

Productive Oilseed Rape Strips Supplement Seminatural Field-Margins in Promoting Ground-Dwelling Predatory Invertebrates in Agricultural Landscapes

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Subject Editor: Kris Godfrey

Received 5 March 2019; Editorial decision 10 May 2019

Abstract

Intensively managed flowering crops like canola (Brassicales: Brassicaceae) (oilseed rape, OSR) provide significant short-term nectar resources for pollen consumers. They may also play important roles as annual “service strips” in temporarily promoting predatory invertebrates. We set out to test this assumption by comparing overall and functional group-specific species richness, activity density, and assemblage composition of carabids (Coleoptera: Carabidae) and spiders (Araneae), in three types of service strips—OSR, woody, and grassy strips established in direct vicinity to cropland. OSR strips were found to harbor the highest carabid species richness and activity density of small carabids. The activity density of carabids overall and of omnivorous species, the species richness and activity density of spiders across size classes and feeding strategies were all significantly reduced in woody strips. The percentage of seminatural habitat in the wider landscape was positively linked to the activity density of spiders overall, ground hunting and large spiders, whereas in carabids, positive effects were limited to large species occurring in grassy strips. Habitat type was the main predictor of both carabid and spider assemblage composition. Our results indicate that carabid and spider activity density across functional groups responded more strongly to changes in the landscape composition than the diversity of individual taxonomic groups. For agricultural landscape management, the establishment of habitat mosaics that include regular OSR could promote abundant, species-rich predatory invertebrates particularly in early spring. In contrast, structurally homogenous woody strips represent limited value in promoting the investigated biological pest control agents.

Key words: carabids, spiders, functional groups, service strips, landscape composition

The increasing intensification of China's agricultural practices in recent decades has resulted in a significant loss of biodiversity and related ecosystem services such as biological pest control (Liu et al. 2013, Zhao and Reddy 2019). In Europe, the conservation and the establishment of seminatural habitats (hereafter SNHs) are regarded as effective approaches in promoting biological pest control in intensively cultivated agricultural landscapes (Tscharntke et al. 2007, Holland et al. 2016). These habitats, often established as strips along field margins, have been shown to serve as refugia and sites for reproduction and hibernation of many beneficial species, such as pollinators or biological pest control agents (Geiger et al. 2009, Sarthou et al. 2014). Accordingly, invertebrate predators such as ground beetles (Coleoptera: Carabidae) and spiders (Araneae) are frequently encountered in greater abundance and species-richness in landscapes with a high amount of SNHs when compared with assemblages in simplified landscapes dominated by large monoculture fields (Liu et al. 2014, Fusser et al. 2016). However, the value of SNHs in

promoting predatory invertebrates appears to be strongly dependent on the type, proportion, and spatial distribution of these habitats within the wider landscape (Arne et al. 2007, Holland et al. 2016).

Although landscape context partly determines the species pool resources of predator populations, field-scale parameters further alter the interactions of these organisms with their prey and hence their overall distribution (Tylanakis and Romo 2010, Duffot et al. 2017). Different SNH types differentiated by their vegetation structure and composition exert a strong influence on the abundance and composition of natural enemy populations in neighboring fields and on the associated contribution of predatory arthropods towards biocontrol (Haddad et al. 2009). Ground-dwelling carabid beetles, for example, are influenced particularly by the density of the herbaceous plant coverage that strongly determines their ability to find shelter (Sarthou et al. 2014) and hunt for prey (Fusser et al. 2016).

In addition to permanent woody and grass-dominated strips, vegetation strips incorporating a high abundance of

herbaceous-flowering plants (“wildflower strips” or “weed strips”) are an anthropogenic “semi-natural” habitat type that are being established to enhance arthropod diversity in agricultural landscapes (Frank and Reichhart 2004, Toivonen et al. 2018). Extensive evidence suggests that wildflower strips, when sown at field margins, can support a higher abundance and diversity of beneficial insect assemblages than woody or grassy habitats (Meek et al. 2002, Hatt et al. 2017a). However, the establishment of wildflower strips is not always efficient or profitable for farmers, as economic losses incurred by converting productive farmland into flower strips may not be compensated by enhanced ecosystem service provisions originating from species assemblages of these strips to the remaining cropland. Amy et al. (2017) suggested that establishing wildflower strips that contained sections strongly dominated by seed flowers such as *Camelina* spp. (Capparales: Cruciferae) can combine the benefits of such strips for the conservation of predatory arthropods with the harvest of valuable seeds. This example shows opportunities of establishing strips of flower-rich plants that can provide direct economic profits for the farmers, as well as enhancing overall biological pest control.

In Anyang city, Henan province, the dominant winter wheat fields are often associated with fields of oilseed rape (hereafter OSR) that represents a key oil crop in this agricultural region of the North China Plain. During their flowering period, these OSR strips could represent a great potential foraging habitat for nectar- and pollen-consuming invertebrates (Van Reeth et al. 2018). They may therefore perform similar roles in agri-ecosystems to wildflower strips at least in spring before the OSR is harvested. Nonetheless, the distribution of beneficial invertebrates in OSR fields has to date chiefly been investigated in view of these habitats as potential target/sink habitats, whereas the role of OSR strips in promoting beneficial invertebrates, particularly in direct comparison to SNHs like woody or grassy field margins, has rarely been assessed. Moreover, few studies have assessed the existence and relative importance of interactions between habitat type and landscape-scale factors on different predatory invertebrate taxa (Fusser et al. 2016). Understanding the contribution of different seminatural and flower crop habitat types in different landscape contexts in the promotion of species richness and abundance of predatory arthropods can nonetheless greatly inform the design of effective biological control strategies that aim at limiting the use of agro-chemicals in the framework of the ongoing ecological intensification of agricultural landscapes (Tittonell 2014).

