Heliyon

Received:
6 January 2019
Revised:
1 February 2019
Accepted:
22 March 2019

Cite as: Damayanti Buchori, Akhmad Rizali, Anik Larasati, Purnama Hidayat, Hien Ngo, Barbara Gemmil-Herren. Natural habitat fragments obscured the distance effect on maintaining the diversity of insect pollinators and crop productivity in tropical agricultural landscapes. Heliyon 5 (2019) e01425. doi: 10.1016/j.heliyon.2019.e01425

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Natural habitat fragments obscured the distance effect on maintaining the diversity of insect pollinators and crop productivity in tropical agricultural landscapes

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Abstract

In tropical regions, habitat change and fragmentation partly occur due to urbanization. This change of land-use can affect many ecosystem services and their providers, such as pollination and pollinators. Within agricultural systems, monoculture systems and pesticide application are the most detrimental to pollinators and insect communities. In this study, we investigated the effect of distance from natural habitat on the diversity of insect pollinators and cucumber productivity. As the independent variable, distance from natural habitats was classified into two different groups i.e. agricultural area near to (less than 200m) and far from (more than 1km) the natural habitat. We found that the abundance

https://doi.org/10.1016/j.heliyon.2019.e01425

of insect pollinators was significantly lower in agricultural areas near to natural habitats compared to those located far from natural habitats. Cucumber farms located near to natural habitats had 54% similar species composition of insect pollinators with cucumber farms located far from natural habitats. The productivity of cucumbers did not differ between cucumber farms near to and far from natural habitats. An expected result was the positive correlation between pollinator abundance (i.e. *Xylocopa* spp.) and the productivity of cucumber. Our findings suggest that the diversity of pollinators in tropical agricultural landscape is influenced more by a landscape composition of high natural habitat fragments than spatial distance between cropland and natural habitats.

Keywords: Environmental science, Ecology

1. Introduction

Land-use change and agricultural intensification have been considered as the main causes to global pollinator decline (Kremen and Ricketts, 2000; Biesmeijer et al., 2006; Klein et al., 2007). Habitat conversions, mainly from forest or natural habitats to agricultural areas, have also contributed to habitat loss for insect pollinators thereby causing local pollinator decline (Kremen and Ricketts, 2000). Like well-managed diverse agricultural areas, natural habitat is an important resource for insect pollinators providing both food and nesting sites (Martins and Johnson, 2009). Pollinator communities can be negatively affected in agricultural areas where only monoculture crops (i.e. reduced spatial heterogeneity, e.g. Baños-Picón et al., 2013) are grown and/or unsustainable agricultural intensification practices are used (e.g. Brittain and Potts, 2011). For example, the increasing use of pesticides has been shown to not only affect target pest populations, but also harm non-target insects, such as pollinators (Desneux et al., 2007; Brittain et al., 2010). Both habitat conversion and agricultural intensification can compound pressures on local pollinator communities, decrease insect pollinators and subsequently reduce crop production through decreased flower-visitation (Garibaldi et al., 2013).

Tropical landscapes are experiencing land-use change and habitat disturbance at an increasing rate (Foley et al., 2005). Land-use change in tropical landscapes (forest) occurs in order to expand crop and pastoral land (Gibbs et al., 2010). In fact, during 1980−2000 it was estimated that over half of the agricultural tropical land expansion replaced intact forests, and over a quarter of the tropical agricultural land expansion replaced disturbed forests (Gibbs et al., 2010). These changes in land cover and landscape composition have been identified as drivers of pollinator declines (Winfree et al., 2011; Senapathi et al., 2015). Studies have also shown that land-use conversion, habitat fragmentation, land-use intensification and further isolation of agricultural land from natural habitat fragments have adverse effects on the richness of

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flower-visiting bees, the density and diversity of insect pollinators and structure, pollination services, and the resulting fruits/yield of the crop (Kremen and Ricketts, 2000; Ricketts et al., 2008).

