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Cover: Digital illustration of *Impatiens chamchumroonii* in Krita by Dupati Poojitha.

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ARTICLE

Community structure of Lepidoptera in Nantu-Boliohuto Wildlife Reserve, Sulawesi, Indonesia

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Abstract: Lepidoptera diversity serves as a vital bioindicator of ecosystem health and environmental quality. This research investigated the Lepidoptera community structure within the Nantu-Boliohuto Wildlife Reserve, Celebes, Indonesia, using a purposive sampling method with insect nets at three distinct stations. Diversity indices at all stations were categorized as moderate: Station I, far from the river area adjacent to Camp Yayasan Adudu Nantu International (H' = 1.57); Station II, at the Babi Rusa wallow area (H' = 2.48); and Station III, the waterfall area (H' = 2.64). Evenness was high at all stations (Station I: E = 0.99; Station II: E = 0.94; Station III: E = 0.98). Dominance was low across all stations: Station I (C = 0.21), Station II (C = 0.09), and Station III (C = 0.08). The species abundance index of *Elymnias resplendens* Martin, 1929 (Nymphalidae) was the highest (Di = 0.124). These findings contribute to environmental quality assessment and serve as a data inventory for Lepidoptera in the Nantu-Boliohuto Wildlife Reserve.

Keywords: Butterfly, checklist, conservation, Gorontalo, Nymphalidae, protected area, specimens, species diversity, tropical forest, Wallacea.

Indonesian: Keanekaragaman Lepidoptera berfungsi sebagai bioindikator vital bagi kesehatan ekosistem dan kualitas lingkungan. Penelitian ini mengkaji struktur komunitas Lepidoptera di Suaka Margasatwa Nantu-Boliohuto, Sulawesi, Indonesia, menggunakan metode purposive sampling dengan jaring serangga pada tiga stasiun yang berbeda. Indeks keanekaragaman di seluruh stasiun dikategorikan sedang: Stasiun I, yang jauh dari area sungai dan berdekatan dengan Camp Yayasan Adudu Nantu Internasional (H'= 1.57); Stasiun II, di area kubangan Babi Rusa (H' = 2.48); dan Stasiun III, di area air terjun (H' = 2.64). Nilai kemerataan tergolong tinggi di semua stasiun (Stasiun I: E = 0.99; Stasiun II: E = 0.94; Stasiun III: E = 0.98), sedangkan nilai dominansi tergolong rendah di seluruh lokasi: Stasiun I (C = 0.21), Stasiun II (C = 0.09), dan Stasiun III (C = 0.08). Indeks kelimpahan spesies Elymnias resplendens Martin, 1929 (Nymphalidae) adalah yang tertinggi (Di = 0.124). Temuan ini berkontribusi pada penilaian kualitas lingkungan dan berfungsi sebagai inventarisasi data Lepidoptera di Suaka Margasatwa Nantu-Boliohuto.

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Author contributions: CJL—research design, conceptualization, taxonomic assessment, field data collection, data analysis, writing, and editing the manuscript. MSH—research design, conceptualization, methodological guidance, data analysis, writing, and editing the manuscript. SS—field data collection, data compilation, methodological guidance, and writing. DWK—data curation, writing, editing the manuscript, and manuscript review.

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INTRODUCTION

The Nantu-Boliohuto Wildlife Reserve is a conservation forest located administratively in three districts: Gorontalo, Boalemo, and northern Gorontalo. Initially designated as a wildlife reserve in 1999 with an area of 31,215 ha, it was later expanded to 51,507.33 ha by Minister of Forestry Decree No. 325/Menhut-II/2010. This area is a tropical forest that retains its original ecosystem, with high biodiversity of plants and animals. The forest vegetation is largely dominated by tall trees with dense canopies, mainly from the families Anacardiaceae, Salicaceae, Guttiferae, Datiscaceae, Annonaceae, Myristicaceae, Apocynaceae, Moraceae, Ebenaceae, Sapotaceae, and a small portion from the Dipterocarpaceae family. There are 204 plant species, 17 of which are endemic and protected under Government Regulation No. 7 of 1999 (Hamidun & Baderan 2014). Additionally, the Nantu-Boliohuto Wildlife Reserve is a habitat and exploration area for endemic species such as Babirusa *Babyrousa celebensis* (Deninger, 1909), Anoa *Bubalus depressicornis* (C.H. Smith, 1827), Sulawesi Black Macaque *Macaca hecki* (Matschie, 1901), Tarsier *Tarsius tarsier* (Erxleben, 1777), Sulawesi Bear Cuscus *Strigocuscus celebensis* (Gray, 1858), Sulawesi Wild Pig *Sus celebensis* (Müller & Schlegel, 1843), 80 bird species, various reptiles, and insects. The biodiversity of the area is a source of livelihood for the surrounding communities, the majority of whom depend on the forest for their livelihoods (Laindi et al. 2021).

