

Butterfly community structure and floral visitation in Sukamade, Meru Betiri National Park, Indonesia

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Abstract. Rohman A, Hasan DA, Subchan W, Prabowo D. 2026. Butterfly community structure and floral visitation in Sukamade, Meru Betiri National Park, Indonesia. *Biodiversitas* 27 (5): d270506. <https://doi.org/10.13057/biodiv/d270506>. This study investigates the community structure of butterflies (Lepidoptera: Papilionoidea) and their associated floral resources in the Sukamade Resort area of Meru Betiri National Park, Indonesia, a crucial conservation area for protected species. The objective was to evaluate how butterfly diversity, species richness, and community composition vary across habitat types and their relationships with vegetation composition and abiotic factors. Butterflies were surveyed using the cruising method along 100 m × 10 m transects across 12 sampling sites representing four habitat types. A total of 423 butterfly individuals representing 26 species from four families were recorded, with *Ypthima horsfieldii* being the most abundant, and the protected *Troides helena* also present. Open Land showed the highest diversity ($H' = 2.72$) and species richness (Margalef Index = 4.67). The Dominance Index was highest in Coastal Forest (0.17), while the Closed-canopy Forest recorded the highest species evenness (0.84). A total of 39 plant species were recorded, with the white-flowered *Chromolaena odorata* showing the highest number of butterfly visits, involving 12 species. Multivariate analyses (Canonical Correspondence Analysis (CCA) and Principal Component Analysis (PCA)) were applied to examine patterns of butterfly distribution in relation to abiotic factors and vegetation composition. These analyses were exploratory and revealed general patterns of association. These findings contribute important ecological information for conservation management and highlight the ecological significance of habitat heterogeneity in supporting butterfly diversity within the park.

Keywords: *Chromolaena odorata*, habitat heterogeneity, Meru Betiri, nectar resources, Papilionoidea diversity

INTRODUCTION

Butterfly communities (Lepidoptera) are among the most diverse insect groups in Indonesia, with approximately 600 species recorded in the Java and Bali regions, of which around 40% are endemic (Koneri and Nangoy 2019). Several species are legally protected under Indonesian Regulation No. 106/MENLHK/SETJEN/KUM.1/12/2018, including *Troides helena*, which has been reported from the Sukamade Resort area of Taman Nasional Meru Betiri (Mustikawati 2003). As a conservation area, Sukamade plays an important role in maintaining biodiversity. However, several challenges related to conservation area management persist. These include human activities within conservation zones that may disturb habitats, as well as the potential for forest fires during the dry season, which can reduce vegetation cover. Therefore, comprehensive studies are essential to assess butterfly diversity in this area.

Butterflies play an important role as bioindicators of environmental change or degradation (Segre et al. 2023). Minor changes in an environment can lead to a decline in butterfly populations. Legal et al. (2020) demonstrated that butterflies are effective bioindicators for passive forest regeneration, with 40–50% of species being associated with habitat conditions and anthropogenic disturbance.

Consequently, experts widely use butterflies as indicators of environmental quality. Furthermore, butterflies also serve as pollinators (Butler and Johnson 2020; Santos et al. 2020). Butterfly pollination activity contributes to the reproductive success of flowering plants, which in turn impacts the genetic diversity of the surrounding flora (Ghazanfar et al. 2016). Their extensive flight activity also facilitates pollen dispersal among fragmented plant populations. This dual role, ranging from pollinators to a food source, underscores the key position of butterflies within food webs. Disruption at any stage of the butterfly life cycle can trigger cascading effects that impact the populations of other plants and animals within the same ecosystem.

Vegetation is a key determinant of butterfly distribution, as it provides both larval host plants and nectar resources for adult butterflies (Hanspach et al. 2014; Nitin et al. 2018). These two ecological components serve distinct functions. Host plants support larval development, while flowering plants provide the nectar required by adult butterflies for survival and reproduction (Harris et al. 2016). In addition, abiotic factors such as temperature, humidity, light intensity, and wind speed influence butterfly activity and spatial distribution (Mahata et al. 2023).

Habitat heterogeneity also plays an important role in butterfly diversity, as each habitat type provides a different combination of microclimatic conditions and vegetation structure (Mahata et al. 2023). The Sukamade Resort comprises various habitats, including Coastal Forest, Closed-canopy Forest, Open Land, and Riverbank, thereby forming a landscape of high ecological value. However, the previous study by Mustikawati (2003) was limited to inventoring butterfly species in a restricted area (camping ground and footpaths corresponding to Open Land habitat), and thus did not examine community structure across various specific habitats nor their ecological associations.

Therefore, this study aims to analyze the community structure of butterflies (Lepidoptera: Papilionoidea) and patterns of floral visitation across different habitat types in the Sukamade Resort area. Specifically, it examines variations in diversity, species richness, and community composition among habitats, as well as their relationships with abiotic factors (light intensity, air temperature, relative humidity, and wind speed) and vegetation composition.

The scientific novelty of this study lies in integrating habitat-based community analysis with multivariate approaches (Canonical Correspondence Analysis (CCA) and Principal Component Analysis (PCA)) and field-based observations of butterfly-plant co-occurrence, providing new insights into habitat-specific patterns of butterfly distribution and floral resource use in a heterogeneous protected landscape.

MATERIALS AND METHODS

Study area

This study was conducted from July to August 2024 during the dry season in the Sukamade Resort area of Meru Betiri National Park, East Java, Indonesia (Figure 1). Sampling locations were determined using a purposive sampling method. Butterfly surveys were conducted at 12 sampling sites, with three replicate surveys per site. Data collection across the 12 sampling sites encompassed four distinct habitat types: Coastal Forest (sites 1-3), Open Land (sites 4-6), Riverbank areas (sites 7-9), and Closed-canopy Forest (sites 10-12). Each habitat type consisted of three sampling sites (Figures 1 and 2). The number of sampling sites was determined to represent the major habitat types within the study area; however, this design may not fully capture fine-scale spatial variability among sites. In addition, the study was conducted during the dry season, which may not fully represent seasonal variation in butterfly communities.

The Coastal Forest habitat is characterized by moderate tree canopy cover and strong coastal winds, with vegetation dominated by *Avicennia marina*, *Pandanus tectorius*, *Hibiscus tiliaceus*, and *Tabernaemontana sphaerocarpa*. Open Land habitats are dominated by herbaceous and shrub vegetation such as *Chromolaena odorata* and *Stachytarpheta jamaicensis*, with high light intensity due to minimal canopy cover. Riverbank habitats occur along river edges with moderate to open canopy cover and vegetation dominated by *Schizostachyum brachycladum* and *Annona muricata*, along with herbs such as *C. odorata*. Closed-canopy Forests are characterized by dense vegetation dominated by *Harpullia arborea*, resulting in lower light intensity and higher humidity (Table 1).

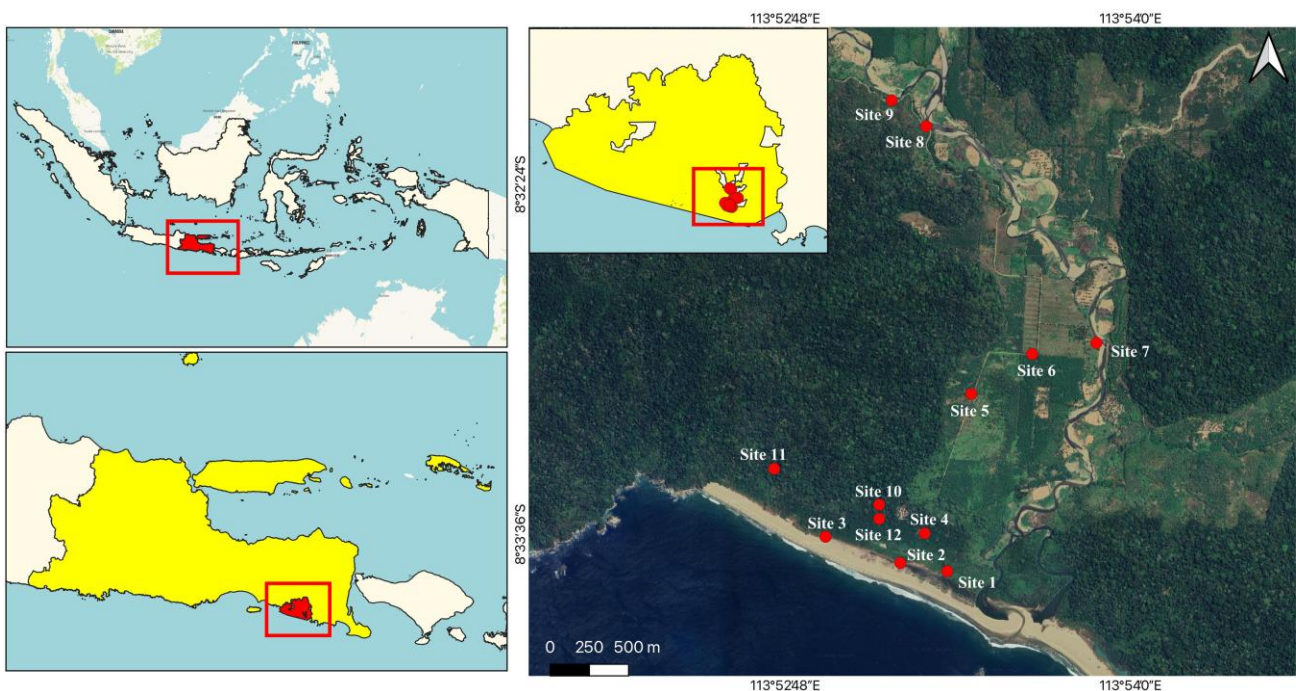


Figure 1. Sampling area in the Sukamade Resort, Meru Betiri National Park, Indonesia