Impacts of environmental parameters on invertebrate diversity have traditionally focused on the diversity and composition of individual taxonomic groups, whereas recently, the diversity of particular functional groups have increasingly become a research focus, since they are thought to strongly influence ecosystem service delivery (Spake et al. 2016), often show highly sensitive responses to environmental change (Woodcock et al. 2014), and can be assessed using rapid field measurements across large landscapes or even ecoregions (Vandewalle et al. 2010). Woodcock et al. (2014) have reported that ground beetle functional redundancy was linked to the cover of SNHs in agricultural landscapes, with patterns being differentiated by body size and dispersal ability. Further studies have shown that the average body size of beetle communities was related to the habitat configuration (Vandewalle et al. 2010, Spake et al. 2016), for example, being related to vegetation structure and canopy cover in both agricultural and forested ecosystems. The development of targeted biological pest control strategies therefore requires a sound understanding of how habitat conditions and landscape compositions are linked to both, taxonomic predator groups overall and individual functional guilds within these taxa.

In this study, we therefore aim to investigate whether productive OSR strips supplement SNHs in promoting ground-dwelling predators. We compared the distribution of carabids and spiders, that we further differentiated into key functional groups, between OSR strips and two dominant SNHs—grassy strips and woody strips composed of monodominant stands of *Populus tomentosa* Carr (Malpighiales: Salicaceae). We specifically hypothesize that 1) OSR strips conserve a higher diversity and activity density of carabid and spider assemblages, as well as a higher activity density of the different functional groups, than woody and grassy strips, due to the provision of abundant pollen and nectar resources for pollinators and omnivorous invertebrates, with this further enhancing the prey availability for strictly predatory invertebrates (Hoffmann et al. 2018, Toivonen et al. 2018); 2) species richness and activity density of carabids and spiders increase with the proportion of permanent SNHs overall at landscape scale (Fusser et al. 2016), but these responses are taxon-specific, and functional groups like feeding guilds respond more sensitively than taxa overall; and 3) the variation in the composition of spider and carabid assemblages between sampling sites depends chiefly on local habitat parameters, rather than on the composition of the wider landscape, since most carabid and spider species have limited dispersal ability (Welsh 1990).

Materials and Methods

Study Area

This study was conducted in northwest suburb of Anyang city, Henan province (36°7'8"–36°12'32"N, 114°4'9"–114°14'20"E). This area represents a typical cereal crop production area within the North China Plain (Yang et al. 2017). The study region is characterized by a semihumid continental monsoon climate, with an average annual temperature of ~13°C and an average annual precipitation of ~544 mm. Intensively managed winter wheat (Graminales: Gramineae)/summer maize (Gramineae: Zea) rotations are the dominant cropping type in this agricultural landscape. Winter wheat is sown in early October and harvested at the beginning of June, whereas maize grows from mid-June to the end of September. During the growing period of winter wheat, OSR is usually sown for the complementary production of edible oil. OSR occupied about 1.84% of the total cropland, whereas winter wheat field occupied 73.36% of the total cropland in Anyang city during the sampling year. The landscape is therefore characterized by a unique winter wheat/OSR mosaic in some regions. OSR starts blooming in late March and is harvested in late May. Despite the existence of these habitat mosaics in spring, agricultural intensification has resulted in an overall highly simplified landscape structure, only interrupted by a low number of SNH patches, mainly in the form of grassy field margins and woodlands or windbreaks composed of monodominant stands of poplar (*Populus tomentosa* Carr). These trees are usually harvested after 5–8 yr, rendering woodland plots a heavily managed habitat type.

We based our study on a total of 13 circular agricultural landscape patches with a 1-km radius that varied in their overall area coverage of SNHs from 5.4 to 35.5%. At the center of each landscape patch, we sampled invertebrates at one grassy margin, one woody strip, and one or two OSR strips, with sampling occurring on a total of 47 study sites (Fig. 1).

Sampling and Characterization of Arthropods

From 9 April to 17 May 2016 before the OSR was harvested, carabids and spiders were sampled in OSR strips, woody strips, and grassy strips using pitfall traps. At each sampling site, five pitfall

traps were set in a straight line in the center of each sampling strip (at least 0.5 m from the habitat edges for grassy strips) to record the invertebrates. The distance between neighboring traps was 10 m. Pitfall traps consisted of 300-ml plastic cups positioned with the upper rim at ground level and filled with 100-ml saturated salt solution (26.7%) and a drop of detergent to break the water surface tension. Four holes with 2.5-mm radii were drilled 1 cm below the upper rim of each cup to allow drainage of potential excess rain-water. The traps were set for 4 d during each sampling event, for a total of four sampling rounds equally distributed over the sampling period.

To investigate the distribution of different functional assemblages within each of the insect taxa, we characterized carabids and spiders according to their body size, with carabids were divided into small (<15 mm) and large species (>15 mm; Cole et al. 2002) and spiders were also classified into two small (<5 mm) and large species (>5 mm), which were reported relevant to the spider's dispersal distance (Bell et al. 2005). Carabids were further differentiated into trophic guilds (Liu et al. 2015) while spiders according to their hunting mode (Cardoso et al. 2011).

