

The response of spiders to less-focused non-crop habitats in the agricultural landscape along the lower reach of the Yellow River

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Abstract: Non-crop habitats have been suggested to impact local biodiversity significantly in agricultural landscapes. However, there have been few studies of the effects of less-focused non-crop habitats (orchard, wetland, pit and ditch) on variation of spider abundance. In this study, spiders in 30 woodlands were captured using pitfall traps in Fengqiu County, China, and the effects of local and landscape variations at different scales (50 m, 100 m, 200 m, 350 m and 500 m) on spider abundance were analysed. The most important variation that influenced spider abundance at the 500 m scale was the less-focused non-crop habitat (LNH) cover, and 10% was an appropriate proportion of LNH cover to sustain high level of spider diversity in the investigated landscape. Non-metric multidimensional scaling analyses revealed that there were significant differences in the spider composition among the high, medium and low LNH coverage. Based on indicator species analysis, different spider species were associated with landscapes with different levels of LNH cover. Lycosidae, which accounted for 48% of the total specimens, preferred woodland habitats neighbouring areas with high LNH cover. Compared with woodland habitats, LNH provided more diverse food sources and habitat to sustain more spider species in the study area. Furthermore, linear elements composed of vegetation, such as pits and ditches, may prevent agricultural intensification by enhancing landscape connectivity and providing habitats for different spiders. Our findings may provide a theoretical basis for biodiversity conservation in agro-ecosystems and top-down control of pests.

Keywords: less-focused non-crop habitats; spider; landscape scale; ecosystem services

1 Introduction

An agricultural landscape is a heterogeneous landscape that is composed of non-crop habitats (farmland boundaries, woodland and hedges) and intensified crop fields (Bennett *et al.*, 2006; Kleijn *et al.*, 2009, 2011). Composition heterogeneity is an important element in spa-

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tial heterogeneity (Fahrig *et al.*, 2005, 2011). Researches conducted at a large spatial scale often find more obvious ecological processes and interactions than those conducted at a small spatial scale; thus, it was necessary to combine spatial patterns with ecological processes at landscape scale (Steffan *et al.*, 2002).

Biodiversity is essential for ecosystem services (Benton *et al.*, 2003; Carrete *et al.*, 2009; Fu, 1995; MEA, 2005). However, biodiversity shows a downward trend in most regions (Butchart *et al.*, 2010; Jenkins *et al.*, 2003; Kerr *et al.*, 2000; Pereira and Daily, 2006; Pimm and Raven, 2000). An increasing number of researchers have begun to pay attention to biodiversity conservation (Rossi, 2011).

It is widely known that agricultural landscape heterogeneity is closely related to biodiversity (Lazzerini *et al.*, 2007; Schneider *et al.*, 2012), as large numbers of non-agricultural species rely on food and habitats that are provided by agricultural landscape (Liu *et al.*, 2006). Meanwhile, different types of non-crop habitats can increase the heterogeneity of an agricultural landscape, which makes them important for biodiversity conservation (Ekroos *et al.*, 2013; Kleijn and Verbeek, 2000). Therefore, low intensified agricultural landscapes with a high proportion of non-crop habitats are able to sustain greater biodiversity than natural landscapes (Carnus *et al.*, 2006; Ernoult and Alard, 2011; Hartley, 2002; Tscharnke *et al.*, 2005). The impact of landscape heterogeneity on biodiversity has attracted the attention of researchers. Research is performed at the field, landscape, regional, and even national scales (Billeter *et al.*, 2008). Arthropods are an important taxa group of terrestrial ecosystems, and there have been extensively studies conducted on arthropods (Deyn *et al.*, 2003; Robertson *et al.*, 1994; Yin, 2001). Researchers mostly focus on ground arthropods in different types of ecosystems, such as farmland (Zhu *et al.*, 2000; Fournier and Loreau, 2001; Gurr *et al.*, 2003; Li *et al.*, 2004; Zhang *et al.*, 2004; Aviron *et al.*, 2005; Hendrickx *et al.*, 2007; Diekötter *et al.*, 2010; Flohre *et al.*, 2011), grassland (Maharning *et al.*, 2009; Louzada *et al.*, 2010), forest (Bird *et al.*, 2000; Conzúlez and Seastedt, 2001; Lavelle *et al.*, 2006; Huhta, 2007; Heiniger *et al.*, 2014) and so on. Researchers have found that the effects of landscape heterogeneity on ground arthropods vary by scale and that different landscapes have different effects on ground arthropods (Liu *et al.*, 2004; Chang *et al.*, 2012).

