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Original Articles

The effect of semi-natural habitat types on epigaeic arthropods: Isolate habitats make critical contribution to biodiversity in agricultural landscape

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ABSTRACT

Semi-natural habitats in agricultural landscapes vary greatly in shape and vegetation characteristics. They can appear either as relatively large patches of several hectares or as narrow bands (less than 1 m wide) between fields and roads and between fields. Semi-natural habitats support biodiversity and associated ecosystem services on farmland, thereby contributing to sustainable agriculture. However, the effects of different semi-natural habitat types on the polytrophic level of epigaeic arthropods are still unclear. In this study, we classified semi-natural habitats into five types. (1) woody areal (WA), (2) woody line (WL), (3) herbaceous areal (HA), (4) herbaceous line (HL) and (5) isolate habitat (IH). We aimed to explore differences in epigaeic arthropod community composition in five different semi-natural habitats and the effects of different semi-natural habitats and different sampling locations on epigaeic arthropod activity-density and diversity. The results showed that epigaeic arthropod communities show significant differences, not only between farmland and semi-natural habitats, but also between different types of semi-natural habitats. Isolate habitats have the highest activity-density of epigaeic arthropods and Linear herbaceous maintain the highest epigaeic arthropod diversity. We also found in this study, both the activity-density and diversity of epigaeic arthropods showed edge-biased distribution. It may be possible to promote sustainable agricultural ecosystems by understanding the effect of semi-natural habitats on epigaeic arthropods, which is conducive to improving the quality of the agricultural ecological environment.

1. Introduction

Agricultural production covers 40 % of the Earth's land surface and is the largest use of land on Earth (Foley et al., 2005; Foley et al., 2011). As the global population grows, agricultural production needs to expand to meet global food needs and maintain food security (Tilman et al., 2011; Viana et al., 2022). Agricultural intensification has become the main way to increase food production worldwide (Emmerson et al., 2016). Although agricultural intensification has brought a series of benefits to food production, it has also caused a certain negative impact on the ecology of agriculture. Increasing use, including fertilizers and pesticides, has accelerated environmental pollution (Campbell et al., 2017). Studies have shown that increased nitrogen fertilizer use is expected to increase nitrogen dioxide emissions from agriculture by 35–60 % by 2030 (Smith et al., 2008). In addition, agricultural intensification accelerates the loss of semi-natural habitats in agricultural landscapes, which has negative impacts on both farmland biodiversity and ecosystem services (Rega et al., 2018; Shi et al., 2021). The decline of farmland birds in Europe was mainly due to habitat loss (Traba and Morales, 2019). Duelli and Obrist (2003) have shown that more than 63 % of arthropod species within intensively managed farmland depend on semi-natural habitats.

Semi-natural habitats (e.g., ditches, woodlands, hedges, etc.) have the potential to support ecosystem services, including support for biological control, pollination, and soil conservation (Holland et al., 2017). They can provide shelter habitat and a stable living environment free from human interference for predators, which is conducive to strengthening pest control (Landis et al., 2000). Semi-natural habitats can also enrich biological groups such as farmland birds and epigaeic arthropods in agricultural ecosystems (Benton et al., 2003; Olimpi et al., 2022). Semi-natural habitat can maintain the species that originally inhabited the field when farmland is resource-poor or heavily disturbed

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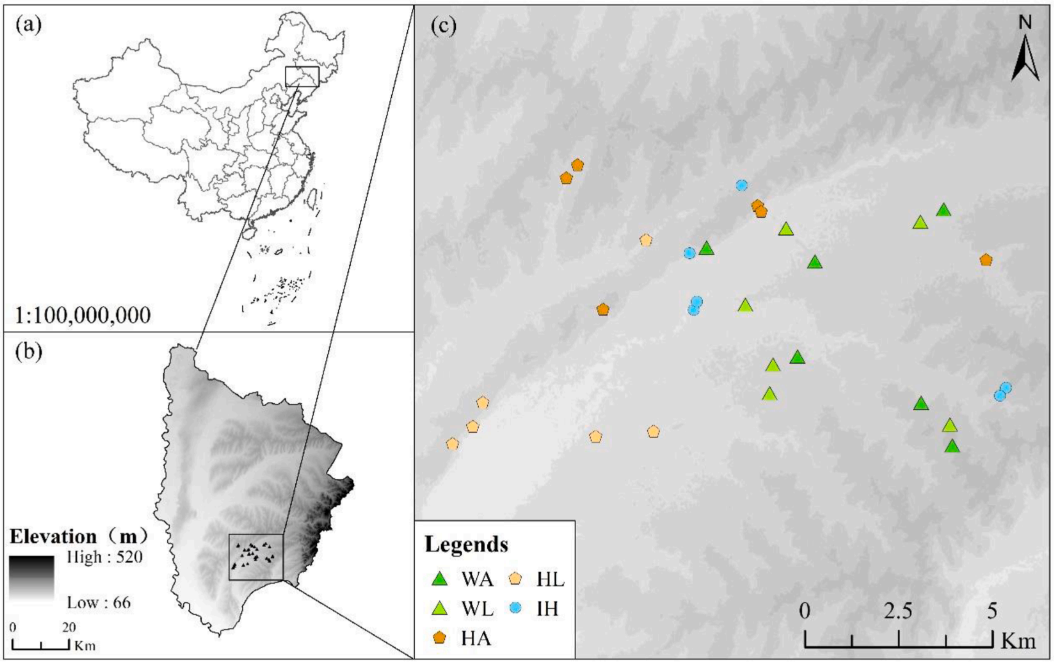