Studies conducted in Indonesia involving pollinators, pollination, and agronomic yield are scant with a few on coffee, mustard and palm oil (Sahari et al., 2010). More research is needed in order to better understand factors affecting pollinators and pollination services and how this in turn affects crop productivity. Understanding the pollinator community and pollination services delivered to crops, such as cucumbers, are locally and regionally as important as cucumbers and gherkins, which are one of Indonesia's top 25 agricultural commodities (FAOSTAT, 2016). Using a standard protocol to detect and assess pollination deficits (Vaissière et al., 2011), this study examined the diversity of insect pollinators in cucumber fields, investigated the effect of distance to natural habitats on the abundance and species richness of insect pollinators, and studied the relationship between pollinator abundance and cucumber productivity.

2. Material and methods

2.1. Research area

All of the study sites (cucumber farms) were located within the agricultural landscape of Bogor, Indonesia. Agricultural landscapes in Indonesia are dominated by small farmers having small patches of land with an average size of 0.25 ha (BPS-Statistics Indonesia, 2013). Similar to crops such as rice, maize, soybean, and cassava, cucumbers are cultivated in this agricultural landscape. In addition to small crop farms, there are also many patches of natural habitats of varying sizes interspersed in the agricultural landscapes. Using categories based on distance to natural habitat, namely near to natural habitat (less than 200m) and far from natural habitat (more than 1km), we examined the effects of natural habitat fragments on pollinator communities which visited small-scale cucumber farms. We selected cucumber plant (*Cucumis sativus*) as the case study in this research, as the plant relies on insects to pollinate the flowers for fruit development (Levin et al., 1968).

For each treatment (distance-based category), there were three study sites (replicates) and a total of six study sites for this experiment. The study sites (n = 6) were separated from one another with a minimum distance of 1.5 km. The six plots had similar topography, soil type, slope, and crop management (Fig. 1).

2.2. Plot establishment

The study design was based on a standard protocol developed by the United Nations Food and Agriculture Organization (FAO) (Vaissière et al., 2011). Each plot has a minimum size of 25 m × 50 m and was planted with only cucumbers (i.e. no

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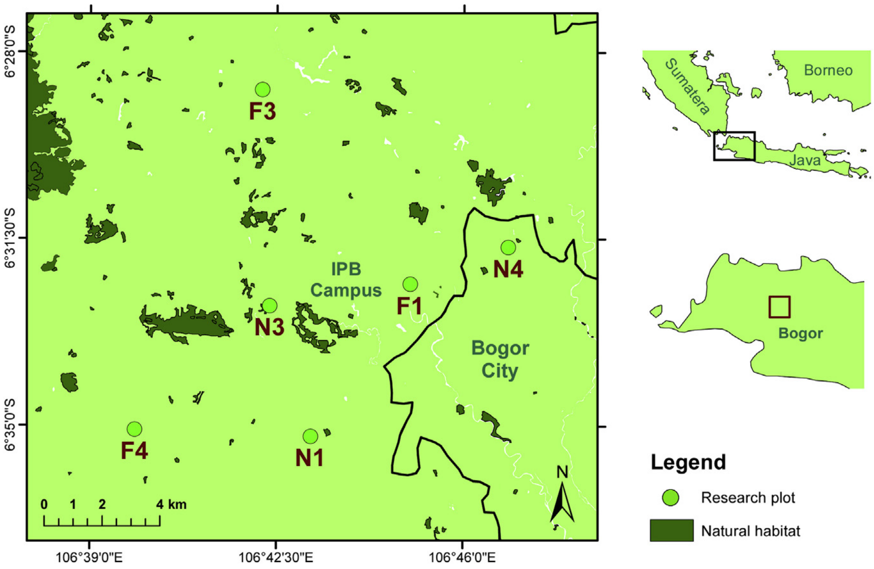

Fig. 1. Map of research area located around Bogor area. Plots indicated with a light green circle and letter F (far) and N (near) from natural habitat. The dark green color indicates small patches of natural habitat that typically occurred in Bogor.

intercropping) (Table 1). The cucumbers were planted in rows (Fig. 2), with each site consisting of 5,000−10,000 plants. The distance between rows was 30 cm, and the distance among plants within rows was 60 cm × 40 cm. The planting of cucumbers was carried out during the week of 17 June -1 July 2013 (Table 1). The planting schedule was staggered, as the land was not available for cucumber plants to be simultaneously planted in all six sites. In terms of management strategy, the cucumber farms had bamboo-crossed scaffolding as trellises to support the cucumber plants. The pesticide was used before the plants bloomed (non-organic farming). Organic and chemical fertilizers were applied at different times.

