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Edge effects at multifunctional agro-landscapes in Jember, Indonesia, on the augmentation of butterfly diversity

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Abstract. *Kurnianto AS, Haryadi NT, Dewi N, Miftachurrohmi, Rohmana A, Amal GI, Septiadi L, Firdaus AS, Magvira NL. 2023. Edge effects at multifunctional agro-landscapes in Jember, Indonesia, on the augmentation of butterfly diversity. Biodiversitas 24: 2231-2241.* Butterflies are important pollinators and bioindicator communities in agro-landscapes. Assessing changes in butterfly communities, such as abundance and diversity, is essential in evaluating the response of butterflies to ecosystem disturbance. However, edge effects on agro-landscapes are highly influenced by land management. This study aims to objectively investigate the interactions between agroforestry management, including mono-shade, complex, and agroforestry-monoculture systems, with butterfly diversity to assess the impact of edge effects on butterfly communities. Sampling was conducted using Van Sommeren traps (T = 150 cm; D = 30 cm) baited with fermented bananas. Each trap was hung three meters high on a tree with three replicates in one location. Within 24 hours, the butterflies were collected, dried in an oven for 3x24 hours, and identified. The ecological indices were calculated using PAST 3.26, including the Shannon-Wiener index, the Simpson dominance index (D), the Simpson diversity index (1_D), the Margalef index, and the Evenness index. Therefore, 61 specimens, including 59 Nymphalidae and 2 Pieridae, were successfully collected. There are Nympahlidae families: *Amathusia phidippus* Linnaeus, 1763 (1), *Elymnias casiphone* Hübner, 1824 (2), *Elymnias hypermnestra* Linnaeus, 1763 (2), *Euthalia aconthea* Cramer, 1779 (1), *Euthalia monina* Fabricius, 1787 (1), *Junonia atlites* Linnaeus, 1763 (1), *Junonia iphita* Cramer, 1782 (1), *Lethe europa* Fabricius, 1775 (1), M*elanitis leda* Linnaeus, 1758 (24), *Melanitis phedima* Cramer, 1782 (4), *Mycalesis fuscum* Felder, 1860 (2), *Mycalesis horsfieldi* Moore, 1892 (1), *Mycalesis janardana* Moore, 1857 (6), *Mycalesis nala* Felder, 1859 (1), *Mycaleses perseus* Fabricius, 1775 (1), *Mycalesis sudra* Felder, 1867 (2), *Orsotriaena cinerea* Butler, 1867 (1), *Orsotriaena medus* Fabricius, 1775 (2), *Polyura athamas* Drury, 1773 (3), *Polyura schreiberi* Godart, 1824 (1), *Tanaecia trigerta* Moore, 1857 (1). There are families Pieridae: *Leptosia nina* Fabricius, 1793 (1), *Eurema blanda* Boisduval, 1836 (2). Comparison between complex and monoculture sites showed substantial differences. Meanwhile, there was no significant difference between mono-shade and monoculture sites. Butterfly diversity at the three locations was categorized as moderate. The highest diversity was observed in mono-shade sites. The three similarity indices showed that the agroforestry complex and monoculture locations have high similarity. *Melanitis leda* Linnaeus, 1758 was found in 3 sites and commonly found in complex sites (16), followed by monoculture (6) and mono-shade (2). This study indicated that edge effects have a significant influence, especially on the diversity of butterflies in the monoculture area.

Keywords: Agro-landscapes, butterflies, diversity, edge effects, van Sommeren's trap

INTRODUCTION

The edge environment has a high density of potential food crops and provides niches for non-forest species. Assessing changes in butterfly communities, as well as the pure number of species or measures of diversity, is very important in evaluating the response of butterflies to ecosystem disturbance. However, edge effects on agro-landscapes receive many impacts from differences in management. Edge effects are always interesting to study because they describe how two ecosystems, in this case, the management results, can impact a community (Berenguer et al. 2014). So far, edge effects anomalies in the area due to the interaction of two or more ecosystems. However, many researchers studied edge effects to describe succession processes (Liu et al. 2018), the complexity of interactions (Evans et al. 2016), and the progress of change and the impact of an ecosystem (Ewers et al. 2013). Areas with a variety of traditional agricultural management illustrate the complexity of the plant and animal communities within them.

Butterflies are essential in agro-landscapes as they contribute to pollination and are significant herbivores (Ghazanfar et al. 2016). A co-evolutionary relationship exists between butterflies and plants, whose lives are closely related. These insects also provide food for other organisms, such as birds, reptiles, and amphibians, and act as biological pest control (Ghazanfar et al. 2016). They have been used as bio-indicators because of their unique relationships with host plants (Ismail et al. 2020), indicating that butterfly diversity may be related to plant variety. However, the relationship between ecosystems and diversity is still being debated. Many invertebrate groups increase their diversity and abundance in disturbed areas such as forest edges (Foggo et al. 2001).

This research was conducted in Rowosari Village, the eastern Jember District, located on the western slope of Mount Raung, Indonesia. Like the condition of a pitch, the Rowosari Village area consists of plateaus, hills, and slopes. The site is fertile due to volcanic influence (Nalurita et al. 2020). Most Rowosari people develop coffee agroforestry and monoculture-rice fields and work as farmers (BPS (2022). This management is chosen because the mountain slopes in Rowosari Village have complex topography, varied agro-landscapes, and heterogenous forest. Therefore it creates microclimatic conditions suitable for coffee plants and reservoirs for water supply for rice plants (Yue 2016; Rahn et al. 2018). Furthermore, Rowosari's people manage agricultural areas organically to increase sustainability through efforts to increase diversity through production inputs (Bedoussac et al. 2015). With the minimal disturbance of agrochemical inputs and the complexity of the landscape in Rowosari, this location is very appropriate to be chosen as a research setting that examines the interaction between butterflies and agricultural management models.

