

The taxon- and functional trait-dependent effects of field margin and landscape composition on predatory arthropods in wheat fields of the North China Plain

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Taxon- and functional trait-dependent effects

Abstract

1. Semi-natural habitats are regularly shown to affect the diversity of predatory invertebrates at both the local and landscape scale. In this study, we investigated the effects of three different vegetated field margins and the surrounding landscape composition on two common ‘natural enemy’ taxa, carabids and spiders, in wheat fields of the North China Plain.

2. Carabids and spiders were sampled using pitfall traps located at 36 wheat fields near three different field margin types - grassy strips, poplar woodlands and unvegetated pathways.

3. In-field diversity of carabids and spiders was not significantly differentiated by field margin type while the species richness of total carabids and the abundance of small spiders increased with increasing field margin width, and the abundance of adult spiders, ground hunting spiders, small and medium-sized spiders decreased with increasing distance to the field margin.

4. At the landscape scale, the abundance of all and large carabids was positively correlated with % woodland, while abundances of all and small carabids were negatively correlated to %

grassy area. The abundance of spiders was positively related to % grassy area, while the links between % woodland and adult spider abundance in the fields varied between field margin types.

5. Our results indicated that natural enemies showed diverging, taxon- and functional group-specific links to semi-natural habitats at both local and landscape scales. Both the creation of mixtures between woodlands and grasslands across agricultural landscapes and an increase in field margin width are identified as efficient measures to promote carabid and spider diversity.

Key words: Carabidae; Araneae; Natural enemy; Semi-natural habitats; Landscape context

Introduction

Biological pest control relies on the presence of sufficient numbers of beneficial predatory invertebrates. This ecosystem service has been severely reduced in many agricultural landscapes due to the loss of semi-natural habitats (SNHs) like extensively managed field margins and hedgerows that provide important overwintering, reproduction and foraging sites for many biological pest control species (Bianchi et al., 2006; Gallé et al., 2018). Even conserving small patches of SNHs can benefit key generalist pest control taxa like spiders and carabids (Knapp & Rezac, 2015). The conservation and creation of such habitats therefore has become an important component in agri-environmental measures aimed at elevating the abundance and diversity of predatory invertebrates (Landis et al., 2000; Tschumi et al., 2016), and subsequently creating “spill-over” effects into adjacent agricultural fields (Gardiner et al., 2009; Tschamntke et al., 2007).

The effectiveness of SNHs in enhancing local diversity and abundance of predator assemblages varies with their local characteristics. For example, local scale plant diversity and land-use intensity of SNHs are important drivers of spider and carabid diversity and functional trait composition in such SNHs (Schirmel et al., 2016). Wooded and grassy margins would play

very different roles in conserving carabid diversity in adjacent corn fields (Varchola & Dunn, 2001). Besides, age and width of SNHs can also be important factors affecting predatory invertebrate assemblages (Haenke et al., 2009; Noordijk et al., 2010). A thorough understanding of the effects different SNHs have on predatory invertebrate taxa hence forms an essential prerequisite to develop habitat management approaches that can effectively promote biocontrol agents in crop fields nearby.

In addition to the establishment and management of local SNHs, the large-scale landscape composition, commonly measured as the % area covered by SNHs in the landscape, has also been shown to play an important role in determining abundance and species richness of predatory invertebrates in agricultural landscapes (Fusser et al., 2017; Sutcliffe et al., 2014). The complexity of landscape composition is often assumed to moderate the effects of local management, including rebuilding of SNHs, on biodiversity and ecosystem services (Diekötter et al., 2010; Tschardt et al., 2012). It was suggested that local management aiming to improve biodiversity and ecosystem services was most efficient in landscapes of intermediate complexity, while negative effects of local management on biodiversity could be partly compensated by a high landscape complexity (Batáry et al., 2010; Tschardt et al., 2012). These results indicate that a local establishment of SNHs targeting improvements in biodiversity and ecosystem services needs to consider the landscape context and landscape-scale composition of SNHs.