Figure 2. Sampling locations in the Sukamade Resort, Meru Betiri National Park, Indonesia. A-C: Coastal Forest habitat (sites 1-3), D-F: Open Land (sites 4-6), G-I: Riverbank habitat (sites 7-9), J-L: Closed-canopy Forest (sites 10-12)

Table 1. Description of the twelve study sites in the Sukamade Resort area, Meru Betiri National Park, Indonesia

| Location | Coordinates | | Elevation (m asl) | Dominant vegetation |
|--------------------------------|--------------|----------------|----------------------|---|
| | Latitude | Longitude | | |
| Site 1 (Coastal Forest) | 8°33'43.6" S | 113°53'21.8" E | 5 | <i>Avicennia marina</i> , <i>Pandanus tectorius</i> |
| Site 2 (Coastal Forest) | 8°33'41.9" S | 113°53'12.0" E | 8 | <i>Hibiscus tiliaceus</i> , <i>Tabernaemontana sphaerocarpa</i> |
| Site 3 (Coastal Forest) | 8°33'36.5" S | 113°52'56.4" E | 8 | <i>Tabernaemontana sphaerocarpa</i> , <i>Hibiscus tiliaceus</i> |
| Site 4 (Open Land) | 8°33'35.8" S | 113°53'17.1" E | 13 | <i>Stachytarpheta jamaicensis</i> |
| Site 5 (Open Land) | 8°33'07.1" S | 113°53'26.8" E | 11 | <i>Chromolaena odorata</i> |
| Site 6 (Open Land) | 8°32'58.9" S | 113°53'39.5" E | 11 | <i>Chromolaena odorata</i> |
| Site 7 (Riverbanks) | 8°32'56.6" S | 113°53'52.9" E | 11 | <i>Schizostachyum brachycladum</i> , <i>Chromolaena odorata</i> |
| Site 8 (Riverbanks) | 8°32'12.0" S | 113°53'17.4" E | 22 | <i>Annona muricata</i> , <i>Chromolaena odorata</i> |
| Site 9 (Riverbanks) | 8°32'06.7" S | 113°53'10.2" E | 27 | <i>Schizostachyum brachycladum</i> , <i>Chromolaena odorata</i> |
| Site 10 (Closed-canopy Forest) | 8°33'29.9" S | 113°53'07.6" E | 28 | <i>Harpullia arborea</i> |
| Site 11 (Closed-canopy Forest) | 8°33'22.5" S | 113°52'45.7" E | 28 | <i>Harpullia arborea</i> |
| Site 12 (Closed-canopy Forest) | 8°33'32.8" S | 113°53'07.6" E | 28 | <i>Harpullia arborea</i> |

Procedures

Butterfly survey

Butterfly surveys were conducted using the cruising method along a 100 m × 10 m transect established at each sampling site. The study included 12 sampling sites

representing four habitat types: Coastal Forest, Open Land, riverbank, and Closed-canopy Forest, with three sites per habitat. At each site, a single transect was established and surveyed three times on different days during the study period, with several days between visits. All repeated

surveys were conducted under comparable environmental conditions, including similar observation periods and suitable weather (clear skies and low wind), to ensure consistent sampling effort.

Surveys were conducted during peak butterfly activity between 08:00 am and 03:00 pm. Each transect was surveyed for approximately 1 hour using a consistent walking pace to maintain equal detection effort across all sites and habitats. During each survey, butterflies encountered along the transect were visually observed, and the number of individuals per species was recorded. Representative individuals of each species were captured using an insect net to confirm species identification. Captured specimens were temporarily placed in triangular paper envelopes labeled with the date, time, and sampling location and assigned identification codes.

To minimize double-counting, butterflies that flew repeatedly along the transect or returned to the observer were recorded only once per survey session. However, repeated detections of highly mobile individuals cannot be completely excluded. Butterfly abundance recorded across repeated surveys was first pooled within each site and subsequently combined across habitat types before analysis, yielding a habitat \times species abundance matrix used for all diversity and community analyses. This pooling approach was applied to characterize butterfly community structure at the habitat level and to facilitate comparisons among habitat types. However, this approach may reduce fine-scale ecological resolution at the site level.

Species identification was conducted using several standard taxonomic references, including Schulze (2005), Scudder and Cannings (2007), and Chahyadi et al. (2020), followed by verification using the Kuponesia application (version 1.3). A butterfly expert subsequently validated identification result. Representative specimens were preserved as vouchers, and photographs of each species were taken as supporting records. Voucher specimens were deposited in the Zoology Laboratory, Department of Biology Education, Universitas Jember, Indonesia.

Abiotic data measurement

Abiotic variables were measured to characterize the environmental conditions in the Sukamade Resort area. The variables recorded included light intensity, air temperature, air humidity, and wind speed, measured using a lux meter, a digital thermometer, a hygrometer, and an anemometer, respectively. Measurements were conducted simultaneously with butterfly surveys at twelve sampling sites. At each site, three measurements were taken at randomly selected locations within the transect and averaged to obtain a representative value for each site. These values were subsequently averaged within each habitat type to correspond with the habitat-level butterfly abundance data used in the Canonical Correspondence Analysis (CCA). This averaging approach may reduce environmental variability and influence the strength of species-environment relationships. The recorded values are presented as mean \pm standard deviation.

Biotic variables: Plant data and floral visitations

Biotic variables were assessed by analyzing plant vegetation at each sampling site in the Sukamade Resort area. Each sampling site also served as a vegetation observation station. Vegetation sampling was conducted using a checkerboard line (zigzag) plot arrangement along each transect, with five plots established at each site. Nested plot sizes were applied according to plant growth stages: 2 \times 2 m² for seedlings, 5 \times 5 m² for saplings, 10 \times 10 m² for poles, and 20 \times 20 m² for trees. Seedlings were defined as individuals with height <1.5 m; saplings as individuals with height \geq 1.5 m and Diameter at Breast Height (DBH) <10 cm; poles as individuals with DBH 10-20 cm; and trees as individuals with DBH >20 cm. The collected data included plant species and the number of individuals of each species recorded within the plots. In total, five plots were established at each of the 12 sampling sites, resulting in 15 plots per habitat type. Based on the largest plot size (20 \times 20 m²), the total sampled vegetation area was approximately 6,000 m² per habitat or 24,000 m² across the entire study area.

Vegetation data from all growth stages were combined to represent overall plant species composition within each habitat type. The Important Value Index (IVI) and plant diversity indices were calculated at the habitat level using the pooled vegetation data for each habitat type to characterize the overall vegetation structure of each habitat. Plant data were collected once per plot by documenting morphological characteristics and collecting leaf samples for species identification. Species identification was conducted using standard botanical references (Steenis 2008), and photographic documentation was also carried out to support the identification process and ensure data accuracy.

In addition, floral visitation by butterflies was recorded during transect surveys through direct field observation. A visit was defined as a butterfly landing on a flower and actively feeding on nectar, involving contact with the floral structure. Observations were conducted simultaneously with butterfly sampling along each transect. Butterfly species visiting flowers were recorded, and the nectar plants were identified and described based on plant habit, flower color, and flower type (Rusman et al. 2016). To avoid overestimation, repeated visits by the same individual within a single observation period were recorded only once, whenever possible. Floral visitation data were documented as the occurrence of interactions between butterfly species and flowering plants, rather than as quantitative visitation frequency. No measurements of visitation frequency, duration, or interaction intensity were conducted in this study.

