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Diversity of Butterflies (Lepidoptera; Rhopalocera) in Three Habitat Types of Forest Edge Area of Bukit Mas Village, North Sumatra, Indonesia

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Abstract

The limited information on butterfly responses to urbanization, particularly in Indonesia, prompted this study, which aims to assess butterfly diversity in different habitats (forest edge, residential areas, and community plantations) within the buffer zone of Gunung Leuser National Park, specifically in Bukit Mas Village, North Sumatra. Observations of plantation habitats were conducted in Aras Napal Hamlet, a buffer zone area, and Bukit Mas Village plantations. This exploratory study, conducted in September 2023, used the Point Count method with 18 points in residential and plantation habitats and 8 points in forest edge habitats. Each count point had a 5-meter radius with 10 minutes of observation, repeated twice daily (08.00–12.00 and 13.00–17.00), and the distance between points was 100 m. A total of 2,536 individuals from 89 species and seven families were recorded, with Nymphalidae being the most dominant family (44 species, 687 individuals). Extrapolation using the iNEXT package shows higher diversity in forest edge as well. At the same time, Residential areas provide a more diverse environment regarding species, while the Forest Edge exhibits the lowest diversity. This study highlights the importance of habitat heterogeneity in maintaining butterfly diversity in buffer zones affected by human activities. In conclusion, species diversity is highest in residential areas, followed by plantations, and lowest in forest edges.

Keywords: butterflies, different habitats, diversity, edge forests

1. Introduction

Forest loss is a significant threat to biodiversity and is largely driven by the conversion of forests into agricultural land [1,2]. This process is largely driven by population growth and increased demand for agricultural products [3,4]. In Sumatra, rainforests are partially converted to monoculture plantations of rubber and coconut [5], which has a major impact on biodiversity [6] owing to the homogenization of the ecosystem structure [1,6]. Deforestation and forest degradation lead to habitat loss, fragmentation, and species isolation [4]. Therefore, a comprehensive understanding of how to design and manage landscapes that mitigate biodiversity loss while maintaining the availability of agricultural products is needed [7].

Urbanization is a global environmental change that affects biodiversity, such as species composition and biotic homogenization. Given the current rate of habitat loss and landscape simplification worldwide, biotic homogenization leading to land-use change is likely an important factor leading to biodiversity loss in different types of ecosystems worldwide [8]. Several studies have shown that deforestation in tropical countries due to illegal logging, clear-cutting, and land clearing is a major cause of biodiversity loss [8]. Several studies have shown that deforestation in tropical countries due to illegal logging, excessive logging, and clearing of forest areas to provide agricultural land can affect the distribution, structure, and composition of communities and species diversity of butterflies [9–13].

Global warming is one of the major environmental issues facing humanity. Increased human activities, such as fossil fuel combustion, increased carbon emissions, deforestation, and other practices, have exacerbated global warming. Apart from humans, such environmental changes affect all living things, including insects, which can be caused by the loss of larval feeding habitats, nectar sources and overwintering habitats, adaptability and productivity problems in their new habitats, attacks by natural enemies, and changes in wind patterns. In addition, an increase in temperature can cause changes in butterfly morphology, such as reduced wing size and reduced flight activity [14].

Butterfly abundance also caused by warm and humid climatic conditions, abundant flowering plants, and less habitat disturbance, and the effects will vary greatly depending on the life stage [15,16]. Butterflies are often used as models by scientists to estimate and predict biodiversity because of local and global climate change, environmental degradation, plant and animal distribution, and forest management in natural ecosystems [12,17]. Butterfly diversity and richness are distinct across various habitat types and elevation ranges because of the heterogeneous resources for butterflies. Habitat characteristics predict the species diversity, abundance, and richness, and their effects vary within individual habitat types [18].

Forest edge areas are vulnerable to deforestation owing to their accessibility. Although deforestation in Gunung Leuser National Park (GLNP) has decreased since 2011, it still occurs at various points in the park [19]. GLNP is a habitat for elephants and other animals, including butterflies, and is under great threat from deforestation through illegal logging activities, as well as the conversion of forest land into agriculture and plantations (oil palm, coffee, rubber, and cocoa) [19]. A total of 61 species found in three habitat types (residential, river, and forest) in the Tangkahan buffer zone of GLNP reported 38 species from five families (Riodinidae, Pieridae, Lycanidae, Papilionidae, and Nymphalidae) at the Butterfly Beach of GLNP [20,21]. The discovery of 75 species in the Alas River, including in the Soraya Research Station area of the Leuser Region, has been reported.