Spiders are an important predatory group and biological-control agent of arthropods (Liu *et al.*, 2016). Additionally, spiders are often abundant in temperate agricultural landscapes (Gardiner *et al.*, 2010; Maisonhaute *et al.*, 2010). The study of spiders in agricultural settings is an important link to other research on top-down control of crop herbivores (Karp *et al.*, 2013). To enhance pest control using spiders, a non-crop habitat should be set in agricultural landscapes to facilitate spider migration into crop fields during early spring (Öberg *et al.*, 2008). Although ameliorating non-crop habitats are a way to protect biodiversity of agricultural ecosystems (Carvell *et al.*, 2007; Pryke and Samways, 2009; Li *et al.*, 2013), most non-crop habitats are still forcefully disturbed by human activity, and biodiversity is also confronted with enormous threats (Vackar *et al.*, 2012). In recent years, studies on landscape heterogeneity, biodiversity and ecosystem services have been increased emphasis (Lu *et al.*, 2014; Tang *et al.*, 2014), but the scale effects of non-crop habitats on spiders are rarely studied.

Fengqiu, a county of Henan Province, is a typical agricultural region in the lower reach of the Yellow River, and is dominated by agricultural landscapes. Understanding the relation-

ship between the composition heterogeneity and biodiversity is critical to maintaining ecosystem services and ecosystem stability in this area.

As a research background, the structural composition of woodland sampling sites that surround landscapes across a mosaic agricultural landscape and different types of land uses at five spatial scales, 50, 100, 200, 350 and 500 m radii from the centre of sampling sites, were assessed. Spiders were collected using pitfall traps from each woodland site and were then analyzed in relation to the land use composition. Hence, this study specifically studied whether the abundance and species composition of different spider groups were influenced by variation of LNH among woodland areas and across landscape in heterogeneous agricultural areas. Aims of the study were to investigate: 1) how did the landscape composition impact spider diversity at different scales? 2) in particular, how did LNH cover impact spider diversity? 3) how did different spider species relate to LNH cover?

2 Methodology and data sources

2.1 Study sites

This study was conducted in agricultural landscape of Fengqiu County in northeast Henan Province, China (34°53′–35°14′N, 114°14′–114°46′E). Fengqiu County is a typical agricultural region in the lower reach of the Yellow River and is characterized by a warm temperate continental monsoon climate. The main soil type is yellow fluvo-aquic soil. The average annual rainfall is 615.1 mm, and the average annual temperature is 14 °C. Landscapes along the Yellow River are mainly alluvial plain characterized by complex habitats and mixed diversity.

Landscape is characterized by a mixture of agricultural fields and more or less non-crop habitats. Agricultural production of annual and perennial cereal crops is the typical land use of this agricultural landscape, with a total area of 81,367 ha, accounting for 66.4% of the total area of the county. The annual crops include corn, wheat, rice and vegetables, while the perennial crops include honeysuckle and raspberry. In this area, farmers sow winter wheat generally at the end of October, and after the harvest of winter wheat, corn is planted continuously. The type of woodland in the study area is an artificial planting of trees with a total area of 8672 ha. Broad-leaved species *Populus spp.* and *Paulownia Sieb. et Zucc.* are the most common species, and the dominant herb species are in the Compositae, Gramineae, Leguminosae, Cruciferae and Labiatae families (Lu *et al.*, 2014).

2.2 Study design

A land use map (1:10,000) of Fengqiu was used to identify different habitats across the landscape, and ArcGIS 10.0 was relied upon for further analysis. A total of 30 sampling sites in woodland habitats were selected, and the distances from sites to the road were measured (Figure 1). Combined with field investigation and actual situation of the study area, the landscape was grouped into 12 categories, i.e., crop, woodland, road, urban land, rural land, industrial land, river, wetland, pit, orchard, ditch and bare land.