Landscape Composition

To assess landscape features and characterize the landscape composition, the proportions of seminatural elements were assessed in each landscape sector (Fig. 1) using GIS software and Worldview-2 satellite imagery (resolution 0.5 m) as a background map. All land cover types and subtypes in the study region were digitally mapped, based on an extensive field mapping survey during the sampling season. SNHs chiefly comprised of woodland, shrubland, young tree plantations (<3 yr of age), grassland, and small areas covered by perennial vegetation or annual grasses. Landscape metrics were calculated using FRAGSTATS 4.2 (McGarigal et al. 2002).

Data Analysis

To investigate the influence of service strip type and landscape composition on the diversity of carabids and spiders, and on their functional groups, a series of Linear Mixed Models (LMMs, command "lme" in the R package *nlme*; R Core Team 2016, Pinheiro et al. 2017) were computed using both local habitat type and percentage of SNHs as fixed factors, whereas study site was included as a random factor. The full models also contained the two-way interaction of habitat type and percentage of SNHs. The size of each sampling strip was used as a control factor in the models. Data from the five pitfall traps at each study site were combined for statistical analysis. The "true" species richness of carabids and spiders was estimate using the Chao 1 estimated and log-transformed for analysis. Activity density recorded by each trap (individuals per cup and day) representing the abundance was transformed using the square-root or arcsine-square-root function for analyses (Supp Table 1 [online only]). We checked the distribution of residuals of final modes for normality using the Shapiro-Wilk test. Models were optimized using the stepwise AIC function in the MASS package (Ripley et al. 2018). Spatial autocorrelation in each model was tested using Moran's I index (command "moran.test" in the R package *spdep*; Bivand 2018), but no spatial autocorrelation was found for any response variable.

To detect the influence of local and landscape parameters on the assemblage composition of carabids and spiders, a series of separate partial redundancy analyses (pRDA) were performed, alternately using one of the predictive variables, including "Percentage of SNHs," "Habitat type," and "Habitat size," as constraining variable and the other two as conditional variables. Data of carabid and spider assemblages were Hellinger-transformed to allow for the use of Euclidean-based ordination methods, with the initial assemblage data containing many zeros (Legendre and Gallagher 2001). Spatial autocorrelations of plots were diagnosed using the "mso" function, but again, no spatial patterns were detected. Calculations were

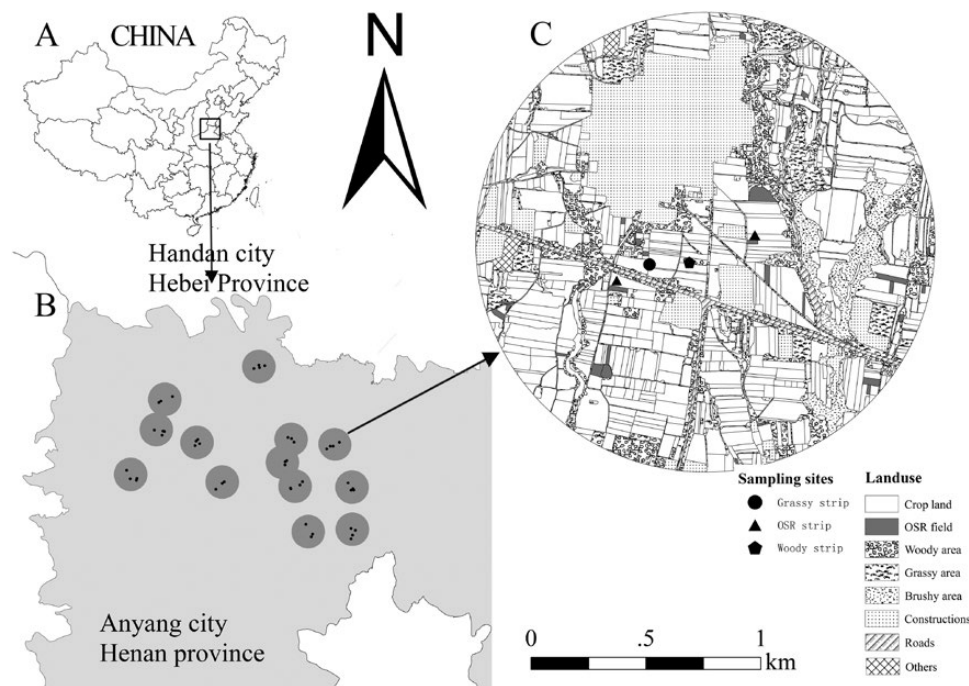


Fig. 1. Map showing the location of the 47 sampling sites within the 13 study landscape patches (1km radius), (A): location of the study region in Henan province, China; B: location of the 13 study landscapes in North Anyang city; C: an enlarged landscape circle with different landscape elements).

performed using the vegan package (version 2.0-2; Oksanen et al. 2012) in R (R Core Team 2016).