Fig. 1. Location of sampling sites in the study area. (a) shows the location of the study area in China; (b) Changtu county, which is located in northern Liaoning. Sample sizes are in the south of the county. (c) shows sampling unit of 5 semi-natural habitat types. WA, woody areal; WL, woody line; HL, herbaceous line; HA, herbaceous areal; IH, isolate habitat.

by humans (such as during the tillage or harvest period). And the species can be returned to the farmland from the semi-natural habitat through spillover effects while the agricultural activity enters a stable period (Blitzer et al., 2012). In addition, the semi-natural habitat itself has the effect of isolating carbon in vegetation and soil, and the presence of plants in the semi-natural habitat can hinder soil erosion and prevent soil erosion (Zuazo and Pleguezuelo,2009). Agri-environmental scheme (AES) has been in place in Europe for many years and aims to protect semi-natural habitats, reverse the decline in biodiversity on farmland and improve and maintain ecosystem services. The protection of threatened semi-natural habitats was also the original purpose of the AES (Batáry et al., 2015). Significant sums of money are also invested each year to compensate farmers for the costs and lost income from the retention of semi-natural habitats (Rotchés-Ribalta et al., 2021).

Semi-natural habitats in agricultural landscapes vary greatly in shape and vegetation characteristics. They can appear either as relatively large patches of several hectares or as narrow bands (less than 1 m wide) between fields and roads and between fields. Hedges and perennial shrubs scattered around the edges of fields are typical examples of striped semi-natural habitats. The size of patches affects biodiversity in farmland, and smaller patches demarcated by semi-natural habitats are more conducive to the maintenance of biodiversity in farmland (Šálek et al., 2018; Benton et al., 2003). Farmland with smaller fields has more habitat edges than landscapes with larger fields, and these boundaries have more resources available to farmland organisms while facilitating the movement of farmland organisms between patches (Fahrig et al., 2015). Vegetation types in semi-natural habitats generally include both woody and herbaceous. Vegetation type is a key determinant of epigaeic arthropod community composition (Mestre et al., 2018). Studies have shown that herbaceous plants are more conducive to the activity density and diversity of epigaeic arthropods than woody plants. But the research evidence is not sufficient (Tougeron et al., 2022). Other studies have explored the effects of semi-natural habitats of different shapes and vegetation types on specific species (e.g., spiders and bees) (Bartual et al., 2019; Mestre et al., 2018). However, studies of the effects of multitrophic species are more useful in developing conservation policies (measures) that are effective for a wide range of species (Sirami et al., 2019). Relevant research is currently scarce.

A key objective of the Quantification of Ecological Services for Sustainable Agriculture (QuESSA) project in Europe is to identify the main types of semi-natural habitats in farmland and to develop a classification system that can be applied universally throughout Europe (Holland et al., 2020). It is classified mainly on the shape of semi-natural habitats and vegetation types. A total of five categories were identified on this basis, covering most types of semi-natural habitat in the European agricultural landscape. (1) woody areal, (2) woody line, (3) herbaceous areal, (4) herbaceous line and (5) fallow. This classification of semi-natural habitats takes into account the structural (shape) and composition (vegetation type) characteristics of semi-natural habitats compared with the previous classification according to land-use types, and the original classification only considers the composition of semi-natural habitats and does not take into account the structural characteristics of semi-natural habitats. Studies have shown that semi-natural habitat structures are critical to farmland landscape heterogeneity and biodiversity (Guo et al., 2022). However, the semi-natural habitat in China is different from that in Europe. The average arable land area (total arable land area/total population) of Chinese is 0.007 km^2, which is only 25 % of the world's per capita arable land area. Therefore, fallow land is relatively rare in China's agricultural landscape. Instead, isolate habitats (lone trees or sporadic meadows in or around farmland) are more common due to the destruction of semi-natural habitats by farmers for agricultural production in northern China. These isolate habitats are considered the cornerstone structures of the landscape, occupying only a small part of the landscape, but of disproportionate ecological importance (Fischer et al., 2010a; Fischer et al., 2010b). Positive effects on farmland organisms such as birds, bats, ants, and beetles have been shown in agricultural landscapes (Prevedello et al., 2018). But isolate habitats are rarely considered in landscape conservation and planning (Wintle et al., 2019; Prevedello et al., 2018).

In this study, we classify semi-natural habitats based on the European classification criteria for QuESSA combining the current state of land use in China and the characteristics of agricultural landscapes. This resulted in five categories being identified. (1) woody areal (WA), (2) woody line (WL), (3) herbaceous areal (HA), (4) herbaceous line (HL)

