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Contribution of Agricultural Landscape Composition on Shaping the Interaction Between Pests and Natural Enemies in Cacao Agroforestry

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ABSTRACT

Studies of the effects of landscape composition on pests and their natural enemies on agroforestry systems is still limited, whereas the system can maintain biodiversity. This research investigated the impact of agricultural landscape composition on shaping the interaction between pests and natural enemies in cacao agroforestry. The study was conducted in twelve cacao plantations spread across five districts in East Java, Indonesia. A sampling of insects was carried out by observing the intensity of pest attacks and the diversity and abundance of predators. The surrounding landscape of the cacao field was characterized by manually digitalizing the land use. The results found two main pests attacking all cacao plantations: cacao pod borer, *Conophomorpha cramerella* (CPB) with attack intensity 0.72-12.05%, and *Helopeltis* sp. with attack intensity 12.39-42.24%. Management of cacao plantations, such as intensification and canopy cover, significantly affected the attack intensity of CPB but not *Helopeltis* sp. Based on the generalized linear model, the landscape composition, especially the patch number of natural habitats, positively impacted CPB attack intensity and predator abundance. However, predator abundance harmed CPB attack intensity. In conclusion, the proportion of natural habitat in agricultural landscapes contributes to reducing the attack intensity of pests via maintaining natural enemy abundance.

INTRODUCTION

Cacao (*Theobroma cacao* L.) is one of the plantation commodities that has an essential contribution to the development of the economy and agroindustry as well as a source of income for farmers in Indonesia. Based on data from BPS (2020), the development of cacao plantation areas in Indonesia during the period 2016-2020 tends to decrease with a rate of decrease between 2.55% to 3.93% per year. However, the reduction in the area is not followed by a decline in the production and productivity of cacao. From 2016 to 2020, the development of cacao production and productivity fluctuated and tended to decline, with the highest show being 767,280 tons in 2018 and a decrease to 720,660 tons in 2020 (BPS, 2020). Several factors, including pest attacks, can cause cacao production and productivity to decline. The attacks of important pests such as fruit-sucking ladybugs, *Helopeltis* sp. and cacao pod borer, *Conopomorpha cramerella* Snellen (CPB) have been accounted for in cacao plantations (Lestari & Purnomo, 2018; Way & Khoo, 1992). Therefore, the control efforts such as the conservation of natural enemies are needed to suppress the pests in cacao plantations.

Natural enemies often found in cacao plantations are predatory groups such as ants and spiders (Rubiyo & Siswanto, 2012). Predatory ants such as *Oecophylla smaradigna*, *Anoplolepis gracilipes*, and *Dolichoderus thoracicus* are reported as effective predators to prey on *Helopeltis*

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sp. and CPB. On the other hand, *D. thoracicus* can attack various stages of CPB on the first to third day after application, with the highest average amount of predation at the larval stage, followed by the egg stage and then the pupa stage (Way & Khoo, 1991). The spiders often found in cacao plantations are the Araneidae (*Gastercantha* spp.) and Tetragnathidae (*Leucauge venusta*). Both group spiders can attack two nymphs of *Helopeltis* sp. for 24 hours of observation (Stenchly, Clough, & Tscharntke, 2012).

The presence of natural enemies in cacao plantations is vital in controlling pest populations and providing ecosystem services that benefit the environment and economy (Bommarco, Kleijn, & Potts, 2013). However, natural enemies need suitable habitat conditions both on field scale and landscape scale that are usually not available in an agroecosystem. At the field scale, agricultural intensification, removal of shade plants, and application of pesticides harm the diversity, abundance, and composition of natural enemies (Kruess & Tscharntke, 1994; Rizali et al., 2013). While at the landscape scale, the composition and configuration of agricultural landscape (e.g., size, shape, and patch number) cannot support the diversity of natural enemies as well as the trophic interactions in an agroecosystem (Bommarco, Kleijn, & Potts, 2013; Gurr, Wratten, & Luna, 2003; Tscharntke et al., 2007). For instance, simplifying and fragmentation of natural habitats in agroecosystems can reduce the biological control of pests by natural enemies (Rusch et al., 2016; Shrewsbury & Leather, 2012). Thus, the management of agroecosystem both of field scale and landscape scale is very essential to maintain ecosystem services to achieve sustainable agriculture.

