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Does Landscape Complexity and Semi-Natural Habitat Structure Affect Diversity of Flower-Visiting Insects in Cucumber Fields?

Akhmad Rizali[1*)], Damayanti Buchori[2)], Susilawati[3)], Pudjianto[2)] and Yann Clough[4)]

[1)] Department of Plant Pests and Diseases, Faculty of Agriculture, Universitas Brawijaya
[2)] Department of Plant Protection, Faculty of Agriculture, Bogor Agricultural University, Indonesia
[3)] Department of Biology Education, Faculty of Tarbiya and Teaching Science, Sultan Thaha Saifudin State Islamic University, Indonesia
[4)] Centre for Environmental and Climate Research, Lund University, Sweden

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[*)] Corresponding author:
E-mail: arizali@ub.ac.id

ABSTRACT

Presence of insects in agricultural habitat is affected by the surrounding circumstances such as the complexity and structure of landscape. Landscape structure is often formed as a consequence of the fragmentation of semi-natural habitat, which can negatively affect species richness and abundance of insects. This study was aimed to study the effect of complexity and structure of landscape on the diversity, abundance and traits of flower-visiting insects in cucumber fields. This study was conducted in cucumber fields surrounded by other agricultural crops, shrubs, semi-natural habitat and housing area, in Bogor, Cianjur and Sukabumi regencies, West Java, Indonesia. In a total of 16 agricultural areas, complexity and parameter of landscape especially class area (CA), number of patches (NumP), mean patch size (MPS), total edge (TE), and mean shape index (MSI) of semi-natural habitats were measured. Sampling of flower-visiting insects was conducted using scan sampling methods. The result showed that landscape complexity affected species richness (but not abundance and trait) of flower-visiting insects both for mobile and less-mobile insects. Flower-visiting insects also responded differently to landscape structure. Species richness, abundance and variation of body size of mobile insects were affected by structure of semi-natural habitat.

INTRODUCTION

Transformation of natural habitats, mainly to agricultural land, plantations, industrial land, and housing, has resulted in habitat fragmentation and has affected the structure and function of the landscape. In agricultural areas, one often distinguishes complex landscapes, with high proportion of natural habitats (or semi-natural habitat), from simple landscapes that are dominated by agricultural crops (Menalled, Marino, Gage, & Landis, 1999; Thies, Roschewitz, & Tscharntke, 2005; Plećaš et al., 2014). The proportion of semi-natural habitat, beside shape the heterogeneity of agricultural landscape, also has important role or function for animal biodiversity. Fahrig et al. (2011) defined the function of semi-natural habitat in agricultural landscape as functional landscape heterogeneity which is the description and measurement of semi-natural habitat heterogeneity based on the expected functions for animal biodiversity such as providing food, nesting sites and dispersal directions.

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The presence of insects in an agricultural landscape is affected by the complexity and the structures of landscape as well as heterogeneity of semi-natural habitat. Previous studies showed that complex landscape with high proportion of non-crop habitat has higher diversity of insects both of natural enemies and other beneficial insects (Bianchi, Booij, & Tscharntke, 2006). Other study by Steffan-Dewenter, Münzenberg, Bürger, Thies, & Tscharntke (2002) found that the diversity and abundance of insect pollinators, such as solitary bees and social bees, were influenced by the landscape structure. Krauss, Steffan-Dewenter, & Tscharntke (2003) also reported that the abundance of butterflies increased with increasing habitat diversity around the landscape. In addition, Bommarco, Marini, & Vaissière (2012) found that the increasing complexity of a landscape affected the abundance of wild insects and the richness of the Syrphidae species.

However, the types of crop plants affect insect diversity in agricultural landscape both for pest and beneficial insects (e.g. natural enemies, pollinators). In case of crop plants with flowers, insects visit the flowers due to attracted on part of flowers, such as color, shape, pollen, nectar, and aroma (Faheem, Aslam, & Razaq, 2004). The visitation of insects especially insect pollinators have an important role in agricultural cultivation systems because they can increase the quantity and quality of crop yield (Allen-Wardell et al., 1998). About one third of crop plant in the world depends on animal pollinators for their pollination processes (Kremen et al., 2007). For instance, Bommarco, Marini, & Vaissière (2012) reported that insect pollinators can increase seed weight of oilseed rape plants by 18 %. Garibaldi et al. (2013) found positive associations of fruit set with flower visitation by insect pollinators in approximately 40 crop systems worldwide.