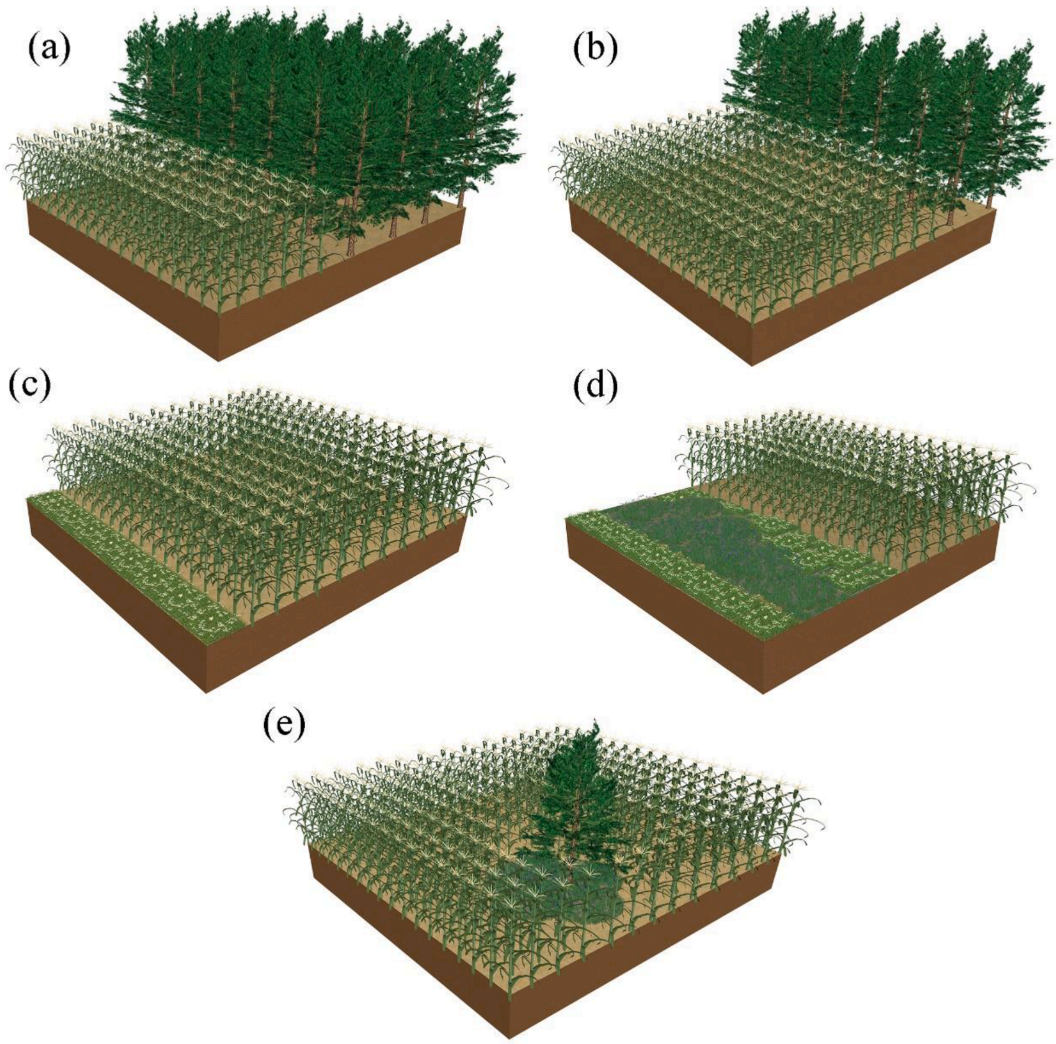

Fig. 2. Profile diagram of the 5 types of sampling areas. (a) woody areal, (b) woody line, (c) herbaceous line, (d) herbaceous areal, (e) isolate habitat.

and (5) isolate habitat (IH). We aimed to explore differences in epigaeic arthropod community composition in five different semi-natural habitats and the effects of different seminal habitats and different sampling locations on epigaeic arthropod activity density and diversity. More specifically, we propose the following assumptions: (1) Due to the different habitat preferences of different species, each semi-natural habitat type has a different composition of epigaeic arthropods. (2) The effects of different semi-natural habitat types on epigaeic arthropod activity density and diversity vary. Isolate habitats play an important role in maintaining the activity-density and diversity of epigaeic arthropods. (3) There are differences in epigaeic arthropod activity density and diversity between sampling locations (semi-natural habitats, boundaries between semi-natural habitats and crops, and within fields). Semi-natural habitats have a higher activity density and diversity than inside the fields.

2. Materials and methods

2.1. Study area

We conducted this study in 2021 in Changtu county (42°33′–43°29′N, 123°32′–124°26′E), north-eastern China (Fig. 1). Changtu county is known for its agricultural productivity. The area of arable land (2667 km^2) accounts for 62 % of the total area of the county (4317 km^2). Moreover, the dominant crop of this area are corn and soybeans. It is following the common land-use system of Northeast China. Therefore, Changtu is regarded as a typical dry farming area in the northern plain. The regional climate is mid-temperate continental monsoon with an annual mean temperature of around 7 °C and annual precipitation of around 600 mm. The rainfall is concentrated in June, July, and August. During this period, the temperature is relatively high. Within the study region we selected 30 study units, which are mainly distributed in the southern part of Changtu County.

2.2. Study design

This study establishes a classification system for semi-natural habitats in China based on the QuESSA project. Semi-natural habitat types were divided into 5 categories according to shape and main vegetation types (Fig. 2). (1) woody areal (WA, woodland), (2) woody line (WL, hedges or linear farmland shelterbelts), (3) herbaceous line (HL, narrow herbaceous edges), (4) herbaceous areal (HA, natural hayfields or abandoned fields that have not developed) and (5) isolate habitat (IH, Lone trees or isolate meadows in or around farmland). The areal semi-natural habitats were at least 25 m wide and 50 m long and should be covered by at least 30 % shrubs and trees. The width of linear semi-natural habitats was between 1.5 m and 25 m. Isolate habitats were irregular in shape and ranged from 1 m^2 to 8 m^2 in size. There are 6 replicates (controls) for each semi-natural habitat type. For example, there are 6 replicates of linear herbaceous habitats and 6 replicates of linear woody habitats, for a total of 30 semi-natural habitat units. Each semi-natural habitat unit was adjacent to a focal field. All focal fields grow corn. Fields are managed in exactly the same way. Sampling within the focal field was done on a transect extending from the edge of the field bordering the semi-natural habitats 50 m into its interior at distances of 10, 20, 30, 40 and 50 m from the edge in each field. We established four sampling points in each semi-natural habitat replicate, two at the edge and two at the interior. Three traps are laid at each sample point. The number of traps per semi-natural habitat unit (including focal plots) is 17. The isolate habitat unit differs slightly from other habitat units in that it has a smaller area of contact with the fields and a smaller area of its own, so two sampling points in each isolate habitat were established, one at the edge and two at the interior. The number of traps per habitat unit (including focus plots) was 11. A total of 474 traps were laid. The trap spacing is 10 m. Epigaeic arthropods collection took place from August 30, 2021 to September 8, 2021.