Agricultural landscape management is a fundamental approach for biodiversity conservation in agroecosystems, especially natural enemies that provide an essential role in controlling pest populations (Marja, Tscharntke, & Batary, 2022; Tscharntke et al., 2007). Managing the agricultural landscape can be done in various ways, for example, by habitat manipulation through planting non-crop vegetation surrounding agricultural fields or protecting natural or semi-natural habitats within the agricultural landscape. However, the management knowledge of the agricultural landscape in agroforestry systems is still lacking because the system is well-known can maintain biodiversity (e.g. Bos, Steffan-Dewenter, & Tscharntke, 2007). Previous research studied annual crops to investigate the effect of landscape composition on biodiversity (e.g., Syahidah, Rizali, Prasetyo, Pudjianto, & Buchori, 2020; Ulina, Rizali, Manuwoto, Pudjianto, & Buchori, 2019). Therefore, this research aims to investigate the effect of agricultural landscape composition (with agroforestry system) on shaping the interaction between pests and natural enemies in cacao agroforestry.

MATERIALS AND METHODS

Research Location and Plot Selection

The research was conducted in twelve cacao plantations spread across five districts in East Java, Indonesia, i.e., Malang, Jombang, Kediri, Blitar, and Trenggalek (Fig. 1, Table 1). The cacao plantations were selected by considering the tree age of cacao plantations ranged from 3-10 years, the minimum size of cacao plantations is about 1,500 m^2, and the distance between locations was at least 2 km to avoid overlapping landscapes (Tischendorf & Fahrig, 2000). In addition, cacao plantations were also varied in altitude (135-670 m.a.s.l) and cultural technique, i.e., government estate (PTPN XII) with an intensive system and smallholder estate with a traditional system (Table 1).

Landscape Characterization

Landscapes were characterized by firstly marking the plot coordinate of each cacao plantation using the Global Positioning System (GPS). Then, based on google maps, the landscape within a 500 m radius from the cacao plantation (the plot as the center point) identified the patches or land uses by conducting a ground check. The results of ground checking were then digitized using QGIS software (QGIS, 2020). Land use types are classified into six categories, i.e., cacao plantations, semi-natural habitats (trees and shrubs), settlements, roads, and water bodies. A package on the QGIS software, the LecoS (land cover statistics), was used to analyze the landscape composition, and the calculated parameters were class area (CA) and the number of patches (NP) of semi-natural habitats and cacao plantations. The value of CA is the area of land use, while the NP is the number of patches and indicates the fragmentation that occurs in the landscape. The more significant number of patches, the greater the fragmentation. If an element's value of NP and CA is substantial, it indicates these elements dominate a landscape (Yaherwandi, Manuwoto, Buchori, Hidayat, & Prasetyo, 2007).

Table 1. Characteristic of research location located in twelve different cacao plantations in East Java. The landscape composition of each cacao plantation is calculated as the patch number of natural habitat (NP.nat) and cacao field (NP.cao) and the area (in ha) of natural habitat (CA.nat) and cacao field (CA.cao) per landscape (500 m radius)

Code	Location	District	Estate	Altitude (m asl)	Age (year)	Canopy cover (%)	Vegetation density	Landscape composition			
								NP.nat	CA.nat	NP.cao	CA.cao
L01	Modangan	Blitar	Smallholder	486	6	63.4	64	9	21.5	2	2.0
L02	Kemloko1	Blitar	Smallholder	347	3	69.9	7.4	39	57.5	3	0.7
L03	Kemloko2	Blitar	Smallholder	310	3	67.1	42.6	41	55.5	2	1.7
L04	Krenceng	Blitar	Smallholder	297	7	78.7	56.3	8	7.8	2	2.8
L05	Plosorejo	Blitar	Smallholder	135	6	56.4	69.2	10	8.4	1	0.4
L06	Babadan	Kediri	Government	402	10	79.1	28	8	11.2	9	18.5
L07	Badek	Kediri	Government	421	10	62.5	27.8	6	1.6	10	15.4
L08	Pakelan	Kediri	Government	396	10	67.5	27.8	0	0	2	17.9
L09	Laharpang	Kediri	Smallholder	670	7	62.7	37.9	20	41.1	1	0.2
L10	Sambirejo	Jombang	Smallholder	406	10	69.7	106.9	26	55.4	3	4.1
L11	Sukodono	Malang	Smallholder	614	3	66.7	149.2	3	19.5	2	1.6
L12	Sukowetan	Trenggalek	Smallholder	140	3	60.6	60.9	9	35.2	2	1.8