Data analysis

Conservation status assessment refers to the International Union for Conservation of Nature's (IUCN) red list of threatened species (www.iucnredlist.org), the Convention on International Trade in Endangered Species (CITES) of wild fauna and flora (cites.org), and Indonesian Regulations (P.106/MENLHK/SETJEN/KUM.1/12/2018). The butterfly community was analyzed using the Shannon-

Wiener Diversity Index (H'), Margalef Index (R), Evenness Index (E'), Simpson's Dominance (D), Relative Abundance (RA), and Importance Value Index (IVI). The Shannon-Wiener Diversity Index (H') (Odum 1996) can be calculated using the formula:

$$H' = - \sum \left\{ \left(\frac{ni}{N} \right) \ln \left(\frac{ni}{N} \right) \right\}$$

Where:

H' : Shannon-Wiener Diversity Index
ni : Number of individuals of type i
N : Number of individuals of all types

The Margalef Index (R) is used to measure species richness in a community by relating the total number of species to the total number of individuals present (Magurran 1988) as follows:

$$R = \frac{s - 1}{\ln(N)}$$

Where:

R : Species Richness Index
s : Total number of species in a habitat
N : Total number of individuals in a habitat

The Evenness Index (E) is used to determine the evenness of the number of individuals that make up a community (Magurran 2004) as follows:

$$E' = \frac{H'}{\ln S}$$

Where:

E' : Evenness Index
H' : Shannon-Wiener Diversity Index
S : Number of species found

Species dominance was determined using Simpson's Index (Odum 1996) using the formula:

$$D = \sum (ni/N)^2$$

Where:

D : Dominance Index
ni : Number of individuals of type i
n : Number of individuals of all types

The relative abundance of butterflies (Odum 1996) was determined using the formula:

$$RA = (ni/N) \times 100 \%$$

Where:

RA : Relative Abundance
ni : Number of individuals of species i
N : Total number of individuals

The important value index (IVI) of butterflies (Ahmad et al. 2015) is determined using the formula:

$$IVI = RD + RF$$

Where:

IVI : Important Value Index
RD : Relative Density
RF : Relative Frequency

The Important Value Index (IVI) of vegetation (Mustapha et al. 2022) is determined using the formula:

$$IVI = RD + RF + RDo$$

Where:

RD : Relative Density
RF : Relative Frequency
RDo : Relative Dominance

All community analyses were conducted using a habitat × species matrix based on butterfly abundance recorded in each habitat type. For multivariate analyses (PCA and CCA), data from the three sampling sites within each habitat were pooled to represent habitat-level patterns. While this approach facilitates comparison among habitat types, it reduces effective statistical replication and limits the strength of ecological inference. Therefore, the results of these analyses should be interpreted as exploratory rather than confirmatory. Similarity among study locations was assessed using the Bray-Curtis index. Rarefaction analysis was performed to standardize sampling effort and to compare species richness among habitats with different numbers of individuals. Abiotic variables were analyzed using CCA and PCA was used to explore patterns between vegetation composition and butterfly species. All data analyses were performed using PAST version 4.09.

RESULTS AND DISCUSSION

Butterfly diversity

A total of 423 individuals representing 26 species across four families were recorded in the Sukamade Resort area (Table 2). *Ypthima horsfieldii* was the species with the highest number of individuals in this study and was found in three habitat types: Coastal Forest, Open Land, and Riverbank. This distribution suggests that the species can occur across a range of habitat conditions. *Ypthima horsfieldii* is known as a relatively common and widespread butterfly species across various vegetation types (Rahman and Maryati 2021). Cleary (2016) also noted that the genus *Ypthima* is generally encountered in open landscapes such as grasslands. The occurrence of this species has also been documented in other locations in Indonesia, including the eastern slope of Mount Argopuro and the forest areas of Mount Bromo (Rohman et al. 2025; Pertiwi et al. 2020).

One notable species recorded in this study was *T. helena*, which is legally protected under Indonesian regulation and listed in Appendix II of CITES. This species belongs to the family Papilionidae and was recorded across all habitat types with relatively low abundance. The persistence of this species may reflect the availability of suitable habitat conditions. Previous studies have reported that *T. helena* occurrence is linked to habitat quality and vegetation structure (Koneri and Maabuat 2016).

Therefore, the presence of this species indicates the potential importance of maintaining habitat conditions that support protected butterfly species within the study area.

Relative abundance of butterflies in Sukamade Resort, Meru Betiri National Park (MNP)

The relative abundance of butterflies was assessed across four habitat types: Coastal Forest, Open Land, Riverbanks, and Closed-canopy Forest. In the Coastal Forest habitat, *Celastrina lavendularis* showed the highest relative abundance, while *Catopsilia pomona* was most abundant in Open Land. In Riverbanks, *Y. horsfieldii* had the highest relative abundance, whereas *Eurema hecabe* dominated in Closed-canopy Forest.

This pattern shows differences in species distribution among habitat types. *Celastrina lavendularis* was found in all habitats, with the highest occurrence in Coastal Forest. Rusman et al. (2016) also reported similar occurrences at different locations, which is consistent with its widespread distribution. In contrast, *C. pomona* and *Y. horsfieldii* were more frequently encountered in Open Land and Riverbank habitats, which, based on field observations, were characterized by higher light intensity and more varied

vegetation structure. Similar patterns have been reported in other studies, where both species are commonly found in more open environments (Withaningsih et al. 2024; Ruslan et al. 2023).

Meanwhile, *E. hecabe* was recorded across all habitat types, with higher abundance in the Closed-canopy Forest. This broad occurrence suggests that the species can occur under a range of environmental conditions. Previous studies have also documented its presence across diverse habitat types (Ruslan et al. 2023).

Family composition of butterflies

This study recorded four butterfly families: Nymphalidae, Papilionidae, Lycaenidae, and Pieridae. Nymphalidae had the highest proportion of species richness and dominated all sampling locations, with the greatest number of individuals (Figure 3). This pattern is consistent with previous studies describing Nymphalidae as a diverse group capable of utilizing a wide range of food resources (Rosmidi et al. 2017; Koneri and Nangoy 2019). Members of this family have also been reported from various habitat types, including both natural and modified environments (Maung et al. 2020; Freire et al. 2022).

Table 2. Checklist of butterfly species in the Sukamade Resort area, Meru Betiri National Park, Indonesia

| Family, Species | Number of individuals | | | | Relative abundance (%) | | | | IUCN | CITES | NS |
|--------------------------------|-----------------------|----|----|-----|------------------------|-------|-------|-------|------|-------|----|
| | CF | OL | RB | CCF | CF | OL | RB | CCF | | | |
| Nymphalidae | | | | | | | | | | | |
| <i>Parantica aspasia</i> | 0 | 1 | 1 | 1 | 0.00 | 0.72 | 0.85 | 1.69 | NE | NA | NP |
| <i>Ideopsis juventa</i> | 12 | 4 | 1 | 3 | 11.11 | 2.90 | 0.85 | 5.08 | NE | NA | NP |
| <i>Melanitis leda</i> | 1 | 1 | 0 | 5 | 0.93 | 0.72 | 0.00 | 8.47 | LC | NA | NP |
| <i>Euploea mulciber</i> | 2 | 8 | 0 | 1 | 1.85 | 5.80 | 0.00 | 1.69 | NE | NA | NP |
| <i>Ypthima horsfieldii</i> | 22 | 20 | 29 | 0 | 20.37 | 14.49 | 24.58 | 0.00 | NE | NA | NP |
| <i>Euploea phaenareta</i> | 3 | 1 | 0 | 0 | 2.78 | 0.72 | 0.00 | 0.00 | NE | NA | NP |
| <i>Mycalesis horsfieldii</i> | 2 | 8 | 11 | 4 | 1.85 | 5.80 | 9.32 | 6.78 | NE | NA | NP |
| <i>Euploea tulliolus</i> | 0 | 7 | 1 | 0 | 0.00 | 5.07 | 0.85 | 0.00 | NE | NA | NP |
| <i>Neptis hylas</i> | 0 | 3 | 5 | 2 | 0.00 | 2.17 | 4.24 | 3.39 | NE | NA | NP |
| <i>Moduza procris</i> | 0 | 1 | 1 | 1 | 0.00 | 0.72 | 0.85 | 1.69 | NE | NA | NP |
| <i>Acraea terpsicore</i> | 0 | 1 | 3 | 0 | 0.00 | 0.72 | 2.54 | 0.00 | NE | NA | NP |
| <i>Tanaecia trigerta</i> | 0 | 0 | 0 | 4 | 0.00 | 0.00 | 0.00 | 6.78 | NE | NA | NP |
| <i>Tanaecia vikrama</i> | 0 | 2 | 0 | 5 | 0.00 | 1.45 | 0.00 | 8.47 | NE | NA | NP |
| <i>Junonia hedonia</i> | 2 | 1 | 0 | 0 | 1.85 | 0.72 | 0.00 | 0.00 | NE | NA | NP |
| <i>Tanaecia julii</i> | 0 | 1 | 0 | 3 | 0.00 | 0.72 | 0.00 | 5.08 | NE | NA | NP |
| Pieridae | | | | | | | | | | | |
| <i>Eurema hecabe</i> | 13 | 17 | 9 | 14 | 12.04 | 12.32 | 7.63 | 23.73 | LC | NA | NP |
| <i>Leptosia nina</i> | 2 | 12 | 5 | 7 | 1.85 | 8.70 | 4.24 | 11.86 | NE | NA | NP |
| <i>Cepora iudith</i> | 1 | 2 | 1 | 0 | 0.93 | 1.45 | 0.85 | 0.00 | NE | NA | NP |
| <i>Catopsilia pomona</i> | 8 | 22 | 20 | 0 | 7.41 | 15.94 | 16.95 | 0.00 | NE | NA | NP |
| Papilionidae | | | | | | | | | | | |
| <i>Papilio memnon</i> | 2 | 1 | 1 | 1 | 1.85 | 0.72 | 0.85 | 1.69 | NE | NA | NP |
| <i>Papilio paradoxa</i> | 0 | 3 | 0 | 0 | 0.00 | 2.17 | 0.00 | 0.00 | LC | NA | NP |
| <i>Troides helena</i> | 1 | 1 | 1 | 3 | 0.93 | 0.72 | 0.85 | 5.08 | LC | A.II | P |
| <i>Papilio polytes</i> | 1 | 3 | 0 | 1 | 0.93 | 2.17 | 0.00 | 1.69 | NE | NA | NP |
| Lycaenidae | | | | | | | | | | | |
| <i>Celastrina lavendularis</i> | 34 | 16 | 4 | 0 | 31.48 | 11.59 | 3.39 | 0.00 | NE | NA | NP |
| <i>Drupadia ravindra</i> | 2 | 2 | 0 | 0 | 1.85 | 1.45 | 0.00 | 0.00 | NE | NA | NP |
| <i>Jamides celeno</i> | 0 | 0 | 25 | 4 | 0.00 | 0.00 | 21.19 | 6.78 | NE | NA | NP |

