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Different response patterns of epigaeic spiders and carabid beetles to varying environmental conditions in fields and semi-natural habitats of an intensively cultivated agricultural landscape

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ABSTRACT

Agricultural intensification has resulted in major losses of biodiversity due to landscape homogenization and an increasing use of agrochemicals. It has often been assumed that associated changes in environmental conditions are impacting composition and diversity of two main ground-dwelling generalist predator taxa, carabid beetles and epigaeic spiders, in similar ways. Here, we test how variations in environmental conditions at local scales (plant diversity and total soil nitrogen, N_{tot}) and landscape-scale (mean patch size) affect species composition, richness and abundance of ground beetles and epigaeic spiders in semi-natural and cultivated habitats of an agricultural landscape. We specifically test the hypotheses that both taxa are more diverse in semi-natural than cultivated habitats, but that due to their weaker dispersal ability, ground beetles are more strongly linked to local factors than spiders. Our results indicate that in our study area, carabid diversity shows no significant difference between semi-natural habitats and cropland, while spider abundance is significantly enhanced in semi-natural habitats. N_{tot} significantly affected carabid species richness and abundance, but had a limited influence on spider abundances. The species composition of both carabids and spiders was influenced by plant diversity, while N_{tot} played a significant role in determining spider assemblages but not carabid composition. There was no significant effect of the mean patch size in the surroundings landscape on either spider or carabid species. Nonetheless, in landscapes with small patch sizes, spider abundance decreased with increasing N_{tot}, while in landscapes with large sized patches, this relationship was reversed. The differences in responses of these taxa to local and landscape-scale environmental factors suggests that scale- and taxon-specific targets need to be established to improve the efficiency of measures aimed at enhancing ecosystem services provisions by these key pest control agents.

1. Introduction

Agricultural biodiversity has greatly suffered due to intensification of agricultural practices (Grez et al., 2008; Tscharntke et al., 2012a; Perrings and Halkos, 2015). Apart from direct effects associated with agro-chemical applications linked with these practices, arthropod communities are further influenced by additional environmental drivers like plant diversity and vegetation structure, general habitat type and management, as well as the overall landscape configuration – that all act on distinctly different spatial scales (Horvath et al., 2015).

A species-rich vegetation can potentially support a large number of specialized herbivores (Siemann et al., 1998), in turn supporting a high diversity of predators. Plant communities can furthermore indirectly influence diversity at higher trophic levels through alterations of the physical habitat structure (Lawton, 1983). In agricultural landscapes, semi-natural habitats with their often greatly enhanced plant diversity in comparison to surrounding fields, could hence be expected to also host more diverse predator communities through the provision of a diverse range of prey, as well as of shelter and generally a more heterogeneous habitat structure (Duflot et al., 2015). Assemblages in unmanaged semi-natural habitats often also experience stable environmental conditions, while managed agricultural habitats undergo regular disturbances. In heterogeneous agricultural landscapes, natural enemies may colonize cropland while conditions are favorable and retreat to semi-natural habitats when field conditions become hostile (Horvath et al., 2015). These movements and spillover effects between

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different habitat in complex landscapes are important for habitat complementarity effects, evolving source-sink relationships and re-colonization processes (Dunning et al., 1992), enhancing the sustainable provision of ecosystem services. Hence, semi-natural habitats are considered not only important for harboring diverse local communities, but also for their contribution to maintaining diverse species assemblages on cultivated lands (e.g. MacLeod et al., 2004). While positive effects of diverse agro-landscapes containing a significant proportion of semi-natural habitats have been widely reported, the influence of individual environmental factors like plant diversity and the wider landscape composition on arthropod assemblages requires further in-depth investigations. The general importance of landscape-level factors in this context is being increasingly recognized (Tscharntke et al., 2012b; Horvath et al., 2013), with studies on effects the fragmentation of semi-natural habitats has on agricultural biodiversity providing strong indications for a decreasing α-diversity with increasing fragmentation (e.g. Yang and Da-Han, 2006; Davis, 2009; Vieira et al., 2009).

With numerous studies of cropland species showing effects of plant diversity, habitat and landscape fragmentation on arthropod diversity, their relative importance has again remained poorly understood (Jamoneau et al., 2012), particularly in view of their potential differential influence on different taxonomic groups. However, this understanding is essential for the design of efficient management strategies that improve cropland biodiversity and associated ecosystem service provisions alike.

China has experienced rapid agricultural intensification over the past decades, with widely unknown consequences for agricultural biodiversity and associated ecosystem services. Large knowledge gaps prevail with regard to the current status of biodiversity across virtually all invertebrate taxa in the resulting intensively cultivated landscape, for example in relation to agriculture management and planting patterns (Liu et al., 2006; Liu et al., 2009; Liu et al., 2013; Luo et al., 2014). This is particularly true for investigations of diversity patterns across taxonomic groups, and we here present a rare example of research simultaneously looking into spiders and carabid beetles as two species-rich taxonomic groups that are both relatively well known taxonomically and ecologically (Wise, 1995; Powell, 2009) and have been proven to be the excellent indicator taxa to evaluate effects of agriculture intensification on biodiversity (Perner and Malt, 2003). In our study, we therefore address persisting knowledge gaps, providing insights into the responses of spider and beetles as key biological pest control agents to local factors of fertilizer application, plant diversity and habitat type, as well as to landscape-scale fragmentation, in a typical, intensively cultivated agricultural landscape located in Hubei province in the central Yangtse Plain of China.