Observation of Pest Attack Intensity and Sampling of Predatory Insects

The field research was conducted from January to March 2020. Observations of pest attack intensity and sampling of predatory insects were done monthly for three months. Observation of the damage symptoms by pests was carried out by direct observation on a hundred cacao trees as unit samples. The attack symptoms caused by *Helopeltis* sp. and CPB were observed on all cacao pods. They were noted later to calculate the percentage of damage intensity based on the formula by Pedigo & Buntin (1993).

A sampling of predatory insects was conducted using three methods: spraying, bait trap, and direct observation. The spraying method was done by spraying a pyrethroid insecticide with the active ingredient Cypermethrin 30 EC on four cacao trees outside a hundred cacao trees. Each cacao tree was sprayed using a knapsack sprayer until the entire canopy was covered with insecticide. The killed insects were collected after 60 minutes of application in a white plastic banner with a size of 2 m x 2 m that was placed above the ground (adopted from Rizali et al., 2013).

The bait trap was set up on nine cacao trees per plot by placing tuna on the branches of the cacao tree. Sampling and observation of predatory insects were conducted every 15 minutes during an hour of observation (Hasriyanty, Rizali, & Buchori, 2015). In addition, direct observations were carried out on a hundred cacao trees by handpicking the predatory insects found in each cacao tree.

All insect specimens were preserved in a plastic vial with 70% alcohol for later identification in the laboratory. Insect specimens were identified until the morphospecies level based on morphological characters using the available references (e.g., Borror, Triplehorn, & Johnson, 1989; Goulet & Huber, 1993).

Vegetation Diversity Observation and Canopy Cover Measurement

Visual observation observed the diversity of shade trees and understorey vegetation, for shade trees were directly observed within a hundred cacao trees. In comparison, understorey vegetation was observed on ten 1 m x 1 m size subplots placed randomly within a hundred cacao trees. Vegetation specimens were taken as photographs and, if needed, were collected in envelopes or plastic separately for later identification (adopted from Tustiyani, Nurjanah, Maesyaroh, & Mutakin, 2019). Vegetation specimens were identified based on available literature (Xu & Zhou, 2017).