Note: Habitat: CF: Coastal Forest; OL: Open Land; RB: Riverbanks; CCF: Closed-canopy Forest. IUCN: NE: Not Evaluated; DD: Data Deficient; LC: Least Concern; NT: Near Threatened; VU: Vulnerable; EN: Endangered; CE: Critically Endangered; EW: Extinct in the Wild and Extinct. CITES: NA: Not Appendix; A.I: Appendix I; A.II: Appendix II; A.III: Appendix III. NS: National Status: P: Protected; NP: Not Protected (P.106 /MENLHK /SETJEN /KUM.1/12/2018

In contrast, Pieridae were more frequently encountered in open habitats, which during field observations were characterized by higher light intensity. Papilionidae and Lycaenidae were recorded in lower numbers and tended to be found in more restricted habitat types.

Parameters of butterfly diversity indices

Figure 4 presents the results of data analysis using the Shannon-Wiener Diversity Index (H'), Margalef Species Richness Index, Dominance Index, and Evenness Index in Resort Sukamade, Meru Betiri National Park. The diversity index values across all habitats fall within the moderate category ($1 \leq H' \leq 3$), with the highest value recorded in Open Land. This pattern is consistent with field observations, where Open Land had more flowering plants, such as *C. odorata* and *S. jamaicensis*, which were observed to be visited by butterflies during data collection.

The relatively higher light intensity may also relate to the greater number of butterfly species found in this habitat. Similar patterns have been reported in other studies, where open habitats with high food resource availability tend to exhibit higher butterfly diversity (Koneri and Nangoy 2019). However, in this study, this pattern reflects field conditions related to the distribution of food resources and does not indicate a direct ecological relationship.

The Margalef Species Richness Index showed a similar pattern, with the highest richness recorded in the Open Land habitat. The other habitats exhibited slightly lower richness values, including Closed-canopy Forest, Coastal Forest, and Riverbanks. Based on general interpretative criteria ($2.5 < R < 4.0$), most habitats in the Sukamade Resort fall into the moderate species richness category, although Open Land reached the high category. This

pattern may be related to the greater diversity of flowering vegetation and higher light intensity observed in this habitat. Previous studies have reported that habitats with more open vegetation structure and higher plant diversity tend to support greater species richness (Wale and Abdella 2021; Fungomeli et al. 2025).

Dominance Index values across all habitats were classified as low ($D \leq 0,5$). Nevertheless, relative differences among habitats were observed, with Coastal Forest showing higher dominance values compared to other habitats, followed by Riverbanks, while Open Land and Closed-canopy Forest. This suggests that no single species strongly dominates the butterfly community, although some species have relatively higher abundances in particular habitats. These differences in dominance values may be related to the uneven distribution of individuals among species in some habitats.

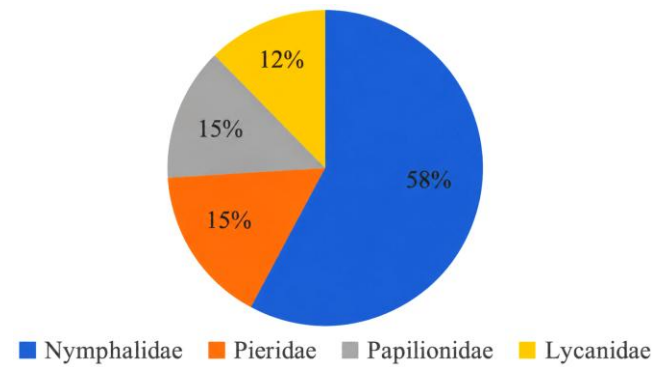


Figure 3. Family composition of butterflies in the Sukamade Resort area, Meru Betiri National Park, Indonesia

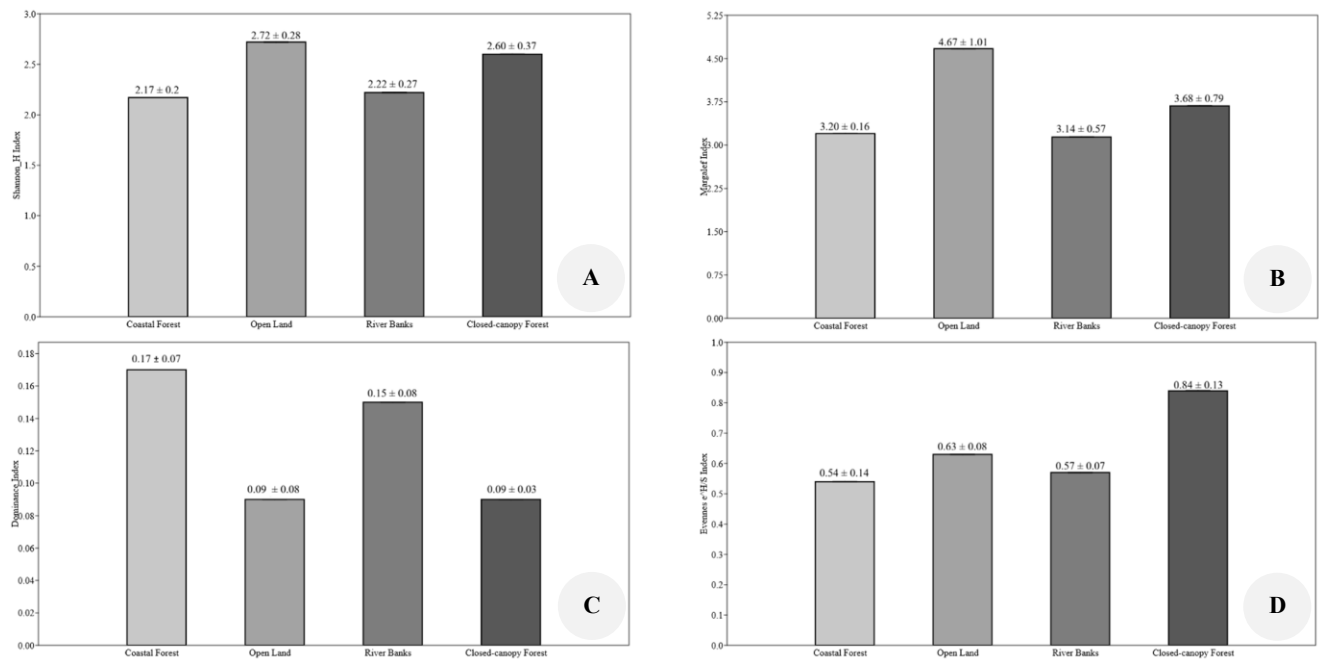


Figure 4. Butterfly diversity index parameters of butterflies in the Sukamade Resort area, Meru Betiri National Park, Indonesia. A. Shannon-Wiener Index, B. Margalef Index, C. Dominance Index, D. Evenness Index

Previous studies have stated that higher dominance values generally occur when the distribution of individuals among species is uneven, whereas low dominance values reflect a more balanced distribution (Pertiwi et al. 2020). Similar findings have also been reported in Argopuro Mountains, which showed low Dominance Index values (Rohman et al. 2025).

The Closed-canopy Forest habitat exhibited the highest evenness value among all habitats ($E > 0.6$), suggesting that butterfly individuals were more evenly distributed across species in this environment. The species composition data are consistent with this pattern, where no single species showed strong dominance and several species were recorded with relatively uniform abundances. This indicates a more even distribution of individuals compared to other habitats, where certain species tend to be more dominant. Microclimatic conditions beneath the dense canopy, such as lower light intensity and higher humidity, may be associated with this pattern (Verdonck et al. 2025; Xing et al. 2016). Similar findings have also been reported in forest habitats with more uniform species distribution (Panjaitan et al. 2016).

Differences in butterfly community structure among habitats may be related to variations in vegetation composition and structure. Open habitats, including Coastal Forest, Open Land, and Riverbanks, were characterized by the presence of shrub species such as *C. odorata* and *S. jamaicensis*, which were observed as locations visited by butterflies during field surveys (Table 7). In contrast, the Closed-canopy Forest habitat was dominated by tree species such as *H. arborea* and several *Ficus* species, forming denser vegetation with lower light availability (Table 5). These differences in vegetation characteristics likely contribute to the variation in butterfly distribution patterns observed across habitats in the study area.