Five plastic pitfall traps (7.8 cm in top diameter, 6 cm in bottom diameter, 17.5 cm in depth and 500 ml in volume) were installed at each site. The traps were placed at 10 m intervals and covered with plastic plates to exclude rain water. When the trapping started, the

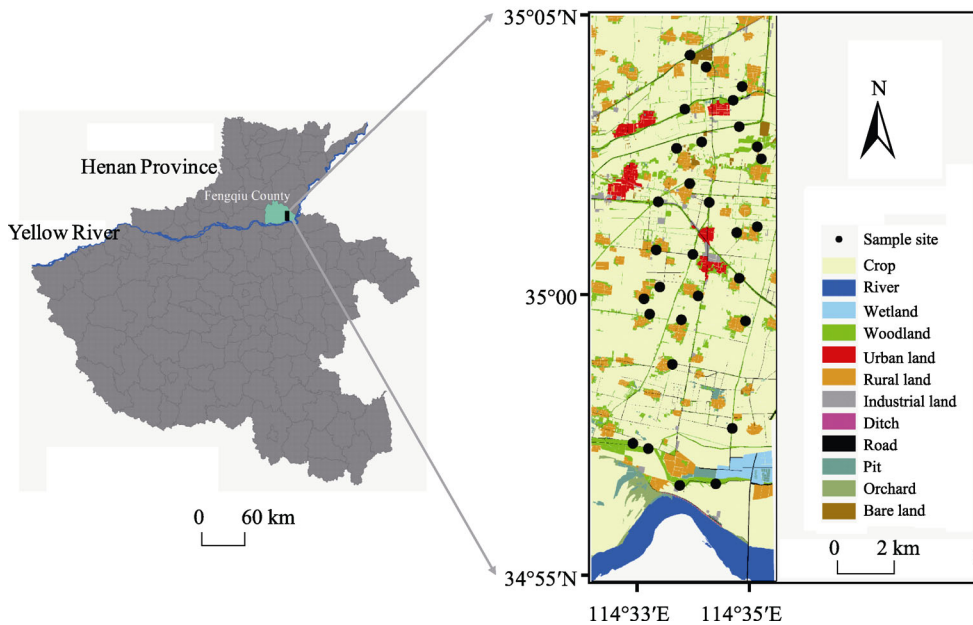


Figure 1 Distribution map of 30 sampling sites in the study area

cups were partially filled with 150–200 ml of 20% ethylene glycol and a drop of detergent as a preservative. The traps were collected every 5 days from each site during the periods from 20 April to 6 May and 10 July to 26 July in 2015, and specimens were collected twice from each site during the two periods. All specimens were transferred to vial tubes with 75% alcohol for later identification by sample number. Collected specimens were sorted in the laboratory into the following categories: beetles (Coleoptera), spiders (Araneae), ants (Hymenoptera) and other insects. Spiders were identified at the species level, while the other taxa were identified to the family or order level. Crops, woodlands and LNHs were inventoried at the centre of sites using a 50 m scale and a schematic map of the land use composition. Based on the inventory, the land use map (1:10,000) was used to digitize the types of land use from field-based maps using ArcGIS 10.0 (ESRI, USA).

The maps were used to calculate the land use proportions by estimating the woodland cover and crop cover for each polygon of land use type from satellite images, and then, the total tree cover and crop cover of each site were calculated. Moreover, LNH areas with orchard, wetland, pit and ditch were pooled together. Using the same satellite images, the proportions of different habitats, including the crop cover, woodland cover and LNH cover, of a wider (within 100, 200, 350 and 500 m radii buffer zones around each site) landscape were calculated to determine the effects of different landscape variables at different scales that affected spider abundance (Kiss and Samu, 2000).

2.3 Statistical analysis

Double factor variance analysis was initially used to determine which of the two factors, landscape composition (patch richness) or configuration (patch density), had a greater influence on spider abundance and species richness. Since landscape composition ($p < 0.05$)

was more significant than the configuration ($p > 0.05$), variables representing the landscape composition at local and landscape scales were chosen as explanatory variables for subsequent analyses (Table 1). The abundance and richness of spiders were treated as response variables in the respective analyses.

A large variation existed at different scales among most of measured variables (Table 1). For example, the percentage of local crop cover ranged from 0 to 94, while that of woodland cover ranged from 4 to 99. The variance of mean crop cover was the greatest at all the four landscape scales, and the variance of mean LNH cover showed a rising trend when the scales increased.