Most previous studies focusing on large-scale landscape composition usually combined various natural and semi-natural elements into one class in the analysis of landscape composition (Fusser et al., 2017; Rusch et al., 2016), therefore failed to account for the variations in taxon-specific responses to different SNHs. Dufnot *et al.* (2015) argued that the role of different semi-natural elements played in agricultural landscape biodiversity conservation should be carefully re-assessed, since the associated differences in vegetation structure and large-scale habitat composition strongly affected the composition of invertebrate assemblages they contained and the

dispersal capacity of these species. In addition, invertebrate assemblages response to landscape composition could be depending on both the landscape-scale distribution of SNH types and taxon-specific or more general functional traits like body size, dispersal ability and feeding habit (Woodcock et al., 2014). Overall, the scarcity of studies investigating the complex and varied effects of different semi-natural landscape components and their interaction effects associated with local field margins in determining different taxa or functional groups in invertebrate assemblages across agricultural landscapes reflects an urgent need for further research (Dufлот et al., 2015; Martin et al., 2016).

Carabid and spider assemblages are two common taxa strongly associated with the mortality of key crop pests like aphids in fields (Kromp, 1999; Schmidt et al., 2004). Both groups were found to strongly respond to variations in landscape composition and the localized presence of semi-natural elements (Duan et al., 2016; Liu et al., 2015), while their responses to landscape and local variables were further differentiated according to functional traits such as feeding habits and body size (Clough et al., 2005; Liu et al., 2015). However, few studies have investigated the congruence or discrepancy in these responses to either landscape or local semi-natural elements across these two taxa. Nonetheless, the identification of their varied responses to local and landscape elements are important for reliable recommendations of local and landscape planning for the conservation and promotion of these biological control agents (Martin et al., 2016; Thies et al., 2003).

The ancient agricultural landscape of the North China Plain, where crops have been produced for at least 3600 years (Hu, 2005), has become highly homogenized in the course of the recent agricultural intensification, resulting in the widespread disappearance of SNHs. The most common remaining SNHs in this region are grassy field margins dividing small fields cultivated by individual households, while woodlands chiefly comprised of *Populus tomentosa* Carr. have been introduced recently as windbreaks. However, whether these two SNHs are effective in

promoting predatory invertebrate assemblages in nearby cropping fields, and whether the efficiency of the two SNHs for boosting natural enemy was affected by landscape complexity and varied among different functional predatory groups in this region remains poorly understood. At the landscape level, the effects landscape composition, further differentiated by different semi-natural elements, has on the local predatory diversity are furthermore poorly understood in the study region. In this study, we therefore aim to examine how different field margin types, field margin width and the compositions of the wider landscape affect the diversity patterns of ground dwelling carabid beetles and spiders. We furthermore aim to examine the degree of spillover from the field margins for both carabids and spiders. We hypothesize that (1) the regionally most common semi-natural field margin types, grassy field margin and woodland field margin, significantly promote the species richness and abundance of carabids and spiders in adjacent wheat fields compared to unvegetated margins; (2) the effects of field margins increases with field margin width, but diminishes with increasing sampling distance from the margin, especially in functional groups with more specific resource requirements like large carabids (Aviron et al., 2005), and with a limited dispersal ability like ground hunting spiders when compared to sheet-web spiders (Weyman et al., 2002); (3) responses to the different semi-natural elements varies between carabids and spiders at the local level (field margin type) and landscape level (% grassy area versus % woodland), with the SNH composition at landscape level potentially moderating effects of local semi-natural field margins on the diversity and abundance of carabids and spiders in the fields.

2. Materials and methods

2.1 Study region

Our study area was located within the North China Plain in the northwest of Anyang in Henan province (36°7'8"-36°12'32"N, 114°4'9"-114°14'20"E). The study area experiences a semi-humid continental monsoon climate, with an average monthly precipitation varying between

5 mm and 172 mm in the study year. The annual average temperature is ~ 13 °C during the sampling year, with a range from -18 °C to 42 °C. Winter wheat/summer maize rotation fields dominate the agricultural landscape, with winter wheat sown in early October and harvested at the beginning of June, while maize then grows from the middle of June to the end of September. Less common cropping systems in the study area include cotton fields, as well as wheat/peanut and wheat/soybean rotations. The average field size is small, ranging from 300 m^2 to 1000 m^2 , due to the land being split between individual households in this densely populated area. Nonetheless, boundaries between individual fields owned by different farmers are often poorly defined, since they are commonly marked only by 10-30 cm high ridges.