The rarefaction curve shows the relationship between the number of observed individuals and the number of butterfly species recorded in the Sukamade Resort area (Figure 5). Open Land exhibited the highest species richness, with 24 species recorded from a total of 138 individuals. In comparison, Coastal Forest and Riverbank habitats each yielded 16 species from 108 and 118 individuals, respectively. Closed-canopy Forest also recorded 16 species, but with a lower number of individuals (59). The rarefaction curves for all habitats showed an increasing trend and had not yet reached an asymptote, indicating that additional individuals may still reveal more butterfly species in the study area.

Nevertheless, the higher curve in the Open Land habitat indicates a tendency toward greater species richness compared to the other habitats. This pattern is consistent with the higher diversity observed in the Open Land habitat (Table 5). Differences among habitats may be related to variation in vegetation characteristics observed during field surveys. Previous studies have suggested that vegetation diversity can be associated with butterfly species richness (Han et al. 2021). However, these patterns should be interpreted cautiously, as the rarefaction curves have not yet reached an asymptote.

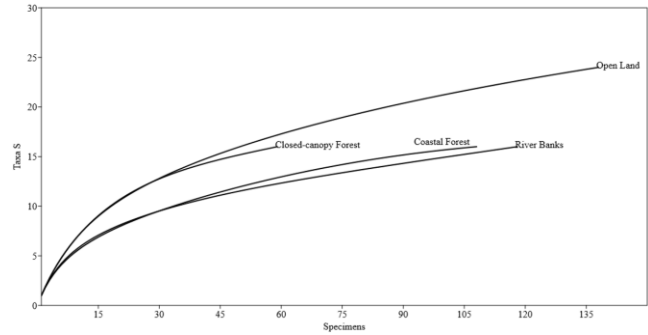


Figure 5. Butterfly rarefaction curve in the Sukamade Resort area, Meru Betiri National Park, Indonesia

Similarity index of butterflies in Resort Sukamade, MBNP

The cluster analysis of butterfly species composition across habitats revealed a clear separation between the Closed-canopy Forest and the other habitats (Figure 6). Coastal Forest and Open Land formed the closest cluster with a similarity value of approximately 0.60, indicating that these two habitats shared the most similar butterfly assemblages. This cluster was subsequently grouped with the riverbank habitat at a lower similarity level of about 0.53, forming a broader habitat group. Within this group, ten butterfly species were commonly recorded, namely *Ideopsis juvenata*, *Y. horsfieldii*, *Mycalesis horsfieldii*, *E. hecabe*, *Leptosia nina*, *Cepora iudith*, *C. pomona*, *Papilio memnon*, *T. helena*, and *C. lavendularis*. In contrast, the Closed-canopy Forest habitat joined the cluster at a much lower similarity level of approximately 0.34, indicating a more distinct butterfly community compared with the other habitats.

Important value index of butterflies in Resort Sukamade, MBNP

Based on Table 3, the butterfly species with the highest Important Value Index (IVI) were *Y. horsfieldii* and *E. hecabe*. In this study, IVI was used to identify butterfly species with relatively high ecological importance within the assemblage by integrating relative abundance and frequency of occurrence. Both species showed relatively high abundance and broad distribution, with *Y. horsfieldii* recorded across three habitat types (71 individuals) and *E. hecabe* occurring in all habitats (53 individuals). This wide distribution and consistent occurrence contributed to their high IVI values. Other species, such as *C. pomona* and *C. lavendularis*, also exhibited relatively high IVI values, indicating their importance within the community.

At the habitat level, differences in dominant species were observed. In Coastal Forest, *C. lavendularis* exhibited the highest IVI, indicating its relative dominance in this habitat. This pattern may be related to habitat characteristics, as vegetation composition and structure differ from those in inland habitats. Its repeated occurrence across sampling sites suggests a consistent presence within the local environmental conditions. Similar patterns have been reported for Lycaenidae species, which often show high IVI due to their adaptive capacity (Ruslan et al. 2023).

Ypthima horsfieldii showed the highest IVI in both Open Land and Riverbanks habitats. This species was commonly recorded in open to semi-open habitats characterized by the presence of grasses and shrubs. In this study, *Y. horsfieldii* was frequently observed visiting flowers such as *C. odorata* during field observations. Similar associations with flowering plants from the Asteraceae family have been reported in previous studies (Rusman et al. 2016). However, these observations are based on occurrence and do not indicate a direct relationship between resource availability and species dominance.

In the Closed-canopy Forest habitat, *E. hecabe* exhibited the highest IVI. This species was recorded across all habitat types, indicating a broad distribution within the study area. Its relatively high IVI in this habitat reflects its consistent occurrence compared to other species. Previous studies have reported associations between *E. hecabe* and host plants from the families Asteraceae and Verbenaceae (Rusman et al. 2016), several of which were also recorded in this study, including *C. odorata*, *S. jamaicensis*, and *Lantana camara*.

Abiotic data measurement

The measurement of abiotic parameters included air temperature, relative humidity, light intensity, and wind speed. Air temperature across the study sites remained within a range suitable for butterfly activity (Table 4). Butterflies require appropriate thermal conditions to regulate body temperature during flight, as temperature strongly influences their mobility, feeding, and reproductive behavior. Previous studies reported that the optimal temperature range for completing the butterfly life cycle is approximately 30–35°C (Granato et al. 2024). Meanwhile, butterflies exhibit a broad thermal range for flight activity, with thoracic temperatures typically ranging from approximately 14.5°C to 39.9°C, indicating the lower and upper limits of their flight performance (Gruber et al. 2025). The temperature variation observed among habitats may also reflect differences in vegetation structure. Open habitats receive more direct solar radiation due to lower canopy cover, resulting in relatively warmer microclimates than those in Closed-canopy Forest habitats.

Relative humidity ranged from moderate to high. Humidity is closely associated with air temperature: higher temperatures generally correspond to lower humidity, and vice versa. The relatively higher humidity observed in Closed-canopy Forest habitats is likely related to dense canopy cover that limits sunlight penetration and reduces evaporation, thereby maintaining a more humid microenvironment. Previous studies reported that butterflies generally require humidity levels of approximately 60–75% for survival, while higher humidity levels of around 84–92% may support reproductive activity (Mahata et al. 2023).

Light intensity varied widely among habitats. Open habitats received substantially higher light levels due to minimal canopy cover, whereas Closed-canopy Forests experienced lower light availability. This substantial variation is reflected in the large standard deviation values,

which indicate pronounced differences in light conditions among habitat types rather than measurement inconsistency. Liao et al. (2020) demonstrated that light intensities between 15,000 and 45,000 lx enable butterflies to absorb sufficient heat to attain thermal equilibrium, thereby increasing flight frequency and mating activity. Furthermore, increased light intensity has been shown to significantly stimulate butterfly flight activity (Liao et al. 2017).

Wind conditions during sampling were generally low. Slightly higher wind speeds were recorded in the Coastal Forest habitat, likely influenced by its proximity to the coastline and its relatively open vegetation structure compared with inland forest habitats. Low wind conditions are generally favorable for butterfly flight and foraging behavior. Koneri et al. (2020) reported a negative correlation between high wind speed and butterfly distribution. Additionally, Chowdhury et al. (2021) indicated that wind plays an important role in butterfly migration, with strong winds hindering movement toward destination sites and weak winds increasing the energetic cost of reaching those sites.

Plant diversity in Resort Sukamade, MBNP

A total of 39 plant species comprising 934 individual plants were recorded in Resort Sukamade, representing 24 families (Table 5). Plant species composition varied among habitats, with 13 species identified in the Coastal Forest, 17 species in Open Land, 11 species along the Riverbanks, and 9 species in the Closed-canopy Forest. Differences in vegetation composition among habitats may influence butterfly community structure because diverse vegetation provides important ecological resources, including flowering plants that serve as nectar sources for adult butterflies and host plants for larval development (Han et al. 2021).

Harpullia arborea was recorded as the most dominant plant species in the Closed-canopy Forest habitat. This plant is characterized by yellowish-white flowers and orange fruits. To date, no study has directly reported *H. arborea* as a nectar-producing plant for butterflies. Previous studies have shown that the presence of flowering plants in general may be associated with butterfly diversity (Kitahara et al. 2008).

Among the plant species found, *C. odorata* was the most frequently encountered plant in Open Land, Coastal Forest, and Riverbank habitats, and received the highest number of butterfly visits during the observations (Table 7). This pattern indicates that butterflies were commonly observed on this species throughout the study period. Previous studies have also reported that *C. odorata* serves as a nectar source for various butterfly taxa (Sáfián 2021; Rusman et al. 2016). However, the observations in this study are based on visit occurrence only and do not reflect preference or ecological importance. In addition, *C. odorata* is known as an invasive species with the potential to affect vegetation composition and habitat structure (Adhikari et al. 2023). Therefore, its presence needs to be carefully considered in area management to maintain the

balance between vegetation and the sustainability of butterfly habitats.