Butterflies (Lepidoptera) are among the insects inhabiting the Nantu-Boliohuto Wildlife Reserve and form part of the biodiversity that must be conserved to prevent extinction or a decline in species diversity, as they play a crucial role in maintaining ecosystems. They aid in the pollination of flowering plants, enabling the natural process of plant reproduction (Adom et al. 2021; Boukouvala et al. 2022). The presence of butterfly populations in a habitat depends heavily on the diversity of host plants, establishing a close relationship between biodiversity and habitat conditions (Ho & Altermatt 2024). Ecologically, butterflies help maintain ecosystem balanceand serve as bioindicators of environmental quality (Kőrösi et al. 2022). Habitat destruction, which leads to a decrease in host plant diversity, is a key factor contributing to the decline in butterfly diversity. Tyler (2020) notes that habitat destruction results from human activities converting natural habitats. Additionally, butterfly diversity is influenced by factors such as altitude, temperature, humidity, light intensity, weather, seasons, and nectar volume in plants.

Butterfly diversity varies from one location to another because their presence in a habitat is closely linked to environmental factors, including abiotic factors such as sunlight intensity, temperature, air and water humidity, and biotic factors such as vegetation and other animals. Indonesia, as an archipelagic country, has diverse environmental factors. These differences cause butterfly species to vary across island habitats. The presence of species in a habitat is inseparable from their distribution and adaptation abilities (Lestari et al. 2015).

Like other animals, butterflies can also face scarcity and extinction. Research by Hamidun et al. (2016) states that there are many butterfly species of the Order Lepidoptera in the Nantu-Boliohuto Wildlife Reserve, but the distribution and diversity of butterflies in various habitat types in the area have not been studied or published. This information is crucial, as many butterfly species rely heavily on one or two host plant species that exist only in certain habitats, and the potential for forest degradation is undeniable. Therefore, before biodiversity, especially butterflies, is lost, it is essential to study their distribution and analyze their diversity as fundamental biodiversity data, for environmental quality assessment, and to establish a Lepidoptera data inventory for the Natural Resources Conservation Center, Conservation Section II, Gorontalo Region. The objective of this research is to analyze the distribution and community structure of Lepidoptera across diverse habitat types within the Nantu-Boliohuto Wildlife Reserve to provide fundamental biodiversity data for environmental quality assessment and an updated species checklist inventory.

MATERIALS AND METHODS

Study area

The research was conducted in the Nantu-Boliohuto Wildlife Reserve, Boalemo, Gorontalo Province, Sulawesi, Indonesia (Image 1A). Three observation stations were involved (Image 1B): Station I, near Camp Yayasan Adudu Nantu International (YANI) (1.314° N, 122.482° E); Station II, Babirusa Wallow area (1.321° N, 122.468° E); and Station III, waterfall areas (1.330° N, 122.470° E). The research took place over five months, from February–June 2023.

Tools and materials

Tools used include an insect net (sweep net) for capturing butterflies and moths, writing utensils for recording collected data, a camera for documenting