Research about how flower-visiting insects are affected by landscape complexity is still limited in Indonesia. The objective of this research was to investigate the effect of landscape landscape complexity and semi-natural habitat structure on species richness, abundance and trait of flower-visiting insects in tropical agricultural area. The cucumber plant was used as a model or case study in this research. Cucumber plant is one of the crop plants that cannot do self-pollination because the location of male and female flowers are spatially separated on the same plant (Johnson, 1972). Therefore, in the pollination process, cucumber plants need insect pollinators especially bees (Hymenoptera: Apidae) (McGregor, 1976). Ecological observation was conducted in agricultural landscape in West Java, Indonesia in regencies of Bogor, Sukabumi and Cianjur. These regencies have unique agricultural characteristics (Widiatmaka, Ambarwulan, & Sudarsono, 2016), are surrounded by mountain areas, have semi-natural habitat remnant dominated by agricultural fields cultivated with rotations of crop plants which are mainly rice and vegetables, including cucumber.

MATERIALS AND METHODS

Study Area and Landscape Characterization

Ecological research was conducted in 16 agricultural areas in West Java, Indonesia, located in regency of Bogor, Sukabumi, and Cianjur (Fig. 1). Each agricultural area had a cucumber field with minimum size 25 m x 50 m (adapted from Vaissière, Freitas, & Gemmill-Herren, 2011). To characterize the landscape type, each agricultural area was mapped using QGIS 2.18 (QGIS, 2016) within radius 500 m from the cucumber field based on satellite image of Google Earth (accessed in 2015), followed by ground checking. The radius of 500 m (Fig. 2a and 2b) was chosen based on previous studies with trap-nesting bees (Gathmann & Tscharntke, 2002; Steffan-Dewenter, 2002), although the social bees that were found in this study were potentially more mobile than the trap-nesting bees. The complexities of landscape were grouped into simple and complex, according to proportion of semi-natural habitat and gardens with trees in each landscape (Table 1, Fig. 2a and 2b). Landscape type had a tendency differ in the amount of proportion semi-natural habitat and gardens with trees which both provide important contribution on diversity and abundance of insects in agricultural area (Steffan-Dewenter, Münzenberg, Bürger, Thies, & Tscharntke, 2002). Complex landscape had the highest proportion of semi-natural habitat and trees, while simple landscape had the lowest proportion of semi-natural habitat and trees (Table 1).