Vegetation index analysis

Table 6 presents the results of vegetation data analysis using the Shannon-Wiener Diversity Index (H'), Margalef Species Richness Index (R), Dominance Index (D), and Evenness Index (E) in Resort Sukamade, Meru Betiri National Park. Vegetation diversity across all habitats was categorized as moderate, with Open Land showing the highest diversity value. This pattern reflects differences in vegetation composition observed among habitat types. Higher Shannon-Wiener Diversity Index values indicate greater community heterogeneity (Zeng et al. 2024).

The Margalef Index also varied among habitats, with the highest value recorded in Open Land, categorized as moderate, while Coastal Forest, Riverbanks, and Closed-canopy Forest were classified as low. These differences indicate variation in plant species richness across habitats. The relatively higher species richness in open habitats is likely related to the vegetation conditions observed during the study. In contrast, the low species richness in Closed-canopy Forest may be attributed to the vegetation characteristics of that habitat (Kermavnar and Kutnar 2020).

The vegetation Dominance Index (D) was highest in Closed-canopy Forest, followed by Riverbanks, whereas Open Land and Coastal Forest showed slightly lower dominance values. However, all habitats fell within the low dominance category ($D \leq 0.5$), indicating that no single plant species overwhelmingly dominated the community (Qur'ani et al. 2026). This pattern is consistent with the vegetation Evenness Index, which was relatively high overall ($E > 0.6$). Coastal Forest exhibited the highest evenness value. High evenness values indicate that plant individuals are distributed relatively evenly across species without pronounced dominance. The combination of low dominance and high evenness suggests a relatively balanced vegetation community structure in each habitat (Katili et al. 2025).

Analysis of the plant's important value index

Analysis of the plant Important Value Index (IVI) showed that *C. odorata* was the most dominant plant species in several habitats, particularly in Open Land, Coastal Forest, and Riverbanks. According to Siregar et al. (2026), a high IVI reflects strong adaptive capacity to environmental conditions, allowing a species to persist and dominate the vegetation community. The dominance of *C. odorata* indicates that it is an important component of the vegetation structure in these habitats. In contrast, the IVI analysis in the Closed-canopy Forest showed that *H.*

arborea had the highest value, indicating its dominance in that habitat. This pattern reflects the differences in vegetation composition among habitats observed during the study. The dominance of certain species contributes to the vegetation structure within each habitat.

Table 3. Analysis of the butterfly important value index in the Sukamade Resort area, Meru Betiri National Park, Indonesia

| Species name | IVI (%) | | | |
|--------------------------------|---------|-------|-------|-------|
| | CF | OL | RB | CCF |
| <i>Parantica aspasia</i> | 0.00 | 1.78 | 2.36 | 3.92 |
| <i>Ideopsis juventa</i> | 24.01 | 7.11 | 2.36 | 11.75 |
| <i>Melanitis leda</i> | 2.54 | 1.78 | 0.00 | 17.36 |
| <i>Euploea mulciber</i> | 5.08 | 12.11 | 0.00 | 3.92 |
| <i>Ypthima horsfieldii</i> | 36.50 | 27.12 | 42.76 | 0.00 |
| <i>Euploea phaenareta</i> | 7.62 | 1.78 | 0.00 | 0.00 |
| <i>Mycalesis horsfieldii</i> | 3.46 | 11.06 | 19.93 | 11.22 |
| <i>Euploea tulliolus</i> | 0.00 | 11.39 | 2.36 | 0.00 |
| <i>Neptis hylas</i> | 0.00 | 5.33 | 10.30 | 7.83 |
| <i>Moduza procris</i> | 0.00 | 1.78 | 2.36 | 3.92 |
| <i>Acraea terpsicore</i> | 0.00 | 1.78 | 7.09 | 0.00 |
| <i>Tanaecia trigerta</i> | 0.00 | 0.00 | 0.00 | 15.67 |
| <i>Tanaecia vikrama</i> | 0.00 | 3.55 | 0.00 | 17.36 |
| <i>Junonia hedonia</i> | 5.08 | 1.78 | 0.00 | 0.00 |
| <i>Tanaecia julii</i> | 0.00 | 1.78 | 0.00 | 11.75 |
| <i>Eurema hecabe</i> | 26.55 | 23.90 | 16.72 | 41.51 |
| <i>Leptosia nina</i> | 5.08 | 17.12 | 10.30 | 22.98 |
| <i>Cepora iudith</i> | 2.54 | 3.55 | 2.36 | 0.00 |
| <i>Catopsilia pomona</i> | 15.47 | 26.47 | 33.62 | 0.00 |
| <i>Papilio memnon</i> | 5.08 | 1.78 | 2.36 | 3.92 |
| <i>Papilio paradoxa</i> | 0.00 | 5.33 | 0.00 | 0.00 |
| <i>Troides helena</i> | 2.54 | 1.78 | 2.36 | 11.75 |
| <i>Papilio polytes</i> | 2.54 | 5.33 | 0.00 | 3.92 |
| <i>Celastrina lavendularis</i> | 50.84 | 21.07 | 6.42 | 0.00 |
| <i>Drupadia ravindra</i> | 5.08 | 3.55 | 0.00 | 0.00 |
| <i>Jamides celeno</i> | 0.00 | 1.78 | 2.36 | 3.92 |

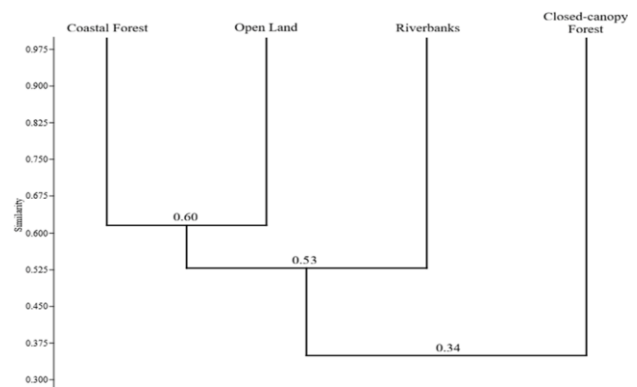


Figure 6. Similarity of butterfly composition in several habitats in the Sukamade Resort area, Meru Betiri National Park, Indonesia

Table 4. Measurement of abiotic parameters in the Sukamade Resort area, Meru Betiri National Park, Indonesia

| | Air temperature (°C) | Air humidity (%) | Light intensity (Lx) | Wind speed (m/s) |
|----------------------|----------------------|------------------|----------------------|------------------|
| Coastal Forest | 33.11±1.27 | 64.00±5.20 | 59477.78±31407.24 | 1.67±0.42 |
| Open Land | 31.00±1.00 | 64.11±10.15 | 79973.22±59145.55 | 0.31±0.45 |
| Riverbanks | 29.62±0.82 | 64.44±5.34 | 44455.56±13921.40 | 0.60±0.47 |
| Closed-canopy Forest | 27.11±0.44 | 88.78±1.20 | 793.00±412.78 | 0.01±0.03 |

Table 5. Plant diversity in the Sukamade Resort area, Meru Betiri National Park, Indonesia