For our study, we selected 36 wheat fields for carabid and spider collection. Twelve of these fields were bordered by poplar woodland, grassy field margin and unvegetated pathway, respectively (Fig.1, Appendix S1). The minimum distance between two sampling fields was > 100 m. The management of the wheat fields was very homogenous, as the use of collective farming management services that include united sowing, pesticide applications, and harvest that are provided by the farmers' union, has become increasingly popular in recent years in response to the increasing shortage of labor in rural areas. During our sampling period, Imidacloprid ($37.5\text{-}52.5\text{ g ha}^{-1}$) and Beta-Cypermethrim ($0.9\text{-}1.35\text{ L ha}^{-1}$) were applied to the wheat fields twice, in early and late May, to control aphids. In addition, chlorsulfuron and isoproturon compound reagents were applied in late March to control for weeds. Furthermore, about 200 kg ha^{-1} $\text{CO}(\text{NH}_2)_2$ and about 90 kg ha^{-1} P_2O_5 were applied during the growing season. Grassy field margins and the undergrowth of the planted poplar woodland consisted of naturally regenerating, unmanaged vegetation, but this vegetation commonly experienced slight disturbances for example by occasional sheep grazing.

Fig. 1. Map of the sampling fields in the North of Anyang city, Henan province, North China Plain

2.2 Invertebrate sampling and identification

Ground-dwelling carabids and spiders were collected during the main growing season of the winter wheat from 10th April to 29th May 2015 in fortnightly intervals using pitfall traps. Inside each sampling field, two sets of 4 pitfall traps were located along two parallel lines at distances of 2 m and 15 m from the field margin. Along each line, the traps were distributed at distances of 10 m from neighboring traps. Pitfall traps consisted of 300 ml plastic cups positioned with the upper rim at ground level. They were 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 radius were drilled 1 cm below the top edge of the cup to allow drainage of excess rainwater. The traps were operated in the fields for 6 days, with intermittent intervals of 7 days, resulting in a total of 4 rounds of sampling and a total of 24 sampling days during the sampling season. Adult carabids were identified to species level based on Zhu et al. (1999), Liu (2010) and Shi (2013). All adult spiders were identified to species level based on Song (1999) and Song and Zhu (1997), while juvenile spiders were discarded for analysis. Carabid voucher specimens are stored in the collections of the College of Resources and Environmental Sciences, China Agricultural University, while all spider samples are stored at the College of Life Science, Hebei University.

2.3 Landscape metrics

The land cover in the study region was classified into 6 categories: fields with annual or perennial crops, SNHs, build-up area, drainage ditches, roads and railway lines, and unutilized lands (Table 1). SNHs were further differentiated into wooded areas that comprised woodland, shrub land and young tree plantations < 3 years of age, and grassy areas. All land-cover types and sub-types in the study region were digitally mapped based on an extensive field mapping survey during the sampling season in combination with an analysis of Worldview-2 satellite imagery (resolution 0.5 m) taken in 2014. The landscape composition, characterized by % grass area and % planted woodland, was recorded at a radius of 500 m around each sampling field, as earlier studies indicated a radius of 500 m to represent a highly suitable scale to the landscape effects on

species richness and abundance for a wide range of taxa, including carabids and spiders (Aviron et al., 2005; Batáry et al., 2007; Batáry et al., 2012). The wooded area (woodland) coverage in these landscapes ranged from 2.86% to 22.15%, while the area covered by grass ranged from 0.78% to 11.82%. Landscape metrics were calculated to represent the landscape composition using FRAGSTATS 4.2 (McGarigal et al., 2002).

Table 1 The compositions of the landscape patches: % major land-use types within a 500 m radius around the landscape center (% (Mean±SD); minimum-maximum (%)).

2.4 Data analysis

Since functional groups often show highly specific responses to changes in environmental conditions (Woodcock et al., 2014), carabids and spiders were sub-divided into different functional groups. Carabids were differentiated into large (>5 mm) and small carabids (<5 mm), while spiders were differentiated into large (>9 mm), medium (<9 mm, >5 mm) and small spiders (<5 mm) according to body size distribution graphs (Jelaska & Durbešić, 2009) (See supporting information Appendix S2). The carabids were further categorized according to their trophic position (Kromp, 1999; Liu et al., 2015), and spiders were further separated into ground-hunting spiders and web-building spiders according to their hunting mode, as web-building spiders mainly constitute of aeronauts with a better dispersal ability due to their ballooning behavior than ground hunting spiders that mainly pursue their prey running along the ground (Luczak, 1979; Weyman et al., 2002). At each sampling field, carabids and spiders from each transect line positioned at a distance of 2 m or 15 m from the field margin into the field, respectively, were pooled for analysis. The effects of field margin and landscape parameters on (i) species richness of carabids and adult spiders, (ii) abundance of carabids and adult spiders, and (iii) the abundance of carabid and spider functional groups were analyzed using mixed-effects models (function “lme” in the R package nlme, Pinheiro et al., 2017; R Core Team, 2016). Species richness of carabids and spiders were estimated based on the Chao 1 species richness estimator calculated in Past3