2.3. Sampling and monitoring of insect pollinators

The samplings of insect pollinator were conducted during the cucumber's flowering season. The flowering was marked by the opening of male and female flowers

Table 1. Planting time and field size variation of research plots.

Plot code	Distance from natural habitat	Village	Latitude	Longitude	Planting time	Plot size (m x m)
F1	Far	Rancabungur	-6.539103	106.750081	29.06.2013	47 × 50
F3	Far	Telagakahuripan	-6.478464	106.703739	01.07.2013	25 × 50
F4	Far	Cibatok	-6.584614	106.663981	22.06.2013	25 × 75
N1	Near	Ciampea	-6.586653	106.719003	22.06.2013	26 × 52
N3	Near	Darulfallah	-6.545883	106.706072	17.06.2013	50 × 57
N4	Near	Kayumanis	-6.527519	106.780597	17.06.2013	25 × 52

https://doi.org/10.1016/j.heliyon.2019.e01425

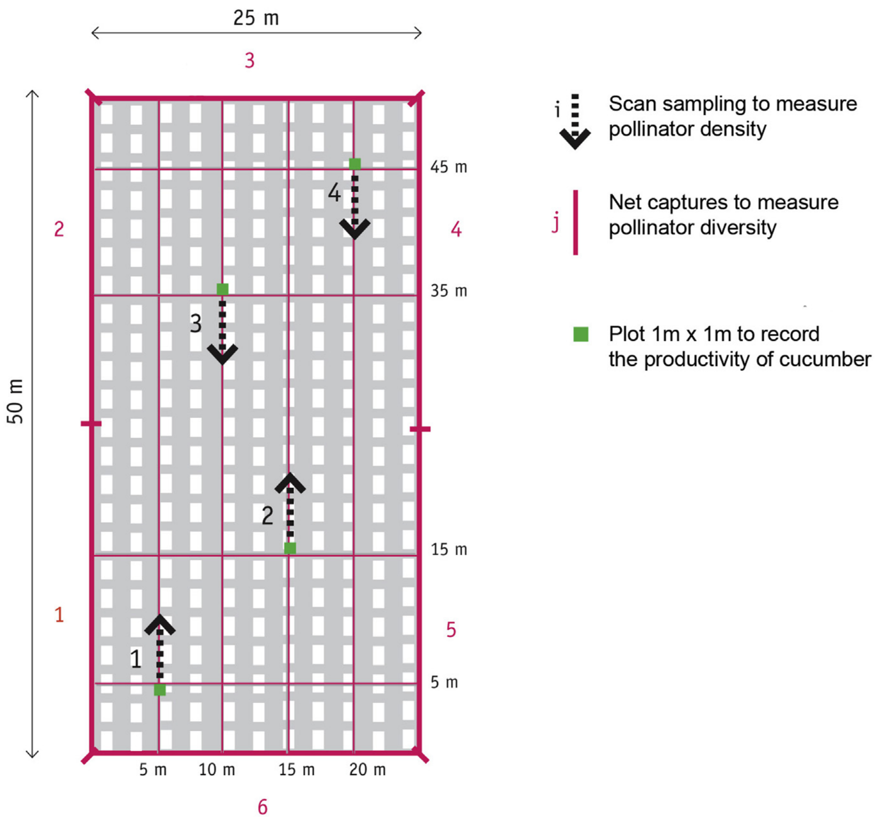

Fig. 2. Design of one cucumber plot which had four transects inside the plot for scan sampling, six transects on the perimeter of a plot for net captures and four subplots for recording cucumber productivity (1 m × 1 m each). Adapted from Vaissière et al. (2011).

approximately 24 days after planting. The samplings for density and diversity of insect pollinators and cucumber productivity (crop yield and several different metrics for quality) followed sampling methods based on the standardized protocol of FAO (Vaissière et al., 2011).