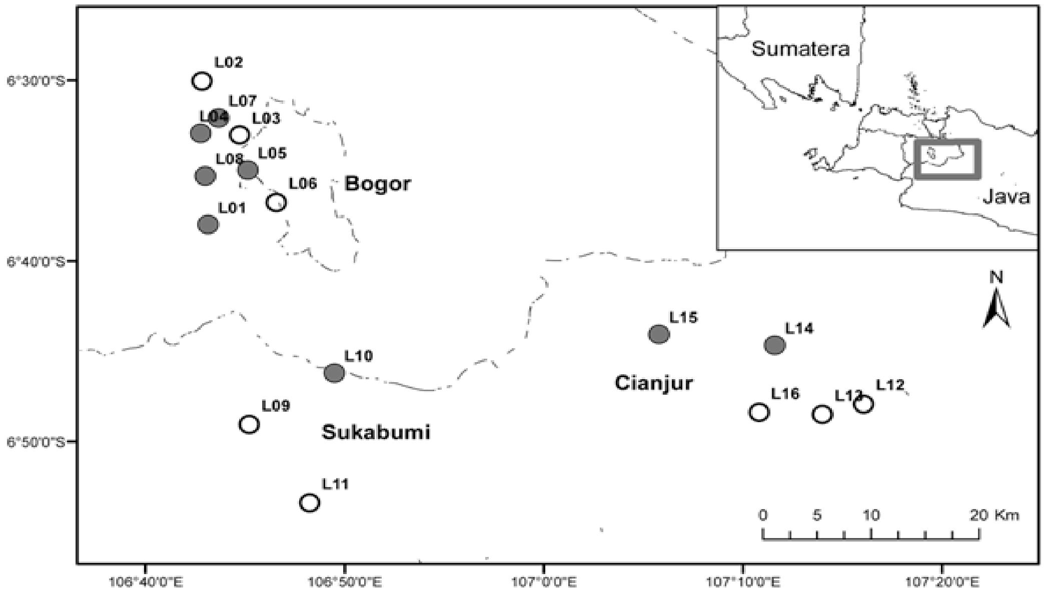

Fig. 1. Research location in 16 agricultural areas in regency of Bogor, Sukabumi, and Cianjur, West Java. Landscape complexity is indicated with closed circle for complex landscape and open circle for simple landscape

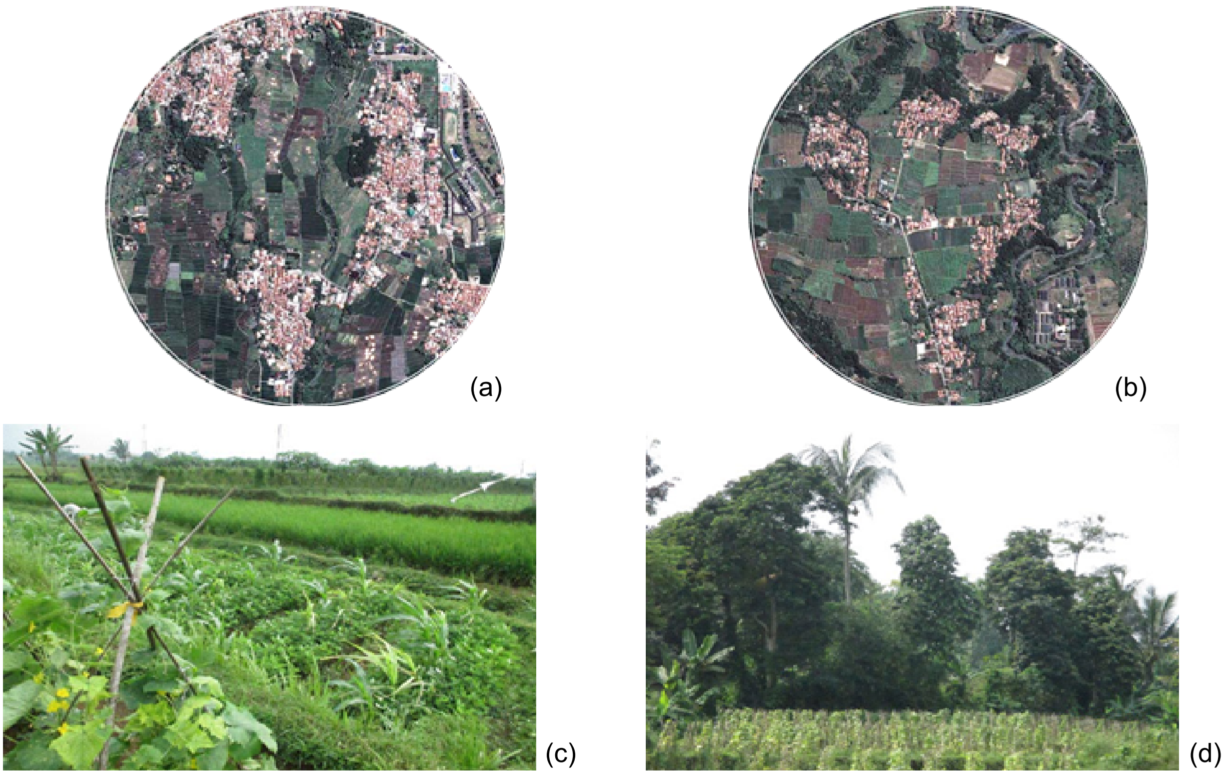

Fig. 2. Satellite image of (a) simple and (b) complex landscape based on Google Earth (accessed in 2015) with radius 500 m from the center (cucumber field). The surrounding condition of cucumber field (c) near other crop plants and (d) near semi-natural habitat