Due to the lack of information on butterfly responses to urbanization and fragmentation, especially in Indonesia, this study aimed to determine butterfly diversity in the Balai Besar Taman Nasional Gunung Leuser (BBTNGL) buffer zone in Bukit Mas Village, North Sumatra, in different habitats (forest edge, residential/residential area, and community oil palm plantation). This study examined the differences in butterfly diversity among several habitat types to understand the response of butterflies to different environmental conditions.

2. Materials and Methods

2.1. Study Area

This study was conducted in three habitat types: forest edge, community oil palm plantation, and residential areas (Figure 1) in Bukit Mas Village, which is directly adjacent to the Gunung Leuser National Park (TNGL) (Figure 2). The observed forest edge was between the secondary forest and community-owned oil palm plantations. This forest is next to agricultural land, creating a clear boundary between natural vegetation and human-modified areas. The distance between the forest edge and the plantation area ranged between 50 and 100 m.

(a) (b) (c)

Figure 1. Examples of different habitat types include oil palm plantation (a), residential (b), and forest edge (c) (personal documentation).

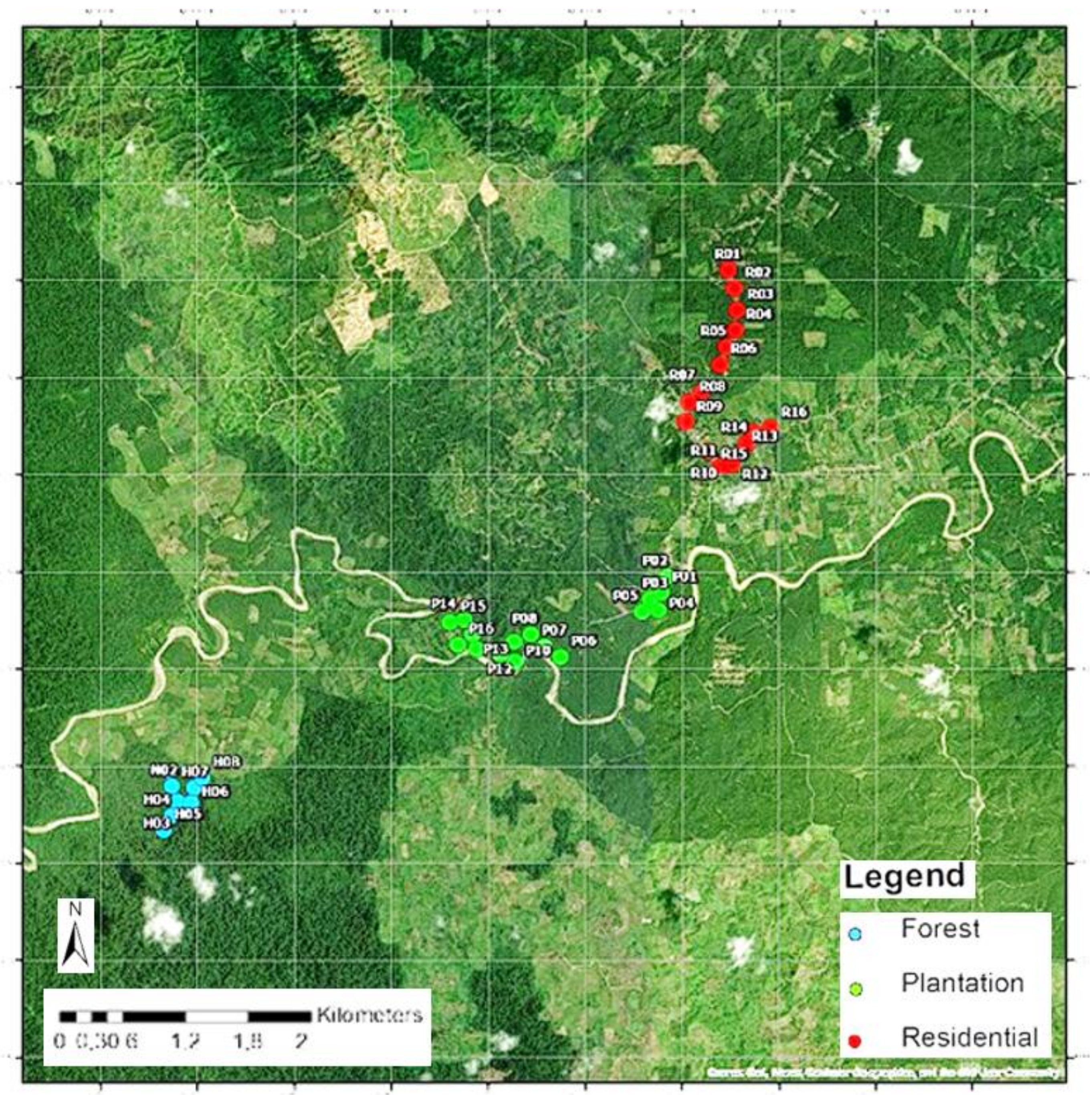

Figure 2. The satellite image map of the study site at Bukit Mas Village, Gunung Leuser National Park, showing survey points at different habitat types.

Observations of plantation habitat types were carried out in Aras Napal Hamlet, a buffer zone, and the plantation, areas owned by Bukit Mas Village residents. The residential area was approximately 200–300 m from the forest edge. These distances emphasize the potential for habitat fragmentation, which may affect butterfly diversity in the region. This study was conducted in September 2023.

2.2. Data Collection

This study utilized several tools to measure environmental conditions and collect butterfly diversity data from the research site. Binoculars were used to observe butterflies from a distance without disturbing their activity, particularly in the canopy or hard-to-reach areas. Using binoculars minimized direct contact, which could interfere with butterfly behavior. We also used a thermohygrometer to measure air temperature and humidity at the observation sites, as microclimatic conditions significantly influence butterfly activity and presence. An anemometer was used to measure the wind speed, which also plays a critical role in butterfly activity. Strong winds can reduce butterfly flight activity, making this parameter essential for recording observations. Other additional equipment included GPS, stopwatch, camera, and stationery.