This study will objectively look at the interactions of agroforestry management: mono-shade, complex, and agroforestry-monoculture systems, and relate them to butterfly diversity to assess the extent of the impact of edge effects on butterfly communities. This study expects to evaluate the development direction of an agroecosystem and provide essential recommendations on the importance of maintaining the complexity of interactions. Although it is projected that agro-landscape management will affect butterfly diversity, only a few studies have been conducted to explore butterflies in this region. Research conducted in other regions in Indonesia shows a link between butterfly diversity and agro-landscape organic management models (Leksono 2017; Campera et al. 2021) Butterflies were chosen as an object of observation in ecological studies because they are easy to identify, observe the dynamics of their abundance, and can describe environmental influences. A study shows that the diversity of butterflies can represent the effect of various habitats on the style and composition of butterflies in a narrow area in the Bangus Valley, India (Dar et al. 2022).

MATERIALS AND METHODS

Study area

Sumberjambe Village (-8.0737 S, 113.9294 E), the western slope of Mount Raung, Jember District, East Java, Indonesia has an agricultural characteristic typical of the highlands. The components of the agro-landscape are very diverse, consisting: of rice fields (rice and horticulture), residential, dry land, wild plants, yards, and simple and complex agroforestry (Figure 1). The proximity of Sumberjambe to preserved forests and springs made it possible to manage several organic rice farming areas. Therefore, the agroforestry system manages many areas bordering agroforestry and organic coffee plantations. Organic Certification Agency has verified this organic management (no: 379-LSO-005-IDN-09-20). Therefore, Sumberjambe Village is a very appropriate site to understand and validate the various roles of biodiversity compared to the diversity and productivity of agricultural commodities.

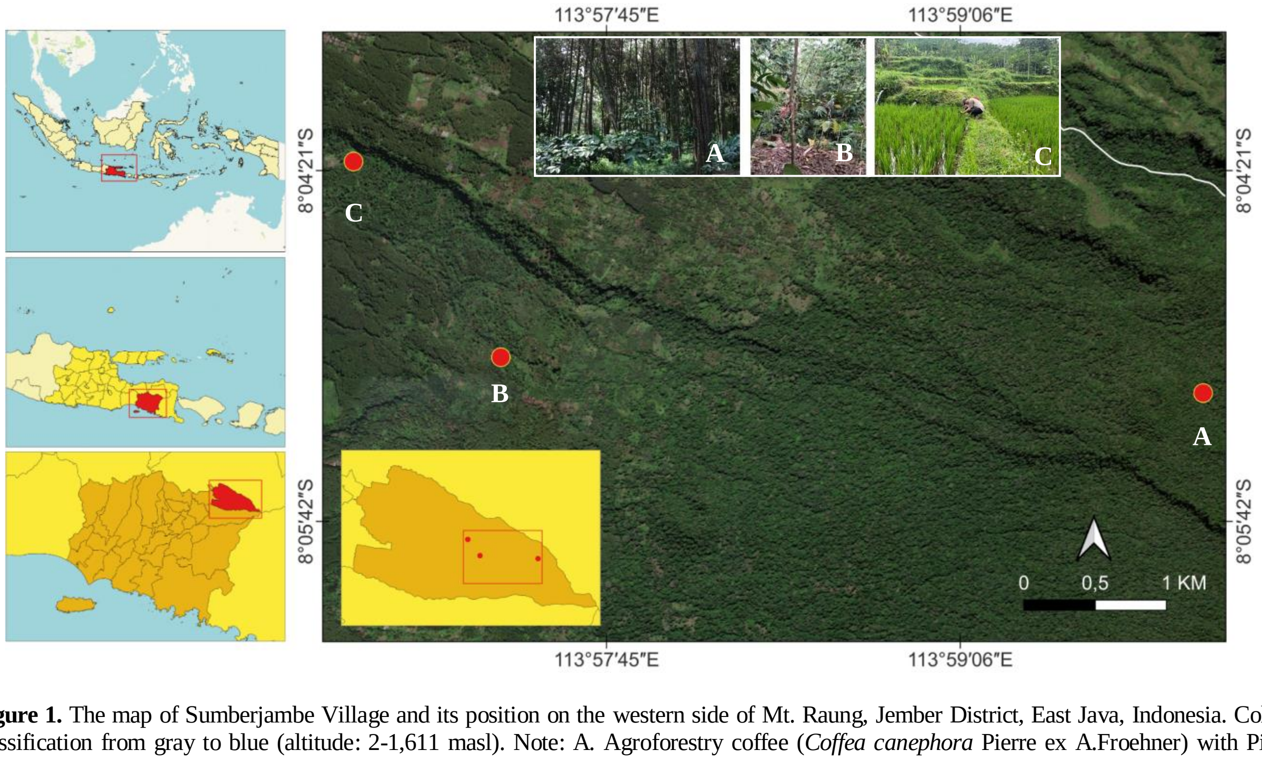

Figure 1. The map of Sumberjambe Village and its position on the western side of Mt. Raung, Jember District, East Java, Indonesia. Color classification from gray to blue (altitude: 2-1,611 masl). Note: A. Agroforestry coffee (*Coffea canephora* Pierre ex A.Froehner) with Pine (*Pinus merkusii* Jungh. & de Vriese); B. Agroforestry complex (*C. canephora*) with heterogeneous vegetation (See Table 1 for an overview of the diversity); C. Paddy (*Oryza sativa* L) monoculture

Procedures

Based on the results of a vegetation analysis in monoculture, complex, and mono-shade agroforestry (prestudy), it was the level of vegetation diversity. It was classified as low to moderate, the level of dominance was classified as low to moderate, and the level of evenness of vegetation types was classified as depressed to unstable communities (see Table 1). The vegetation found was classified based on two types of vegetation: seedling (height = 0-1.5 m) and tree (diameter >20 cm). As an impact of agroecosystem management, the tree shade diversity cannot be categorized as high. For example, the research conducted on complex agroforestry systems in Harapan Makmur Village, Bengkulu, Indonesia, shows low vegetation diversity (0.99, Wiryono et al. 2016). Another study at Central Tapanuli also observed the diversity of understory plants in 2 management, i.e., agroforestry and monoculture. The result was classified as moderate (2.62 and 2.35, respectively; Muhdi et al. 2020). This previous study held two plots with two repetitions: 20x20 m for the tree and 1x1 m for the seedling. Rice was planted 25x25 cm for monoculture management, and the sample was collected on the bunds.