Results

Species Composition in Different Habitats

In total, 486 carabid specimens representing 23 species were collected. The two dominant species were *Dyschirius biogoensis* Bates and *Asaphidion semilucidum* Motschulsky, accounting for 25.7 and 21.0% of the total specimens, respectively. *Harpalus simplicidens* Schauburger was furthermore uniquely captured in woody strips, whereas the four species *Amara brevicollis* Chaudoir, *A. gigantea* Motschulsky, *Bembidion incidiosum* Solsky, and *Pheropsophus jessoensis* Morawitz were only captured in the grassy strips, and the seven species *Amara communis* Panzer, *Harpalus amputatus* Breit, *H. corporosus* Motschulsky, *Mastax poecila* Schaum, *Microlestes plagiatus* Duftschmid, *M. sp.*, and *Syntomus sp.* were only recorded in traps located in OSR strips (Supp Table 2 [online only]).

The mature spider samples contained 1797 specimens representing 35 species. The wolf spider *Pardosa astrigera* L. Koch was a mega-dominant species in the sampled assemblages, accounting for 61.9% of the total adult spider specimens caught. Among the 35 species, two species, *Clubiona pseudogermanica* Schenkel and *Raveniola sinensis* Zhu et Mao, were exclusively found in woody strips, whereas *Erigone prominens* Bösenberg & Strand was uniquely encountered in OSR strips and the seven species *Gnathonarium dentatum* Wider, *Paracoelotes spinivulva* Simon, *Sitticus sinensis* Schenkel, *Stemmops nipponicus* Yaginuma, *Trachyzelotes adriaticus* Caporiacco, *Xysticus hedimi* Schenkel, and *Zodariellum chaoyangense* Bösenberg & Strand were only found in grassy strips (Supp Table 3 [online only]).

Effects of Habitat Type and Landscape Composition on the Diversity and Activity Density of Carabids

Six linear mixed models were selected to describe the carabid data based on the lowest AIC (Supp Table 1 [online only]). The estimated species richness of carabids, and the activity density of overall carabids, small sized species, and omnivorous species, was only significantly associated with the habitat type. The OSR strips contained a significantly higher carabid species richness and activity density of small carabids than woody and grassy strips (Fig. 2a and c). The activity density of carabids overall and of omnivorous species were significantly higher in OSR and grassy strips than in woody strips, with no significant differences observed for these groups between OSR and grassy strips (Fig. 2b and d). In contrast, local habitat type and landscape composition showed interacting links with the activity density of large carabids (Supp Table 1 [online only]). The activity density of large carabids increased significantly with the percentage of SNHs in the surrounding landscapes in grassy strips, whereas no significant responses to landscape composition were observed at OSR strips or woody strips (Fig. 3). The activity density of predatory carabids did not show any significant links to local habitat type nor to the landscape composition (Supp Table 1 [online only]).

Effects of Habitat Type and Landscape Composition on the Diversity and Activity Density of Spiders

Six linear mixed models were created for spiders, again based on the lowest AIC (Supp Table 1 [online only]). The habitat type was found to significantly influence species richness and activity density of all spider assemblages. Spider species richness and activity density of sheet-web spiders were significantly higher in grassy strips than in woody strips, whereas assemblages at OSR strips showed no significant differences

to assemblages at the other two habitats (Fig. 4a and f). The activity density of overall spiders, ground hunting species, and different size classes were all found to be significantly lower in woody strips in comparison to both, OSR strips and grassy strips, with no significant difference found between OSR strips and grassy strips (Fig. 4b–e). The landscape composition was found to exert a significant influence on the activity density of spiders overall, of large spiders, and ground hunting spiders (Supp Table 1 [online only]). The activity density of these spiders increased significantly with an increase in the percentage of SNHs in the surrounding landscape (Fig. 5). We did not find any interaction between habitat type and landscape composition on the species richness of spiders or on the activity density of different spider assemblages.

Effects of Local Habitats and Landscape Composition on the Assemblage Composition of Carabids and Spiders

The partial RDA revealed that only the percentage of SNHs in the surrounding landscapes and the habitat type significantly influenced carabid composition. The local habitat type explained a larger proportion of the total explained variance (8.2%) in comparison to the percentage of SNHs encountered in the landscape patches (4.1%; Table 1). For spider assemblages, the pRDA showed that only habitat type significantly related to spider compositions, explaining 13.0% of the total variance (Table 1). No significant links were found between habitat size and composition of either carabid or spider assemblages (Supp Fig. 1 [online only]).

Discussion

Effects of Habitat Type on Diversity and Activity Density of Carabids and Spiders

In line with our first hypothesis, we found that OSR strips contained the highest diversity and activity density of carabid and spider species in comparison to the two permanent SNH types, woody strips and grassy strips. We also established a higher activity density across most functional groupings at OSR strips, which indicates that productive OSR strips could effectively supplement seminatural strips in promoting ground-dwelling carabids and spiders in agricultural landscapes at least in the spring season. In this regard, it needs to be acknowledged that OSR fields usually contain a considerable amount of vegetation during the winter months when compared with most other arable fields, which is considered to be an important factor benefiting overwintering arthropods (Pffner and Luka 2000, Frank and Reichhart 2004). Also, previous studies have shown that invertebrates appear to be particularly attracted to flower strips and can even aggregate in flower-rich habitats from neighboring permanent SNHs in early spring (Hatt et al. 2017a,b), further highlighting the potential importance of productive OSR strips in agricultural landscapes. Nonetheless, due to their harvest in early summer, OSR strips must be regarded as comparatively unstable habitats over the year when compared with the permanent woodlands and grassy strips.,