The identification guides used in this study included *Getting to Know Butterflies* by Peggie [2], *The Butterflies of the Malay Peninsula* by Rastogi et al. [22], *Sembilang Dangku butterflies* by Aprillia et al. [23], and *Jambi butterflies (Sumatra, Indonesia; An Efforts Field Guides* by Panjaitan et al. [24]. Furthermore, several journals and websites, such as iNaturalist (www.inaturalist.org) and Biodiversity of Singapore (www.singapore.biodiversity.online), were consulted as additional species identification references.

This exploratory study used the Point Count method in three habitat types with several points distributed proportionally to the area. There were 16 points in each residential and plantation area and eight points in the forest edge habitat due to limited area and access. The allocation of observation time at each count point was 10 minutes [25]. Observations were made twice, in the morning (08.00–12.00) and afternoon (13.00–17.00), with a 5 m radius. The distance between points was 100 m.

2.3. Data Analysis

Species richness and abundance data were analyzed using Shannon–Wiener, dominance, and evenness indices. Diversity data were projected using extrapolation with the iNEXT package [26] to provide a clearer view of the differences in diversity across habitats. Butterfly species diversity was calculated using the Shannon-Wiener diversity index with the formula [27]:

$$H' = -\sum \mathrm{pi.Ln\ pi\ where\ Pi} = \mathrm{ni}/\mathrm{N} \quad (1)$$

where H' is Shannon–Wiener diversity index, Pi is proportion of species I to individuals of all species, N is total number of individuals of all species, Ni is number of individuals of each species, and Ln is natural logarithm.

To determine the dominant, medium-dominant, or non-dominant butterfly species in an observation using the dominance index (D), the formula used by Odum [27] is as follows:

$$D = \sum \mathrm{Pi}^2 \quad (2)$$

where D is butterfly species dominance index, Pi is number of individuals of a butterfly species, and N is number of individuals of all butterfly species.

3. Results

This study identified and recorded 87 species (2,533 individuals) from six families. Of these, six species were found in all habitat types, 10 species were found only in residentials, eight species were found only in plantations, and 19 species were found only in forest edges (Table 1). No endangered species were identified in the present study. The families identified were Nymphalidae, Papilionidae, Lycaenidae, Pieridae, Hesperiidae, and Riodinidae. Nymphalidae was the most dominant family, with 40 species and 1,192 individuals (44.90%), followed by Pieridae with 11 species and 672 individuals (18%) (Figure 3), and Nymphalidae was the dominant family found in all habitat types.