Butterflies are the easiest group of invertebrates to survey at a landscape scale in Sumberjambe. The sampling was conducted at three managed-organically locations: pine agroforestry, complex agroforestry, and monoculture. The pine agroforestry represents a single shade tree with coffee as the main commodity bordered by preserved upland tropical forest (1,225 masl, see Figure 1 for altitude visualization). Complex agroforestry has the complexity of shade trees and coffee as the main commodities and is directly adjacent to urban areas and highways (1,118 masl). Finally, monoculture is an agroecosystem with a single rice item directly adjacent to complex agroforestry (1,116 m asl).

The butterfly sampling process was carried out using butterfly traps (Van Sommeren traps baited with fermented bananas, T = 150 cm; D = 30 cm). Each trap was suspended 3 meters from a tree, with three replicates in one location (Figure 2). Within 24 hours, the butterflies were collected and stored on Papilio paper. First, the specimens were pinned (pin length = 40mm; D = 0.56mm) on the thorax, positioned in the center gap of the pinning board, and then the wings were stretched. Next, the wings are covered with thin paper and pinned with insect needles. These specimens were then dried in an oven for 3x24 hours and stored in entomological boxes. Finally, specimens are identified with the identification book (Wijeyeratne 2006; Schultze 2007; Kirton 2014).

Data analysis

The ecological indices used include the Shannon-Wiener index, the Simpson dominance index (D), the Simpson diversity index (1_D), the Margalef index, and the Evenness index. Data were also analyzed using a bar chart to determine the habitat conditions favored by butterflies: sun-like, shade-like, intermediate (see Table 2), and their role in the ecosystem (Pollinator, Pest, and Free Living). Ecological roles are classified as follows: Pollinator (PO): Butterfly that has an interest in commodity plant flowers in the study area; Pest (PE), which in large quantities, in the larval stage, is the potential to become a commodity Pest; and Free Living (FL): Butterflies that are mostly Free Living or whose ecological role is unknown (Ryan et al. 2019; Ghazanfar et al. 2016). Statistical and Principle Component Analysis (PCA) was performed using the Paleontological Statistics Software Package for Education and Data Analysis (PAST) version 3.26. PCA shows a preference for the abundance of butterflies in the three group study sites (Hammer et al. 2001). Significant differences were analyzed using the Mann-Whitney U non-parametric difference test using SPSS 16.0 software. Expected species richness was also calculated based on non-parametric estimators and test site similarity (Bray Curtis, Jack Knive, and Bootstrap) using PAST software version 3.26.

RESULTS AND DISCUSSION

Results

Sixty-one butterfly specimens, of which 59 Nymphalidae and 2 Pieridae members were recorded, were collected from the research site (see Table 3). Satyrinae is the group with the most prominent member findings. Most are Free Living and found in bush areas. Another subfamily, Amathusiinae, was the fewest finding. Next, Charaxiane and Coliadinae are found with two members each. Finally, Nymphalinae is found with five members.

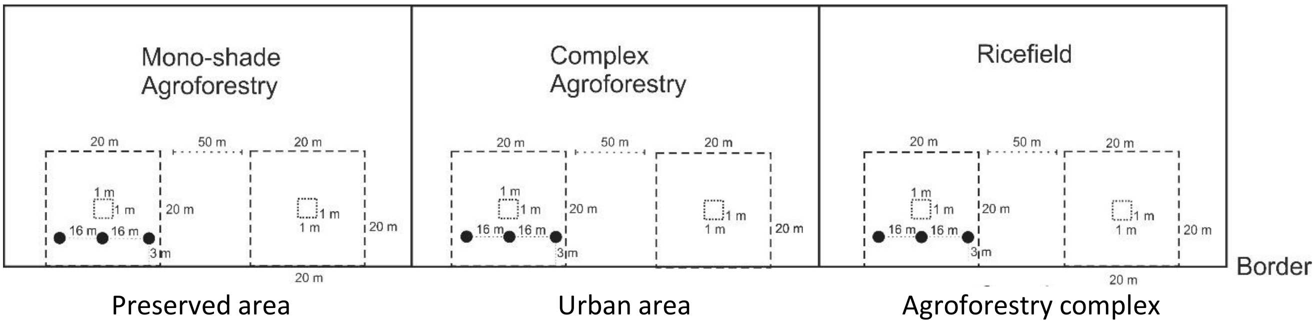

Figure 2. The schematic design of the study area. Note: Dot: Butterfly Trap; dashed lines: The plots of vegetation analysis

Table 1. Prestudy results of vegetation analysis at 3 locations

Location	Type	IVI ; species	H'	D	E
Monoshade agroforestry	Seedling	67.6; *Oplismenus undulatifolius* (Ard.) P.Beauv.	1.576 (moderate)	0.307	0.536
	Tree	98.1; *Coffea canephora* Pierre ex A.Froehner	0.760 (low)	0.556	0.428
Complex agroforestry	Seedling	50.0; *Colocasia esculenta* (L.) Schott	1.894 (moderate)	0.212	0.475
	Tree	88.9; *Coffea canephora* Pierre ex A.Froehner	0.991(low)	0.584	0.245
Monoculture	Seedling	49.9; *Pistia stratiotes* L	2.211 (moderate)	0.207	0.415