The differences in carabid and spider species richness and activity density between OSR strips and grassy strips were small, which is consistent with observations from Toivonen et al. (2018), who reported that the abundance of carabid beetles and spiders did not differ between wildflower and grassy fallow strips. Since the conservation and construction of grassy habitat patches has been reported as an efficient landscape management approach to enhance beneficial invertebrate assemblages in surrounding cropland at both local and landscape scales (Hof and Bright 2010, Al Hassan et al. 2013), the significantly higher carabid species richness in OSR strips than in grassy strips further

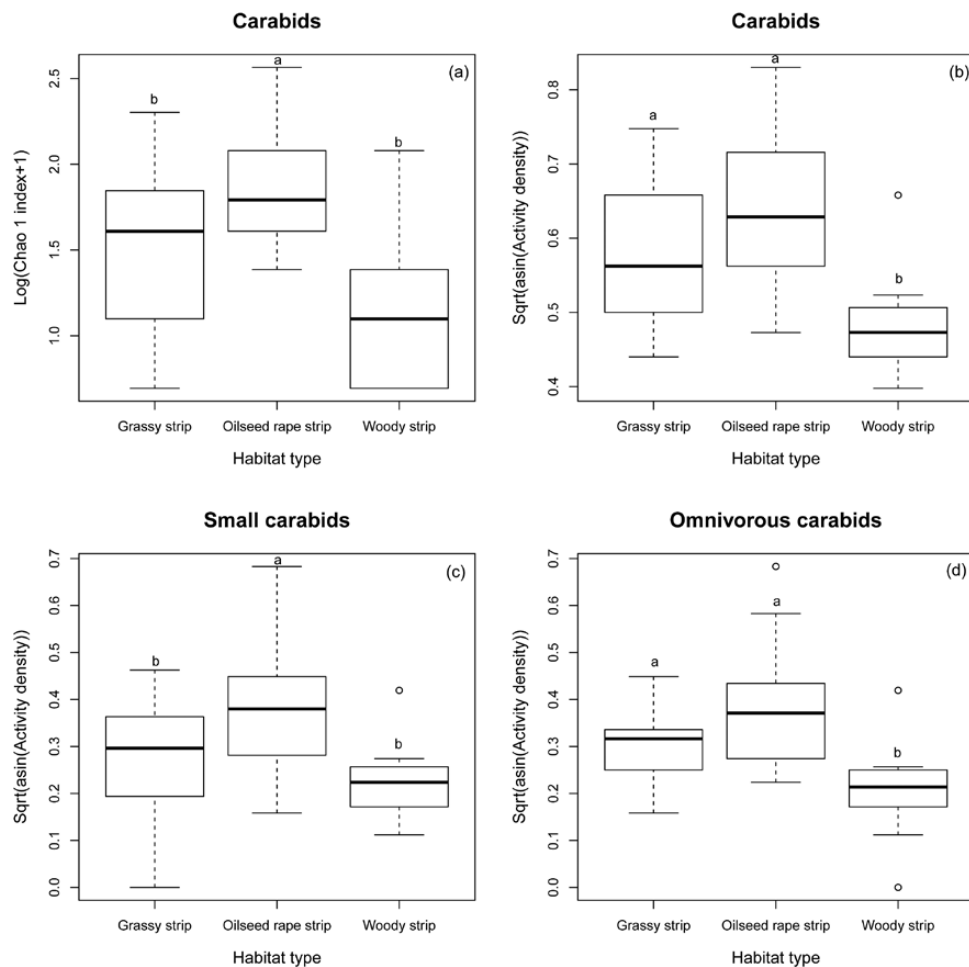


Fig. 2. Effects of habitat type on (a) carabid species richness, activity density of (b) overall carabids, (c) small carabids, and (d) omnivorous carabids. Significance was tested with linear mixed models and ANOVA ($P < 0.05$).

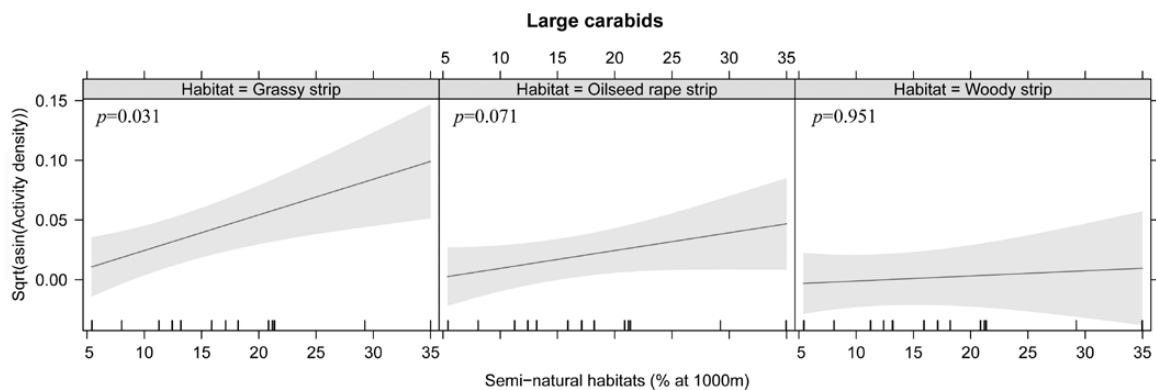


Fig. 3. Interaction of habitat type and landscape composition (expressed by the proportion of SNHs within a 1 km radius of the sampling strips) on activity density of large carabids. Significance was tested with linear mixed models and ANOVA ($P < 0.05$).

emphasized the importance of OSR habitats for the enhancement of ground beetle assemblages and their associated ecosystem services.