Table 1 Explanatory variables at the local (50 m) and landscape (100, 200, 350 and 500 m radii buffers) scales

Variables	Spatial scale (m)	Range (min–max)%	Mean \pm SD
Crop cover	Local	0–94	27.3 \pm 25.3
Woodland cover	Local	4–99	63 \pm 25.1
Distance from road (m)	Local	18.2–1269.5	434.1 \pm 397.2
Crop cover	Landscape (100 m)	8.1–91.2	44.1 \pm 20.3
Woodland cover	Landscape (100 m)	3–82	41.4 \pm 19.1
LNH cover	Landscape (100 m)	0–15.3	3.2 \pm 5.4
Crop cover	Landscape (200 m)	28–84.5	55.7 \pm 14.5
Woodland cover	Landscape (200 m)	5.2–56.7	26.2 \pm 12.1
LNH cover	Landscape (200 m)	0–30	3.4 \pm 6.5
Crop cover	Landscape (350 m)	35.5–81.5	60.4 \pm 11.4
Woodland cover	Landscape (350 m)	3–47.7	18.4 \pm 9.8
LNH cover	Landscape (350 m)	0–24.8	3.6 \pm 5.3
Crop cover	Landscape (500 m)	38.5–82.6	62.5 \pm 10.6
Woodland cover	Landscape (500 m)	3.9–42.8	15.5 \pm 8.6
LNH cover	Landscape (500 m)	0.2–19.8	4.1 \pm 6.1

Before modelling the abundance against landscape variables, the collinearity among measured explanatory variables was tested, and then, all of variables that had no collinearity (Condition Index < 10) were selected for subsequent analyses (Montgomery *et al.*, 2016). Three variables used at the local scale were crop cover, woodland cover and distance from road. At each landscape scale (100, 200, 350 and 500 m), three variables, crop cover, woodland cover and LNH cover, were included for analysis. Owing to the correlation among the landscape variables, only one landscape-scale variable was included in each model, followed by repeated local variable analysis for each of the remaining four landscape variables. Therefore, we used four models: Models 1–4. The best models were those with the lowest Akaike Information Criteria (AIC) values using the stepAIC function within the MASS package (Venables and Ripley, 2002) in the R program (RDCT, 2011). Because of the small sample sizes, AICc was used instead of AIC. The calculated Akaike Weights (Wi) were used

to measure the influence of each variable in every model.

We divided the 30 sampling sites into three groups equally based on their LNH cover at the landscape (500 m radius) scale: 1) a high LNH cover (landscape cover > 2.9%); 2) a medium LNH cover; and 3) a low LNH cover (landscape cover < 1.8%) (Figure 2). The logistic fitting method was used to study the effect of LNH cover changes on spider diversity at 500 m scale in MATLAB software. In the following analysis, a non-metric multidimensional scaling analysis (NMDS) based on the lower-triangular dissimilarity matrix in the Vegan package was used to determine differences in the spider composition. Indicator species analysis with the IndVal function was performed to characterize the taxa of spiders in relation to the three groups of LNH cover in the Labdsv package (Dufrêne and Legendre, 1997). Here, indicator value of taxon for a group was calculated based on a combination of its occupancy among sites and relative abundance of the particular group.

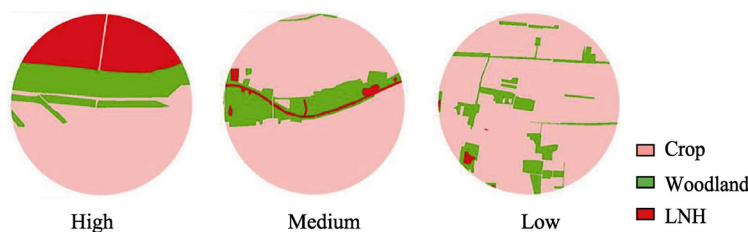


Figure 2 Three LNH cover groups at 500 m scale (each group has only one chosen typical site)

3 Results

3.1 Abundance of spiders

Five hundred sixty-nine spiders (3–56 individuals per site) belonging to 21 taxa and 9 families (Figure 3) were caught. The dominant species were *Pardosa astrigera*, *Hitobia unifascigera*, *Pirata piratoides* and *Drassyllus shaanxiensis*, accounting for 29.5%, 12.7%, 11.1% and 10.1% of the total individuals, respectively.