| Family | Species name | Number of individuals | | | | IVI (%) | | | |
|----------------|-------------------------------------|-----------------------|----|----|-----|---------|-------|-------|-------|
| | | CF | OL | RB | CCF | CF | OL | RB | CCF |
| Combretaceae | <i>Terminalia catappa</i> | 3 | 0 | 0 | 0 | 3.94 | 0.00 | 0.00 | 0.00 |
| Apocynaceae | <i>Tabernaemontana sphaerocarpa</i> | 47 | 0 | 0 | 0 | 35.16 | 0.00 | 0.00 | 0.00 |
| Malvaceae | <i>Hibiscus tiliaceus</i> | 36 | 0 | 0 | 3 | 26.99 | 0.00 | 0.00 | 9.09 |
| Malvaceae | <i>Pterospermum javanicum</i> | 0 | 0 | 1 | 4 | 0.00 | 0.00 | 2.48 | 10.21 |
| Pandanaceae | <i>Pandanus tectorius</i> | 23 | 0 | 0 | 0 | 19.58 | 0.00 | 0.00 | 0.00 |
| Acanthaceae | <i>Avicennia marina</i> | 12 | 0 | 0 | 0 | 9.96 | 0.00 | 0.00 | 0.00 |
| Rubiaceae | <i>Mitragyna speciosa</i> | 17 | 0 | 0 | 0 | 13.15 | 0.00 | 0.00 | 0.00 |
| Calophyllaceae | <i>Calophyllum inophyllum</i> | 4 | 1 | 0 | 0 | 4.29 | 1.89 | 0.00 | 0.00 |
| Fabaceae | <i>Delonix regia</i> | 0 | 3 | 0 | 0 | 0.00 | 4.09 | 0.00 | 0.00 |
| Fabaceae | <i>Albizia chinensis</i> | 0 | 10 | 5 | 0 | 0.00 | 7.81 | 8.31 | 0.00 |
| Euphorbiaceae | <i>Hevea brasiliensis</i> | 0 | 14 | 23 | 0 | 0.00 | 10.62 | 26.37 | 0.00 |
| Euphorbiaceae | <i>Ricinus communis</i> | 0 | 0 | 11 | 0 | 0.00 | 0.00 | 10.93 | 0.00 |
| Rubiaceae | <i>Neolamarckia cadamba</i> | 0 | 15 | 0 | 0 | 0.00 | 10.92 | 0.00 | 0.00 |
| Rubiaceae | <i>Coffea</i> sp. | 0 | 6 | 3 | 0 | 0.00 | 6.59 | 5.39 | 0.00 |
| Arecaceae | <i>Dyopsis lutescens</i> | 0 | 4 | 0 | 0 | 0.00 | 4.39 | 0.00 | 0.00 |
| Arecaceae | <i>Cocos nucifera</i> | 0 | 2 | 0 | 0 | 0.00 | 2.20 | 0.00 | 0.00 |
| Moraceae | <i>Ficus septica</i> | 0 | 3 | 0 | 0 | 0.00 | 4.09 | 0.00 | 0.00 |
| Moraceae | <i>Ficus benjamina</i> | 0 | 0 | 0 | 1 | 0.00 | 0.00 | 0.00 | 3.98 |
| Moraceae | <i>Streblus asper</i> | 0 | 0 | 0 | 1 | 0.00 | 0.00 | 0.00 | 3.98 |
| Moraceae | <i>Ficus variegata</i> | 0 | 0 | 0 | 6 | 0.00 | 0.00 | 0.00 | 15.31 |
| Moraceae | <i>Ficus racemosa</i> | 0 | 0 | 0 | 3 | 0.00 | 0.00 | 0.00 | 9.09 |
| Annonaceae | <i>Annona muricata</i> | 0 | 8 | 38 | 0 | 0.00 | 7.20 | 28.84 | 0.00 |
| Meliaceae | <i>Swietenia mahagoni</i> | 0 | 1 | 0 | 0 | 0.00 | 1.89 | 0.00 | 0.00 |
| Meliaceae | <i>Dysoxylum loureirii</i> | 0 | 0 | 0 | 2 | 0.00 | 0.00 | 0.00 | 7.96 |
| Poaceae | <i>Schizostachyum brachycladum</i> | 0 | 0 | 33 | 0 | 0.00 | 0.00 | 14.41 | 0.00 |
| Sapindaceae | <i>Harpullia arborea</i> | 0 | 0 | 0 | 50 | 0.00 | 0.00 | 0.00 | 96.18 |
| Asteraceae | <i>Chromolaena odorata</i> | 73 | 90 | 67 | 0 | 36.94 | 44.90 | 51.71 | 0.00 |
| Asteraceae | <i>Sphagneticola trilobata</i> | 18 | 0 | 0 | 0 | 12.05 | 0.00 | 0.00 | 0.00 |
| Verbenaceae | <i>Stachytarpheta jamaicensis</i> | 36 | 60 | 24 | 0 | 24.09 | 30.99 | 24.77 | 0.00 |
| Verbenaceae | <i>Lantana camara</i> | 0 | 17 | 0 | 0 | 0.00 | 11.53 | 0.00 | 0.00 |
| Lamiaceae | <i>Salvia misella</i> | 13 | 0 | 0 | 0 | 8.86 | 0.00 | 0.00 | 0.00 |
| Linderniaceae | <i>Torenia crustacea</i> | 6 | 46 | 0 | 0 | 4.98 | 18.79 | 0.00 | 0.00 |
| Malvaceae | <i>Hibiscus surattensis</i> | 0 | 12 | 0 | 0 | 0.00 | 8.42 | 0.00 | 0.00 |
| Cleomaceae | <i>Cleome rutidosperma</i> | 0 | 27 | 0 | 0 | 0.00 | 16.17 | 0.00 | 0.00 |
| Convolvulaceae | <i>Ipomoea longifolia</i> | 0 | 0 | 6 | 0 | 0.00 | 0.00 | 8.74 | 0.00 |
| Fabaceae | <i>Mimosa pigra</i> | 0 | 0 | 12 | 0 | 0.00 | 0.00 | 11.36 | 0.00 |
| Amaranthaceae | <i>Celosia argentea</i> | 0 | 0 | 6 | 0 | 0.00 | 0.00 | 6.70 | 0.00 |
| Acanthaceae | <i>Pseuderanthemum variabile</i> | 0 | 0 | 0 | 19 | 0.00 | 0.00 | 0.00 | 44.21 |
| Araceae | <i>Colocasia esculenta</i> | 0 | 9 | 0 | 0 | 0.00 | 7.51 | 0.00 | 0.00 |

Floral visitations of butterflies

Table 7 presents data on butterfly visits to various flowering plant species from several families. However, visits were not evenly distributed across all plant species. *Chromolaena odorata* (Asteraceae) and *S. jamaicensis* (Verbenaceae) were the most frequently visited plants. *Chromolaena odorata* received visits from the highest number of butterfly species (12 species) among all recorded plants, reflecting its frequent occurrence in visitation records during the study. Shrubs were more frequently recorded as visitation sites compared to herbs, lianas, or trees, indicating that flowering plants in the shrub layer were commonly observed as butterfly visitation locations. Similar patterns have been reported in previous studies, where shrubs often serve as accessible nectar sources for butterflies (Rusman et al. 2016).

In terms of flower morphology, compound (head) and tubular flower types have been reported to be frequently visited by butterflies across various studies. Compound flowers consist of numerous small florets within a single

inflorescence, while tubular flowers possess a structure compatible with the butterfly proboscis, enabling access to nectar (Anderson et al. 2014). In this study, several butterfly species were observed on white and purple flowers such as *C. odorata* and *S. jamaicensis*, while visits to yellow and orange flowers were recorded less frequently. This pattern indicates variation in flower color observed during butterfly visits. Flower color is known to function as a visual cue that assists butterflies in locating nectar sources (Cepero et al. 2015).

Several butterfly-plant interactions recorded in this study were not reported in the cited references (Rusman et al. 2016; Sáfián 2021). These observations may provide additional field-based information on butterfly-plant associations within the Sukamade landscape, although they should not be interpreted as definitive evidence of novel ecological relationships. However, it is important to note that floral visitation data in this study were based on occurrence observations rather than quantitative measurements; therefore, the results reflect field co-

occurrence only and do not indicate visitation frequency, preference, or interaction strength.

Canonical Correspondence Analysis (CCA)

CCA was applied to visualize patterns of butterfly species distribution along gradients of measured environmental variables (Figure 7). The first axis had an eigenvalue of 0.3144 and explained 43.91% of the data variation, while the second axis had an eigenvalue of 0.2771, contributing 38.69%. Cumulatively, both axes explained approximately 82.6% of the variation in species-environment relationships. However, permutation tests indicated that neither the overall CCA model nor the individual axes were significant (Trace $p = 0.838$; Axis 1 $p = 0.70$; Axis 2 $p = 0.96$).

Visually, the CCA ordination showed certain clustering tendencies. Several species were found near with Closed-canopy Forest, while other species clustered around Coastal Forest and Open Land habitats. Another group of species

tended to be located near areas representing Riverbank habitat. On the other hand, some species were positioned in the center of the diagram, indicating no clear separation along the measured environmental gradients.

The environmental vectors indicated that certain species were oriented in the direction of specific variables such as air humidity, temperature, wind speed, and light intensity. However, this pattern is only visual and does not indicate a statistically verifiable relationship. Thus, the CCA ordination diagram merely reflects spatial tendencies of species distribution within the analysis space. Given that the CCA results are non-significant, interpretations regarding the proximity of species positions to environmental variables should be made cautiously. Such patterns can only be considered as preliminary indications, not as evidence of a strong ecological relationship between butterfly distribution and the measured abiotic factors.

Table 6. Vegetation index analysis in the Sukamade Resort area, Meru Betiri National Park, Indonesia

| | Coastal Forest | Open Land | Riverbanks | Closed-canopy Forest |
|------------------|----------------|-----------|------------|----------------------|
| Shannon_H | 2.18±0.20 | 2.30±0.11 | 2.08±0.28 | 1.43±0.24 |
| Margalef | 2.00±0.34 | 3.00±0.22 | 2.02±0.51 | 1.80±0.41 |
| Dominance_D | 0.13±0.03 | 0.14±0.04 | 0.15±0.05 | 0.37±0.05 |
| Evenness e^H/S | 0.70±0.05 | 0.56±0.10 | 0.66±0.04 | 0.46±0.12 |