Note and standards: MC: Monoculture; C: Complex Agroforestry; M: Monoshade Agroforestry; IVI: Important Value Index; H': Shannon-Wiener Diversity Index (H'<1: low diversity; 1<H'<3: moderate diversity; H'>3: high diversity); D: Simpson Dominance (D < 0.4: low domination, 0.4< D<0.6: moderate domination, D>0.6); E: Evennes (0.00<E< 0.5: depressed community, 0.50< E<0.75: unstable community, 0.75< E<1.00: stable community)

Table 2. Categories of butterfly character and behavior are classified in several references

Categories	Behavior, Characteristics	Family: Subfamily/species	References
Sun-like	They are found in grassland, urban or without shade, and are mostly brightly colored.	Nymphalidae: Nymphalinae; Pieridae: Coliadinae	Christharina and Fatimah 2022; Jugovic et al. 2017
Shade-like	They are found in heavily shaded lands and mostly are with dark/dull colors.	Nymphalidae: Satyrinae	Khanal 2018; Freitas et al. 2015; Brattström et al. 2015
Intermediate	They can be found on the edge of shaded areas and in two other categories.	Nymphalidae: Amathusiinae; Nymphalidae: Charaxinae	Gueratto et al. 2020

Table 3. The abundance of butterflies and their roles. Roles are based on most of their observed behavior by reference. Note: check: confirmed role; MC: Monoculture; C: Agroforestry Complex; M: Monoshade Agroforestry; PE: Pest; PO: Pollinators; FL: Free Living (relatively unknown)

Family: subfamily	Species	Abundance			Ecological role			References
		M	C	MC	PO	PE	FL	
Nymphalidae: Amathusiinae	*Amathusia phidippus* Linnaeus, 1763		1			✓		Layek et al. (2022);
Pieridae: Coliadinae	*Leptosia nina* Fabricius, 1793			1	✓			Islam et al. (2016);
	Eurema blanda Boisduval, 1836			1		✓		Sholahuddin et al (2019);
Nymphalidae: Nymphalinae	*Junonia atlites* Linnaeus, 1763		1		✓			Behera (2021);
	Junonia iphita Cramer, 1782	1			✓			Cleary (2016);
	Tanaeceia trigerta Moore, 1857	1					✓	Kathiresan et al. (2017);
	Euthalia aconthea Cramer, 1779			1		✓		Tara and Gupta (2016);
	Euthalia monina Fabricius, 1787	1					✓	Scriven et al. (2017);
Nymphalidae: Satyrinae	*Lethe europa* Fabricius, 1775		1			✓		Toussaint et al. (2015)
	Melanitis leda Linnaeus, 1758	2	16	6		✓		
	Melanitis phedima Cramer, 1782		3	1	✓			
	Mycalesis fuscum Felder, 1860	1	1				✓	
	Mycalesis horsfieldi Moore, 1892			1			✓	
	Mycalesis janardana Moore, 1857	6					✓	
	Mycalesis nala Felder, 1859	1					✓	
	Mycalesis parseus Fabricius, 1775		1				✓	
	Mycalesis sudra Felder, 1867	2					✓	
	Orsotriaena cinerea Butler, 1867		1				✓	
	Orsotriaena medus Fabricius, 1775		2		✓			
	Elymnias casiphone Hübner, 1824	2				✓		
	Elymnias hypermnestra Linnaeus, 1763		1	1		✓		
Nymphalidae: Charaxinae	*Polyura athamas* Drury, 1773.		1	2	✓			
	Polyura schreiber Godart, 1824		1				✓	

Based on the Mann-Whitney U non-parametric test, the results of comparing the mono shade and complex agroforestry showed significant differences (Table 4). Furthermore, a comparison between complex and monoculture locations showed substantial differences. Meanwhile, there was no significant difference in mono-shade and monoculture locations. The results illustrate the complete picture of a location with vegetation complexity, such as complex agroforestry having a different effect than monoculture. Although monocultures are managed without trees, the results at sampling points on the border with complex agroforestry significantly affect their diversity.

Table 4. The p-value of the Mann-Whitney U non-parametric difference test with 5% confidence.

	M	C	MC
M		0.009*	0.272
C			0.005*
MC			

Note: MC: Monoculture; C: Complex Agroforestry; M: Monoshade Agroforestry; *: Significant Difference

Although the hypothesis always shows that vegetation complexity is closely related to butterfly diversity, the edge effect has impacted this research. The ecological index describes how the butterfly community forms in each study area. Based on the dominance index, complex sites had the highest butterfly dominance compared to mono-shade and monoculture locations (Figure 3). Butterfly diversity at the three locations was moderate. The highest diversity was found in mono-shade locations. Margalef index value shows the three locations have medium species richness. The species richness index value is closely related to the results of the domination index calculation, where the higher the dominance index and Margalef index values indicate that the diversity of butterflies is high. The complex agroforestry location has the highest Margalef index value, indicating a high similarity of butterfly species. Based on the Simpson diversity index calculation results, the three locations are classified as high, with the highest value in the mono-shade location. The higher the Simpson diversity index (1-D), the higher the species diversity found. The Evenness index value in the complex location shows that the community is depressed, the monoculture is classified as unstable, and the mono-shade is classified as stable.