Table 1. List of species with families and relative abundance in the three types of habitats From Bukit Mas Village, North Sumatra, Indonesia

Family	Species	Total species	Relative abundance		
			Residential	Plantation	Forest edge
Papilionidae	*Graphium agamemnon*	7	3.89	2.65	0.00
	Papilio demoleus		2.02	1.87	0.00
	Papilio nephelus sunatus		0.22	0.00	2.79
	Papilio memnon memnon		2.39	3.05	0.00

Family	Species	Total species	Relative abundance		
			Residential	Plantation	Forest edge
	Papilio memnon egenor		0.30	0.00	0.00
	Papilio polytes		2.77	4.03	0.00
	Papilio polytes romulus		0.30	0.00	1.12
Nymphalidae	*Acraea terpsicore*	40	2.99	0.00	0.00
	Acraea violae		0.97	0.00	0.00
	Amathusia phidippus		0.67	2.16	0.00
	Athyma perius		3.66	0.29	0.00
	Cirrochroa aoris olivia		0.00	0.00	1.12
	Danaus genutia		1.80	0.00	0.00
	Doleschallia bisaltidae		1.65	0.20	0.00
	Deodorix staudingeri		0.82	0.00	0.00
	Eulaceura ostrea		0.97	0.29	0.56
	Elymnias hypermnestra		1.87	13.27	0.00
	Elymnias nesaea		0.75	2.65	0.00
	Euthalia aconthea		0.75	0.49	0.00
	Euploea aglea		1.35	0.00	1.12
	Euploea mulciber		0.90	0.29	0.56
	Euploea rhadamanthus		0.30	0.39	0.00
	Faunis canens		0.00	0.10	2.23
	Hypolimnas bolina		5.53	2.36	0.00
	Ideopsis juventa		0.97	0.79	0.00
	Junnonia almanac		2.32	2.95	0.00
	Junonia atlites		2.09	0.39	0.00
	Junonia hedonia		1.27	2.65	0.00
	Junonia orythya		3.81	0.69	0.00
	Lexias pardalis		0.22	0.00	1.12
	Melanitis leda		2.24	0.00	0.00
	Moduza procris		0.00	0.20	0.00
	Mycalesis janardara		0.00	1.08	0.00
	Mycalesis orseis		0.00	0.00	9.50
	Mycalesis perseus		2.47	0.49	0.00
	Neptis hylas		4.56	1.47	0.00
	Neptis soma		0.00	0.00	1.68
	Orsotriaena medus		2.17	1.77	0.00
	Paduca fasciata		0.00	0.00	1.12
	Pantoporia hordonia		0.00	0.00	1.12
	Ragadia macuta		0.00	0.00	1.12
	Tanecia lepidea		0.00	0.00	1.68
	Tanecia iapis		0.00	0.20	6.70
	Terinos terpander reobertsia		0.00	0.00	7.82
	Thaumantis klugius		0.00	1.67	1.12
	Ypthima horsfieldii		0.00	1.67	1.68
	Ypthima philomela		2.69	6.00	0.56
Pieridae	*Appias olferna*	11	3.07	2.26	0.00
	Appias libythea		3.59	0.59	0.00
	Appias lyncida		0.37	0.00	0.00
	Catopsilia pomana		0.97	0.39	0.00
	Catopsilia sycylla		0.00	0.39	0.00
	Delias hyparete		0.00	0.69	1.12
	Eurema hecabe		3.81	3.34	0.00
	Eurema sari		1.27	8.26	0.00
	Eurema sari sodalist		0.00	2.56	7.82
	Leptosia nina		8.90	16.91	0.00
	Udaiana cynis		0.00	0.20	0.00