(Hammer et al., 2001). The field margin type, field margin width, sampling position, % grassy area, % woodland as well as the interaction between landscape variables and margin type were included as fixed effects, and study field was included as a random effect (Zuur et al., 2009). All variables were standardized (z-scored transformation) prior to analysis. All models were validated by checking the residuals according to the protocol of Zuur et al. (2009) to ensure that deviance residuals met normality and homoscedasticity assumptions. We selected the best predictive models for each response variable with multi-model inference, by ranking models according to AICc values using the 'dredge' function from the 'MuMIN' package (Bartoń, 2017) and selected those top-ranked models within $\Delta\text{AICc} < 2$ to estimate the model parameters (Grueber et al., 2011). The conditional average results were reported in this paper. Spatial autocorrelation in each response variable was tested using Moran's I index (function 'moran.test' in the R package spdep) (Bivand, 2018), and no spatial autocorrelation was found for any response variable.

3. Results

3.1 Species composition

Overall, 1395 carabid specimens representing 28 species were captured (Appendix S3). Among these, the two dominant species, *Asaphidion semilucidum* (48.5% of all specimens) and *Dyschirius hiogoensis* (24.1%), as well as a further six species were defined as 'small' species and accounted for 75.3% of the total catch. The remaining 20 species, accounting for 24.7% of the total catch, were classified as 'large' carabids (Supporting Information Appendix S2). A further 16 species, representing 85.9% of the caught individuals, were classed as omnivores, while the remaining 12 species representing 14.1% of the total catch were classed as true predators.

The spider samples contained 2217 adults representing 41 species (Appendix S4). Among these, there were 1324 ground hunting spiders representing 31 species and accounting for 59.7%

of the adult spider individuals, and 893 web-building spiders representing 10 species and accounting for 40.3% of the total adult spider individuals in the samples. Eighteen species representing 26.3% of adult spiders were classed as ‘small’, whereas 16 species representing 64.3% of adult spiders were classed as ‘medium’ and the remaining 7 species representing 8.6% of all adult spider individuals, were classed as ‘large’ spiders (Supporting Information Appendix S2).

3.2 Effects of local field margin and landscape compositions on carabids and spiders

With the increase of field margin width, species richness of carabids as well as the abundance of small spiders increased (Fig. 2 a-b). The sampling position in the field, reflecting the distance to the field margin, affected the abundance of all adult spiders, ground hunting spiders, small and medium-sized spiders that was higher at 2 m from the margin than at 15 m within the field (Fig. 3 a-d). In contrast, the distance to the field margin had no effect on web-building spiders, large spiders, total carabids or any carabid functional group (Table 2). Moreover, the field margin type did not exert a significant influence on any of the response variables for either, carabids or spiders (Table 2).

Table 2 Model-averaged results for carabids with field margin type, field margin width, sampling position, landscape composition as explanatory variables, significant values ($p < 0.05$) are highlighted in bold.

Fig. 2. Effects of field margin width on (a) Species richness of total carabids and (b) abundance of small spiders (p value < 0.05).

Fig. 3. Mean abundance of (a) adult spiders; (b) ground hunting spiders; (c) small spiders and (d) medium-sized spiders at interior wheat field that 2 meters and 15 meters from the field margin (* $p < 0.05$, ** $p < 0.01$).