Based on the analysis results using the ecological indexes of Bray Curtis, Jack Knives, and BootStrap, the results were obtained regarding the proximity of butterfly species found in 3 locations (Figure 4). The three similarity indices show that the agroforestry complex and monoculture locations have close findings. On the other hand, the mono-shade locations are not close to the butterfly species found. Based on the Bray-Curtis index, the mono-shade and complex sites are separated at a distance of about 0.4 scales. On the other hand, the mono-shaded sites are separated from the monoculture at a distance of about 0.15 scales. Based on Jack Knive's index, the mono-shade and complex areas are separated by a distance of about 0.24 scale. In comparison, the mono-shade and complex locations are separated by monoculture at a distance of about 0.11 scale. Based on BootStrap, the mono-shade and complex sites are divided by approximately 0.9. In contrast, the mono-shade and complex locations are separated by a monoculture separated by a distance of about 0.11. These three results show that mono-shade agroforestry strongly influences the preserved area, especially the emergence of species interacting with natural forest habitats.

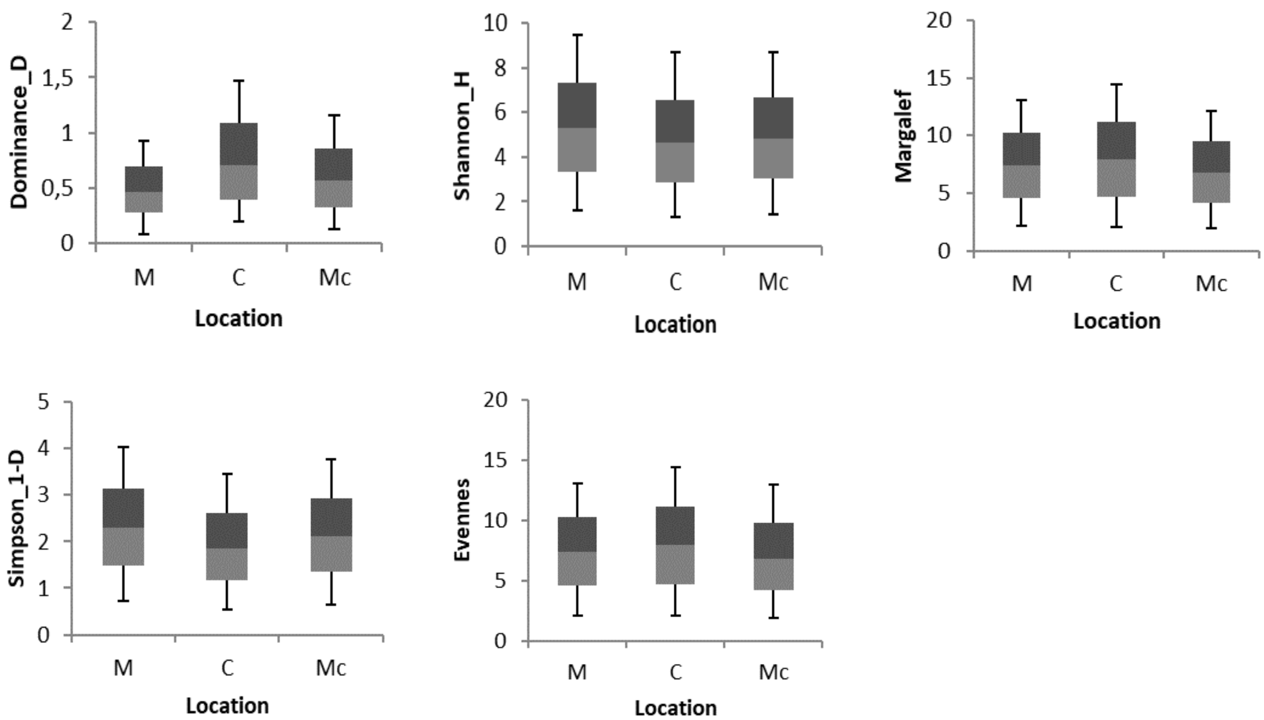

Figure 3. The comparison of Boxplot graph on various ecological indices at 3 observation areas. Note: MC: Monoculture; C: Complex Agroforestry; M: Monoshade Agroforestry; H': Shannon-Wiener Diversity Index (H'<1: low diversity; 1<H'< 3: moderate diversity; H'>3:high diversity); D: Simpson Dominance (D<0.4: low domination, 0.4<D< 0.6: moderate domination, D > 0.6); R: Margalef Species Richness Index (R< 2.5: low species richness; 2.5<R<4: medium species richness; R>4: high species richness); E: Evennes (0.00< E<0.5:depressed community, 0.50< E< 0.75:unstable community, 0.75 < E <1.00: stable community)