Family	Species	Total species	Relative abundance		
			Residential	Plantation	Forest edge
Lycanidae	*Allotinus unicolor*	16	0.00	0.00	5.59
	Allotinus davidis		0.00	0.00	0.56
	Arhopala centaurus		0.07	0.10	0.00
	Arhopala epimuta		0.00	0.00	1.68
	Arhopala muta		0.00	0.00	2.79
	Chilades pandava		2.17	0.00	0.00
	Drupadia theda		0.07	0.20	12.29
	Eooxylides tharis		0.00	0.00	1.68
	Flos apidanus		0.00	0.10	0.00
	Jamides celano		3.52	1.28	6.70
	Prosotas dubiosa		0.00	0.29	0.00
	Rachana jalindra burbona		0.00	0.00	1.68
	Rapala manea		0.00	0.00	1.12
	Spindasis lohita		0.00	0.00	1.12
	Tajuria cippus		0.22	0.00	0.00
	Zizina otis		5.46	0.29	0.00
Hesperidae	*Ancistroides nigrita*	12	0.07	2.46	0.00
	Caltoris cromasa		0.00	0.10	4.00
	Hasora schoenherr		0.15	0.00	3.00
	Iambrix stellifer		1.05	0.69	0.00
	Korothaialos Sindu		0.00	0.49	6.00
	Oriens gola		0.45	0.10	0.00
	Pelopipidae agna		1.27	0.00	0.00
	Potanthus omaha		0.90	0.79	3.00
	Sabera dobboe		0.07	0.49	0.00
	Telicota colon		0.82	0.20	0.00
	Udaspes folus/Ancistroides folus		0.00	0.49	0.00
	Unkana ambasa		0.00	0.20	0.00
Riodinidae	*Zemeros emesoides*	1	0	0	4
Total number of individuals			1337	1017	179
Total number of species			54	55	36

Riodinidae was the least common family, with only one species of four individuals. The Riodinidae family was only found in forests but not in plantations or residentials (Table 1). The highest species abundance was *Leptosia nina* (291 individuals), followed by *Elymnias hypermnestra* (160 individuals), and the lowest was *Allotinus davidis* and *Flos apidanus*, each with only one individual. Six species were found in the three habitats, which include *Eulaceura ostrea* (Nymphalidae), *Euploea aglea* (Nymphalidae), *Euploea mulciber* (Nymphalidae), *Ypthima philomela* (Nymphalidae), *Drupadia theda* (lycanidae), *Potanthus omaha* (Hesperidae) (Table 1 and Figure 3).

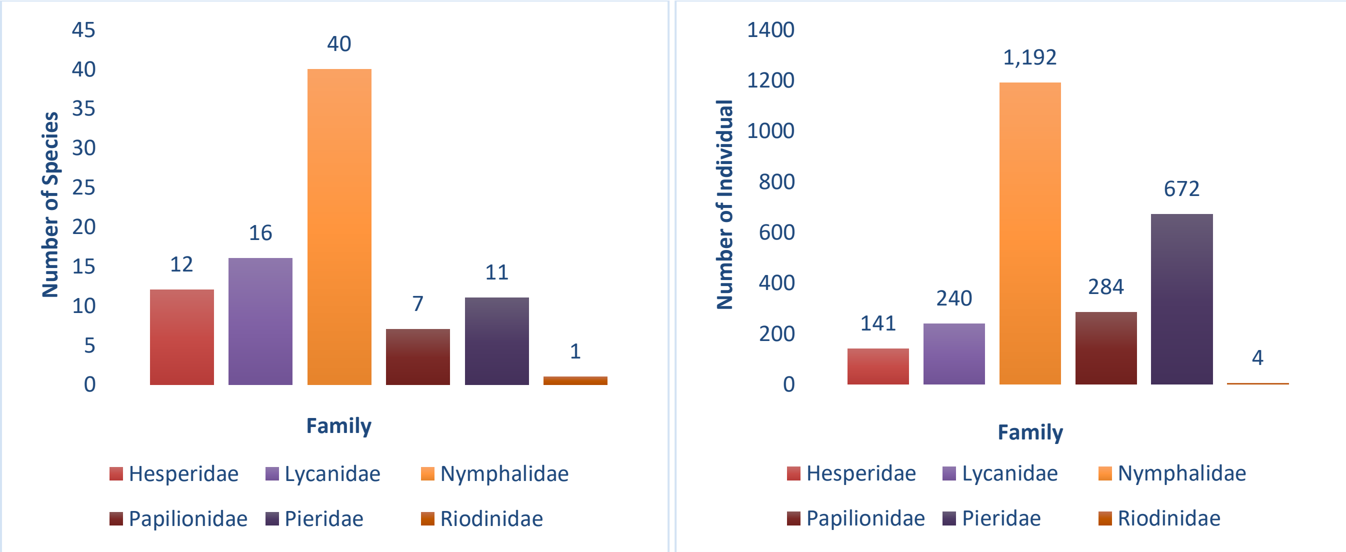

Figure 1. The number of species and individuals for each family found in the three types of habitats at Bukit Mas Village, North Sumatra, Indonesia.