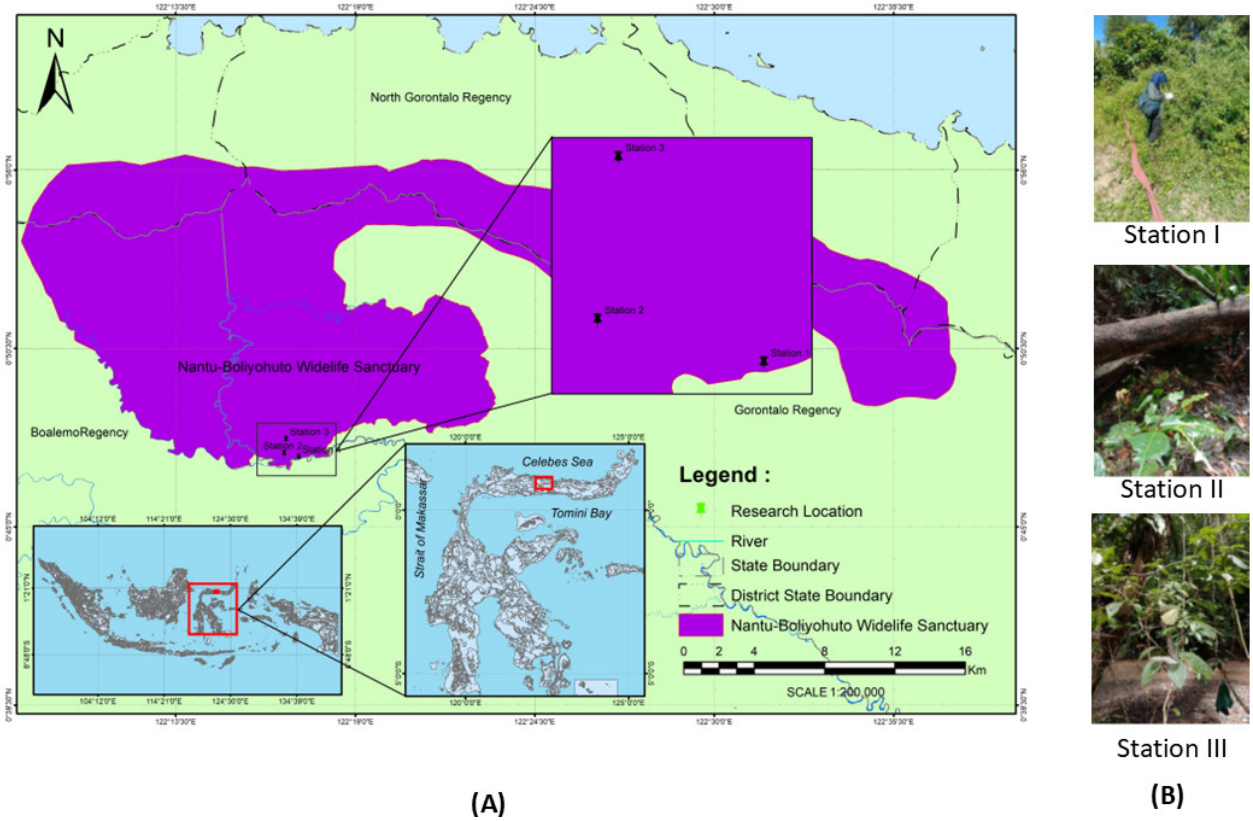

Image 1. Research location: A—map of Nantu-Boliohuto Wildlife Reserve, Boalemo, Gorontalo Province | B—types of habitats present at different observation stations.

activities and specimen samples, perforated plastic jars as temporary containers for butterflies in the field, a thermohygrometer for measuring humidity, a lux meter for measuring light intensity, a thermometer, GPS (global positioning system) for marking locations, a ruler for measuring specimens, butterfly identification books, insect specimen boxes, and insect pins. Materials used include captured Lepidoptera, ethyl acetate, and envelope paper or paper envelopes as specimen containers.

Procedures

Collection, specimen fixation, and identification

Data collection was conducted through survey methods using purposive sampling at three observation stations, following the modified Pollard Walk method (Caldas & Robbins 2003; Longcore et al. 2004). Two transects were placed in each habitat type at predetermined locations based on the need to represent distinct habitat types and environmental characteristics variations of each station, specifically the open-canopy near camp area, the semi-closed canopy babirusa wallow areas, and the dense-canopy waterfall zone. Transect lines were established along lengths of 200 m, totaling 400 m per station, which aligns with the standard observation by Hamer et al. (1997). Lepidoptera, including diurnal moths, were collected using the sweep net method (Hamer et al. 1997; Le & Vu 2024) between 0800–1200 h and 1300–1600 h (Scherrer et al. 2013; Peggie et al. 2022). Only one specimen of each species was collected. If the same species was encountered again, it was released to prevent possible double-counting. Specimens were fixed by placing them in jars containing cotton soaked in ethyl acetate, which were then closed and left until the specimens died. They were then placed in triangular paper envelopes measuring 30 × 20 cm with wings spread.