Some spiders like linyphiids are known to frequently use ballooning for dispersal (Oleszczuk and Karg, 2012), allowing them to disperse over large areas, whereas ground-dwelling carabids, although regularly still in possession of functioning wings, appear to move on the ground as their preferred mode of more limited and targeted dispersal (Venn, 2016). This, as well as differences in their feeding habits and associated diversity of hunting approaches, mean that spiders will likely react more strongly to the configuration of the wider landscape, as also indicated by Gardiner et al. (2010), whereas carabids will likely respond more strongly to factors at local scale than spiders.

In this study, we specifically test the hypotheses that both spiders and carabid beetles are more diverse in semi-natural habitats than in cropland due to the higher diversity of plant species and resulting higher structural diversity in the former habitat types, but that due to the greater dispersal ability of spiders, this taxon is less strongly affected by local factors, instead responding to changes in the overall landscape configuration, while we hypothesize that carabids respond more strongly to local factors like plant diversity and the application of agro-chemicals on the studied habitat patches.

2. Materials and methods

2.1. Study area and sampling plot

The study region is located at Qianjiang (30°25′ ~ 30°23′ N, 112° 50′ ~ 112° 53′ E), Hubei province, a region characterized by sandy to loam-dominated soils on the central Yangtse Plain. The region experiences a sub-tropical climate, with a mean annual temperature of ~16 °C and the mean annual precipitation exceeding 1100 mm. The dominating rice paddy fields are sown at the beginning of May and harvested in the middle of October, while rainfed fields are cultivated for oilseed rape/peanut and oilseed rape/soybean rotation double cropping systems, as well as for rotations of rape, wheat and soybean and the cultivation of cotton.

In recent decades, the Jianghan Plain, where our study region is located, has experienced a rapid urbanization and agricultural intensification. According to the Statistical Yearbook of Hubei Province (http://www.stats-hb.gov.cn/info/iList.jspcat_id10554), the cultivated land on the Jianghan Plain increased by 362.2%, while the area of construction land increased by 1089.7%, between 1993 and 2013. In our study region, analysis of aerial photos and remotely sensed images indicates that the agricultural land area actually decreased by a more moderate 37%, while the area occupied by semi-natural habitats decreased by 38% and the land area used for construction increased by 84%.

Eight common habitat types were selected for sampling: four cultivated habitats (vegetable fields, paddy fields [rice/broad bean cultivation], rainfed fields [soybean/wheat cultivation], and tidal flat fields [peanut/wheat cultivation]) and four semi-natural habitats (field margins, woodland, grassland, shelterbelt). Three separate $20 \times 20\,m^2$ plots in different patches of each habitat type were established as the basis for carabid, spider and vegetation recording, resulting in a total of 12 study plots, each, representing cultivated and semi-natural habitats, respectively. Sample plots were spread out across the study area, resulting in a minimum distance of more than 500 m between individual plots (Fig. 1).

2.2. Beetle and spider sampling

Carabids and spiders were sampled over 4-day periods in the middle of each month from May to October 2013 using pitfall traps. Sets of three pitfall traps were placed in parallel lines 5 m and 10 m from the field margin, with distances between individual traps along the lines also of 5 m. All pitfall transects established in the field were also positioned in N-S direction. The pitfall traps themselves measured 7 cm in diameter and 14 cm in depth, and they were filled with 75% alcohol and a few drops of detergent to break the water surface tension. All adult spiders and carabid beetles contained in the pitfall traps were identified to species level.

2.3. Environmental variables

The coverage and species richness of vascular plants was surveyed in June and September 2013, one to two weeks before harvesting. Each $20 \times 20\,m^2$ plot was divided into four $10 \times 10\,m^2$ sub-plots. All trees and shrubs were recorded in the sub-plots, and herbaceous species were recorded in four randomly placed $1 \times 1\,m^2$ plots, one within each sub-plot. We recorded all plant species using the six-point Braun-Blanquet-scale (Braun-Blanquet et al., 1979) to quantify species abundance.

Land-use types in the study region were digitized in extensive field mapping surveys based on high-resolution 2013 Quick Bird satellite images (resolution 0.6 m). Landscape metrics within a radius of 250 m were considered in this study. This scale has been recommended as an appropriate scale at which many carabids and spiders are affected by the patterns of the agriculture landscapes (Maisonhaute et al., 2010; Gallé and Schweger, 2014). The Mean Patch Size (MPS)-index