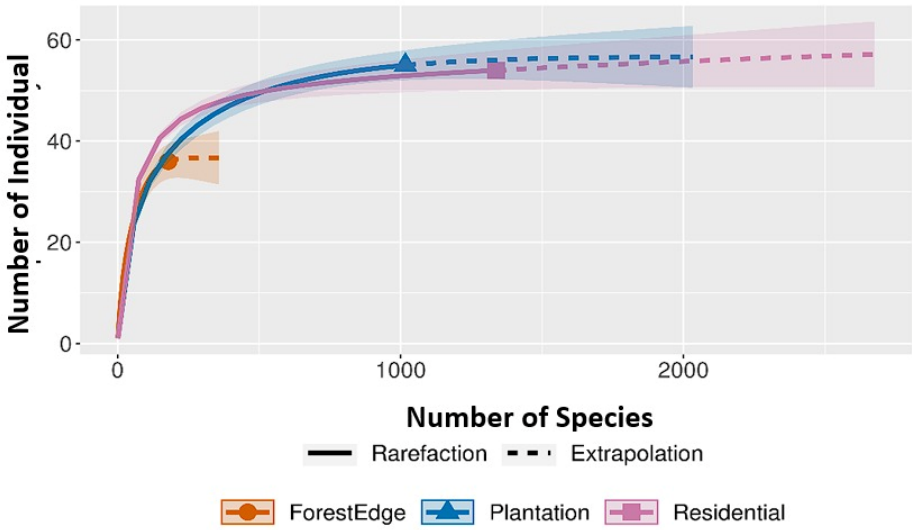

Figure 2. Species accumulation curves were generated for three different habitats (Forest edge, Plantation, and Residential) in Bukit Mas Village, North Sumatra Province, using the iNEXT package. The curves include rarefaction and extrapolation to analyse species richness patterns based on the number of individuals sampled.

Figure 4 demonstrates that species diversity increases with the number of individuals sampled but reaches a point of diminishing returns, particularly in residential and forest-edge areas. Plantations have the highest potential for further species discovery, whereas the forest edge shows the least diversity, although this might be related to the fewest points visited due to limited access. Extrapolation suggests limited further increases in diversity with more sampling across all areas, although plantations exhibited a higher capacity for additional species discovery.

Based on Shannon analysis (q = 1) using the iNEXT package (Figure 5), the highest species diversity was found in the residential ecosystem, followed by plantation and forest edges. The rarefaction curve indicated that, after a certain number of individuals were sampled, the increase in species diversity became minimal, especially at the forest edge. Residential areas provide a more diverse environment for species, whereas the forest edge exhibits the lowest diversity.

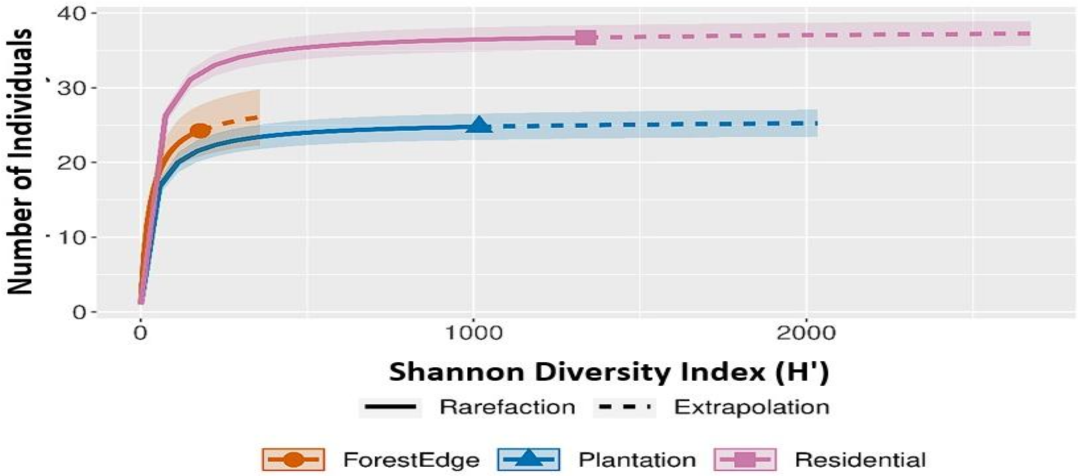

Figure 3. Shannon Diversity Index accumulation curves for forest edge, plantation, and residential habitats in Bukit Mas Village, North Sumatra, extrapolated using the iNEXT package.