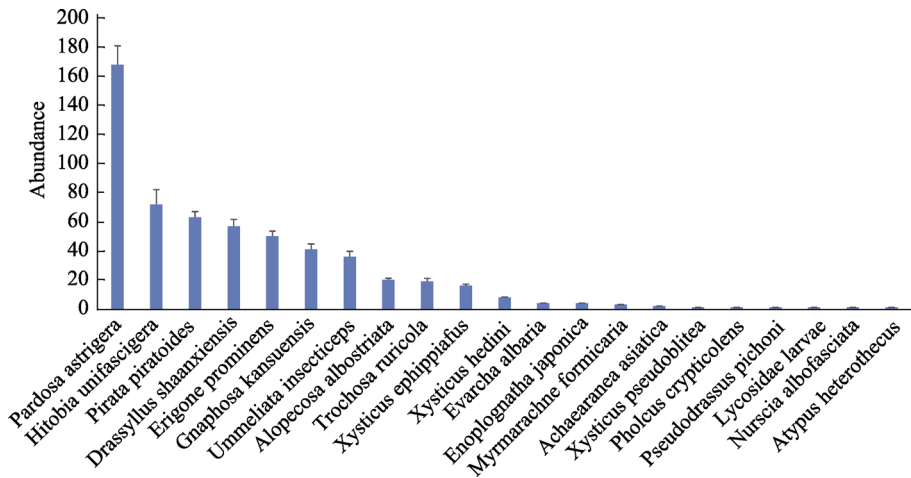


Figure 3 Abundance of spiders

3.2 Response of spider abundance to landscape composition variables at different scales

The statistical models showed a complex interaction between local and landscape variation, which affected abundance of spiders (Table 2). In all models, local variation played an important role in affecting spider abundance, especially crop cover. While crop cover did not have significant effects on the spider abundance at all landscape scales, except at the 100 m scale, neither did woodland cover. LNH cover showed more significant impacts on spiders as the scale increased. For example, the most important variation that influenced spider abundance at the 500 m scale was LNH cover ($W_i= 0.36$), which replaced local crop cover.

Table 2 Results of the information theoretic model selection and multi-model inference explaining spiders at the local (50 m) and landscape (100, 200, 350 and 500 m) scales

Model	Spatial scale	Adjusted R ²	Loglik	df	AICc	W _i
Model 1		0.177	-5.5798	8	32.2505	
	Crop cover	Local				0.29
	Woodland cover	Local				0.17
	Distance from road (m)	Local				0.18
	Crop cover	Landscape (100 m)				0.21
	Woodland cover	Landscape (100 m)				0.07
	LNH cover	Landscape (100 m)				0.06
Model 2		0.052	-7.7082	8	36.5073	
	Crop cover	Local				0.34
	Woodland cover	Local				0.20
	Distance from road (m)	Local				0.21
	Crop cover	Landscape (200 m)				0.09
	Woodland cover	Landscape (200 m)				0.07
	LNH cover	Landscape (200 m)				0.08
Model 3		0.148	-6.1067	8	33.3043	
	Crop cover	Local				0.30
	Woodland cover	Local				0.18
	Distance from road (m)	Local				0.19
	Crop cover	Landscape (350 m)				0.06
	Woodland cover	Landscape (350 m)				0.06
	LNH cover	Landscape (350 m)				0.21
Model 4		0.170	-5.7152	8	32.5213	
	Crop cover	Local				0.24
	Woodland cover	Local				0.15
	Distance from road (m)	Local				0.15
	Crop cover	Landscape (500 m)				0.05
	Woodland cover	Landscape (500 m)				0.05
	LNH cover	Landscape (500 m)				0.36

Notes: Bolded print indicates the most powerful factors in each model.

The following analysis used three categories, High, Medium and Low, to describe LNH cover at 500 m scale. The results indicated that abundance and richness of spiders in wood-

land were greater in landscapes with a higher LNH cover than those with a lower LNH cover (Figures 4a and 4b). The increasing rate slowed with a LNH cover greater than 10% (Figures 4c and 4d), and 10% might be the best trade-off between set-aside and biodiversity.