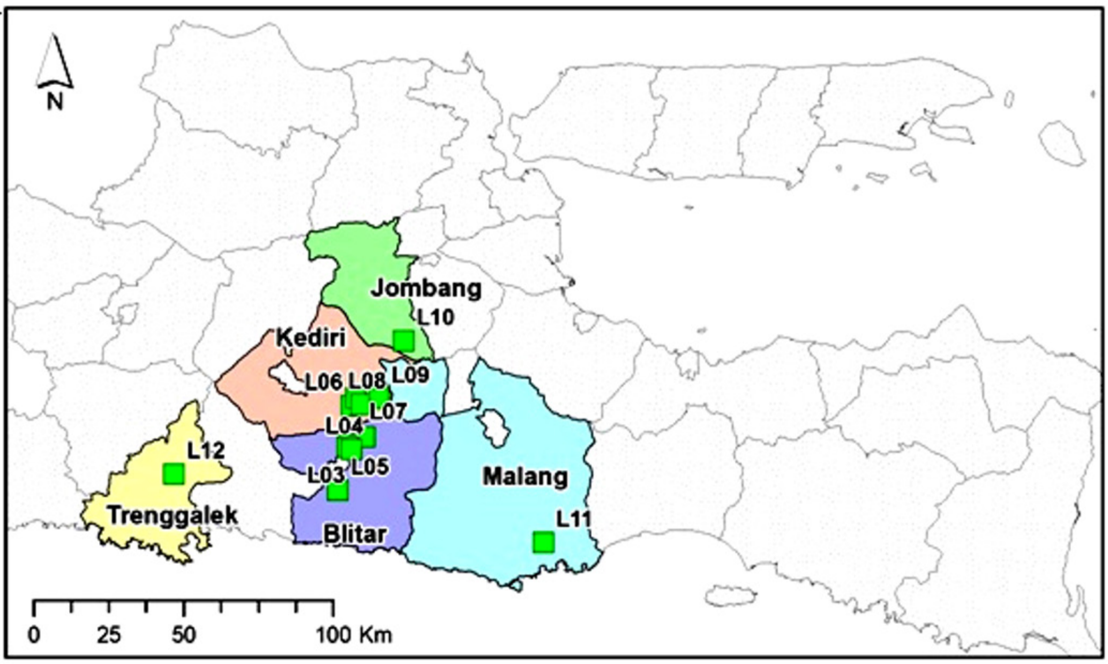

Fig. 1. Map of research location in twelve cacao plantations in East Java, Indonesia. The letter and number refer to the plot code listed in Table 1.

In addition, canopy covers were measured by randomly taking a photo of the canopy at three places in each plot. The canopy image was taken by placing the camera on the ground between four cacao trees. The canopy photos were then analyzed, and the percentage of canopy cover (canopy closeness) was calculated using the ImageJ software (Rueden et al., 2017).

Data Analysis

The difference in attack intensity between cultivation systems was analyzed using the analysis of variance (ANOVA). The relationship between vegetation density, the attack intensity of pests, and the diversity and abundance of predators were analyzed using Pearson correlation. The influence of landscape composition and other environmental factors on the pest attack intensity as well as the diversity and abundance of predators were analyzed by fitting a generalized linear model (GLM) without interaction (Ulina, Rizali, Manuwoto, Pudjianto, & Buchori, 2019) and using a quasi-poisson distribution to count for overdispersion (Zuur, Ieno, Walker, Saveliev, & Smith, 2009). Explanatory variables included class area (CA.nat) and patch number (NP.nat) of natural habitat, class area (CA.crop) and patch number (NP.crop) of cropland, altitude, canopy cover, vegetation density, and predator abundance. All analyses were performed using R statistical software (R Core Team, 2021).

RESULTS AND DISCUSSION

Diversity and Attack Intensity of Pests in Cacao Plantations

The attack intensity of cacao pests both of CPB and *Helopeltis* sp. showed variation between all research locations. The attack intensity of CPB varied from 0.72 to 12.05%, while *Helopeltis* sp. from 12.39 to 42.24 % (Table 2). Based on the ANOVA, the cultivation system of cacao plantations significantly affected the attack intensity of CPB (F=4.420; P=0.040) but did not affect *Helopeltis* sp. (F=0.860; P=0.360). The traditional cultivation system (smallholder, n=9, $\bar{x}$=4.77%) has a higher CPB attack intensity than the intensive cultivation system (government, n=3, $\bar{x}$ =1.58%). This is because traditional cultivation systems have higher vegetation density than intensive ones. This condition probably facilitates the CPB's higher attack intensity in conventional cultivation systems.