Table 1. The proportion difference of patch area from total landscape area (mean (%) ± SD) between landscape types. Significance different based on ANOVA: *P < 0.05

Proportion of patch habitat (%)	Landscape type		$F_{(1,14)}$	P
	Simple (n=8)	Complex (n=8)		
Semi-natural habitat	0.167 ± 0.064	0.333 ± 0.156	7.692	0.015*
Gardens with trees	0.122 ± 0.076	0.271 ± 0.128	8.006	0.013*
Farmland	0.536 ± 0.145	0.481 ± 0.144	0.571	0.462
Shrubs	0.045 ± 0.036	0.061 ± 0.075	0.322	0.580
Annual crop	0.536 ± 0.145	0.461 ± 0.174	0.883	0.363
Oil palm plantation	0.000 ± 0.000	0.021 ± 0.043	1.855	0.195
Housing	0.260 ± 0.119	0.164 ± 0.059	4.106	0.062
Road	0.018 ± 0.016	0.010 ± 0.010	1.303	0.273
Water body	0.020 ± 0.029	0.012 ± 0.013	0.534	0.477

Table 2. Description of some landscape parameters based on McGarigal & Marks (1995)

Landscape parameter	Description
Class area (CA)	Total area of habitat in the landscape (m^2)
Number of patches (NumP)	Number of patches in the landscape
Mean patch size (MPS)	Average patch size (m^2)
Total edge (TE)	Total length of all edges (m)
Mean shape index (MSI)	Sum of patch perimeter/square root of patch area, adjusted constant/number of patches

Beside landscape complexity, each agricultural area was also calculated using FRAGSTATS v4 (McGarigal, Cushman, & Ene, 2012), the landscape parameter of semi-natural habitat included class area (CA), number of patch (NumP), mean patch size (MPS), total edge (TE) and mean shape index (MSI) (Table 2). Although NumP and TE (r=0.67) and MSI and TE (r=0.59) were correlated each others, these landscape parameters were still used due to expected relationship with the presence of flower-visiting insects. Previous study for instance showed that linear habitat strips (TE) affected species and abundance of insects (Holzschuh, Steffan-Dewenter, & Tscharntke, 2010; Šálek et al., 2015).

Sampling of Flower-Visiting Insects

Samplings of flower-visiting insects were conducted from December 2014 to May 2015. The weather condition were predominantly clear sky, no rain, low wind and dry vegetation (Westphal et al., 2008). In each cucumber field, four transects were selected for insect sampling (Fig. 3). Flower-visiting insects were observed along the transects using the scan sampling method, adapted from Vaissière, Freitas, & Gemmill-Herren (2011). The scan sampling was done by walking slowly along transect (between rows) and recorded the numbers of flower-visiting insects that were found in each individual floral unit (well exposed flower). Flower-visiting insects were observed within 100 units cucumber flowers in each transect and were collected using hand netting or small brush during 15 minutes. Some insects were also collected and preserved with alcohol 70 % in plastic vials for later identification in the laboratory. Observations were conducted in four different times i.e. 09.00, 11.00, 13.00, and 15.00 which each time was carried out in different day.

For each cucumber field, species richness and abundance of flower-visiting insects was calculated. Species richness was the total of insect species that recorded from all observations, while abundance was the total individual of insects that have been observed from all observations.