Identification and classification of the lepidopterans were conducted at the Zoology Laboratory, Department of Biology, Faculty of Mathematics and Natural Sciences, Gorontalo State University using identification books: referring to “Butterflies of the South East Asian Island, Part I Papilionidae, Part II Pieridae-Danaidae, Part III Satyridae-Lybytheidae, Part IV Nympalidae (I), Part V Nympalidae (II)” (Tsukada & Nishiyama 1982), “The Complete Field Guide to Butterflies of Australia” (Braby

2004), "Practical Guide to Butterflies at Bogor Botanical Gardens" (Peggie & Amir 2006), "Neotropical Genera of Emerald Moths (Geometrinae)" (Pitkin 1996), "Geometrid Moths of the World: A Catalogue" (Scoble 1999), and "The Moths of Borneo: Family Geometridae" (Holloway 1996). The Global Biodiversity Information Facility (GBIF 2025), Funet (Savela 2025), and Catalogue of Life (Bánki et al. 2025) online databases were also consulted for species occurrence data, updated accepted names, and digital images of species. After identification, classification was carried out. The protection status of the recorded butterfly species was assessed according to the Regulation of the Ministry of Environment and Forestry Indonesia No. P. 106/2018, and the International Union for Conservation of Nature's Red List of Threatened Species (IUCN Red List) was used to determine the conservation status of the Lepidoptera species.

Data analysis

Community structure was evaluated based on species abundance, defined as the total number of individuals per species recorded in each habitat. Species diversity was assessed using the Shannon-Wiener diversity index $H' = -\sum_{i=1}^{S} \text{pi}\, ln\, \text{pi}$, where: pi = *ni* / *N*, n_i is the number of individuals of the *i*-th species, *N* is the total number of individuals, and *S* is the total number of species. Diversity levels were categorized as high (H' > 3), moderate, (1 ≤ H' ≤ 3) and low (H' < 1) (Shannon & Wiener, 1963). Relative abundance ($Di = \frac{ni}{N} x\ 100\%$) was calculated to determine if a species is dominant (Di > 5%), sub-dominant (2 < Di < 5%), and non-dominant (Di < 2%). Additionally, the distribution of individuals was analyzed using the Pielou Evenness Index (E = H' / ln S) (Ludwig & Reynolds 1988). Dominance (D) is analyzed using the Simpson formula

$$D = \sum \frac{(ni\ (ni-1))}{(N\ (N-1))},$$

where the value of 0 < D < 0.5 indicates no species dominate over others, suggesting a stable community structure; 0.5 < D < 1 indicates some species dominate over others, suggesting a labile community structure due to ecological pressures.

RESULTS AND DISCUSSION

Result

Based on the results in Table 1, eight families of Lepidoptera were found: Geometridae, Erebidae, Uraniidae, Nymphalidae, Hesperiidae, Papilionidae, Lycaenidae, and Pieridae. There are 18 genera: namely *Eumelea* Duncan [& Westwood], 1841; *Asura* Walker, 1854; *Idea* Fabricius, 1807; *Acropteris* Geyer, 1832; *Erionota* Mabille, 1878; *Moduza* Moore, [1881]; *Elymnias* Hübner, 1818; *Sithon* Hübner, [1819]; *Cepora* Billberg, 1820; *Graphium* Scopoli, 1777; *Hebomoia* Hübner, [1819]; *Chilasa* Moore, 1881; *Appias* Hübner, [1819]; *Parthenos* Hübner, [1819]; *Catopsilia* Hübner, [1819]; *Parnara* Moore, [1881]; *Faunis* Hübner, [1819]; and *Hypolimnas* Hübner, [1819]. The total number of Lepidoptera found in the Nantu-Boliohuto Wildlife Reserve was 1,269 individuals. At Station I, located near the Adudu International Foundation (YANI) camp, far from the river and dominated by shrub and grass habitat, 186 individuals were found. Station II, the Babirusa Wallow Area, with habitat dominated by trees and proximity to a water source, recorded 487 individuals. The highest number, 596 individuals, was found at Station III, the Waterfall Area, which has a plant-and understory-dominated habitat near the river (Table 1 & Image 1B). The identification of Lepidoptera species in the Nantu-Boliohuto Wildlife Reserve is presented in Image 2.

Based on Figure 1, all stations showed moderate diversity. As their Shannon diversity index (H') values fell within the 1 ≤ H' ≤ 3 range. Station I, near the Adudu International Foundation (YANI) Camp, recorded the lowest diversity among the stations with an H' of 1.57. Station II, in the Babirusa Wallow area, showed a higher diversity level with an H' of 2.48, while the highest diversity was found at Station III, located in the waterfall area, with an H' of 2.64. Although all stations are classified as moderate, the increasing trend from Station I to III reflects the greater habitat complexity and proximity to water sources in the waterfall zone.

