Agriculture, Ecosystems and Environment 166 (2013) 94–101

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Solitary bee abundance and species richness in dynamic agricultural landscapes

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ARTICLE INFO

Article history:
Received 17 November 2010
Received in revised form 2 June 2011
Accepted 22 June 2011
Available online 26 July 2011

Keywords:
Crop rotations
Heterogeneity
Landscape context
Mass flowering crops
Wild bees

ABSTRACT

We investigated the influence of the landscape structure on solitary bee abundance and species richness in an agricultural area of western France. We focused on the role of semi-natural habitats, oilseed rape (OSR) and other crops. Our originality was to consider not only the spatial heterogeneity of the crop field mosaic but also its temporal heterogeneity through the crop rotations.

Solitary bees were caught with colored pan traps in 15 margins of OSR fields and 35 margins of non-OSR fields. We found that solitary bee abundance and species richness were higher in margins of OSR fields than in margins of non-OSR fields, showing that early spring-flying species widely use this mass flowering crop. However the high number of rare species in margins of non-OSR fields (21 species recorded exclusively in these margins) highlighted the importance of these margins for the conservation of solitary bee diversity.

The influence of the landscape context on solitary bees showed contrasted results according to the type of margin and the spatial scale. At the finest spatial scale, abundance in margins of OSR fields increased with increasing proportion of non-flowering crops (cereals and temporary grasslands) in the current year. At large spatial scales, solitary bee abundance in margins of non-OSR fields was positively affected by the proportion of long-term grasslands. Moreover, the proportion of fields only sown with cereals during the last 5 years negatively affected abundance and species richness at the large scales whereas the proportion of mixed fields (at least 1 year of grassland in the rotation) had a positive effect on species richness.

We showed that accounting for the cumulative effects of field cover and management through the crop rotations is relevant for studying solitary bee communities. The introduction of less intensive covers, such as temporary grasslands, in cereal rotations positively influences these communities.

1. Introduction

Pollinators provide a crucial ecosystem service through their role in the sexual reproduction of both wild plants and crops (Klein et al., 2007). Bees (Hymenoptera, Apiformes) are known to be the most important group of pollinators worldwide, and their ongoing decline and its potential ecological and economic consequences are therefore of major concern (Biesmeijer et al., 2006; Gallai et al., 2009; Potts et al., 2010). To maintain their populations in a landscape, wild bees require nectar and pollen as food for brood and adults as well as suitable nesting sites (Westrich, 1996). These resources must occur within the foraging range of the species, which ranges from several hundred meters for most solitary bees to a few kilometers for larger species such as bumblebees (*Bombus* spp.) (Gathmann and Tscharntke, 2002; Greenleaf et al., 2007).

A recent large-scale study, carried out on five arthropod taxa in seven European countries, showed that bees are among the most sensitive species to agricultural intensification (Hendrickx et al., 2007). Intensive agriculture negatively affects wild bees for several reasons: crop fields replace suitable habitats while being themselves unsuitable (Klemm, 1996) because of (i) disturbance like harvesting and tillage that impede the nesting of most ground-nesting species (Shuler et al., 2005; Morandin et al., 2007), (ii) fertilizers, herbicides and intensive grazing that reduce floral

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0167-8809/$ – see front matter
doi:10.1016/j.agee.2011.06.020

resources in fields and in their adjacent elements (such as field margins or roadsides) (De Snoo and Van der Poll, 1999; Kleijn and Verbeek, 2000; Hyvönen et al., 2003), (iii) insecticides and other pesticides that induce direct mortality or sublethal effects (Desneux et al., 2007).

At the field scale, the negative effects of intensive farming practices on bees have been demonstrated mostly by comparing organic and conventional agriculture (Morandin and Winston, 2005; Clough et al., 2007; Holzschuh et al., 2007). At the landscape scale, most studies have dealt with the effects of semi-natural habitat area and fragmentation (Steffan-Dewenter and Westphal, 2008). Bee abundance and diversity are typically fostered as the proportion of semi-natural habitats (grasslands, wooded elements as forests and hedgerows, etc.) increases in a given area (Steffan-Dewenter, 2002; Steffan-Dewenter et al., 2002; Sjödin et al., 2008; Le Féon et al., 2010). In landscape-scale studies, cropland is generally considered as a homogeneous unsuitable area for bees, except entomophilous crops, such as oilseed rape (OSR) *Brassica napus*. OSR provides open flowers so that nectar and pollen are readily available to a wide range of flower-visiting insects. Moreover it flowers in early spring when wild flowers are rare in semi-natural habitats. Westphal et al. (2003, 2009) and Herrmann et al. (2007) demonstrated that this crop positively enhance early colony growth in some bumblebee species. Delbrassine and Rasmont (1988) and Calabuig (2000) showed that many solitary bee species are present in OSR fields but little is known about the influence of OSR on the spatial distribution of solitary bees at the landscape scale.