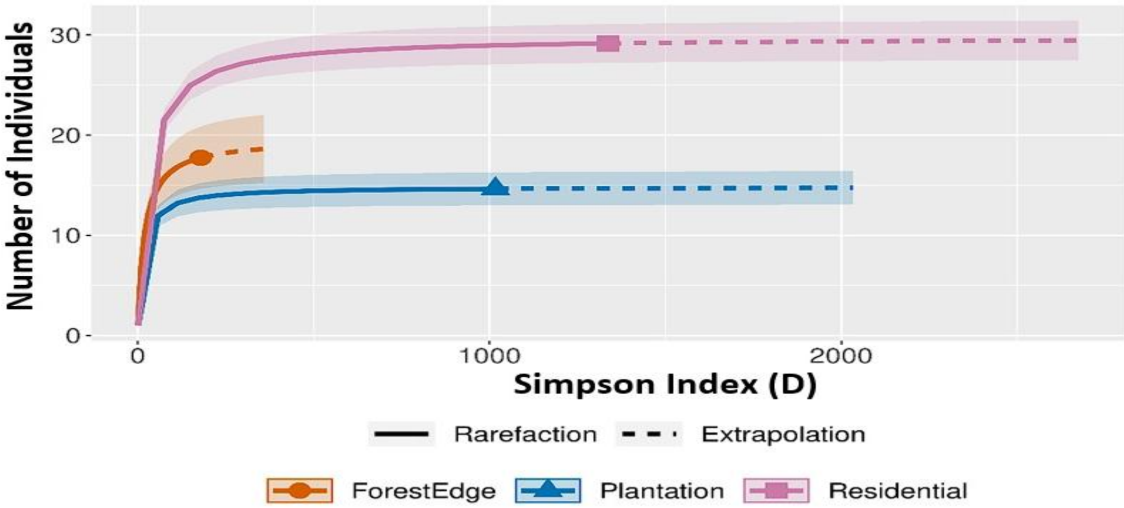

Figure 4. Simpson Diversity accumulation curves for forest edge, plantation, and residential habitats in Bukit Mas Village, North Sumatra, extrapolated using the iNEXT package.

This analysis (Figure 6) used the Simpson index (q = 2) with the iNEXT package, which is more sensitive to dominant species. These results show that the residential ecosystem has a more even distribution of species, meaning that dominant species do not significantly suppress the presence of other species. In contrast, the forest edge exhibited a higher level of dominance, where a few species dominated the community, thus reducing overall diversity. In conclusion, species diversity was highest in residential areas, followed by plantations, and was lowest in forest edges.

4. Discussion

Our studies suggest that Nymphalidae (34%) and Pieridae (34%) have more individuals than other families. These results are similar to those of Ramadhani et al. [28], Mukherjee [29], Karmakar et al. [16], Munisi et al. [30], Setiawan et al. [31], and Mercado-Gómez et al. [32], who also reported that Nymphalidae was the most abundant family. The dominance of Nymphalidae in this study, with 40 species and 1,192 individuals, can be attributed to its polyphagous nature, as noted by Aprillia et al. [23], indicating that members of this family can utilize a variety of host plants when their primary hosts are unavailable. This adaptability allows Nymphalidae species to thrive in diverse habitats, including modified environments, such as plantations and residential areas. Additionally, nectar plants in these habitats provide ample opportunities for butterflies to feed on and lay eggs.

Pieridae, with 11 species and 672 individuals, was the second-most abundant family in this study. Like Nymphalidae, Pieridae members are adaptive and can exploit diverse environments. The high abundance of *Leptosia nina* (291 individuals) and *Elymnias hypermnestra* (160 individuals), two common species in Southeast Asia, aligns with studies suggesting that oil palm-dominated landscapes are often inhabited by widespread and generalist species [33,34]. Another similar study showed that *Leptosia nina*, the largest species found in all areas, was because the research area was dominated by grass, which is a favourable habitat for this type [35]. This indicates that modified landscapes, such as plantations, can support certain butterfly species, although diversity tends to favor more adaptable species. Another similar study showed that Pieridae was the most abundant butterfly family found in disturbed and undisturbed habitats at a college in central Nigeria [36]. Ojianwuna and Umoru [37] found that Nymphalidae and Pieridae were observed year-round in large numbers around riversides and water puddles.