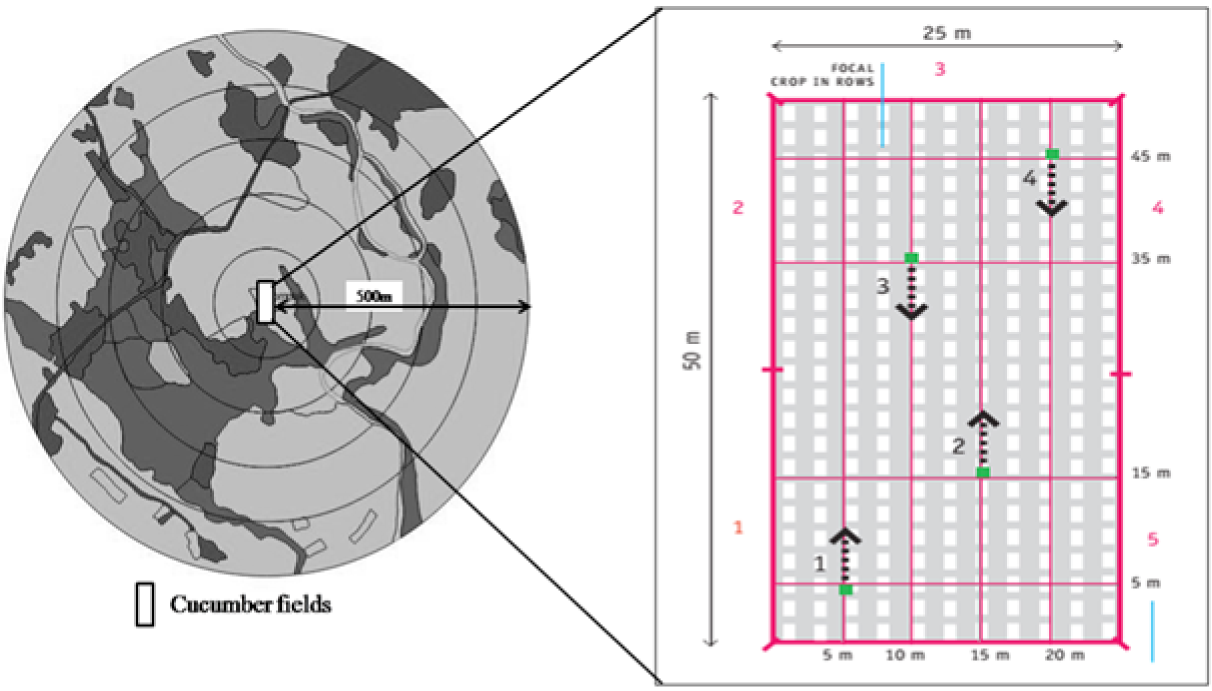

Fig. 3. Sampling layout to measure abundance and diversity of flower visiting insect on cucumber fields in each landscape. Walking direction along transects is indicated with arrows.

Identification, Classification and Traits Measurement of Flower-Visiting Insects

Flower-visiting insects were identified until morpho-species level using available identification books (e.g. McAlpine, 1987; Goulet & Huber, 1993; Bolton, 1994; CSIRO, 1991). Insects were than classified into three groups based on behavioral characteristic and movement capability (Ouin, Aviron, Dover, & Burel, 2004) i.e. mobile insects, less mobile insects and Apidae. Mobile insects are flower-visiting insects that actively utilize their wings for foraging or moving such as bees, wasps, flies, and butterflies. Less mobile insects are flower-visiting insects that not actively utilize their wings or even have no wings such as ants, aphids and earwig. The Apidae are flower-visiting insects from Order Hymenoptera, Family Apidae, which is a group with important pollinators such as honey bees (*Apis* spp.) and carpenter bees (*Xylocopa* spp.), amongs others (Steffan-Dewenter, Münzenberg, Bürger, Thies, & Tscharntke, 2002).

To study the relationship between landscape structure and morphological trait of flower-visiting insects, body size of each species of insects were measured using tpsDig (Rohlf, 2004). Specimens of insects were photographed using a microscope mounted with a digital camera in order to measure the body size (from head to abdomen). Afterwards, the community-weighted mean (CWM) of body size (trait value) per site or landscape was calculated using formula CWM = $\sum_{i=1}^{n} p_i x_i,$ where p_i is the relative abundance of species i in a specific transect and x_i is the trait value of species i (Ricotta & Moretti, 2011).