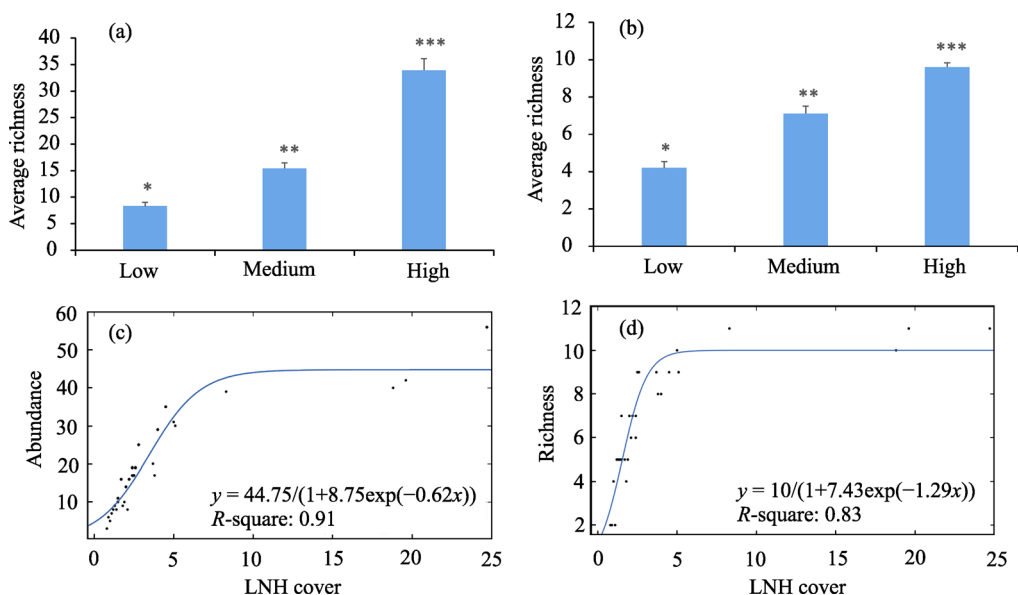


Figure 4 Abundance and richness of spiders in relation to LNH cover (500 m). The three LNH cover classes are based on the combination of orchard, wetland, pit and ditch areas at 500 m scale: 1) high LNH cover (High); 2) medium LNH cover (Medium); and 3) low LNH cover (Low). In the first row (a, b) the symbol (*) among LNH cover classes (High, Medium and Low) indicates significant differences in abundance and richness of spiders. The second row (c, d) shows the logistic trend-line of the abundance (or richness) and LNH cover.

3.3 Species composition

We used NMDS to compare differences in spider community composition. The results revealed that each plot had a distinct value from the others based on the lower-triangular dissimilarity matrix calculation (Figure 5). There were significant differences in the species composition of spiders within communities among different scales of LNH cover. Relatively, the spider composition in habitats that had a high LNH cover were more similar to those in habitats that had a medium LNH cover and those in habitats that had a low LNH cover.

Some 48% of all collected spiders (9 families) were in the Lycosidae family (wolf spiders). Indicator species analysis showed that the majority of spider taxa with a distinct indicator value had higher indicator values in woodland with a high LNH cover

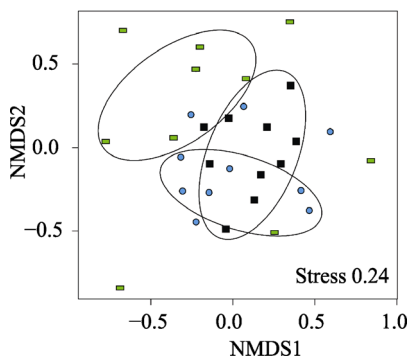


Figure 5 NMDS plot of three categories based on the spider composition at 500 m scale. Black symbols represent plots with a high LNH cover, blue symbols represent plots with a medium LNH cover, and green symbols represent plots with a low LNH cover.