The significantly higher diversity and activity density of spiders in grassy strips than in woody strips could be associated with the denser ground vegetation in grassy margins, which could constitute better shelter. [Fusser et al. \(2016\)](#) found that, at local scales, the percentage of shrub cover was negatively correlated with richness and activity density of carabids, whereas the percentage of grass cover positively contributed to spider richness. The potential of woody strips to support

natural enemy populations has been shown to most strongly depend on the composition of tree species, their management, and on the understorey vegetation ([Maudsley 2000](#), [Holland et al. 2016](#)). In our study area, herbaceous coverage in woody strips was significantly lower than in grassy strips and OSR strips ([Supp Table 4 \[online only\]](#)). With an average age of 5–8 yr, the woody strips investigated here represented an early succession stage that is being maintained for forestry purposes. They were characterized by a relatively homogeneous vegetation structure compared with secondary or mature forest ecosystems.

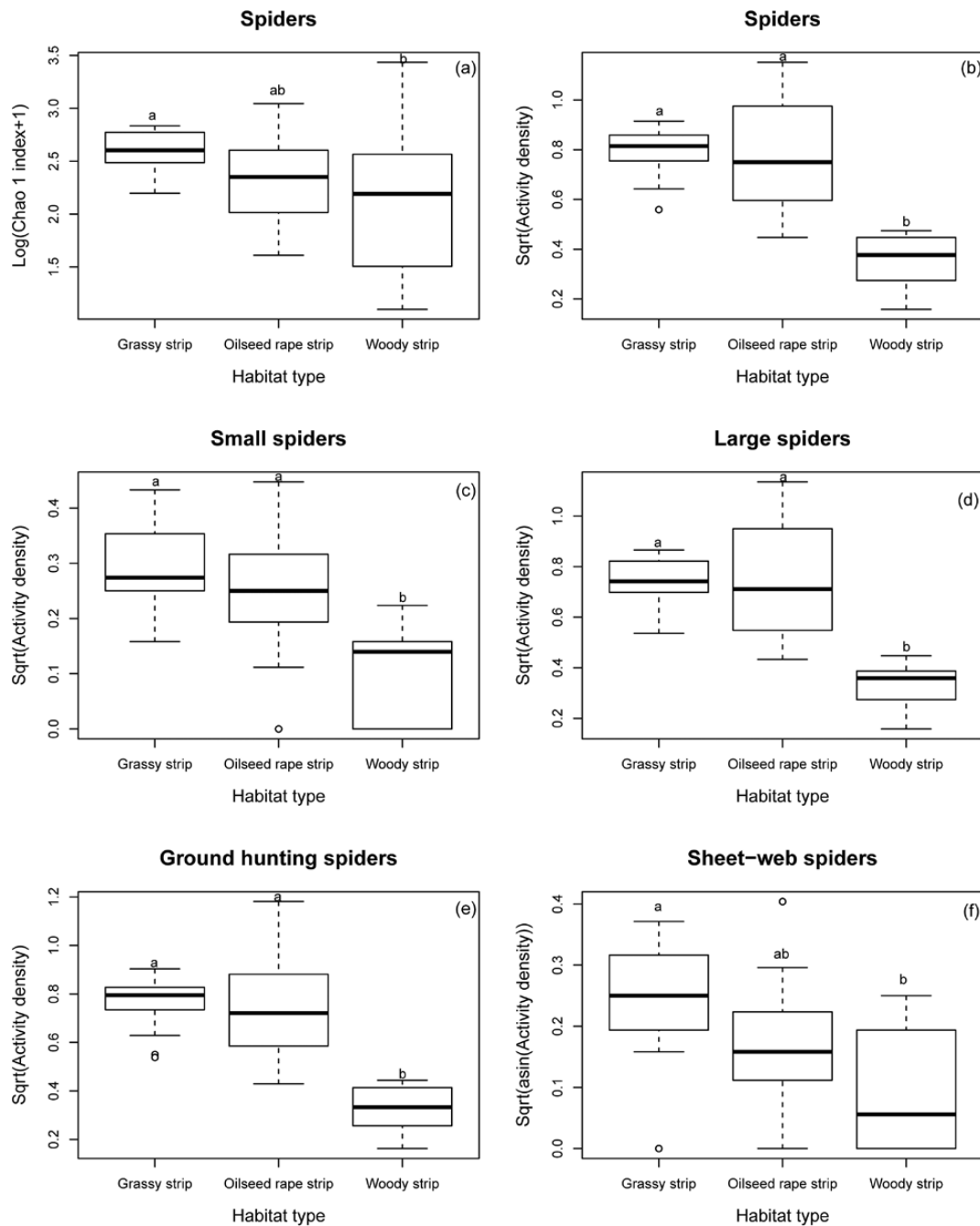


Fig. 4. Effects of habitat type on (a) spider species richness, activity density of (b) spiders overall, (c) small spiders, (d) large spiders, (e) ground hunting spiders, and (f) sheet-web spiders. Significance was tested with linear mixed models and ANOVA ($P < 0.05$).