Conversely, the family Riodinidae had the lowest representation in this study, with only one species and four individuals (1%). This finding is important because it reflects the sensitivity of forest specialist species to habitat modifications. Riodinidae members were only found in forest edges, suggesting that they depend on more intact and less disturbed habitats. This is consistent with studies by Panjaitan et al. [38] and Kwatrina et al. [39], which suggested that rainforest butterfly communities, particularly forest specialists, must be better maintained in agricultural or plantation systems. The iNEXT analysis indicated that species diversity was highest in residential areas, followed by plantations, and lowest at the forest edges. Increasing the number of sampled individuals initially increases species diversity but eventually plateaus, especially at the forest edges. Shannon's analysis revealed that residential areas had the highest diversity, while Simpson's analysis indicated that residential areas had a more even species distribution.

In contrast, certain species dominate forest edges; there are 17 species found only in forest edge habitats, which include *Papilio polytes romulus* (Papilionidae), *Cirrochroa aoris olivia* (Nymphalidae), *Mycalesis orseis* (Nymphalidae), *Neptis soma* (Nymphalidae), *Paduca fasciata* (Nymphhalidae), *Pantoporia hordonia* (Nymphalidae), *Tanecia lepidae* (Nymphalidae), *Ragadia macuta* (Nymphalidae), *Allotinus unicolor* (Lycanidae), *Allotinus davidis* (Lycanidae), *Eooxylides tharis* (Lycanidae), *Rachana jalindra burbona* (Lycanidae), *Rapala manea* (Lycanidae), *Spondaic lohita* (Lycanidae), and *Zemeros emesoides* (Riodinidae). This number is even more than the species found only in residential and plantation habitats.

The development of monoculture palm oil plantations significantly alters species composition, with plantation habitats supporting fewer forest-dependent species and more generalists [32,39]. Agroforestry systems may provide a more biodiversity-friendly alternative. As reported by Zaki et al. [40], agroforestry plantations support greater butterfly diversity than rubber and oil palm monocultures because of the presence of heterogeneous landscapes that offer a variety of microhabitats and plant species. Our study also found that habitat heterogeneity, especially in residential areas with more diverse vegetation, is associated with higher butterfly diversity and evenness.

Management practices in palm oil plantations can mitigate some negative impacts on butterfly communities [41]. Reiss-Woolever et al. [42] found that plantations with less intensive understory clearing supported healthier butterfly populations, suggesting that maintaining vegetation complexity can help to conserve butterfly diversity. Similarly, Harianja et al. [43] found that the choice between monoculture and polyculture systems had relatively minor effects on butterfly diversity. Instead, specific management practices such as maintaining vegetative edges and understory complexity were more significant in supporting diverse butterfly assemblages.

Finally, environmental factors such as climate and plant structure influence butterfly diversity and abundance. Studies in Brazil's Serra do Cipó region show that as altitude increases, butterfly diversity tends to decrease owing to changes in temperature, humidity, and rainfall [44]. Similar environmental factors likely played a role in the distribution of butterflies in our study area, where forest edge habitats exhibited higher species richness than plantations and residential areas. This underscores the importance of conserving forest edges as critical habitats to maintain butterfly diversity in fragmented landscapes.

5. Conclusions

In conclusion, while the highest species richness was observed at the forest edge, the highest butterfly diversity based on the Shannon Diversity Index was found in residential habitats. Nymphalidae was the most dominant family in all habitats. Residential habitats exhibited higher species diversity and evenness, possibly because of the more uniform habitat conditions. In comparison, the forest edge supported greater species richness, likely because of the transitional nature of the habitat between natural and modified environments. Factors such as understory vegetation management, climate conditions, plant structure, and habitat fragmentation contribute to the varying butterfly diversity and abundance levels across different ecosystems. Understanding these factors is crucial for guiding conservation efforts to preserve butterfly populations and habitats.

Author Contributions

N: Conceptualization, Methodology, Software, Visualization, Analysis, Investigation, Writing - Review & Editing; **MPP**: Writing - Review & Editing, Supervision, Validation; **NLW**: Writing - Review & Editing, Validation; **FH**: Visualization, Writing - Review & Editing.

Conflicts of Interest

There are no conflicts to declare.

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