Based on Figure 2, the species with the highest

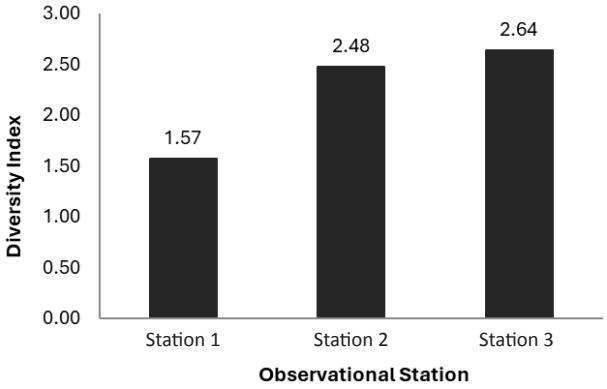

Figure 1. Shannon diversity index (H') in the Nantu-Boliohuto Wildlife Reserve.

Table 1. Identification of Lepidoptera species in the Nantu-Boliohuto Wildlife Reserve, Boalemo, Gorontalo Province.

Family	Species	Number of individuals			Total number of sampled individuals
		ST I	ST II	ST III	
Hesperiidae	*Erionota thrax* (Linnaeus, 1767)	-	57	-	57
	Parnara bada (Moore, 1878)	-	33	25	58
Lycaenidae	*Sithon nedymond* (Cramer, 1780)	-	-	50	50
Pieridae	*Cepora timnatha* (Hewitson, 1862)	31	31	44	106
	Hebomoia glaucippe (Linnaeus, 1758)	-	22	56	78
	Appias nero (Fabricius, 1793)	-	10	46	56
	Appias zarinda (Boisduval, 1836)	-	17	37	54
	Catopsilia pomona (Fabricius, 1775)	51	8	21	80
Papilionidae	*Graphium eurypylus* (Linnaeus, 1758)	-	-	35	35
	Chilasa veiovis (Hewitson, 1853)	-	-	32	32
Nymphalidae	*Parthenos sylvia* (Cramer, 1776)	-	-	37	37
	Elymnias hypermnestra (Linnaeus, 1763)	48	-	-	48
	Idea blanchardii Marchal, 1845	-	37	57	94
	Cyrestis themire Honrath, 1884	-	44	33	77
	Faunis canens Hübner, [1826]	23	-	-	23
	Elymnias resplendens (Martin, 1929)	-	81	76	157
	Hypolimnas bolina (Linnaeus, 1758)	33	-	-	33
	Moduza lymire lymire (Hewitson, 1859)	-	35	-	35
Uraniidae	*Acropteris ciniferaria* (Walker, 1866)	-	51	25	76
Geometridae	*Eumelea rosalia* (Stoll, 1781)	-	42	-	42
Erebidae	*Asura* sp.	-	19	22	41
Total individuals overall		186	487	596	1269