2.3. Epigaeic arthropod sampling

Epigaeic arthropods were collected using pitfall traps. Pitfall traps were made of plastic cups with a bottom diameter of 6 cm, a top diameter of 10 cm, and a depth of 13 cm. All cups were filled with 150–200 ml of ethylene glycol solution (20 %) and a few drops of detergent to reduce surface tension. Pitfall traps were dug into the soil with the rims at ground level. Plastic roofs were used to protect from rainfall and litter. Epigaeic arthropods were picked up into pre-coded polyethylene bottles after 6 days in fields. Epigaeic arthropods were stored in 70 % ethanol until identification. All epigaeic arthropods were identified to family.

Two metrics were used to describe the epigaeic arthropod characteristics, Average activity-density (average number of individuals caught per trap) and diversity (effective number of species convert Simpson dominance indices into true diversities. The formulas are as follows).

$$C = \sum_{i=1}^{S} p_i{}^2 D = \frac{1}{C}$$

where, S is the number of species, p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N).

2.4. Statistical analysis

Non-metric multidimensional scaling (NMDS) was used to understand the differences among epigaeic arthropod community structures between different semi-natural habitat types and different sampling locations. A stress coefficient was used to test the reliability of the results. NMDS provides a visual representation of the dissimilarity in epigaeic arthropod taxa composition between samples (Shepard, 1962). Based on Bray-Curtis indices, we analyzed differences in community composition using PERMANOVA, which provide significance tests for the independent variables (Anderson, 2001). After the PERMANOVA, we further performed a pairwise multilevel comparison to test for significant differences among semi-natural habitat types and sampling locations. Analyses were carried out using the software PAST 3.14. Two-way ANOVA was used to compare differences in the activity-density and diversity of epigaeic arthropods among different semi-natural habitats and sampling locations. Least significant difference (LSD) was used to compare differences between factor levels. The analysis was conducted with SPSS version 25.0.

Table 1
Bray Curtis indices for the similarity of epigaeic arthropod communities of different habitat types. ($p = 0.006$).

Semi-natural habitat types	WA	WL	HL	HA	IH
WA		0.355	**0.001**	0.095	0.471
WL	74.86		0.218	0.619	0.574
HL	65.89	71.91		0.417	0.273
HA	73.63	71.16	81.91		0.228
IH	74.21	69.37	73.48	87.61	

Note: Bottom left: Higher values indicate higher similarity. Top right: p-values from pairwise multilevel comparisons after PERMANOVA (permutations = 999). Significant *p*-values are given in bold.

3. Results

3.1. Epigaeic arthropod description and statistics

A total of 13,129 epigaeic arthropods were captured, belonging to 5 classes, 10 orders, and 41 families. The catch was dominated by Gryllidae and Carabidae which accounted for 76 % of the total catch. Common families included Formicidae Scarabaeidae Chrysomelidae Catantopidae Pyrgomorphidae Agelenidae Linyphiidae Protolophidae, and Paradoxosomatidae, totaling 2776 and accounting for 21 % of the total catch. The remaining 30 families were comparatively rare (Appendix Table 1).

3.2. The similarity of epigaeic arthropod communities of different semi-natural habitat types

Epigaeic arthropod communities varies significantly between different semi-natural habitat types. HL maintains the largest number of families in total of 32 families. Lowest values on WA, which contained 25 families. There were 17 families in the five semi-natural habitats, and the number of unique families was 9 (Fig. 3a, 3b). Bray Curtis indices revealed the lowest similarity of epigaeic arthropod communities between WA and HL (65.89 %), while the types of HA and IH showed the highest similarity (87.61 %; Fig. 3a, Table 1). Epigaeic arthropods differed significantly among semi-natural habitat types ($p = 0.006$). Pairwise multilevel comparison showed that there is a significantly different in epigaeic arthropod communities between WA and HL (Table 3). The result of NMDS and Bray Curtis showed that families community composition significantly differed between sampling locations although there is high similarity of arthropod communities between crop fields and inside (80.84 %) and edge (79.2 %) of semi-natural habitats (Fig. 4, Table 2).

3.3. Effects of semi-natural habitat types and sampling locations on activity-density and diversity of epigaeic arthropod

The results of the two-way ANOVA results show that habitat type and sampling location has a significant effect on activity-density (F = 6.696, $p < 0.001$; F = 4.394, $p = 0.016$) and diversity (F = 4.438, $p = 0.003$; F = 7.436, $p = 0.001$) of epigaeic arthropod. However, the interaction between the two did not have a significant effect on the activity-density and diversity of epigaeic arthropods ($p > 0.05$) (Table 3). It means that habitat type and sampling location independently affected the activity density and diversity of soil arthropods, and there was no interaction.