The result of ANOVA showed a significant effect of canopy cover on CPB attack intensity (F=3.997; P=0.028), but not the attack intensity of *Helopeltis* sp. (F=1.146; P=0.330). Canopy cover can affect microclimate conditions around cacao plantations. The correlation test revealed a negative correlation between canopy cover and air temperature (r=-0.911; P<0.01) and a positive correlation between canopy cover and air humidity (r=0.885; P<0.01). Suherlina, Yaherwandi, and Efendi (2020) found the high activity of CPB in cacao plants with high canopy cover due to facilitating the shelter of CPB adults. As a nocturnal insect, CPB is active at night and takes advantage of staying during the day in cacao fields with high canopy cover (Day, Mumford, & Hing, 1995; Samsudin, 2014). Although in this research, canopy cover did not affect the attack intensity of *Helopeltis* sp., Khoo & Ho (1992) reported the development of *Helopeltis* sp. was influenced by the microclimate (air temperature and air humidity) in cacao plantations. *Helopeltis* sp. prefers low-temperature conditions with high humidity and low light intensity. However, CPB and *Helopeltis* sp. have indirect interaction mediated by the plant that CPB has no preference to attack the damaged fruits by *Helopeltis* sp. (Wielgoss, Clough, Fiala, Rumede, & Tscharntke, 2012; Wielgoss et al., 2014).

Table 2. Average of attack intensity of cacao pod borer (CPB) and *Helopeltis* sp. at twelve cacao plantations

Code	Location	Attack intensity (%)	
		CPB	*Helopeltis* sp.
L01	Modangan	4.10	26.96
L02	Kemloko 1	7.88	35.35
L03	Kemloko 2	4.98	39.96
L04	Krenceng	2.09	12.39
L05	Plosorejo	1.02	25.17
L06	PTPN Babadan	0.72	26.03
L07	PTPN Badek	0.92	28.47
L08	PTPN Pakelan	3.09	27.95
L09	Laharpang	3.58	40.35
L10	Sambirejo	6.18	33.89
L11	Sukodono	12.05	42.24
L12	Sukowetan	1.05	29.58
	Average	3.90	29.67

The understorey vegetation diversity from all cacao plantations recorded 27 species belonging to 15 families dominated by *Peperomia pellucida* and *Ageratum conyzoides*. Based on the correlation analysis, the diversity of understorey vegetation had a positive relationship with the attack intensity of CPB (r= 0.427; P=0.009) but did not correlate with the attack intensity of *Helopeltis* sp. (r= 0.156; P= 0.361). Understorey vegetation can provide a suitable microclimate for insect pests, such as shelter or hiding from predators (Landis, Wratten, & Gurr, 2000). According to Barbercheck & Wallace (2021) several weed species have an important role as food sources and alternative hosts for several pest species.

Diversity and Abundance of Predatory Insects

The diverse predatory insects from all cacao plantations are 5574 individuals belonging to 3 orders, seven families, and 22 species. The orders are Hymenoptera (1 family and 8 species), Araneae (4 families and 10 species), and Coleoptera (2 families and 4 species) (Table 3). The ant species *D. thoracicus* has the highest abundance compared to other predatory species (3442 individuals or 61.75%). Way & Khoo (1991) also found that *D. thoracicus* were abundant in cacao plantations, especially in stems, twigs, and cacao pods. In cacao plantations, *D. thoracicus* has an important role as the natural enemy of CPB and *Helopeltis* sp. This ant is also related to the food sources, such as the presence of mealybugs (e.g., *Planococcus* sp. as trophobiont) that produce honeydew as additional food for ants (Lach, Parr, & Abbott, 2009). This research also found a positive relationship between the abundance of mealybugs and the abundance of *D. thoracicus* (r= 0.449, P<0.001). Besides trophobiont, ants can guard mealybugs against predators (Riyanto, 2007).

Table 3. Species richness and abundance of predators from 12 research locations

No.	Order	Family/Subfamily	Species	Individual
1.	Hymenoptera	Formicidae/ Dolichoderinae	*Dolichoderus thoracicus*	3442
2.			*Technomyrmex albipes*	1094
3.		Formicidae/ Formicinae	*Anoplolepis gracilipes*	387
4.			*Polyrhachis* sp.	198
5.			*Oecophylla smaragdina*	83
6.		Formicidae/Myrmicinae	*Monomorium* sp.	94
7.			*Camponotus* sp.	69
8.			*Solenopsis* sp.	58
9.	Coleoptera	Staphylinidae/Steninae	*Stenus* sp.	13
10.		Carabidae	*Harpalus* sp.	12
11.		Anthicidae	*Anthicus* sp.	9
12.		Coccinellidae	*Menochilus sexmaculatus*	4
13.	Araneae	Salticidae	*Epocilla* sp1	7
14.			*Epocilla* sp2	14
15.			*Heliophanus* sp1	8
16.			*Heliophanus* sp2	6
17.			*Heliophanus* sp3	10
18.		Araneidae	*Nephila pilipes*	10
19.			*Paraplectana* sp.	6
20.		Linyphiidae	*Erigone* sp.	18
21.		Oxyopidae	*Oxyopes* sp.	24
22.			*Tetragnatha* sp.	8
Total				5574