Note: The dash (-) indicates the absence of individuals recorded.s

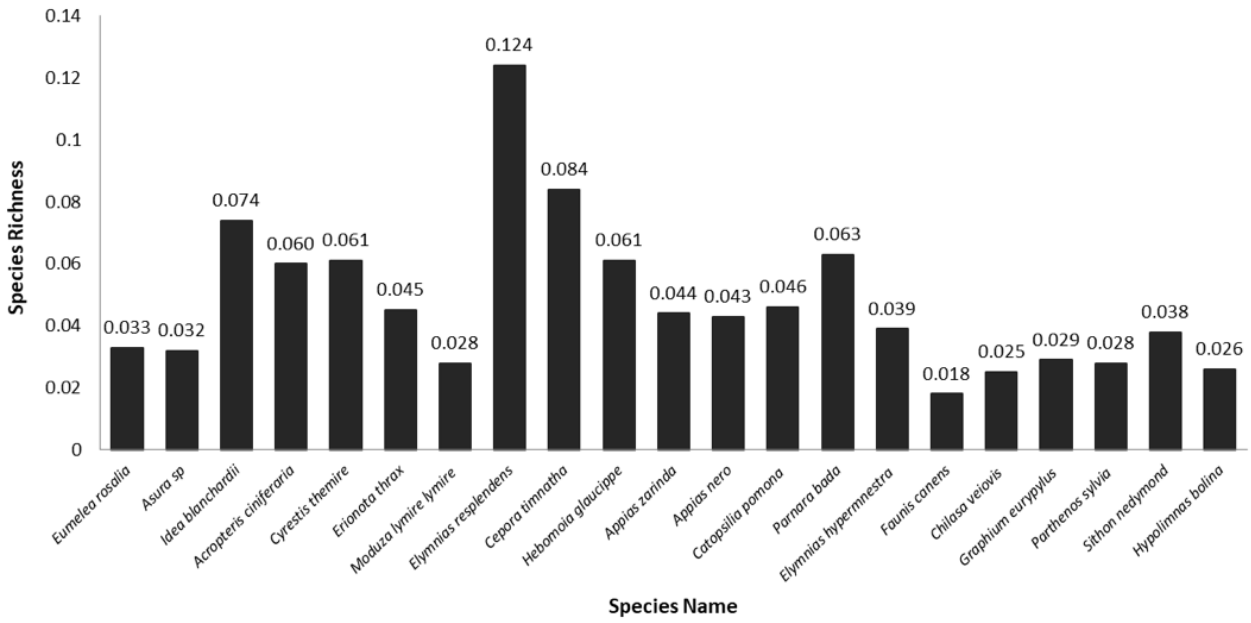

Figure 2. Species richness in the Nantu-Boliohuto Wildlife Reserve.