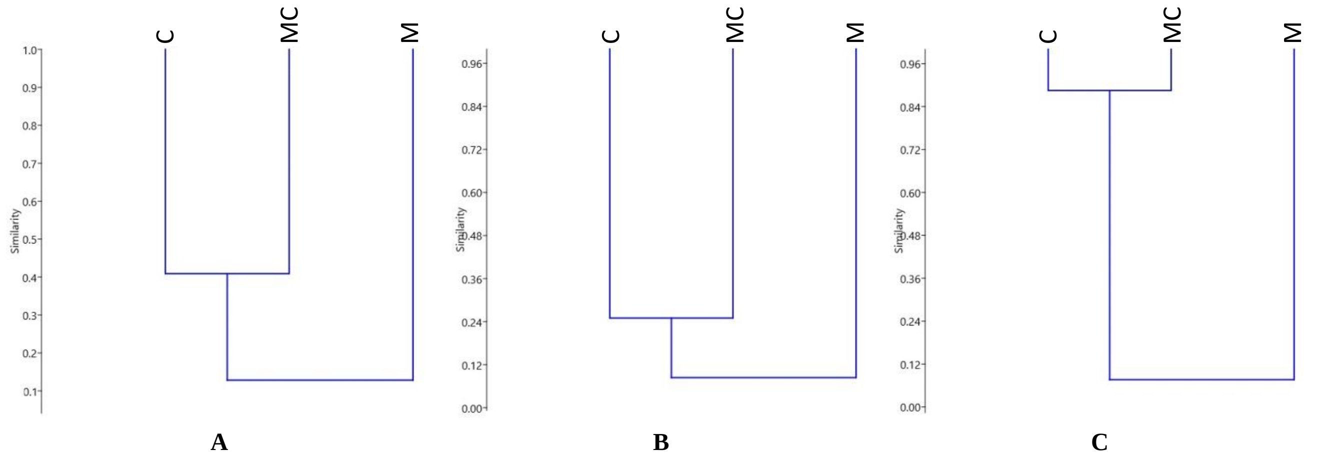

Figure 4. Dendrogram of similarity index. Note: A. Bray-Curtis index, B. Jack-Knife Index, C. Boot-Strap Index, MC: Monoculture; C: Agroforestry Complex; M: Monoshade Agroforestry

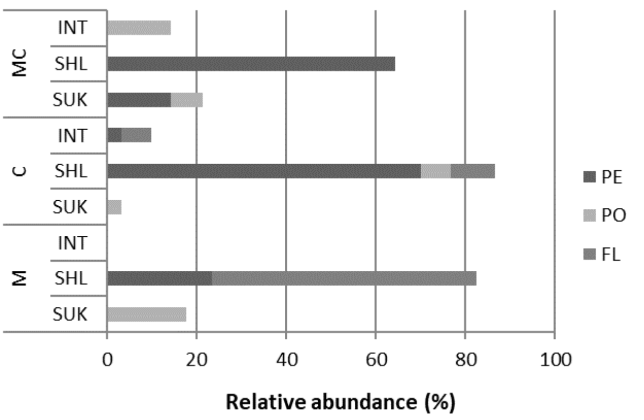

Figure 5. Relative abundance (%) of multiple ecological roles of butterflies. Note: MC: Monoculture; C: Complex Agroforestry; M: Monoshade Agroforestry; INT: Intermediate; SHL: Shade-liked Butterflies; SUK: Sun-liked Butterflies; PE: Pest; PO: Pollinators; FL: Free Living (relatively unknown)

The various roles of butterflies in the edge area are very diverse. It shows that edge effects have a real influence, especially on the diversity of butterflies in the monoculture area (Figure 5). Monoshade agroforestry is more of a habitat for shade-like butterflies (82%). Butterflies that were found play a role as a pest by 24%, and 58% of their role in the agroecosystem was unknown (Free Living). Only a small number of sun-liked butterflies were found (18%); they act as pollinators. Complex agroforestry is more dominant as a habitat for shade-like butterflies (87%). Most of these butterflies act as pests (70%), 10% have no known role in agro landscapes, and 7% act as pollinators. Butterflies can also be found in intermediate areas (partially shaded) with a percentage of 10%. Of these butterflies, 3% play a role as pests and 7% of their role in the agroecosystem is still unknown. Only 3% of butterflies are found in areas exposed to sunlight, and all the butterflies act as pollinators.

The monoculture location served as a habitat for shade-liked butterflies (64%), where all the butterflies found had a role as pests. In addition, there are small groups of sun-like butterflies (22%). A small portion act as pests (14%) and pollinators (8%). Intermediate butterflies occupy the order of the smallest composition (14%), where they all act as pollinators.

Based on the PCA graph, it can be interpreted that the groups of butterflies found were not separated at 3 locations (Figure 6). PC's value for component 1 is 75.267%, and for component 2 is 24.733%. All groups showed slices-species found in 3 locations: *M. leda* (Figure 7C). *M. leda* was most commonly found in complex areas, with a total of 16, followed by monoculture areas, with many 6 and mono-shade areas with a total of 2.

Some of the same species can be found in more than one location. For example, in the exact location: monoculture and complex, *M. phedima* (Figure 7B), *P. athamas* (Figure 7D), and *E. hypermnestra* (Figure 7E) were recorded. *M. phedima* was found in complex locations (n = 3) and monoculture (n = 6). *Polyura athamas* were found in complex (n = 1) and monoculture (n = 2) locations. *E. hypermnestra* in agroforestry complex and monoculture were each found in small numbers (n = 1). *M. phedima* can be found in abundant grass-weed vegetation, which can be found in complex and monoculture locations.

Several locations that are habitats for one type of shade-like butterfly are complex and mono-shade types. The species found at the 2 locations is *Mycalesis fuscum* (Figure 7F), with the same number at each location (n = 1).