The density of insect pollinators was observed by scan sampling four transects in the plot (Fig. 2). Insects found on every 100 flowers as a fixed unit sampling were recorded and counted for each transect to measure pollinator abundance. Afterward, the diversity of insect pollinators was measured using the net capture (sweep net) in six transects on the plot's perimeter (Fig. 2). Net captures were conducted every five minutes for each transect. Both the density and diversity of insect pollinators were observed at four different times, i.e. 9.00 am, 11.00 am, 13.00 pm and 15.00 pm. Different plots were rotated at possible times of the day when they would be sampled. After the insect specimens were collected, they were stored in an insect container for later identification in the laboratory.

The cucumbers' productivity was observed from the subplot located in the starting point of each transect for pollinator density (Fig. 2). The variables that were recorded

https://doi.org/10.1016/j.heliyon.2019.e01425

from each plot were the number of fruits, the fruit's weight, the fruit's length, the fruit's width, the number of seeds, and the total dry weight of seeds.

2.4. Insect identification

The insect specimens were initially sorted and identified using relevant taxonomic literature (e.g. Goulet and Huber, 1993; Borror et al., 1996) and the reference collection of Zoological Museum, LIPI, Indonesia. The identifications process was carried out by Anik Larasati and Bayu Aji Pamungkas. The specimens were deposited in the Laboratory of Biological Control, the Department of Plant Protection, IPB.

2.5. Data analysis

The difference of pollinator abundance between plots was analyzed using the F test. ANOVA was also used to analyze the difference of pollinator abundance between time observations. The difference of pollinator species composition was calculated using nonmetric multidimensional scaling (NMDS) based on the Bray-Curtis dissimilarity index (Magurran, 2004). The difference of cucumber productivity between plots was analyzed using the F test. The relationships between pollinator abundance and cucumber productivity were analyzed using Pearson's correlation. The analyses were performed using the R statistic (R Core Team, 2018) with the vegan package for diversity analysis (Oksanen et al., 2018).

3. Results

3.1. The diversity of insect pollinators in the cucumber field

In total, 13 species of insect pollinators belong to three orders (Hymenoptera, Diptera, and Lepidoptera) and seven families were collected from whole plots in the cucumber field in Bogor (Table 2). Order Hymenoptera was the most abundant pollinators especially Apidae's group (bees) that dominated by *Apis mellifera, A. cerana*, *Xylocopa confusa,* and *X. latipes*. Some species of insect pollinators were only found in single individual i.e. *Ceratina* sp, *Xylocopa* sp, *Nomia* sp, *Megachile disjuncta*, *Papilio memnon*, and *Eurema* sp.

3.2. The effect of distance to natural habitat on the abundance and species richness of insect pollinators

The abundance of pollinators was significantly higher in cucumber fields located far from natural habitats for *Apis* spp. ($F = 155.190$, $P = 0.013$), Apidae's group ($F = 64.693$, $P = 0.030$) and all insect pollinators ($F = 54.243$, $P = 0.036$), except *Xylocopa* spp. ($F = 1.346$, $P = 0.852$) (Fig. 3). Based on Bray-curtis index, the species composition of insect pollinator between cucumber fields located far from and near

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Table 2. Diversity of insect pollinators collected from six plots both in near and far from natural habitat.