Recently, the heterogeneity of farming practices in arable land has been studied at the landscape scale: Williams and Kremen (2007) and Holzschuh et al. (2008) have shown that bee diversity, abundance and offspring production are enhanced by the proportion of organic *vs*. conventional crop fields. These studies referred to the spatial heterogeneity of the crop field mosaic. On the contrary the link between the temporal heterogeneity of the crop field mosaic and bee communities remains mostly undocumented. In particular, the relationship between the past use of fields and their suitability for bees, or for biodiversity in general, has been poorly investigated. Crop rotation is a traditional farming practice that aims at maintaining soil fertility and preventing the magnified impacts of pathogens, pests or weeds that often occur when a single species is cropped repeatedly. Allowed by increasing use of pesticides and fertilizers, the simplification of crop rotations is synonymous with agricultural intensification (Stoate et al., 2001). The diversification of rotations is thus presented as a possible mean of reducing chemical inputs and enhancing biodiversity in agricultural landscapes (McLaughlin and Mineau, 1995). Positive impacts of the diversification of crop rotations on biodiversity may result from: (i) the direct consequences of the global decrease of chemical inputs on the fauna and flora; (ii) the covers introduced in the rotations that may provide additional food resources or better conditions than intensively managed crops. For example, covers like temporary grasslands or fallows provide relatively stable habitats for the maintenance of wildlife in a landscape (Stoate et al., 2001), and legumes, used for their ability to fix atmospheric nitrogen, are mass flowering resources for flower-visiting insects (Köpke and Nemecek, 2010).

So far, the influence of crop rotations on bee communities has been mostly ignored in the literature. Yet, current bee abundance and diversity may be seen as the result of the cumulative effects of landscape composition over the recent years. In this study, our main hypothesis is that accounting for the recent history of field use, through crop rotations, is relevant to better understand the impact of agricultural intensification on bee communities. We investigated whether the composition and structure of the agricultural landscape affect solitary bee abundance and species richness by testing the following specific hypotheses:

(1) *Role of mass flowering crops*: OSR locally enhances the presence of solitary bees.
(2) *Role of the current landscape*: when considering the landscape composition on the year of sampling, semi-natural habitats (wooded elements and long-term grasslands) have positive effects on solitary bee abundance and species richness whereas crop fields have negative effects.
(3) *Role of crop rotations*: accounting for the recent past use of crop fields allows studying the cumulative effects of field covers on solitary bees. Therefore it provides better or different insights about landscape effects, compared with the standard approach that considers only current land use. Our hypothesis is that rotations with grasslands are associated with greater solitary bee abundance and species richness than cereal-dominated rotations.

In temperate landscapes, authors typically distinguish two groups of wild bees (e.g. Steffan-Dewenter et al., 2002; Winfree et al., 2009): bumblebees (*Bombus* spp.), which are eusocial species, and "solitary bees" (even if different forms of primitive or advanced social behavior exist in some species). We focused on solitary bees for two main reasons: (i) several studies carried out in temperate landscapes have shown that solitary bees are more sensitive to human disturbance than bumblebees because of their more specialized floral or habitat requirements and usually smaller foraging ranges (Steffan-Dewenter et al., 2002; Biesmeijer et al., 2006) and (ii) these species have a low reproductive rate compared to social bees and many other insects (Tepedino and Parker, 1983; Danforth, 1990) so that a small reduction in offspring numbers may have large consequences if it occurs repeatedly over several years.

2. Materials and methods

2.1. Study area

Our study area was a hedgerow network ("bocage") landscape of 10 km east–west by 15 km north–south, located 60 km north of Rennes, Brittany, France (48°36′N, 1°32′W). This area called "Zone-Atelier de Pleine-Fougères" and mainly devoted to milk production is part of the International Long Term Ecological Research (ILTER) sites and French "Zones Ateliers" networks. Our study area was composed of: (i) semi-natural elements: hedgerows, small woodlots, and long-term grasslands; (ii) cropland (cereals – maize, *Zea mays*, wheat, *Triticum aestivum* and barley, *Hordeum vulgare* – and temporary grasslands) that was examined through two approaches, with and without accounting for their land use history over the recent years; (iii) some OSR fields.

2.2. Bee sampling

Solitary bees were sampled in 2007 on 50 field margins, 15 of which were along OSR fields and the 35 others were randomly located among other fields (grasslands or cereals). OSR was a minor crop and those 15 fields were almost all the OSR fields in the study area in 2007. They ranged in size between 0.4 and 4.9 ha with an average of 2.5 ha. A set of three colored pan traps (one yellow, one white and one blue) was placed linearly in random order 2 m from one another in the middle of each field margin. The traps were made of 500 ml plastic bowls (http://www.pro-pac.de/) with the inside sprayed with an UV-reflecting paint. They were mounted on a wooden pole at vegetation height, filled with 400 ml of water with a drop of detergent and then exposed for 24 h following Westphal