Table 7. Floral characteristics of plants visited by butterfly species in the Sukamade Resort area, Meru Betiri National Park, Indonesia

| Nectar plants | Plant habits | Flower color | Flower type | Butterfly species visited the flowers |
|-----------------------------------|--------------|-----------------|-------------|---|
| Acanthaceae | | | | |
| <i>Pseuderanthemum variabile</i> | Herb | Pink | Tube | <i>Eurema hecabe</i> |
| Asteraceae | | | | |
| <i>Chromolaena odorata</i> | Shrub | White | Head | <i>Celastrina lavendularis</i> , <i>Ideopsis juvenata</i> , <i>Euploea mulciber</i> , <i>Ypthima horsfieldii</i> , <i>Euploea phaenareta</i> , <i>Euploea tulliolus</i> , <i>Papilio memnon</i> , <i>Catopsilia pomona</i> , <i>Troides helena</i> , <i>Mycalesis horsfieldii</i> , <i>Papilio paradoxa</i> , and <i>Jamides celeno</i> |
| <i>Sphagneticola trilobata</i> | Herb | Yellow | Head | <i>Ypthima horsfieldii</i> |
| Cleomaceae | | | | |
| <i>Cleome rutidosperma</i> | Herb | Purple | Dish | <i>Leptosia nina</i> |
| Convolvulaceae | | | | |
| <i>Ipomoea longifolia</i> | Shrub | Orange | Tube | <i>Catopsilia pomona</i> |
| Fabaceae | | | | |
| <i>Mimosa pigra</i> | Shrub | Pink | Brush | <i>Acraea terpsicore</i> |
| Lamiaceae | | | | |
| <i>Salvia misella</i> | Herb | Bluish purple | Tube | <i>Jamides celeno</i> and <i>Celastrina lavendularis</i> |
| Sapindaceae | | | | |
| <i>Harpullia arborea</i> | Tree | Yellowish white | Brush | <i>Moduza procris</i> , <i>Tanaecia trigerta</i> , <i>Tanaecia vikrama</i> , <i>Junonia hedonia</i> , and <i>Tanaecia julii</i> |
| Linderniaceae | | | | |
| <i>Torenia crustacea</i> | Herb | Bluish purple | Funnel | <i>Celastrina lavendularis</i> |
| Verbenaceae | | | | |
| <i>Stachytarpheta jamaicensis</i> | Shrub | Purple | Tube | <i>Eurema hecabe</i> , <i>Papilio memnon</i> , <i>Parantica aspasia</i> , <i>Leptosia nina</i> , <i>Cepora iudith</i> , <i>Ideopsis juvenata</i> , <i>Drupadia ravindra</i> , <i>Catopsilia pomona</i> , and <i>Papilio polytes</i> |
| <i>Lantana camara</i> | Shrub | Orange | Tube | <i>Catopsilia pomona</i> |

Principal Component Analysis (PCA)

PCA was used to visualize the distribution patterns of butterfly species and vegetation across four habitat types (Figure 8). This analysis employed a combined data matrix of species abundance in each habitat using a correlation matrix approach to reduce the effects of differing measurement scales. The first two principal components explained 78.63% of the total variation, with PC1 accounting for 54.30% and PC2 accounting for 24.33% of the variation.

The PCA ordination diagram showed a separation between Closed-canopy Forest and the other three habitat types. Closed-canopy Forest was located in a distinct position in the ordination space, while Open Land, Coastal Forest, and Riverbank tended to be located in the same direction and within the same quadrant. This pattern suggests similarities in species composition distribution

among these three habitats within the analysis space. Furthermore, the distribution of species in the ordination diagram showed that some species were concentrated in specific areas, while others were more widely scattered without clear separation patterns. The proximity of butterfly species positions to particular vegetation groups in the ordination space merely reflects distribution patterns within the analysis and cannot be interpreted as direct ecological relationships.

Overall, PCA only describes variation in species composition among habitats. Given that this analysis used only four habitat units, interpretation requires caution and remains descriptive. Therefore, these results are insufficiently robust to support inferences regarding the strength of interactions or strong ecological relationships between butterflies and vegetation.

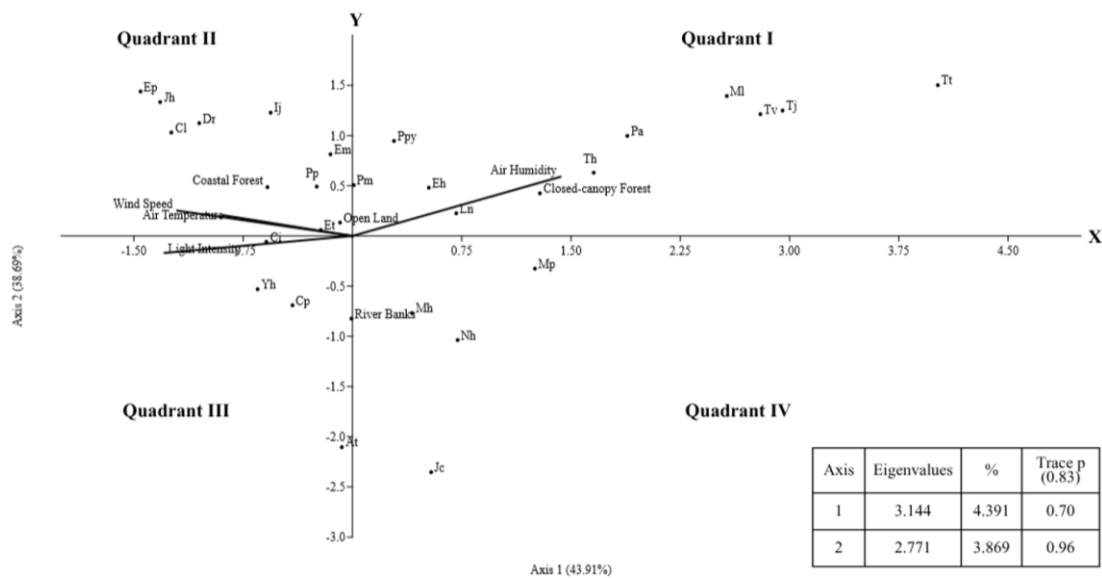


Figure 7. Canonical Correspondence Analysis of butterflies in the Sukamade Resort area, Meru Betiri National Park, Indonesia

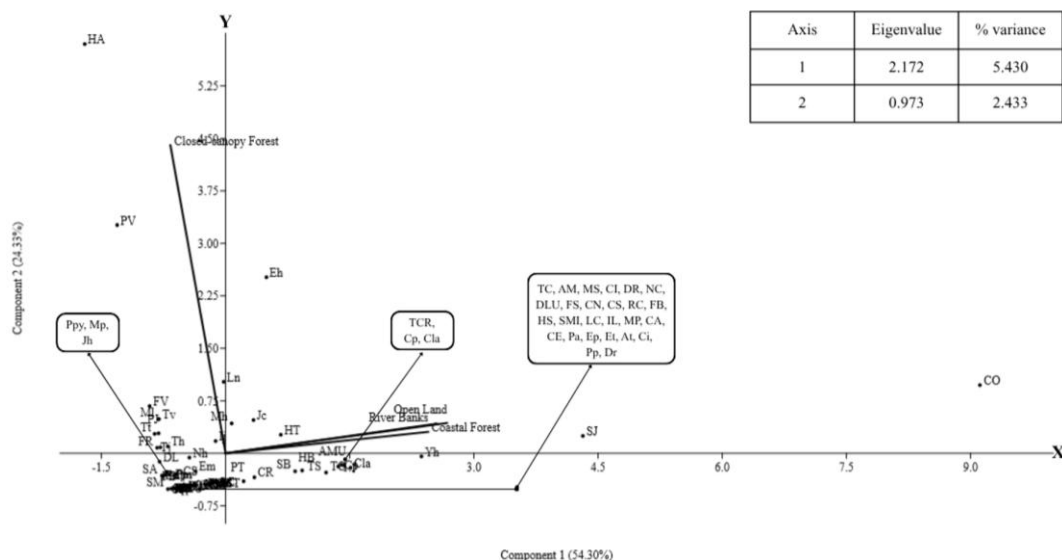


Figure 8. Principal component analysis of butterflies in the Sukamade Resort area, Meru Betiri National Park, Indonesia

The ecological patterns observed in this study have important implications for conservation management. The findings highlight the importance of habitat heterogeneity in supporting butterfly diversity in the Sukamade area. Although the Open Land habitat exhibited higher species richness and diversity, other habitat types, including Riverbanks, Closed-canopy Forest, and Coastal Forest, also contribute to overall community structure by supporting different species compositions. These results indicate that each habitat type plays a complementary role in maintaining butterfly communities. Therefore, conservation management should focus efforts on maintaining a mosaic of various habitat types and preventing habitat degradation, rather than prioritizing one particular habitat type. This approach plays a crucial role in preserving overall butterfly diversity, including protected species such as *T. helena*.

In conclusion, butterfly diversity in the Sukamade Resort area of Meru Betiri National Park was categorized as moderate, with the highest diversity recorded in Open Land habitats ($H': 2.72$), which also supported the highest species richness. Differences among habitats were also reflected in community structure, with more even species distribution observed in the closed-canopy forest. These findings indicate variation in butterfly assemblages across habitat types within the study area. However, several limitations should be acknowledged. Vegetation data were analyzed at the pooled-habitat level, and the multivariate analyses were exploratory, yielding non-significant CCA results that may limit inference about species–environment relationships. In addition, the study was conducted over a limited time period, potentially missing seasonal variation. Floral visitation data were based on occurrence observations and do not represent quantitative interaction measures. Future studies incorporating longer sampling periods and more detailed quantitative approaches are needed to improve understanding of butterfly–habitat relationships.

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