Order	Family	Species	Near	Far	Total
Hymenoptera	Apidae	*Amegilla whiteheadi*	2	1	3
		Apis cerana	3	13	16
		Apis mellifera	21	144	165
		Ceratina sp	1		1
		Xylocopa confusa	36	31	67
		Xylocopa latipes	28	26	54
		Xylocopa sp		1	1
	Halictidae	*Nomia* sp		1	1
	Megachilidae	*Megachile disjuncta*		1	1
Diptera	Syrphidae	*Syrphus* sp	12	7	19
Lepidoptera	Nymphalidae	*Hypolimnas bolina*	8	4	12
	Papilionidae	*Papilio memnon*	1		1
	Pieridae	*Eurema* sp		5	5
Total			112	234	346

to natural habitats was 54% similar. Four species were only recorded in cucumber field located far from natural habitat and two species were only recorded in cucumber field near to natural habitat (Table 2). However, species composition of insect pollinators among plots located near to natural habitats was more similar than plots located from far from natural habitats (Fig. 4).

Different sampling times also affected the presence of insect pollinators in the cucumber field. Pollinators tended to be more active in the morning (9.00 and 11.00 am) than in the noon or afternoon (Fig. 5). However, these patterns were only clearly found in plots located near to natural habitats (Fig. 5b).

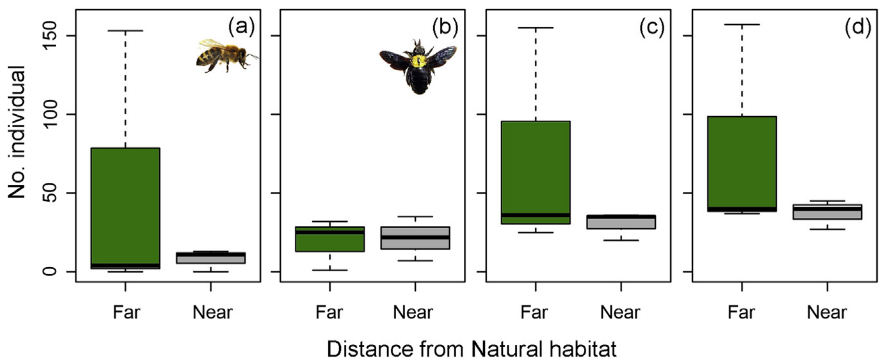

Fig. 3. Abundance of insect pollinators between far and near distance from natural habitat. (a) *Apis* spp (F = 155.190, P = 0.013), (b) *Xylocopa* spp (F = 1.346, P = 0.852), (c) Apidae's group (F = 64.693, P = 0.030) and (d) all pollinators (F = 54.243, P = 0.036).

https://doi.org/10.1016/j.heliyon.2019.e01425

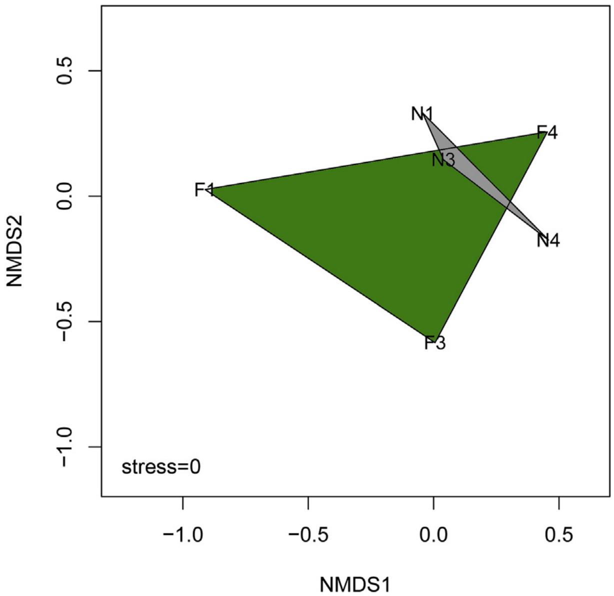

Fig. 4. Nonmetric multidimensional scaling (NMDS) of species composition of insect pollinators between near (front letter N) and far (front letter F) from natural habitat, based on Bray-Curtis's dissimilarity index.