Predators in the agroecosystem are related to suitable microclimate and food sources (pollen and nectar). In cacao plantations, the microclimate is influenced by the canopy cover. In this research, canopy covers significantly affected predator abundance (F=4.709; P=0.016). Many predators were found in the cacao plantation with a canopy cover of around 70%. This is probably related to high humidity and low temperature suitable for ant breeding (Rizal, Rifanjani, & Kartikawati, 2020). Adonovan, Wulandari, & Linda (2016) revealed that increasing canopy cover causes decreased light penetration to the ground surface and, consequently, has a higher abundance of predatory ants.

The understorey vegetation diversity was also strongly related to predator diversity in cacao plantations. Increasing the density of understorey vegetation causes decreasing the species number (r=-0.510; P=0.001) and abundance (r=-0.611; P<0.001) of predators in cacao plantations. The result is surprising due to other research finding a positive relationship between the diversity of understorey vegetation and the diversity of predators, such as providing a suitable microclimate, supporting pollen and nectar, and alternative prey (Landis, Wratten, & Gurr, 2000).

Table 4. Generalized linear models relating attack intensity of cacao pod borer (CPB) and *Helopeltis* sp. to patch number (NP.nat) and class area (CA.nat) of natural habitat, patch number (NP.cao), and class area (CA.cao) of cacao field, altitude, canopy cover, understorey vegetation density and predator abundance (*D. thoracicus*). Significant level, *: P<0.05

Variable	CPB			*Helopeltis* sp.		
	Estimate	SE	P	Estimate	SE	P
NP.nat	0.098	0.05	0.043*	0.006	0.01	0.655
CA.nat	-0.041	0.03	0.140	0.008	0.01	0.309
NP.cao	-0.164	0.09	0.109	-0.009	0.03	0.792
CA.cao	-0.039	0.05	0.382	0.028	0.02	0.177
Altitude	0.002	0.00	0.046*	0.001	0.00	0.042*
Canopy cover	0.028	0.03	0.351	-0.028	0.01	0.039*
Vegetation density	0.012	0.01	0.016*	0.002	0.00	0.267
D. thoracicus	-4.859	1.99	0.022*	0.339	0.73	0.644

Table 5. Generalized linear models relating species richness and abundance of predators to patch number (NP.nat) and class area (CA.nat) of natural habitat, patch number (NP.cao) and class area (CA.cao) of cacao field, altitude, canopy cover, understorey vegetation density, and predator abundance (*D. thoracicus*). Significant level, *: P<0.05, **: P<0.01

Variable	Species richness			Abundance		
	Estimate	SE	P	Estimate	SE	P
NP.nat	-0.001	0.01	0.974	0.012	0.01	0.031*
CA.nat	0.001	0.01	0.916	0.012	0.01	0.490
NP.cao	-0.021	0.03	0.400	-0.084	0.01	<0.001**
CA.cao	-0.011	0.01	0.416	0.005	0.01	0.408
Altitude	0.001	0.00	0.034*	0.001	0.00	0.018*
Canopy cover	0.005	0.01	0.578	0.020	0.00	<0.001**
Vegetation density	-0.006	0.00	0.002**	-0.006	0.00	<0.001**
D. thoracicus	-0.001	0.01	0.974	0.012	0.00	0.031*