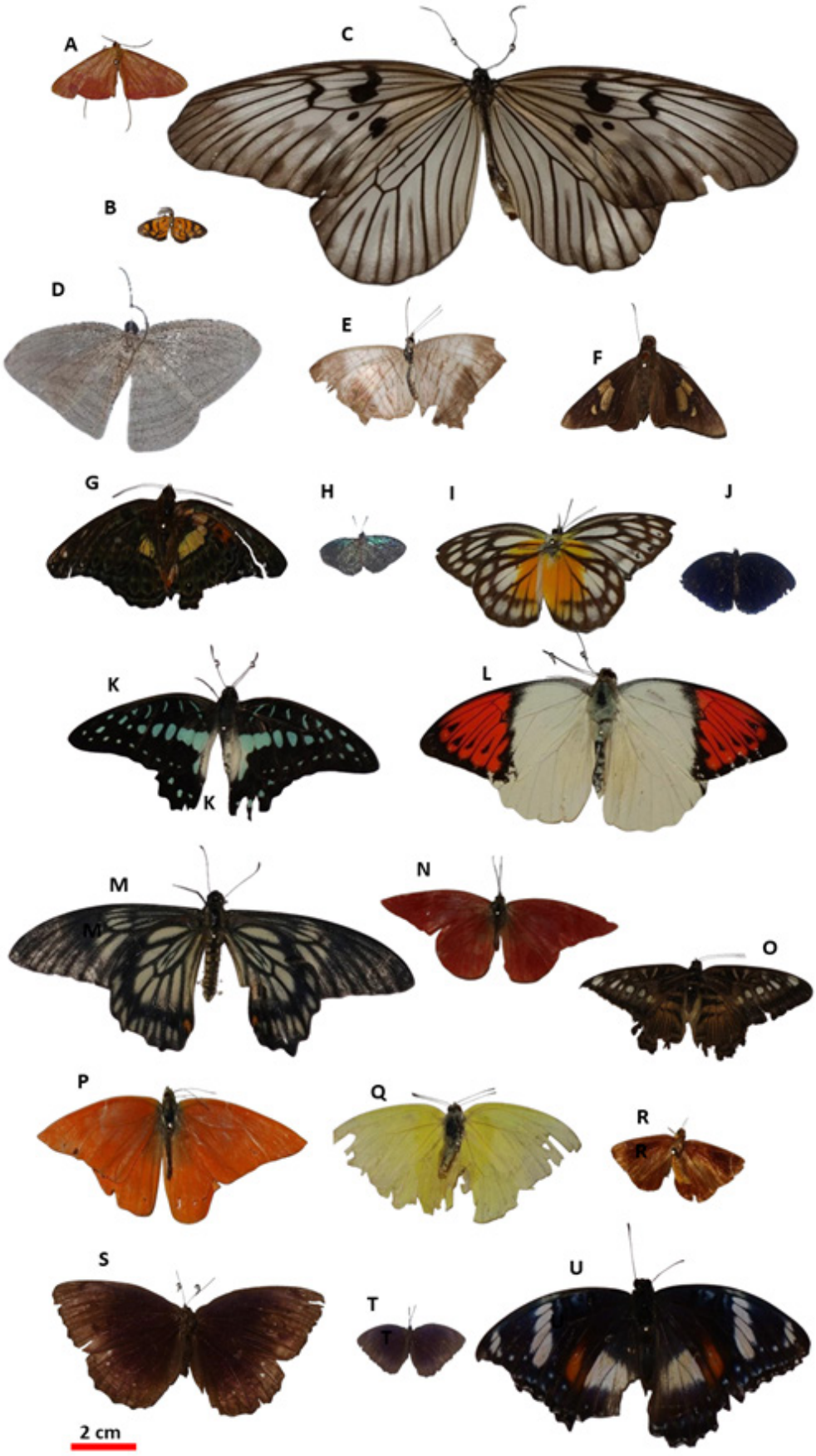

Image 2. Lepidoptera in the Nantu-Boliohuto Wildlife Reserve, Boalemo, Gorontalo Province: A—*Eumelea rosalia* (Stoll, [1781]) | B—*Asura* sp. | C—*Idea blanchardii* Marchal, 1845 | D—*Acropteris ciniferaria* (Walker, 1866) | E—*Cyrestis themire* Honrath, 1884 | F—*Erionota thrax* (Linnaeus, 1767) | G—*Moduza lymire lymire* Hewitson, 1859 | H—*Elymnias resplendens* Martin, 1929 | I—*Cepora timnatha* (Hewitson, 1862) | J—*Sithon nedymond* subsp. ismarus Fruhstorfer, 1912 | K—*Graphium eurypylus* (Linnaeus, 1758) | L—*Hebomoia glaucippe* (Linnaeus, 1758) | M—*Chilasa veiovis* (Hewitson, 1853) | N—*Appias zarinda* (Boisduval, 1836) | O—*Parthenos sylvia* (Cramer, [1776]) | P—*Appias nero* (Fabricius, 1793) | Q—*Catopsilia pomona* (Fabricius, 1775) | R—*Parnara bada* (Moore, 1878) | S—*Faunis canens* Hübner, [1826] | T—*Elymnias hypermnestra* (Linnaeus, 1763) | U—*Hypolimnas bolina* (Linnaeus, 1758).

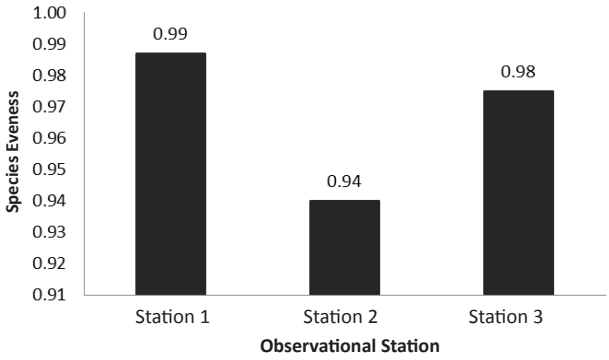

Figure 3. Species evenness in the Nantu-Boliohuto Wildlife Reserve.

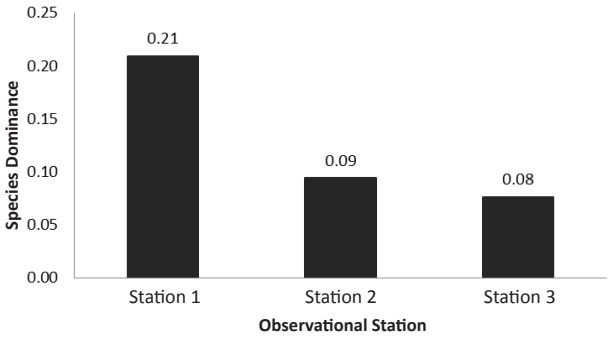

Figure 4. Species dominance in the Nantu-Boliohuto Wildlife Reserve.

abundance is *Elymnias resplendens* Martin, 1929. The *E. resplendens* is found at two research stations: station II in the Babirusa Wallow Area and station III in the waterfall area of the Nantu-Boliohuto Wildlife Reserve, with a Di value of 0.124. The species with the lowest abundance level is *Faunis canens* Hübner, [1826], with a Di value of 0.018.

According to Figure 3, the evenness index of Lepidoptera in the Nantu-Boliohuto Wildlife Reserve varies across the three stations. At station I, the value is E = 0.99; at station II, E = 0.94; and at station III, E = 0.98. Based on the evenness index criteria, the values at all three stations are considered relatively high, indicating a high level of evenness.

Based on the data analysis of the dominance index of Lepidoptera in the Nantu-Boliohuto Wildlife Reserve area (Figure 4), the values obtained for each station are as follows: Station I, the camp area, D = 0.21; Station II, the Babirusa Wallow area, D = 0.09; and Station III, the waterfall area, D = 0.08. According to the dominance index criteria, these values indicate a low dominance index.