3.3. The relationship between pollinator abundance and cucumber productivity

The productivity of cucumbers did not differ between crop fields located near to and far from natural habitats including the fruits' weight (F = 1.275, P = 0.694), the fruits' width (F = 1.226, P = 0.741), the seeds' number (F = 1.018, P = 0.976), and the seeds' dry weight (F = 1.774, P = 0.356) (Table 3). However, for the fruits'

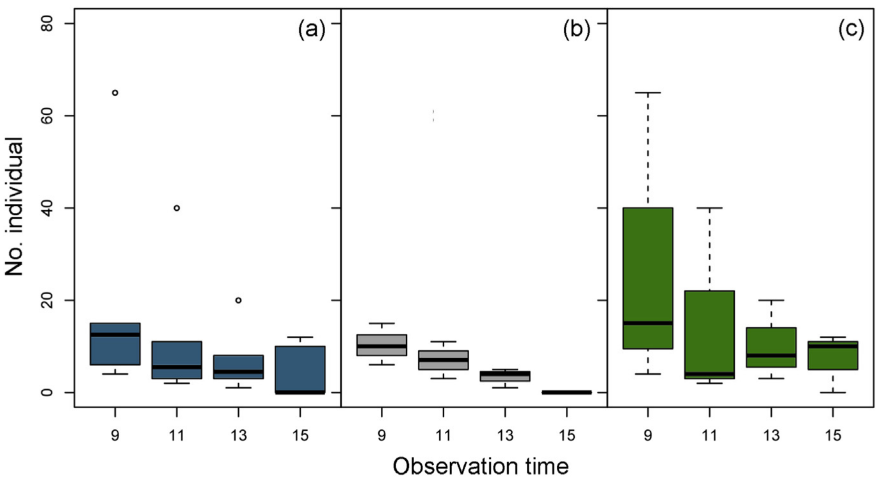

Fig. 5. Abundance of Apidae's group in different day times. (a) All plot ($F_{1,22}$ = 4.151, P = 0.054), (b) Near from natural habitat ($F_{1,10}$ = 22.15, P = 0.0008) and (c) Far from natural habitat ($F_{1,10}$ = 2.017, P = 0.186).

https://doi.org/10.1016/j.heliyon.2019.e01425

Table 3. Cucumber productivity between near and far plots from natural habitat.

Variable	Near ±SD	Far ±SD	Significance
Fruit			
weight (g)	255.4 ± 38.7	283.4 ± 45.0	F = 1.275, P = 0.694
length (cm)	19.5 ± 1.3	21.2 ± 1.2	F = 6.741, P = 0.004
width (cm)	5.4 ± 0.3	6.2 ± 0.2	F = 1.226, P = 0.741
Seed			
number of seed	201.6 ± 27.6	201.1 ± 18.5	F = 1.018, P = 0.976
dry weight (g)	3.0 ± 0.4	3.3 ± 1.1	F = 1.774, P = 0.356

length the cucumbers were significantly longer in the cucumber fields located far from natural habitats ($F = 6.741$, $P = 0.004$).

Based on correlation analysis, there was positive correlation between *Xylocopa* spp. abundance and cucumber productivity especially the fruit weight, the seed number and the dry weight of seeds (Table 4, $P < 0.01$). We omitted to analyze the relationship between cucumber productivity and other dominant species of insect pollinators (i.e. *Apis* spp.) due to had a strong negative correlation with *Xylocopa* spp. ($r = -0.745$, $P < 0.001$).

4. Discussion

Findings in this study reveal that the abundance and species richness of insect pollinators in cucumber fields were not related to spatial distance from natural habitats. Agricultural landscape compositions with high proportion of natural habitat fragments obscured the "distance effect" on the abundance of insect pollinators. The abundance of insect pollinators was higher in croplands located far from natural habitats. This is arguably due to the strong influence of landscape composition in comparison to the distance of croplands from natural habitats. Previous research by Hass

Table 4. Correlation between cucumber productivity and pollinator abundance for *Xylocopa* spp, Apidae's group and all pollinators. Analyzed using Pearson's correlation.