(Table 3), especially for spiders in the Lycosidae and Gnaphosidae families. However, a few spider taxa, such as *Achaearanea asiatica* in the Theridiidae family, *Pholcus crypticolens* in the Pholcus family, and *Lycosidae Larvae* in the Lycosidae family, were typical and more frequently appeared in woodland with a medium or low LNH cover (Table 3). According to indicator species analysis, some spider taxa also had a relatively high indicator value (> 0.2), which was associated with a medium or low LNH cover (Table 3). Examples of such taxa were: *Pardosa astrigena* (Lycosidae), *Erigoneprominens* (Linyphiidae), *Drassyllus shaanxiensis* and *Hitobia unifascigera* (Gnaphosidae). In addition, two spider species were characterized as indicator species (IndVal values between 45% and 70%, Table 3) for the three different levels that were analysed in this study. The indicator species that we identified in this study could be a useful tool for detecting changes of the landscape structure in habitat patches and in the landscape matrix at both levels.

Table 3 Responses of spiders to LNH cover at 500 m scale by indicator species analysis

Taxa	Family	LNH coverage classes (500 m) and indicator values		
		Low	Medium	High
<i>Pardosa astrigena</i>	Lycosidae	0.13	0.25	0.49
<i>Pirata piratoides</i>	Lycosidae	0.03	0.17	0.29
<i>Trochosa ruricola</i>	Lycosidae	0.01	0.08	0.48
<i>Alopecosa albostrata</i>	Lycosidae	0	0.02	0.44
<i>Lycosidae Larvae</i>	Lycosidae	0.10	0	0
<i>Gnaphosa kansuensis</i>	Gnaphosidae	0.10	0.13	0.34
<i>Drassyllus shaanxiensis</i>	Gnaphosidae	0.13	0.20	0.40
<i>Hitobia unifascigera</i>	Gnaphosidae	0.13	0.21	0.39
<i>Pseudodrassus pichoni</i>	Gnaphosidae	0	0	0.10
<i>Erigone prominens</i>	Linyphiidae	0.25	0.11	0.30
<i>Ummeliata insecticeps</i>	Linyphiidae	0.04	0.14	0.17
<i>Xysticus hedini</i>	Thomisidae	0	0.03	0.20
<i>Xysticus ephippiafus</i>	Thomisidae	0.11	0.05	0.11
<i>Xysticus pseudoblitea</i>	Thomisidae	0	0	0.10
<i>Evarcha albaria</i>	Salticidae	0	0.10	0.10
<i>Myrmarachne formicaria</i>	Salticidae	0	0.05	0.05
<i>Enoplognatha japonica</i>	Theridiidae	0.03	0.03	0.05
<i>Achaearanea asiatica</i>	Theridiidae	0	0.10	0
<i>Pholcus crypticolens</i>	Pholcus	0	0.10	0
<i>Nurscia albofasciata</i>	Titanoecidae	0	0	0.20
<i>Atypus heterothecus</i>	Atypidae	0	0	0.10

4 Discussion

4.1 Role of crop cover and LNH cover at different scales

With the change of scales, the responses of spiders also changed. In this study, the most effective landscape variance for spider abundance was crop cover (Local scale) at 100, 200,

and 350 m scales (Table 2). Several previous studies agreed with the above findings and suggested that abundance or richness of spiders was related to a local variable (Batáry *et al.*, 2008; Herrmann *et al.*, 2010; Öberg *et al.*, 2008; Schmidt and Tscharnkte, 2005; Schmidt *et al.*, 2008). Owing to their natural enemies, spiders often immigrated from the surrounding landscape to arable fields where they controlled pests (Schmidt *et al.*, 2008). Spiders were also influenced by local management practices (ploughing, fertilization, and pest management), agricultural practices (mowing and grazing) and plant and litter cover, which could significantly affect the hunting spider and, to some extent, web-building spider communities (Batáry *et al.*, 2008; Horváth *et al.*, 2015).