Effects of Landscape Composition on Diversity and Activity Density of Carabids and Spiders

As hypothesized, the activity density of carabids and spiders increased with the proportion of permanent SNHs overall, whereas another study also found the contrary response trend on carabids which might be explained by the different species pool of the study regions (Rusch et al. 2016). The influences of landscape composition were not observed with regards to carabid and spider richness, whereas different functional groups in both taxa were more sensitive to changes in the landscape composition than the respective taxon overall. The lack of strong links between landscape composition and the diversity of carabids and spiders overall, as well as on the activity density of most functional groups, could potentially be related to the scale at

which the study landscape was characterized potentially not representing the optimal response scale in terms of the dispersal ability of the different taxa. Previous studies have shown that the influence of landscape composition on biodiversity was indeed strongly scale- and taxon-dependent and varied with the content of seminatural elements (Dufлот et al. 2015). Spiders were found to be significantly correlated with the landscape composition at spatial scales varying from 95 to $>>1000$ m (Schmidt et al. 2008), whereas ground beetle assemblages appeared more strongly linked to landscape structure at smaller spatial scales (Aviron et al. 2005, Batáry et al. 2007). Additionally, for carabids the influence of local parameters not considered in our study, such as vegetation structure and soil factors, may be stronger than landscape effects (Maisonhaute et al. 2010, Li et al. 2018).

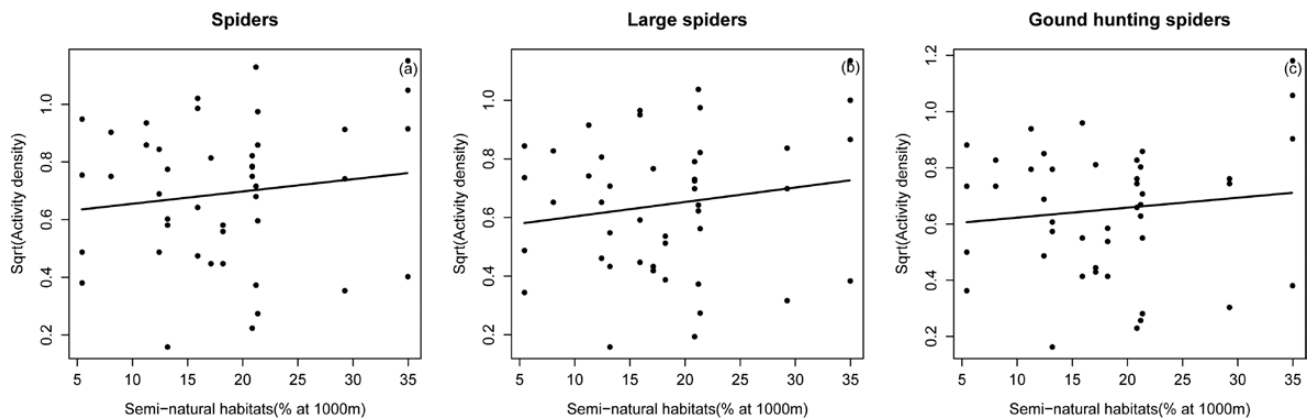


Fig. 5. Effects of landscape composition, expressed by the proportion of SNHs in 1 km radius, on activity density of (a) overall spiders, (b) large spiders, and (c) ground hunting spiders. Significance was tested with linear mixed models and ANOVA ($P < 0.05$).

Table 1. Species composition of carabids and spiders, percentage of variance explained, and P -values (Monte Carlo test) by variables in partial RDA. P values < 0.05 indicate a significant effect

Assemblages	Predictor variables	Explains%	Pseudo-F	df	P
Carabids	Habitat type	8.2	1.913	2	0.018
	Percentage of SNHs	4.1	1.897	1	0.044
	Habitat size	2.4	1.104	1	0.356
Spiders	Habitat type	13.0	3.215	2	0.001
	Percentage of SNHs	1.7	0.823	1	0.645
	Habitat size	2.2	1.076	1	0.340

In agricultural settings, large and predatory carabids are commonly found to be more sensitive to landscape structure than small and omnivorous carabids (Aviron et al. 2005, Silva et al. 2017), since these latter groups have been shown to be well-adapted to cultivated fields (Saska et al. 2007) and widely distributed in agricultural landscapes. For spiders, differences in dispersal abilities and dispersal modes can be linked to the different responses of different spider functional groups to the landscape composition. Ground hunting spiders and large spiders that are believed to rarely create webs disperse primarily by movements on the ground, whereas sheet-web spiders and small spiders often disperse chiefly using ballooning (Weyman et al. 2002, Bell et al. 2005)—resulting in a much weaker dispersal ability for hunting and large spiders in comparison to sheet-web and small spiders. This means that the latter two groups can be expected to respond to the landscape composition at much larger scales than the former groups with their poorer dispersal ability. Moreover, ground hunting and large-sized spiders such as Lycosidae disperse at adult or subadult stages chiefly in spring, whereas sheet-web and small-sized spiders like Linyphiidae are often showing ballooning throughout their life cycles (Weyman et al. 2002, Bell et al. 2005), which results in difficulties in the monitoring of the dispersal and distribution patterns of ballooning groups over just one season sampling period.

The combined, possibly interactive effects of local SNHs and landscape compositions on carabids and spiders have rarely been tested (Fusser et al. 2017). We found that large carabids were positively correlated to percentage of seminatural areas only in grassy habitats, which indicates that landscape management aimed at enhancing populations of large carabids should focus on increasing seminatural areas especially where grassy field-margin habitats are common. On the other hand, the lack of interactions between local and landscape parameters for the other carabid and spider assemblages are somewhat surprising. It needs to be considered that the overall influence of SNH types and their environmental conditions on biodiversity pattern

will strongly rely on the surrounding landscape context that determines the overall species pool (Tschamtker et al. 2012), but these interactive links are difficult to ascertain by field studies. These large scales interactions may best be explored through modeling studies.