The results show that isolate habitats are beneficial to the activity density of epigaeic arthropods, and herbaceous lines are more conducive to the maintenance of epigaeic arthropod diversity (Fig. 5). The activity-density of epigaeic arthropods was highest in IH, and was significantly higher than that in WA, WL, and HA. Epigaeic arthropod diversity was the highest in HL, and significantly higher than in WA. High activity-density and diversity of epigaeic arthropods maintained at the edge of semi-natural habitats. The activity-density of epigaeic arthropods at the edge was significantly higher than inside of semi-natural habitats. The

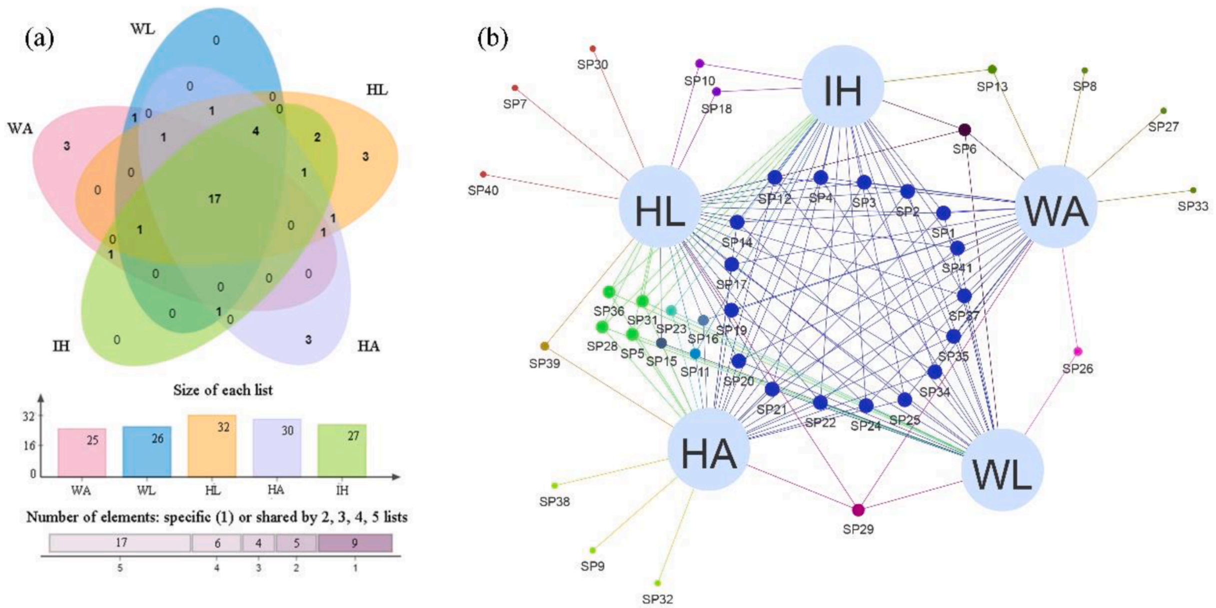

Fig. 3. Venn and Venn network diagram of epigaeic arthropod. (a) Different colors represent different semi-natural habitats, the number of overlapping sections represents the number of families shared in different semi-natural habitat types, and the number of non-overlapping parts represents the number of families unique to different semi-natural habitats. (b) Venn network displayed codes for shared and unique families in different habitat types (codes please see Appendix Table 1).

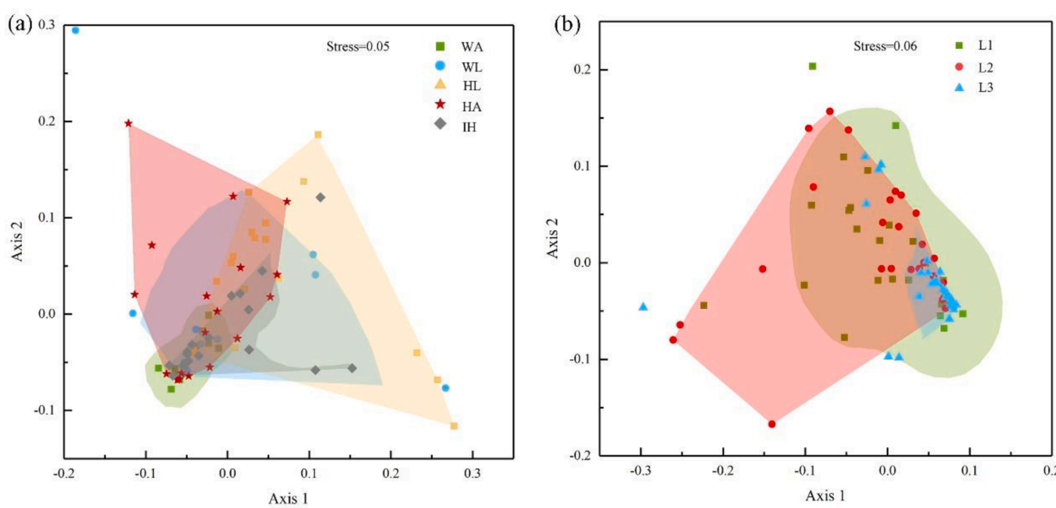

Fig. 4. Non-metric multidimensional scaling analysis (NMDS) for epigaeic arthropod (a) across five habitat types and (b) across three sampling locations.

Table 2
Bray Curtis indices for the similarity of epigaeic arthropod communities of different sampling locations. ($p = 0.005$).