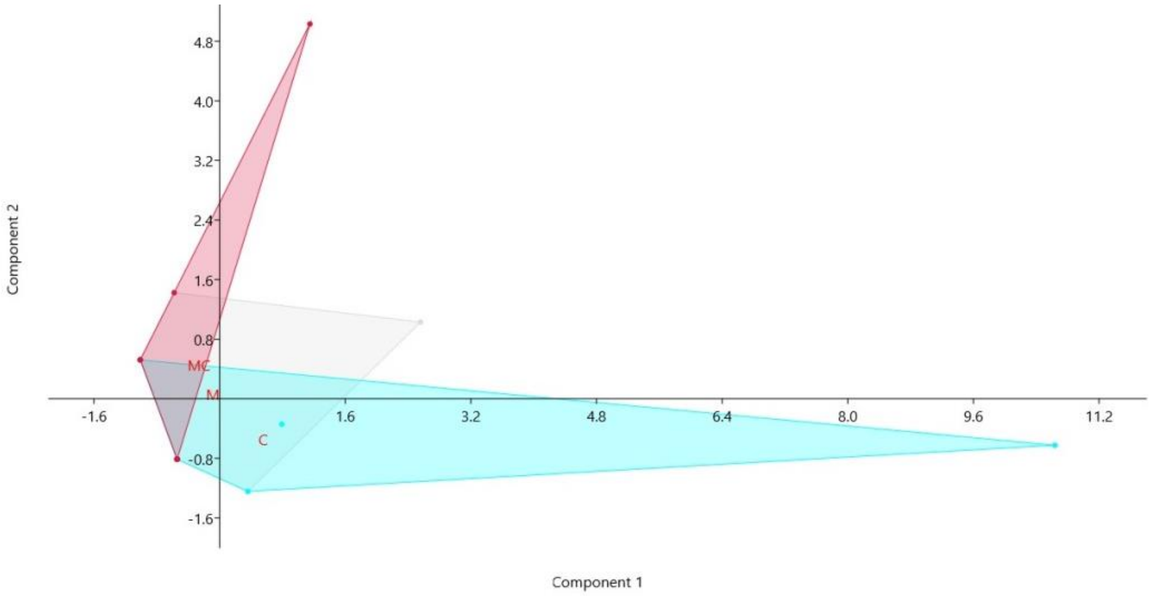

Figure 6. The abundance of three locations. Note: M: Agroforestry coffee (*C. canephora*) with Pine (*P. merkusii*), C: Agroforestry complex (*C. canephora*) with heterogeneous vegetation, MC: Paddy (*O. sativa*) monoculture

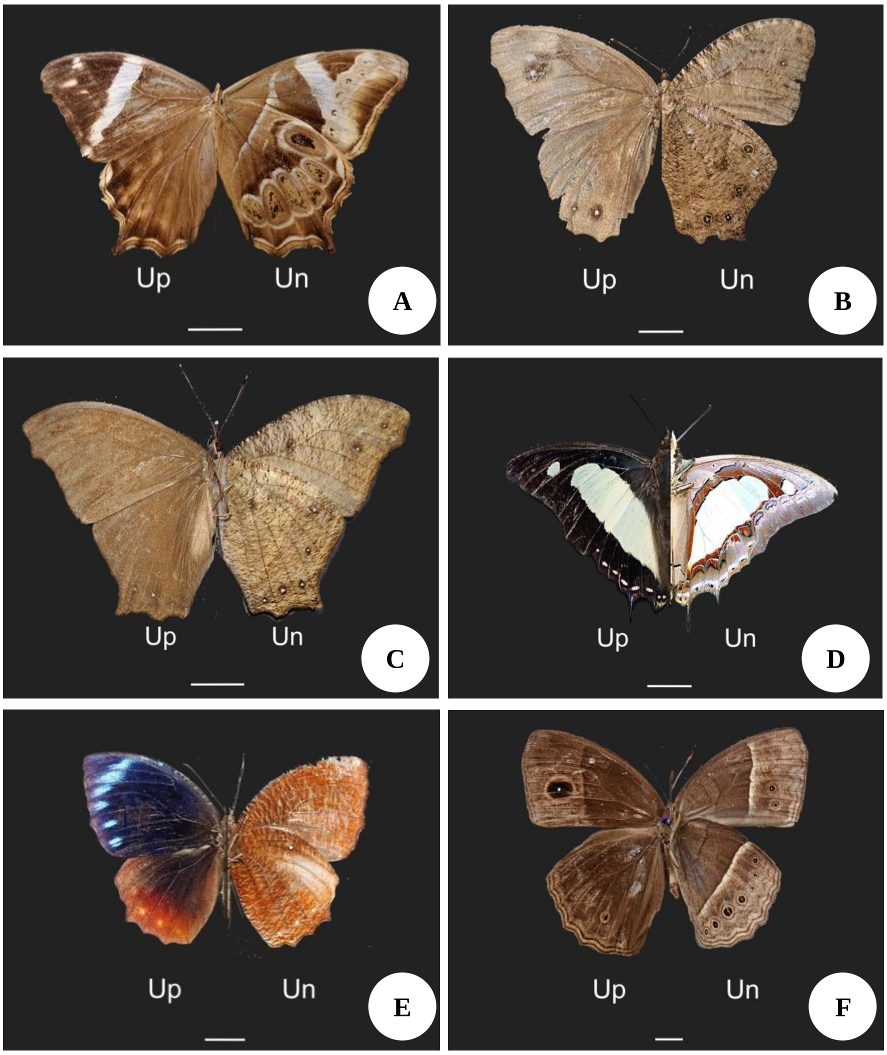

Figure 7. Some important butterfly species in the study site are A. *Lethe europa*, B. *Melanitis phedima*, C. *Melanitis leda*, D. *Polyura athamas*, E. *Elymnias hypermnestra*, F. *Mycalesis fuscum* (scale bar 1 cm). Note: Up: Upperside, Un: Underside

Discussion

The index calculation results show that the mono-shade location has high diversity and richness of butterfly species, so the evenness of species at that location is relatively stable. The mono-shade location is agroforestry between coffee and pine trees surrounded by protected forest. Agroforestry creates environmental conditions similar to natural forests, where the shade from tree structures creates suitable biophysical conditions for invertebrate life, such as butterflies (Kuyah et al. 2017). The location of mono-shade agroforestry management is close to a preserved forest, making the records more diverse. In addition, there is a higher uniqueness of species. Forests are essential for butterfly conservation, impacting the high abundance of unique species (Jain et al. 2017). The diversity of butterflies found in monoculture locations was higher because they were in proximity to complex agroforestry locations.

The highest level of butterfly dominance was found in agroforestry complex locations with high butterfly species similarity. This makes the community in complex agroforestry locations depressed. The proximity of this area to residential areas causes an edge effect which can reduce butterfly diversity. Changes in butterfly diversity occur when species that can adapt to the disturbance are found close to the disturbance source (Uehara-Prado et al. 2006). Locations affected by edge effects are unable to maintain community diversity. Pressure makes the habitat in the main ecosystem disturbed or damaged, so the interaction network can no longer support the life of butterflies that depend on the main ecosystem (Filgueiras et al. 2016).