The landscape composition significantly affected the species richness of all carabids, the abundance of all carabids, large carabids, small carabids, adult spiders and ground hunting spiders and medium-sized spiders (Table 2). However, the different taxa and functional groups responded differently to the landscape compositions. Even the same response variable would respond

differently to different landscape semi-natural elements. The abundance of carabids overall in wheat fields was negatively correlated to % grassy area, but positively related to the % woodland area in the surrounding landscape (Fig 4 a, d). However, the species richness of all carabids and the abundance of large carabids in wheat fields were positively related to % woodland area (Fig 4 b-c), while the abundance of small carabids was negatively correlated to % grassy area in the landscape (Fig 4 e). The abundance of adult spiders, ground hunting spiders and medium spiders in the wheat fields showed significantly positive associations with % grassy area in the landscape (Fig.5 a-c). The abundance of omnivorous carabids, predatory carabids and web- building, large and small spiders, on the other hand, showed no significantly correlation with any landscape variable (Table 2).

An interaction effect between landscape composition and field margin type was found only in spiders. The abundance of adult spider showed a different response to % woodland in the wheat fields near grassy field margins in comparison to unvegetated margins (Table 2). With increase of woodland area in the landscape, the abundance of adult spiders increased in wheat fields with grassy and woodland margins, while the abundance of spiders decreased at wheat fields with unvegetated margins (Fig. 5 d).

Fig. 4. Effects of % woodland on (a) abundance of total carabids; (b) species richness of total carabids; (c) abundance of small carabids; effects of % grassy area on abundance of (d) total carabids and (e) large carabids (p value < 0.05).

Fig. 5. Effects of % grassy area on the abundance of (a) adult spiders; (b) ground hunting spiders; (c) medium spiders and (d) interactions between % woodland and field margin type on abundance of adult spiders (p value < 0.05). The abundance of adult spiders increased with % woodland in wheat fields neighborhood with grassy margin ($p = 0.011$) and woodland margin ($p = 0.019$) compared to unvegetated pathway.

4. Discussion

4.1 Effects of local SNHs on the species richness and abundance of carabids and spiders within wheat fields

In contrast to our first hypothesis, our results showed that the species richness and abundance of both carabids and adult spiders in wheat fields adjacent to semi-natural field margins were not significantly higher than in wheat fields bordered by unvegetated paths. This stands in contrast to previous studies that have repeatedly shown an important positive influence of both wooded habitats and grass-dominated field margins on the diversity of carabids and spiders in neighboring fields (Knapp & Rezac, 2015; Petit & Usher, 1998). The diverging patterns observed by us can be related to several factors: On one hand, habitat quality such as vegetation structure has been identified as important factors in enhancing species pools in our target taxa at local scales (Horváth et al., 2015; Rouabah et al., 2015). The positive impacts of SNHs in promoting invertebrate diversity are furthermore commonly associated with these habitats experiencing less disturbance and containing a much more diverse vegetation than the agricultural fields, hence providing shelters, overwintering sites as well as alternative food resources (Bianchi et al., 2006; Gallé et al., 2018). In our study area, the grassy field margin and poplar woodland undergrowth was grazed and had overall low levels of vegetation diversity, which might result in less diverse carabid and spider assemblages inhabiting these areas, particularly when compared to conservation headlands or similar agri-environmental scheme-related SNHs in European agricultural landscapes. On the other hand, unvegetated field margins experienced only low levels of disturbance. However, consistent with the first part of our second hypothesis, a positive impact of field margin width was observed on both carabids and spiders, indicating that wide field margins are required to optimize carabid conservation and the associated ecosystem services.

The decrease in abundance of all adult spiders, ground hunting spiders, small and medium-sized spiders with increasing distance to the field margin, which contrasts patterns in ground beetles, web-building and large spiders, highlights both taxon- and functional group-specific differences in the “spill-over” effects from field margins into adjacent agricultural fields. Possible explanations for these differences could relate to carabids found in the study area mainly

representing farmland species, or species that mainly lived on farmland during our sampling season leading to a relatively homogenous distribution across the field during the main winter wheat growing season, and to the fact that in comparison to ground-hunting spiders, web-building spiders have a better dispersal ability due to their ballooning behavior (Luczak, 1979; Weyman et al., 2002), that again results in a widespread relatively homogenous distribution of web-building spiders inhabiting agricultural fields across these habitats. Therefore, spatial differences relating to small-scale spillover effects of web-building spiders that frequently balloon throughout their life cycle are more difficult to detect than similar effects in ground-hunting spiders (Bell et al., 2005; Drapela et al., 2008). The lack of significant links between large spiders and the sampling position may be related to the small number of individuals caught that fell within this category (only 8.6% of the adult spiders belonged to 'large' species). Moreover, some of the most abundant large spiders like *Pirata piratoides* were shown to be habitat specific and prefer semi-aquatic habitats - which leads to random distribution patterns on wheat fields (Graham et al., 2003).