Sampling locations	Inside of semi-natural habitats	Edge of semi-natural habitats	Crop fields
Inside of semi-natural habitats		0.104	**0.032**
Edge of semi-natural habitats	80.77		**0.002**
Crop fields	80.84	79.2	

Note: Bottom left: Higher values indicate higher similarity. Top right: p-values from pairwise multilevel comparisons after PERMANOVA (permutations = 999). Significant *p*-values are given in bold.

Table 3
Two-way ANOVA of variance of semi-natural habitats and sampling locations on activity-density and diversity of epigaeic arthropods.

Factors	df	Activity-density		Diversity	
		F	*p*	*F*	*p*
Semi-natural habitats	4	6.696	<0.001	4.438	0.003
Sampling locations	2	4.394	0.016	7.436	0.001
Semi-natural habitats × Sampling locations	8	0.301	0.963	0.708	0.683

diversity of epigaeic arthropods in the semi-natural habitats and edge was significantly higher than in fields.

4. Discussion

In accordance with our expectations, epigaeic arthropod

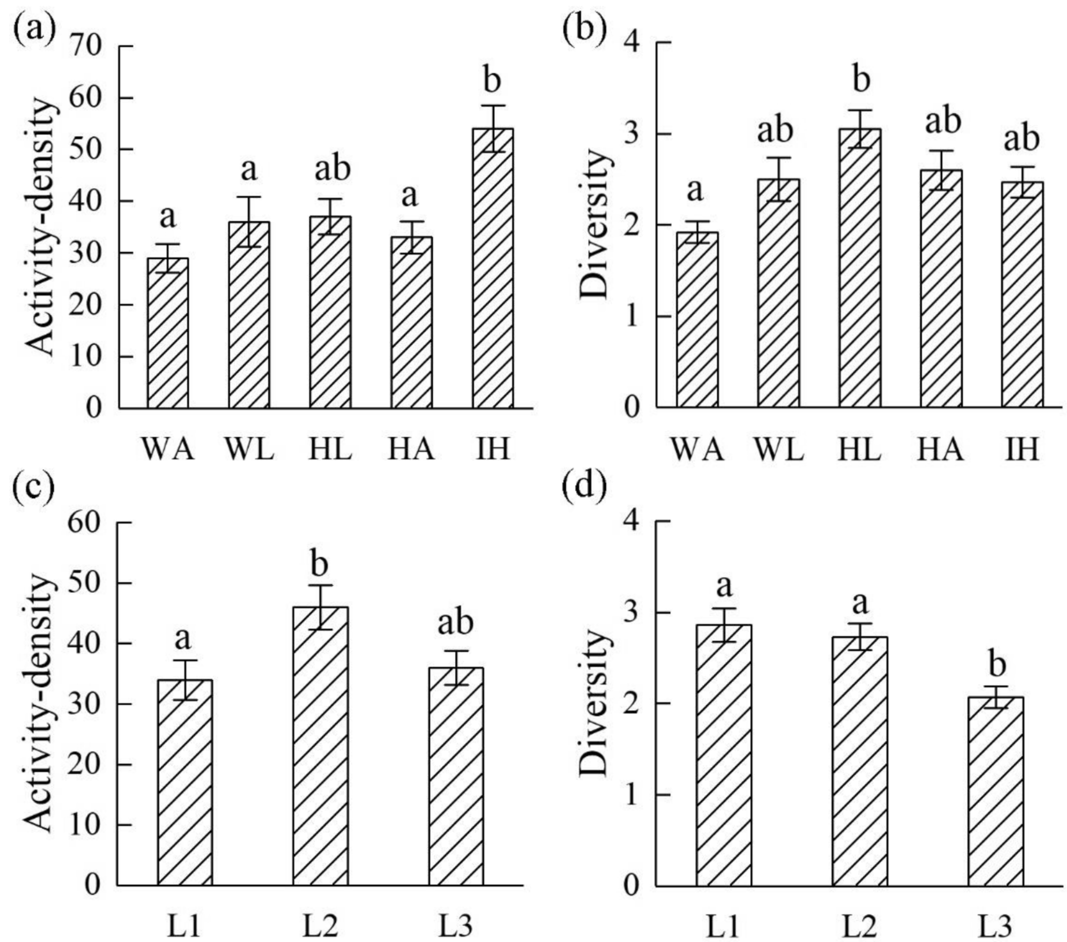

Fig. 5. The activity-density and diversity of epigaeic arthropods on semi-natural habitat types and sampling locations. Bars with a common letter are not significantly different, otherwise bars are significantly different at the $p < 0.05$ level based on Duncan's multiple range test. WA, woody areal. WL, woody line. HA, herbaceous areal. HL, herbaceous line and IH, isolate habitat. L1, inside of semi-natural habitats. L2, edge of semi-natural habitats. L3, crop fields. (a) Activity-density of epigaeic arthropods in semi-natural habitat types. (b) Diversity of epigaeic arthropods in semi-natural habitat types. (c) Activity-density of epigaeic arthropods in sampling locations. (d) Diversity of epigaeic arthropods in sampling locations.

communities show significant differences, not only between farmland and semi-natural habitats, but also between different types of semi-natural habitats. The similarity of epigaeic arthropods in semi-natural habitats and edge is high, and there are significant differences between the two groups and those in crop fields. The lowest similarity of epigaeic arthropod communities between HL and WA. Gryllidae and Carabidae are dominant taxa found in different habitats and locations. Our second and third hypotheses were also tested. Both semi-natural habitat types and sampling locations have significant effects on epigaeic arthropods activity-density and diversity. However, there was no interaction between semi-natural habitat types and sampling locations, and the two variables were independent of each other.