Effects of Service Strips and Landscape Composition on Carabid and Spider Assemblage Composition

Consistent with our last hypothesis, the composition of spider and carabid assemblages in different habitats was chiefly determined by the local habitat type, rather than by the percentage of SNHs in the surrounding landscape. Habitats strongly differing in their vegetation composition and structure will be characterized by very different microclimatic conditions and generally in their environmental parameters, hence enabling them to harbor significantly different invertebrate assemblages (Hof and Bright 2010, Fusser et al. 2016). These environmental differences will affect assemblages and related organismic interactions both directly and indirectly (Tylianakis and Romo 2010, Duflo et al. 2017), for example, via shifts in the food-web structure and competitive balances within the ecosystems (Haddad et al. 2009). Furthermore, many carabid and spider species are widely distributed across agricultural landscapes, with many species considered to be either habitat generalists or farmland specialist species (Ekschmitt et al. 1997, Kromp 1999, Schmidt and Tschamtker 2005) so that these landscapes are characterized by a relatively homogenous regional species pool that is then chiefly shaped at local scales by the prevailing environmental conditions and specific species interactions of the forming communities. Based on island biogeography predictions, a larger habitat island can be expected to support larger populations (Shaffer 1981), whereas Knapp and Řezáč (2015) found that even a small seminatural island with an area $< 100 \text{ m}^2$ can contribute positively to the activity density, species richness, and species composition of

ground-dwelling arthropod assemblages. The effects of habitat patch size on carabids and spiders therefore might be less important than the habitat type itself, which is corroborated by our study.

Notably, the variation in the assemblages of both, carabids and spiders, explained by the environmental parameters we recorded was very low—also when compared with previous studies (Aviron et al. 2005). A large proportion of the variations in carabid and spider composition not measured in this study could be related to abiotic parameters such as soil texture and nutrient contents, as well as biotic interactions across the community. For example, Drapela et al. (2008) found that site characteristics (stand density, insecticide applications, and late autumn ground cover) and landscape factors (woody areas and fallows at a radius of 500 m around study plots) were important parameters explaining changes in species composition. Thus, conservation of biodiversity needs to take a holistic view of environmental factors such as local management and the landscape composition and diversity in relation to the different landscape elements.

Implication for Conservation

In China, a combination of small areas permanently covered by SNHs especially grassy field margins, established within a mosaic of cereal and flowering crops like OSR, in our view represents a very promising way in balancing biodiversity conservation and agriculture production across the agricultural landscape. Given China's large human population and the resulting pressure on high-quality agricultural land, a transformation of large proportions of highly productive farmland into unproductive habitats like wildflower strips in contrast would be difficult to implement. Looking at the management of SNHs, future grassland and field-margin management could be targeted at increasing flowering plant species that can provide a complementary pollinator food resource when OSR and other flower-producing crops do not provide any nectar and pollen resources for pollinator communities. In the context of the species-poor assemblages of epigeous predators in our study area, we believe the quality of the woody habitat can be significantly improved to provide a better resource for beneficial arthropods inhabiting the agricultural landscape. Planting of patches covered by grass or a mixture of grass and flowering herbaceous species underneath the trees could be an effective solution to enhance the resident assemblages and allow for potential spill-over effects into the agricultural fields.

Conclusion

Overall, diversity and composition of carabids and spiders and of their different functional groups were strongly influenced by the respective habitat type and with OSR strips, even when managed under annual rotation, showing strong potential contributions towards carabid and spider conservation at least during their flowering period in early spring. This potential beneficial role of flowering crops opens new perspectives for farmers to enhance biological control in their fields while simultaneously gaining economic benefits. To the contrary, woody strips showed great limitation in promoting carabids and spiders compared with grassy and OSR strips. In these habitats, management directed at an increase in coverage of herbaceous plants—both grasses and flowering herbs—might greatly enhance their contribution to the species pool and abundance of invertebrate predators. Since each habitat type harbors unique assemblages, conserving and floristically enriching vegetation in SNH appears a complementary measure for establishing flower-rich crops in conserving the regional carabid and spider species pools. Our study confirms that an increase in the

percentage of SNHs in the wider landscape benefits carabid and spider conservation. Functional groups in both study taxa showed more sensitive responses to both local and landscape parameters than the taxa themselves. Specifically, the significantly positive effects of landscape composition on large carabids, spiders, hunting, and large spiders gave us a clear indication for management targeting the enhancement and conservation of these target predator groups by increasing the percentage of SNHs in the surrounding landscape, while also hinting at the value of cropped habitats like OSR strips in enhancing the diversity and abundance of predators and associated biocontrol. In this context, more knowledge is still required regarding the temporal dynamics in predator habitat use between crop fields and SNHs that will be crucial for landscape management that optimized biological control by the local predator communities.

Acknowledgments

We thank Prof. Jacques Baudry for his kind suggestions for our field work and the aid from Dr. Liang Hongbin for ground beetle identification. This research was financially supported by the National Natural Science Foundation of China (31470514 and 41871186) and the National Key R&D Program of China (No. 2018YFC0507204).

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