4.2 Taxon- and functional trait-dependent responses of carabid and spider diversity and abundance to the composition of the wider landscape

Our results clearly indicated diverging responses of carabids and spiders to the relative proportions of woodland and grassland areas in the wider landscape. While woodlands in the study region generally represented artificial plantations or planted windbreaks characterized by a homogeneous vegetation structure, there were two explanations for the positive association between % woodland and carabid species richness and the abundance of all and large carabids. On one hand, despite the grazing that was observed in the studied woodlands, they were low disturbance habitats at least in comparison to crop fields that could also provide important shelters for carabids during the harvest season at a local scale, and facilitated their migration as corridor habitats on the landscape scale. On the other hand, woodland and windbreaks could improve and diversify local microclimatic conditions to favor ground beetles.

The negative associations of overall carabids and small carabids with the % grassy area could relate to the dense grassy areas in our study region potentially representing a significant barrier for dispersal and hunting activities of these species, resulted in a preference for woodland habitats (Schirmel et al., 2016). The most abundant species *Asaphidion semilucidum*, for example, occurred more frequently at wheat fields neighborhood with woodland than grassy margins. In addition, as previous studies indicated, cropland could conserve a significantly higher carabid diversity than grassland (Callaham et al., 2006), particularly in situations where, like in the North China Plain, cropland had been the most dominant land-use type for very long time periods, and the local species pool would have adapted to the regular disturbances and general structure of cropland. In such circumstance, a sole increase in grassy areas could result in an actual loss of more suitable habitats. The observed different responses of large and small carabids to landscape compositions finally could relate to the more stable habitat conditions require particularly by large carabids for their larval phases, while small carabids with often shorter life cycles were usually considered better adapted to farmland habitats with their more regular, stronger disturbance regimes (Aviron et al., 2005; Silva et al., 2017). While, partly contradicting previous studies which reported that trophic level modulated the response of carabids to landscape structures (Purtauf et al., 2005; Vandewalle et al., 2010), neither omnivorous nor predatory carabids were found to show significant links to % woodland and % grassy area in the surrounding landscape in this study. Higher trophic level groups are commonly believed to respond sensitively to landscape structure (Davies et al., 2000; Purtauf et al., 2005). However, small numbers of predatory carabids (161 individuals, only) in our samples limit the scope to establish significant correlations. The lack of links between % woodland and % grassy area in omnivorous carabids, on the other hand might be due to their flexible use of various food sources encountered in both, arable fields and semi-natural habitats.

Spiders are generally considered to have a better dispersal ability than carabids, not least through the use of ballooning for dispersal (Bell et al., 2005). The spiders distribution patterns we report confirm earlier reports linking their populations to the amount of grass-dominated area in the landscape (Schmidt et al., 2008; Schmidt & Tschardtke, 2005), with linear grassland potentially serving as suitable dispersal corridors or stepping stones for these species (Gruttke & Willecke, 2000). The lack of significant links between web-building spider assemblages and the landscape compositions could again be related to the strong dispersal ability of this functional group, potentially triggering responses to landscape variables only observable at larger spatial scales than the 500 m radius used here. Overall, there is a distinct overlap in species categorized as ‘web-building’ and ‘small’ (see Appendix S4) potentially explaining the insignificant response of small spiders to changes in the landscape compositions. The lack of significant correlations between large spiders and landscape composition could again be explained by the limited sample size of spiders in this category.

In contrast to our hypothesis that landscape composition would moderate the effects of local management on natural enemy biodiversity, we found that the effects of landscape composition on abundance of spiders varied with local field margin types. With an increase in the proportion of woodland in the wider landscape, abundance of adult spiders increased in fields bordered by either grassy or woodland margins, but decreased when field margins were unvegetated. Generally, woodland could provide habitats with comparatively open ground vegetation as corridors for many ground-dwelling invertebrates (Neumann et al., 2016; Silva et al., 2009), while an increase in the proportion of woodland in the wider landscape also increased both landscape diversity and connectivity for species that inhabit wheat fields in neighborhood to SNHs. Woodland could therefore promote diversity and abundance of spiders in wheat fields surrounded by woodland and grassy field margins, while differences in the species assemblages between fields surrounded by SNH and unvegetated margins could explain the overall divergence