Bray Curtis similarity revealed at least partly rather low resemblances between epigaeic arthropod communities of different semi-natural habitats. In particular, the similarity of epigaeic arthropods showed significant differences in HL and WA (Table3). Habitat complexity conferred by vegetation characteristics determines epigaeic arthropod community assemblage (Nooten et al., 2019). Different epigaeic arthropods have different needs for vegetation characteristics (Peng et al., 2020). Some taxa show particular preference for HL and WA. SP7, SP30 and SP40 were only found in HL, whereas SP8, SP27 and SP33 were only found in WA. In our study, Linear herb habitats maintained higher diversity of epigaeic arthropods (Fig. 5). Linear semi-natural habitats can function as biological corridors, facilitating movement of epigaeic arthropods between habitats in an intensive farmland (Van Geert et al., 2014; Schirmel et al., 2016). Although the area of HL is generally smaller than that of WA, the study found that the diversity of epigaeic arthropods is not positively correlated with the area of semi-natural habitats (Knapp and Řezáč, 2015). Studies have shown that smaller patches (whether semi-natural habitat patches or crop patches) are also beneficial for the maintenance of biodiversity in agricultural landscapes (Lindenmayer, 2019; Wintle et al., 2019). There are several reasons why small patches can make an important contribution to biodiversity conservation. Firstly, Large patches in agricultural landscapes are gradually decreasing, only small patches are remains (Gibbons and Boak, 2002). Therefore, small patches may be critical for species survival and community resilience. A second reason is they can act as stepping stones that promote connectivity and support species dispersal in farmland landscapes (Kremen and Miles, 2012; Mitchell et al., 2013). Linear elements have been proven to be more beneficial to landscape connectivity compared to area habitats (Fahrig and Merriam, 1985; Van Geert et al., 2010; Anderson et al., 2022).

Our study found that the activity-density of epigaeic arthropods was significantly higher in IH than in WA, WL and HA (Fig. 5). Isolate habitats provide disproportionately diverse ecological functions in agricultural landscapes relative to their small size, including pollination, nutrient cycling, and pest control (Prevedello et al., 2018; Froidevaux et al., 2022). Isolated habitats are declining from agricultural landscapes (Fischer et al., 2010a; Fischer et al., 2010b; Orłowski and Nowak, 2007), often being considered incompatible with current agricultural intensification and mechanization (Gibbons et al., 2008). The decline of isolate habitats leads to potential reductions in biodiversity and economically relevant ecosystem services (De Boever et al., 2015). However, people have paid more attention to large patches of semi-natural habitats in conservation programs and landscape planning, and often rarely considered the important role of isolate habitats in agricultural landscapes (Athayde et al., 2015). Our study provides evidence that isolate habitats have strong positive effects on activity-density of epigaeic arthropods, consistent with the results of previous studies (Frizzo and Vasconcelos, 2013; Fischer et al., 2010a; Fischer et al., 2010b). Considering that isolate habitats occupy a small area of a landscape, they could presumably support lower diversity of epigaeic arthropods. However, we did not found diversity of epigaeic arthropods in IH significantly different from other habitats, but this difference occurred between HL and WA. This may be mainly due to two reasons. On the one hand, the taxa composition of the epigaeic arthropod communities were highly sensitive to vegetation type (Yekwayo et al., 2016), with herbaceous and woody semi-natural habitats hosting distinct assemblages (Mestre et al., 2018). A study in the Netherlands showed that spiders prefer herbaceous habitats to woody habitats (Geiger et al., 2009). In addition, woody habitats maintain a certain number of birds, and some epigaeic arthropods are food sources for birds (Nyffeler et al., 2018). Therefore, these epigaeic arthropods prefer to survive in herbaceous habitats. On the other hand, there is a larger edge area between linear habitats and fields, which is more conducive to the survival of epigaeic arthropods (Wimp and Murphy, 2021). Linear habitats are superior to woody habitats both in maintaining epigaeic arthropod activity-density and diversity in our study.

Our study also found that the edge of semi-natural habitat maintained the highest activity-density of epigaeic arthropods. Inside and edge of semi-natural habitats, in contrast with crop fields, hosted significantly more diversity of epigaeic arthropods. By being relatively less disturbed and providing more varied vegetation structure, these habitats maintain more microhabitats than most crop fields and thus enhance activity-density and diversity of epigaeic arthropods (Boutin and Jobin, 1998). They also have many arthropods that cannot survive in crop fields (Gallé et al., 2018). Pecheur et al. showed that field edges were beneficial for herbivorous beetles (Pecheur et al., 2020). However, field interiors were dominated by carnivore carabids (Rusch et al., 2015). Presumably because they benefit from the different food resources. In fact, many studies have demonstrated that species richness at the edge of the field is generally higher than in the interior of the field (Wimp and Murphy, 2021; Gallé et al., 2020; Nguyen and Nansen, 2018). Edge-biased distributions occur not only in cultivated land systems, but also in forest ecosystems and orchard systems. For example, a study of macro-arthropods in six regions of Western Europe revealed

Table A1
Types and quantities of epigaeic arthropods.