Variable	*Xylocopa* spp.	Apidae's group	All pollinators
Fruit			
weight (g)	r = 0.538, P = 0.007	r = -0.240, P = 0.260	r = -0.240, P = 0.258
length (cm)	r = 0.245, P = 0.250	r = 0.025, P = 0.905	r = 0.017, P = 0.937
width (cm)	r = 0.083, P = 0.701	r = 0.097, P = 0.654	r = 0.108, P = 0.616
Seed			
number of seed	r = 0.520, P = 0.009	r = -0.250, P = 0.239	r = -0.270, P = 0.204
dry weight (g)	r = 0.556, P = 0.005	r = -0.437, P = 0.033	r = -0.453, P = 0.026

https://doi.org/10.1016/j.heliyon.2019.e01425

et al. (2018) revealed that landscape configuration promotes the abundance of wild bees and pollination services, while high crop diversity reduces the abundance of bees in agroecosystems. Another study by Holzschuh et al. (2010) also found that landscape composition with high proportions of conventional management and large crop fields threatened pollination services on a landscape scale.

The effects of spatial distance from natural habitats on croplands are especially complex in tropical regions. Sahari et al. (2010) discussed that the species richness of flower-visiting bees, pollination, and fruit sets were found to be either negatively or positively correlated with the increased isolation of natural habitats. Habitat isolation is commonly related to spatial distance between the agricultural habitat and the natural habitat. In the case of pollinators, habitat isolation may affect insect pollinators' species richness with increased isolation resulting in the decrease of insect pollinators' richness and visitation rate (Ricketts et al., 2008). In contrast, the different taxa of pollinator taxa may increase with increased isolation from natural habitats. Klein et al. (2002) found that the solitary bee species profit from the increased isolation or management intensification of cacao agroforests. The study conducted by Greenleaf and Kremen (2006) also revealed that different species of pollinators may respond differently towards habitat modification or habitat isolation.

Results in this study also demonstrated that the productivity of cucumbers especially the fruits' length was longer in cucumber fields located far from natural habitats. This indicates that the high abundance of insect pollinators may increase the pollination success of cucumber flowers. The fruits' length can be an indicator of the optimum pollination in crop plants (Vaissière et al., 2011). Therefore, cucumber fields located far from natural habitats may receive optimum pollination due to the high abundance and visitation rate of insect pollinators.

An expected finding was the positive correlation between the abundance of pollinators and the productivity of cucumber seeds. This pattern confirmed prior research on the correlation between the abundance of pollinators and the increased quality of seeds (e.g. Bommarco et al., 2012). Yet this pattern was for *Xylocopa* spp. and conversely for *Apis* spp. (especially *A. mellifera*) that indicated the competition between both species. As introduced species, *A. mellifera* can have negative impact on local bees (Paini, 2004; Russo, 2016). Previous study revealed that *A. mellifera* cause negative impact on *Bombus* spp (Thomson, 2006) as well as *Xylocopa* spp through competition for nectar (Schaffer et al., 1983; Sampson et al., 2004).

In conclusion, there is a need for further experimental studies focusing on the effects of pollinator abundance on seed quality and the complexity of native vs introduced-pollinator interaction on a landscape level. Such studies are needed to better understand the role of natural habitat fragments in maintaining pollinator diversity as well as crop productivity in tropical agricultural landscapes.

 https://doi.org/10.1016/j.heliyon.2019.e01425

Declarations

Author contribution statement

Damayanti Buchori: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Akhmad Rizali: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Anik Larasati: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Purnama Hidayat, Hien Ngo, Barbara Gemmil-Herren: Conceived and designed the experiments; Wrote the paper.

Funding statement

This work was supported by the GEF through the Food and Agriculture Organisation of the United Nations (FAO).

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

We are grateful to the six cucumber farmers for providing access to their fields for this study. We would like to thank Bayu, Mahardika, Rado and other assistants who conducted insect sampling and pollinator monitoring. We also thank Inditian Latifa for checking the language of the manuscript submitted for publication.

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