between the communities. Spiders sampled in wheat fields surrounded by unvegetated margins mainly represented species showing a stronger preference for cropping fields than for SNHs. For example, the five species *Centromerus forficatus*, *Pardosa laura*, *Thanatus neimongol*, *Xysticus hedini* and *Zelotes exiguous* were only present at wheat fields near unvegetated pathways, with *Centromerus forficatus* and *Pardosa laura* in particular showing strong affiliations with arable land since both species were missing from samples collected directly within SNHs in the study region Zhang et al. (2019). In contrast to trends observed in carabids, an increase in the proportion and area of woodland habitats in the wider landscape could result in a decrease of suitable habitat for these species. Generally, our results highlight that local management can moderate landscape effects related to the proportion of semi-natural elements at the landscape level. An efficient conservation of natural enemy communities in arable fields therefore requires consideration of both, local and landscape scale patterns of SNHs.

5. Conclusions

Our results highlighted that both local field margin types and the wider landscape composition were important factors strongly linking to the species richness and abundance of both carabids and spiders encountered in wheat fields. Both taxa appeared to benefit from the existence of wide field margins. Carabids in particular showed diverging responses to different types of SNHs in the surrounding landscape, with a positive association observed between large and total carabids and woodland area, and a negative correlation between small carabids and the proportion of grassy areas. Spiders, on the other hand, appeared to benefit from grassy areas in the surrounding landscape. We furthermore observed that abundance of spiders, but not carabids, decreased with increasing distance to the field margin. Overall, our results highlight that the importance of local field margins traits and the overall landscape compositions for the distribution and diversity patterns of epigeic natural enemies are highly taxon- and functional group-specific,

and management of semi-natural habitats needs to consider both strongly localized as well as landscape-scale effects.

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Tables

Table 1 The compositions of the landscape patches: % major land-use types within a 500 m radius around the landscape center (% (Mean±SD); minimum-maximum (%)).

Code	Land-use type	Mean±SD (%)	Range (%)
1	Annual arable crops	54.73±12.85	40.42~89.36
	Perennial crops	0.64±1.68	0~6.26
2	Semi-natural habitats	21.81±10.92	4.68~40.45
	Woodland	10.02±5.88	2.40~23.80
	Shrubland	5.77±8.02	0~24.81
	Young tree plantation	0.50±1.20	0~3.86
	Grassy area	5.63±4.20	0.41~12.69
3	Build-up area	17.21±7.75	3.50~30.21
4	Drainage ditches	1.23±2.24	0~7.93
5	Roads and railway lines	2.47±0.87	0.75~4.04
6	Unutilized lands	0.77±0.65	0.08~2.79

Table 2 Model-averaged results for carabids with field margin type, field margin width, sampling position, landscape composition as explanatory variables, significant values ($p < 0.05$) are highlighted in bold.

Taxa/functional groups	Response variables	Explanatory variables	Estimate	SE	z-value	p-value
Total carabids	Species richness (Chao1 index)	(Intercept)	-0.120	0.165	0.708	0.479
		Position2m	0.361	0.187	1.865	0.062
		Margin width	0.285	0.120	2.300	0.022
		% Woodland (500m)	0.322	0.128	2.425	0.015
		% Grassy area (500m)	-0.179	0.127	1.356	0.175
	Abundance	(Intercept)	0.000	0.134	0.000	1.000
		Margin width	0.242	0.133	1.751	0.080
		% Grassy area (500m)	-0.340	0.146	2.249	0.025
		% Woodland (500m)	0.322	0.146	2.130	0.033
Omnivorous carabids	Abundance	(Intercept)	0.000	0.134	0.000	1.000
		Margin width	0.232	0.133	1.679	0.093
		% Grassy area (500m)	-0.284	0.144	1.906	0.057
		% Woodland (500m)	0.205	0.142	1.388	0.165
Predatory carabids	Abundance	(Intercept)	0.021	0.155	0.130	0.896
		% Woodland (500m)	0.232	0.148	1.509	0.131
		Position2m	-0.145	0.157	0.887	0.375
		% Grassy area (500m)	-0.121	0.155	0.751	0.452
Small carabids	Abundance	(Intercept)	0.000	0.134	0.000	1.000
		% Grassy area (500m)	-0.304	0.142	2.065	0.039
		Margin width	0.194	0.133	1.410	0.159
		% Woodland (500m)	0.180	0.143	1.208	0.227
Large carabids	Abundance	(Intercept)	0.000	0.134	0.000	1.000
		Margin width	0.219	0.134	1.580	0.114
		% Woodland (500m)	0.325	0.141	2.224	0.026
		% Grassy area (500m)	-0.137	0.145	0.906	0.365
Adult spiders	Species richness (Chao1 index)	(Intercept)	-0.126	0.197	0.625	0.532
		Position2m	0.352	0.231	1.471	0.141
		Margin width	0.188	0.117	1.550	0.121
		Grassy Margin (GM)	-0.067	0.282	0.228	0.820
		Woodland (WL)	0.477	0.282	1.628	0.104
		% Grassy area (500m)	0.157	0.120	1.262	0.207
		% Woodland (500m)	-0.140	0.125	1.077	0.281
	Abundance	(Intercept)	-0.242	0.189	1.238	0.216
		Position2m	0.544	0.189	2.774	0.006
		% Grassy area (500m)	0.255	0.124	1.971	0.049
		Grassy Margin (GM)	-0.379	0.283	1.287	0.198
		Woodland (WL)	0.153	0.283	0.518	0.605