Epigaeic arthropods			Numbers	Taxa codes	Percentage	Dominance
Classes	Orders	Families				
Insecta	Coleoptera	Carabidae	3136	SP4	23.89	+++
		Aphodiidae	7	SP6	0.05	+
		Crioceridae	1	SP7	0.01	+
		Cleridae	6	SP8	0.05	+
		Scarabaeidae	94	SP12	0.72	++
		Elateridae	2	SP13	0.02	+
		Nitidulidae	8	SP18	0.06	+
		Tenebrionidae	30	SP22	0.23	+
		Melolonthidae	4	SP23	0.03	+
		Curculionidae	2	SP26	0.02	+
		Mycetophagidae	1	SP27	0.01	+
		Lucanidae	21	SP28	0.16	+
		Hydrophilidae	1	SP30	0.01	+
		Histeridae	5	SP31	0.04	+
		Chrysomelidae	100	SP34	0.76	++
		Silphidae	3	SP39	0.02	+
		Ptinidae	11	SP40	0.08	+
	Orthoptera	Oedipodidae	57	SP1	0.43	+
		Catantopidae	83	SP2	0.63	++
		Acrididae	49	SP11	0.37	+
		Gryllotalpidae	8	SP16	0.06	+
		Gryllidae	6832	SP25	52.04	+++
		Pyrgomorphidae	70	SP41	0.53	++
	Hemiptera	Aradidae	21	SP3	0.16	+
		Pyrrhocoridae	1	SP9	0.01	+
		Nabidae	2	SP10	0.02	+
		Reduviidae	3	SP15	0.02	+
		Coreidae	1	SP38	0.01	+
		Alydidae	2	SP32	0.02	+
	Hymenoptera	Formicidae	1177	SP35	8.96	++
	Homoptera	Cicadellidae	2	SP33	0.02	+
Arachnida	Araneae	Lycosidae	20	SP14	0.15	+
		Agelenidae	259	SP17	1.97	++
		Linyphiidae	108	SP21	0.82	++
		Thomisidae	18	SP29	0.14	+
		Araneidae	40	SP37	0.3	+
	Opilliones	Protolophidae	349	SP20	2.66	++
Chilopoda	Scutigeromorpha	Scutigeridae	7	SP36	0.05	+
	Lithobiomorpha	Lithobiidae	41	SP24	0.31	+
Malacostraca	Isopoda	Oniscidae	11	SP5	0.08	+
Diplopoda	Spirobolida	Paradoxosomatidae	536	SP19	4.08	++
Sum			13,129		100	

Note: +++ means the number of individuals accounts for more than 10 % of the total catch; ++ means the number of individuals accounting for 0.5–10 % of the total catch, and + means the number of individuals accounting for less than 0.5 % of the total catch.

that activity-density was higher in forest edges compared to forest interiors (De Smedt et al., 2019). In addition, higher bee activity was noted along orchard edges compared to orchard interior (Sheffield et al., 2008). The activity-density of epigaeic arthropod in semi-natural habitats is low, even lower than that in crop field. This may be closely related to the sampling season. Epigaeic arthropods distributions within agro-ecosystems can be highly variable over time (Schmidt and Tscharntke, 2005). Since our study was conducted during the growing season, crop fields were less disturbed and sufficient food resources compared to other periods. Accordingly, a different distribution pattern might be found in other times of the year (Lemke and Poehling, 2002).

The effect of isolate habitats on activity-density and the edge-biased distributions of epigaeic arthropods have been confirmed in this study. However, isolate habitats are considered an obstacle to the process of agricultural intensification and isolate habitats are not conducive to agricultural machinery operations (Gibbons et al., 2008). Moreover, isolate habitats are also considered to have a potential negative effect on food production due to the need to occupy a certain area of farmland. Therefore, researchers pay more attention on the question of how to balance the positive effects of isolate habitats on land ecology with the negative effects on food production. However, we seem to overlook the fact that some of the many ecosystem services provided by isolate habitats are beneficial to food production. Such as pollination and pest control can have a positive effect on food production (Barton et al., 2016). Studies have shown that the presence of semi-natural habitats does not affect food production (Tamburini et al., 2020). What we really need to think about is how isolate habitats can be appropriately configured in landscape planning. (Wintle et al., 2019). On the one hand, there is an urgent need to retain isolate habitats in agricultural. On the other hand, Agricultural landscape management should be taken seriously in agricultural policy making.

5. Conclusions

Our study highlights the critical role of different semi-natural habitat types and habitat edges in maintaining the activity-density and diversity of epigaeic arthropod. The similarity of epigaeic arthropods between different semi-natural habitat types and different sampling locations showed significant differences. Therefore, the protection of various semi-natural habitat types, including woody and herbaceous vegetation, is crucial for the conservation of farmland biodiversity. Even isolate habitats that are often overlooked. Isolate habitats have effects that do not correspond to their size. They have the highest activity-density of epigaeic arthropod. They should be included in agricultural landscape semi-natural habitat conservation plans. Linear herbaceous maintain the highest epigaeic arthropod diversity, which plays a crucial role in the connectivity of farmland landscapes. In this study, both the activity-density and diversity of epigaeic arthropods showed edge-biased distribution. Improved knowledge and awareness of edge-biased distribution can greatly facilitate the development and implementation of precision agriculture, such as optimizing sampling efforts and creating more accurate insect distribution maps for targeted application of treatments.

CRediT authorship contribution statement

Xiaoyu Guo: Conceptualization, Methodology, Writing – original draft, Formal analysis, Investigation. **Zhenxing Bian:** Writing – review & editing, Funding acquisition, Supervision. **Jun Zhou:** Conceptualization, Data curation, Software, Visualization. **Shuai Wang:** Writing – review & editing, Visualization, Software. **Wei Zhou:** Software, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix

Table A1

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