Data Analysis

The difference of four groups of flower-visiting insects between landscape types were analyzed using ANOVA including species richness, abundance and CWM of body size. The relationship between all variables of flower-visiting insects and landscape structure (especially CA, NumP, MPS, TE and MSI of semi-natural habitat) were analyzed using regression analysis. All analyses were done using the statistical package R (R Core Team, 2016).

RESULTS AND DISCUSSION

Diversity of Flower-Visiting Insects in Cucumber Field

In total, 11,017 individuals of flower-visiting insects belonging to 188 species, 10 orders and 76 families were found (Table 3). The most abundant flower visitors were less mobile insects (80 % from total individual, but only 28 % from total species) and the least abundant were mobile insects (20 % of the total number of individuals, but 72 % from total species). Less mobile insects that found with high abundance were ants (Formicidae, 4,787 individuals of 26 species), aphids (Aphididae, 1947 individuals of 1 species) and thrips (Thripidae, 1751 individuals of 3 species). In the case of the Apidae, 10 species were recorded from all landscapes with species that had high abundance were *Apis cerana* (195 individuals), *Apis mellifera* (53 individuals), *Xylocopa confusa* (60 individuals) and *Xylocopa latipes* (20 individuals).

The diversity of flower-visiting insects in the cucumber fields was affected by landscape complexity and semi-natural habitat structure. However, habitat types surrounding cucumber field also influenced the presence of insects in cucumber plants. Mostly cucumber field in Bogor, Sukabumi and Cianjur regency were cultivated near rice field. As consequence, the insect from rice field were also found in cucumber field. For example, the brown planthopper, *Nilaparvata lugens* (Hemiptera, Delphacidae) and the Asian rice gall midge, *Orseolia oryzae* (Diptera, Cecidomyiidae), both well-known rice pests, were found in cucumber flowers. Other habitats such as waterstreams also affected the diversity of flower-visiting insects in cucumber field. *Acentrella* sp. for instance, was found in cucumber flowers. *Acentrella* sp. (Ephemeroptera, Baetidae) is an aquatic insect that live in clean or unpolluted water (Alba-Tercedor & El-Alami, 1999). In addition, some of flower-visiting insects such as *A. cerana* and *A. mellifera* were always found in all cucumber fields although with different surrounding habitat types. Both species are known as pollinators of cucumber (Shwetha, Rubina, Kuberappa, & Reddy, 2012). *Diaphania indica* and *Aulacophora* sp. were also usually found in the studied cucumber field, both species being pests of crops in the Cucurbitaceae family (Ganehiarachchi, 1997; Muniaapan, Shepard, Carner, & Ooi, 2012). Less mobile insects i.e. aphids, thrips and ants were the most abundant and always found in all landscape types. As generalist pests, aphids (*Aphis gossypii*) and thrips (*Thrips parvispinus*) have wide range of host plants including cucumber. While, ants especially *Tapinoma melanocephalum* (the most common ant species found) is known as tramp species that always co-exist with human existence and activities (McGlynn, 1999).

Effect of Landscape Complexity on Species Richness, Abundance and Morphological Trait of Flower-Visiting Insects

Landscape complexity significantly affected species richness but not abundance and morphological trait of flower-visiting insects (Table 4). Species richness both of mobile ($F_{1,14}$ = 6.733; P = 0.021) and less mobile insects ($F_{1,14}$ = 5.764; P = 0.031) were higher in complex than in simple landscapes. Landscape complexity did not affect species richness of Apidae. There was a non-significant trend for mobile insects to be more abundant in complex than in simple landscapes ($F_{1,14}$ = 4.347; P = 0.055). Body size (CWM) of flower visiting-insects in general, but also of mobile insects, less mobile insects and Apidae considered separately, was not significantly different between landscape types.