Edge responses have been studied for decades and are critical to how organisms like butterflies respond to landscape structure and habitat fragmentation. However, a conceptual framework is needed to demonstrate the patterns and variations reported in the literature regarding edge effects. Research shows a substantial edge effect from the external environment on the sampling location. Abundance increased in areas surrounded by grasslands and lands not applied to pesticides. In addition, the impact of managed grassland can also increase the height of specialized butterfly species (Habel et al. 2021). Large landscapes with high heterogeneity positively affect taxonomic diversity in research locations. However, the high management intensity in the landscape around the study site may illustrate the opposite. Community composition, including taxonomic composition, correlates with patches and landscapes, such as forest cover and habitat structure (tree density and richness). A study also showed that small fragments distinguish the arrangement of fruit-feeding butterflies in the forest by increasing species abundance with specialist edges. Conversely, several forest-dependent species were lost in small fragments and at the forest edge (Filgueiras et al. 2016).

On the other hand, urban influences, as shown in this research, act as an edge effect for research locations where vegetation is hypothetically capable of supporting diversity. Nevertheless, urban, semi-urban, and rural areas did not show significant variations, as confirmed by the present study. This area indicates a limiting dispersion and avoiding predation across urbanization gradients (Iserhard et al. 2019). Although the intensity of the findings may vary due to edge effects, other research results indicate the presence of other factors. For example, butterfly diversity may decrease with increasing site altitude. In the notes found by Gulmarg, India, the diversity of the 2,700 masl butterflies was classified as moderate based on several ecological indices (Dar et al. 2021). In addition, the climate has an impact on diversity. Vegetation is the most affected community object, followed by butterflies and birds (Zellweger et al. 2017).

M. leda explosion was found in many ecosystems with abundant grass vegetation. This happens because *M. leda* makes various types of grass as host plants to complete their life cycle (Molleman et al. 2020). Therefore, the *M. leda* is called a grass-feeding butterfly. Most of the plants from the Poaceae family are suitable hosts for *M.leda,* such as *Bambusa arundinacea* W.T.Aiton, *Oryza sativa* subsp. *indica* Shig.Kato, and *Zea mays* L., so they act as pests on these plants (Kathiresan et al. 2017). The abundance of *Melanitis leda* butterflies at the complex location occurred because of abundant host plants, namely *B. arundinacea* and grassy weeds. In mono-shade and monoculture locations, the grass is the only available host plant for *M. leda*.

Lethe europa is one of the shade-liked species found in the complex area (Figure 7A). Its existence is quite rare and illustrates the impact of the management of the study site, which has a diversity of vegetation. For example, *P. athamas* is a fruit-feeding butterfly that prefers ground-level rotten fruits (Toussaint et al. 2015). The abundance of fruiting plant vegetation makes the availability of sufficient food for *P. athamas.* This fact is supported by the discovery of butterflies in mono-shade locations and monocultures that are close to complex agroforestry. The larvae of *E. hypermnestra* are one of the important pests on Palmaeceae (Palm family), like *Cocos nucifera* (Cleary 2016). The most influential factor causing *E. hypermnestra* in monoculture and complex locations is the abundant availability of host plants, *Cocos nucifera* L..

M. fuscum likes shady habitats where many trees can live with varying degrees of 40% -65% shade (Harmonis and Sutedjo 2021). Therefore, this butterfly species occupies many secondary forest and plantation habitats. The conditions at the complex and mono-shade locations where many shade types were found make it very suitable for the *M. fuscum* habitat.

M. leda is found in large numbers, so the graphs in monoculture and complex areas appear to extend from the scale of 0 (Figure 6). *M. leda* can be found in these locations due to many weeds and rice (Poaceae) as host plants. In addition, the host plants include *Eleusine indica* (L.) Gaertn., *Pennisetum setaceum* (Forssk.) Chiov., and *Axonopus compressus* (Sw.) P.Beauv. (Roy et al. 2021). These plants in monoculture and complex locations were found to be in abundance, which affected the abundance of the *M. leda* butterfly species.

Edge effects influence the similarity of species records in the three fields. Although complex agroforestry has heterogeneous vegetation, butterfly records, which should have a higher diversity, are low due to the effect of adjacent urban areas. Meanwhile, monocultures are suspected of having lower diversity; they have similar records with complex locations due to complex agroforestry areas' edge effects. Preserved forest area influences the butterfly community in mono-shade agroforestry. Forest areas are capable of providing positive edge effects. Therefore, forests can help conserve biodiversity, including those around them (Mahata et al. 2019).

The proximity of species records found in monoculture and complex locations made the lack of absolute separation on the PCA graph. Based on that insight, the two locations have no preference for species. Heterogeneous vegetation in the adjacent area makes the butterflies found in monoculture areas more diverse and strengthens the stability of butterflies' existence (Slancarova et al. 2014).

The PCA graph also shows the impact of edge effects from urban areas around the complex agroforestry. That makes the records different from mono-shade agroforestry, even though both are the same management system. Urban settlements have a negative edge effect due to the lack of vegetation and physical disturbances from human activities (Leston and Koper 2017). High disturbance from adjacent areas reduces or even disappears biodiversity (Barlow et al. 2016). This effect can limit the availability of host plants and food for butterflies, affecting species diversity and abundance.

In conclusion, the similarity index shows that complex agroforestry and monoculture systems have close records. In addition, both differ greatly from mono-shaded agroforestry systems. PCA graph shows 3 locations share several species records. Mono-shade and complex agroforestry have significant differences. Edge effects from adjacent areas affect research sites and lead to complex ecological interactions.

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