The most effective landscape variable affecting the spider abundance shifted to LNH cover at 500 m scale ($W_i = 0.36$), and spider abundance was positively related to LNH cover (Figure 4c). There existed some researches supporting this result. Schmidt and Tscharnkte (2005) found that spider density was positively related to the percentage of non-crop habitats in conventional fields. At the landscape scale, the species richness of spiders was enhanced in non-crop habitats (Schmidt *et al.*, 2008). In smaller spider groups, such as Linyphiid spiders, the abundance was enhanced by high percentages of non-crop habitats in a 1–3 km circumference (Öberg *et al.*, 2008). By contrast, no significant landscape effects were found on abundance and richness of spiders (Batáry *et al.*, 2008). This difference might be due to differences in landscape matrix, the landscape matrix of this study was farmland, while the study of Batáry *et al.* (2008) was pastures. Therefore, the effect of landscape variance was ignored in this study because local variance produced the most significant effects on spider abundance. The orchard was the landscape matrix used in Herrmann's study (2010), which led the spider abundance associated with meadow to be affected by plant diversity at the local scale, but not by fragmentation at the landscape scale. The study by Batáry *et al.* (2008) yielded the same result. In this study, the correlation between spider abundance and LNH cover increased gradually with the increasing scale.

4.2 Spider demand for ecosystem services varies at different scales

Why was the most important variation for spider abundance that of crop cover (50 m) at the 100, 200, 350 m scales, and why did it become a non-crop habitat cover at 500 m scale? What roles did the different habitats play in the effects on spider abundance? It could be speculated that because ecosystem services included supplies, regulations and other services, different ecosystem services might be emphasized for each habitat in agricultural ecosystems, which suggested that the different habitats had their own main ecosystem services (Zhang *et al.*, 2018). In this study, the ecosystem services of the crop habitat for the spider focused on the supply service and the ecosystem services of non-crop habitat, which included woodland and LNH, focused on regulation services (mainly for providing refuge and overwintering sites). The results showed that LNH coverage was low at small scale (100 and 200 m), which provided less regulation services. At this scale, woodland habitats provided regulation services for most spiders, thus, woodland habitats had a high impact on spider diversity. The coverage of LNH increased with scale, and the regulation services that could be provided also increased rapidly. LNH provided more regulation services than woodland habitats (the woodland in the study area was artificial woodland and the vegetation cover was rare) at a larger scale. Furthermore, linear elements composed of vegetation-like pits

and ditches might prevent agricultural intensification by enhancing landscape connectivity and providing habitats for different spiders. Thus, LNH had a higher impact on spider diversity at larger scales (350 and 500 m) than that at smaller scales (100 and 200 m). Previous studies found that larger spider species were sustained in complex landscapes with a higher availability of refuge and overwintering habitats (Schmidt *et al.*, 2005, 2008).

The results showed that at smaller scales (100, 200 and 350 m), the supply service (provided by local crop cover) was the most important service for spiders, which could allow them to hunt for living prey in crops. Woodland provided the most important regulation service at 100 and 200 m scales. Considerable regulation services were provided to spiders by the landscape LNH cover at 350 and 500 m scales. Especially at 500 m scale, the considerable important variation was LNH cover (Table 2). The results demonstrated that at a greater scale, regulation was more important than supply services for spider abundance and illustrated that the improvement of landscape heterogeneity stimulated the increase of spider abundance in this study area (Figure 4). Therefore, the percentage of non-crop habitat needed to be considered, especially that of LNH cover. However, either mainly in crop habitats (Ricci *et al.*, 2009) or both in crop habitats and non-crop habitats (Rusch *et al.*, 2013), it was found that insect pests respond to the spatial distribution of their host plant resources, so the increased LNH proportion should be limited. Other predatory arthropod families, such as the Carabidae, could be used instead of spiders in future studies.

5 Conclusions

In this study, we studied the multi-scale effects of landscape composition heterogeneity on spider diversity. Our results indicated that the most important variation for spider abundance was that of crop cover (50 m) at 100, 200 and 350 m scales and became LNH cover at 500 m scale. Abundance of spiders was positively related to the LNH cover at 500 m scale, and 10% of LNH cover was appropriate for spider diversity. According to our findings, we believed that the crop habitat could provide a supply service (mainly for food resources) and that woodland and LNH habitats could provide regulation services (mainly for providing refuge and overwintering sites) for spiders. At the large scale, regulation services were more important than supply services for spiders. We should enhance the protection of LNH in the region because regulation services were mainly provided by LNH at the larger scale. This study on spiders contributes to research on top-down pest control, which is more beneficial to agricultural landscape than the use of pesticides. Our research could provide some theoretical guidance for landscape management and biodiversity conservation. Future studies should focus on observing and comparing the response of other predatory arthropod families, such as the Carabidae, to those of spiders in LNH.

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