Complex landscapes dominated by semi-natural habitat, might provide populations of flower-visiting insects with alternative hosts, food, shelter or nesting sites (Bianchi, Booij, & Tscharntke, 2006). Research by Menalled, Marino, Gage, & Landis (1999) found that complex landscape had higher diversity of parasitoids Braconidae than in simple landscape. In this study, abundance of flower-visiting insects did not differ between complex and simple landscape, a similar result to Westphal et al. (2008) who found landscape complexity, characterized by the proportion of semi-natural habitat, did not affect the abundance of bees. Instead, abundance of bees was more affected by the occurrence of flowering plants in the landscape. Furthermore, the community-wide body size of flower-visiting insects also did not differ between landscape complexities. This result was similar with Persson, Rundlöf, Clough, & Smith (2015) that thorax width, which was linked to body size, did not depend on the landscape complexity.

Table 3. Diversity of flower-visiting insects from 16 cucumber fields

Flower-visiting insects	Group			
	All insects	Mobile insects	Less mobile insects	Apidae
Order	10	8	6	1
Family	76	63	18	1
Species	188	136	52	10
Individual	11,017	2,171	8,846	378

Table 4. Species richness, abundance and morphological trait (CWM) of flower-visiting insects in different landscape type. Significance different based on ANOVA: *P<0.05.

Flower-visiting insects	Landscape type		Statistic	
	Simple	Complex	$F_{(1,14)}$	P
Species richness				
All insects	28.50 ± 6.35	43.38 ± 10.97	11.03	0.005*
Mobile insects	20.13 ± 6.42	30.13 ± 8.81	6.733	0.021*
Less mobile insects	9.13 ± 1.89	13.63 ± 4.96	5.764	0.031*
Apidae	3.25 ± 1.04	3.88 ± 1.36	1.074	0.318
Abundance				
All insects	628.25 ± 327.74	748.88 ± 451.95	0.373	0.551
Mobile insects	115.50 ± 50.78	174.38 ± 61.64	4.347	0.055
Less mobile insects	528.25 ± 326.16	577.50 ± 443.22	0.064	0.804
Apidae	17.25 ± 11.51	30.00 ± 17.00	3.084	0.101
CWM				
All insects	2095.5 ± 860.9	3194.6 ± 1690.1	2.686	0.123
Mobile insects	864.5 ± 256.5	1303.4 ± 660.5	3.070	0.102
Less mobile insects	1066.8 ± 958.7	1859.7 ± 1563.9	1.495	0.242
Apidae	271.9 ± 155.0	402.5 ± 157.9	2.784	0.117

Table 5. Relationship between species richness, abundance and morphological trait (CWM) of flower-visiting insects and landscape parameters. CA = class area, NumP = number of patches, MPS = mean patch size, TE = total edge, and MSI = mean shape index. R^2 = adjusted R-squared. Significance different based on ANOVA of regression analysis: *P<0.05.

Flower-visiting insects	Landscape parameters of semi-natural habitat patch									
	CA		NumP		MPS		TE		MSI	
	R^2	P	R^2	P	R^2	P	R^2	P	R^2	P
Species richness										
All insects	0.208	0.043*	0.140	0.085	0.115	0.108	0.278	0.021*	0.144	0.082
Mobile insects	0.033	0.239	0.241	0.031*	-0.043	0.543	0.239	0.032*	0.182	0.056
Less mobile insects	0.473	0.002*	-0.069	0.870	0.562	0.001*	0.089	0.139	-0.056	0.655
Apidae	-0.060	0.709	0.013	0.292	-0.047	0.576	-0.068	0.827	-0.023	0.429
Abundance										
All insects	-0.048	0.583	-0.051	0.609	0.010	0.303	-0.032	0.478	0.087	0.141
Mobile insects	0.154	0.074	0.105	0.119	0.063	0.179	0.299	0.017*	0.185	0.055
Less mobile insects	-0.067	0.812	-0.018	0.407	-0.020	0.417	-0.065	0.770	0.027	0.254
Apidae	0.130	0.093	0.114	0.109	-0.048	0.575	0.218	0.039*	-0.065	0.781
CWM										
All insects	0.240	0.031*	-0.059	0.690	0.409	0.005*	0.063	0.178	0.079	0.153
Mobile insects	0.446	0.003*	-0.013	0.382	0.419	0.004*	0.110	0.113	-0.069	0.855
Less mobile insects	0.047	0.208	-0.040	0.531	0.154	0.074	0.008	0.308	0.112	0.112
Apidae	0.130	0.093	0.063	0.177	-0.016	0.398	0.119	0.103	-0.070	0.848