		% Woodland (500m)	-0.507	0.209	2.331	0.020
		% Woodland (500m):GM	0.742	0.281	2.528	0.011
		% Woodland (500m):WL	0.675	0.276	2.340	0.019
		Margin width	0.109	0.126	0.834	0.404
Ground hunting spiders	Abundance	(Intercept)	-0.229	0.199	1.113	0.266
		Position2m	0.569	0.187	2.945	0.003
		Grassy Margin (GM)	-0.497	0.286	1.673	0.094
		Woodland (WL)	0.144	0.286	0.486	0.627
		% Grassy area (500m)	0.279	0.121	2.212	0.027
		Margin width	0.130	0.124	1.011	0.312
Sheet-web spiders	Abundance	(Intercept)	-0.029	0.145	0.196	0.845
		% Grassy area (500m)	0.137	0.124	1.061	0.289
		Position2m	0.227	0.220	0.995	0.320
Small spiders	Abundance	(Intercept)	-0.216	0.218	0.967	0.334
		Position2m	0.563	0.212	2.565	0.010
		Margin width	0.400	0.151	2.572	0.010
		% Grassy area (500m)	0.099	0.107	0.893	0.372
		Grassy Margin (GM)	-0.369	0.259	1.373	0.170
		Woodland (WL)	-0.594	0.462	1.236	0.217
Medium spiders	Abundance	(Intercept)	-0.180	0.200	0.879	0.380
		Position2m	0.464	0.159	2.816	0.005
		% Grassy area (500m)	0.320	0.136	2.276	0.023
		Grassy Margin (GM)	-0.527	0.315	1.609	0.108
		Woodland (WL)	-0.062	0.315	0.188	0.851
		% Woodland (500m)	0.096	0.144	0.643	0.520
Large spiders	Abundance	(Intercept)	-0.102	0.173	0.571	0.568
		Position2m	0.359	0.214	1.621	0.105
		Margin width	0.142	0.125	1.097	0.273
		% Grassy area (500m)	0.116	0.126	0.889	0.374

Figures

Fig. 1. Map of the sampling fields in North Anyang city, Henan province, North China Plain.

Fig. 2. Effects of field margin width on (a) Species richness of total carabids and (b) abundance of small spiders (p value < 0.05).

Fig. 3. Mean abundance of (a) adult spiders; (b) ground hunting spiders; (c) small spiders and (d) medium spiders at interior wheat field that 2 meters and 15 meters from the field margin (* $p < 0.05$, ** $p < 0.01$).

Fig. 4. Effects of % woodland on (a) abundance of total carabids; (b) species richness of total carabids; (c) abundance of small carabids; effects of % grassy area on abundance of (d) total carabids and (e) large carabids (p value < 0.05).

Fig. 5. Effects of % grassy area on the abundance of (a) adult spiders; (b) ground hunting spiders; (c) medium spiders and (d) interactions between % woodland and field margin type on abundance of adult spiders (p value < 0.05). The abundance of adult spiders increased with % woodland in wheat fields neighborhood with grassy margin ($p = 0.011$) and woodland margin ($p = 0.019$) compared to unvegetated pathway.