Effect of Landscape Composition on Pest Attack Intensity and Predator Diversity

As a result of landscape characterization from all research locations, semi-natural habitats were found as the dominant elements within the agricultural landscape (Table 1). Based on the ground checking, semi-natural habitats consist of bushes and trees that are dominated by rambutan (*Nephelium lappaceum*), durian (*Durio zibethinus* Murr.), coconut (*Cocos nucifera*), sengon (*Albizia chinensis*), teak (*Tectona grandis*), and several other tree species. The GLM analysis showed that landscape composition did not affect the attack intensity of *Helopeltis* sp. Still, landscape composition, especially the patch number of semi-natural habitats, positively affected the attack intensity of CPB (Table 4). This is arguably related to alternative host plants for CPB in semi-natural habitats. One of the dominant trees in semi-natural habitat is the rambutan which can act as an alternative host for CPB (Wiryadiputra, 1996). Galindo & Loquias (2019) also reported that CPB could attack rambutan fruit. Although the attack symptoms are not apparent, they can be seen in the fruit covered with exudate fluid from the larvae of CPB.

In addition, the attack intensity of CPB was also influenced by the abundance of *D. thoracicus* (Table 5). *D. thoracicus* is well-known as the natural enemy that effectively controls CPB in cacao plantations. Research by Way & Khoo (1992) showed that the presence of *D. thoracicus* can suppress CPB attacks in cacao plantation. Other research by Wielgoss et al. (2014) also revealed that *D. thoracicus* could reduce the attack intensity of CPB similar with invasive *Philidris* ant.

Based on the GLM analysis, landscape composition had no effect on the species richness of predators but positively affected the abundance of predators, especially the patch numbers of semi-natural habitats (Table 5). In contrast, the patch numbers of cacao fields harmed a lot of predators. The existence of semi-natural habitats can provide a source of biodiversity in cacao plantations. Bianchi, Booij, & Tscharntke (2006) showed that natural habitats support food, shelter, and nesting sites and alternative hosts or prey for natural enemies. Research by Bos, Steffan-Dewenter, & Tscharntke (2007) showed that ant species could use cacao plantations that are close to natural habitats for alternative habitats.

Increasing patch numbers of semi-natural habitats indicates the rate of fragmentation in the agricultural landscape. Based on Rösch, Tscharntke, Scherber, and Batáry (2015), natural habitats consisting of several small fragments have higher species richness and abundance of insects than single large fragments. In addition, edge habitats also create a new environment for species that are tolerant of open areas (Murcia, 1995) and increase the dissimilarity of species composition (Rizali, Karindah, Nugroho, & Rahardjo, 2021). Prasetyo (2017) argued that the additive effect of fauna caused by edge habitats or intersection between two different fragments affects species composition and abundance changes. The edge area can also affect the predation ability of predators that prefer in edge habitat as a hunting area (Gunawan, Prasetyo, Mardiastuti, & Kartono, 2010). Research by Wimp, Ries, Lewis, & Murphy (2019) also found the edge habitats positively responded to generalist predators, especially the hunting spider *Clubiona* sp. and *Pardosa littoralis*.

The abundance of predators is also influenced by the patch numbers of cacao fields in the agricultural landscape (Table 5). Increasing the patch number of cacao fields as a consequence of reducing semi-natural habitat can cause a decrease in the abundance of predators. Gunawan & Prasetyo (2013) showed that the decreasing area of semi-natural habitats harms the diversity and abundance of beneficial insects. Therefore, although in agroforestry systems, semi-natural habitats are still vital due to having a direct effect on the balance of insect populations which was also corroborated in coffee agroforestry system (Muhammad, Rizali, & Rahardjo, 2022).

CONCLUSION AND SUGGESTION

The attack intensity of CPB and *Helopeltis* sp. showed variation between twelve cacao plantations. The attack intensity of CPB and the abundance of predators were influenced by canopy cover and vegetation diversity in cacao plantations. The landscape composition, especially the patch number of semi-natural habitats, had a positive relationship with the attack intensity of CPB and the abundance of predators. It indicates that the existence of semi-natural habitats contributes to conserving natural enemies in cacao plantations. However, the management of area and vegetation in semi-natural habitats surrounding cacao plantations should be considered to avoid alternative host plants for pests.

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