Relationship between Species Richness, Abundance and Morphological Trait of Flower-Visiting Insects and Structure of Semi-Natural Habitat

The different groups of flower-visiting insects responded differently to semi-natural habitat structure (Table 5). Species richness of mobile insects had relationship with NumP (R^2 = 0.241; P = 0.031) and TE (R^2 = 0.239; P = 0.032) of semi-natural habitat, while less mobile insects with CA (R^2 = 0.473; P = 0.002) and MPS (R^2 = 0.562; P = 0.001). Relationship between semi-natural habitat structure with insect abundance was shown between TE and mobile insects (R^2 = 0.299; P = 0.017) and TE and Apidae (R^2 = 0.218; P = 0.039). In addition, CA and MPS of semi-natural habitat showed influence on increasing variation of body size of mobile insects in cucumber field.

Landscape parameters of semi-natural habitat have relationship with species richness, abundance and variation of body size of all groups of flower-visiting insects. The relationship between proportion of semi-natural habitats and insect species richness were also found for trap-nesting bees, wasps and their natural enemies (Steffan-Dewenter, 2002) as well as wild bee (Steffan-Dewenter, Münzenberg, Bürger, Thies, & Tscharntke, 2002). Size of habitat directly affect the resources to support the insect population, for example patch size of flower plants influenced the composition of insect pollinators (Sowig, 1989). Other research by Blaauw & Isaacs (2012) also showed that patch size of wildflower had positive relationship with species richness of predator and parasitoid on agricultural landscape.

Total edge of semi-natural habitat was associated with higher diversity of mobile insects either because the longer edges increased the spill-over between habitats, or because the ecotone zone between the two habitats allowed additional species to persist in the landscape (Fig. 2d). Edge in the landscape could effectively increase the migration of species into or out of a habitat and could be used as a simple corridor for several species of insects (Jauker, Diekötter, Schwarzbach, & Wolters, 2009). This is similar to the research result by Holzschuh, Steffan-Dewenter, & Tscharntke (2010) that showed bees were enhanced by high edge density of non-crop habitat. Linear habitat strips are examples of applications on the edge of agricultural landscapes to maintain the diversity and abundance of insects. Other experiments also showed the benefit of grass strips corridors to nest colonization by wasps (Holzschuh, Steffan-Dewenter, & Tscharntke, 2009) as well as species richness of syrphids (Ernoult et al., 2013) in the agricultural landscape.

In this study, landscape effects were detected on species richness of flower-visiting insects. Species richness was higher in landscapes with high proportion of semi-natural habitat which caused distance from cropland to semi-natural habitats became closer. The close distance likely facilitates the mobility of flower-visiting insects from semi-natural habitat to cropland. In addition, the presence of diverse non-crop habitats in structurally complex landscapes also enhances the activity of flower-visiting insects. This indicates that complex landscape can support a variety of flower-visiting insects which has a variety of function. Thus, habitat complementarity and increasing the spatial interspersion of different habitats, allow more spill-over of flower-visiting insects in agricultural area.

CONCLUSION

From 16 agricultural landscapes, we found 188 species of flower visiting insects belong to 10 order and 76 families. The most abundant flower visitors were less mobile insect (80 % individual and 28 % species). Landscape complexity positively affected species richness, but not abundance and morphological trait, of flower-visiting insects both for mobile and less mobile insects. Flower-visiting insects also had different response on semi-natural habitat structure in agricultural landscape. Species richness and abundance of flower-visiting insects were higher in landscapes with high proportion of semi-natural habitat. In conclusion, the existence of semi-natural habitat surrounding farmland could facilitate the presence of flower-visiting insects, including insect pollinators, and provided benefit for crop plants.

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