.

2.2. Bee traits

Four ecological and life-history traits were chosen according to their implication in the response of wild bees to environmental changes and because of their availability in the literature (Table 1): body size (measured as inter-tregular distance or ITD), sociality, nest location and diet breadth (Williams et al., 2010; Forrest et al., 2015; Kremen and M'Gonigle, 2015). Sources for trait information were the ALARM project database (Settele et al., 2005; Michener, 2000; Gathmann and Tschardt, 2002; Bommarco et al., 2010; Fortel et al., 2014; Forrest et al., 2015). There were no body size values for five taxa, so we measured ITD on at least five female individuals per taxon, and queens were used for eusocial species. Social bees were defined as species that live in colonies characterized by cooperative brood care, therefore including eusocial and primitively social species. Solitary bees were defined as species that care only for their own offspring. We were able to obtain trait values for 57 of 77 species in our data (representing 98.7% of the 2494 sampled individuals). The 20 remaining species were removed from the trait analysis.

2.3. Assessment of nesting resources in permanent grasslands

Using aerial photographs (IGN, 2013), the different land cover types (woodlands, hedgerows, permanent grasslands, built area and crop fields) were mapped within 500-m buffers (hereafter landscapes) centered on the field border transect of each sampling site, using ArcGIS 10.2 (ESRI). This mapping was validated by ground surveys in July 2013 and May 2014.

Our first objective was to detect zones of sparse vegetation (high percentage of bare ground) in permanent grasslands using remote sensing imagery (Fig. 2). First, we isolated grassland polygons that were previously mapped and we removed their margins by using inner buffers of 10 m, to avoid neighboring effects on the number of vegetation classes (extra classes due to the presence of hedgerows, woodland edges

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