The environmental parameters varied significantly across the stations, directly influencing Lepidoptera abundance (Table 2). Station I recorded the highest temperature (34 °C) and light intensity (5,501 lx), but the lowest humidity at 20%. While 20% is exceptionally low for a tropical forest, this value reflects the micro-climate of the open-canopy camp area, which is dominated by shrubs and grasses and located far from the river. This extreme condition creates the lowest abundance (186 individuals) recorded at this site. In contrast, Stations II and III exhibited more stable tropical forest conditions, with higher humidity levels (67% and 78%, respectively) and lower temperatures (29 °C). These conditions, found in the Babirusa wallow and waterfall areas, provide the necessary moisture and thermal buffering required for high species diversity and abundance.

Tabel 2. The abiotic environmental parameters at the research sites.

	Environmental factors	Station			Mean
		I	II	III	
1	Temperature (°C)	34	29	29	30.7
2	Light intensity (lx)	5,501	105	120	1,908.7
3	Humidity (%)	20	67	78	55

Discussion

The Nantu-Boliohuto Wildlife Reserve supports a diverse Lepidoptera community, evidenced by the 1,269 individuals across eight families. The presence of five butterfly and three moth families, particularly diurnal moths like *Eumelea rosalia* and *Erionota thrax*, suggests that the Reserve provides a broad range of ecological niches. Notably, this study recorded *Cyrestis themire,* which is currently assessed as 'Least Concern' (LC) according to the IUCN Red List (Müller & Tennent 2011). Combined with a moderate diversity index (H') ranging 1.57–2.64 across all stations, these finding reflect a balanced ecosystem capable of sustaining diverse tropical Lepidoptera populations. This moderate diversity indicates a stable community structure where resources are sufficient to prevent the total dominance of any single species, a condition further supported by the high evenness and low dominance indices recorded. As noted by Ahmed et al. (2022), such indices suggest a healthy, competitive environment where critical resources, including nectar and host plants, are distributed effectively across the landscape.

The variation in H' values is closely tied to the micro-climatic gradient of the stations. Station I's lower diversity (1.57) is a direct consequence of its extreme environmental conditions—high temperature (34 °C)

and intense solar radiation (5,501 lx). As explained by Liang et al. (2021), elevated temperatures and dry air accelerate the evaporation of body fluids and decrease nectar secretion in flowers. This forces butterflies to minimize activity to conserve energy and avoid desiccation, ultimately limiting species richness in open habitats. While butterflies generally survive within a range of 18–38 °C, the lack of canopy cover at Station I intensifies heat stress beyond the tolerance levels of many sensitive species. In contrast, the higher diversity recorded at Station III (2.64) is supported by the dense canopy and proximity to the waterfall, which provide a critical thermal buffer and high humidity (78%). According to Liao (2020), light intensity and the resulting heat energy are necessary for butterflies to maintain metabolic balance; however, the stable environment at Station III prevents the metabolic exhaustion associated with extreme heat. This creates an ideal refuge where moisture and temperature are balanced, facilitating a more diverse and active Lepidoptera community compared to the physiologically demanding conditions of the open-canopy camp area (Station I).

The abundance of specific species like *Elymnias resplendens* at Stations II and III highlights the importance of habitat preservation and water proximity. Butterflies are naturally drawn to damp areas (mud-puddling) for essential salts and minerals (Wilson et al. 2022). Conversely, the moth species *E. rosalia* was found only at station II, while *Asura* sp. and *A. ciniferaria* were found only at stations II and III during twilight hours. These moth species are most active during dusk and dawn (Pop et al. 2024).

Differences in the abundance of Lepidoptera species in the Nantu-Boliohuto Wildlife Reserve area can be attributed to variations in the types of plants that serve as food sources and the lack of plants that provide food for Lepidoptera species. The success of butterfly colonization depends on suitable habitats, particularly the availability of food sources (Tepa-Yotto et al. 2021). *Faunis canens* is the species with the lowest abundance value. This is because the *F. canens* is found only at station I, an area without a canopy where only shrubs are present (Image 1B). This is supported by Christharina & Abang (2022), who explained that, in general, the family Nymphalidae has a wide distribution and prefers places such as forests, open areas, and fields like stations II and III (Figure 1B). The combination of grassland vegetation, scrubland, and dominant trees inthe Nantu-Boliohuto Wildlife Reserve provides essential shelter from predatory insects, ensure sufficient food availability, and provide environmental factors that support butterfly life.

The evenness index in the Nantu-Boliohuto Wildlife Reserve is categorized as high (Figure 3). This means that the number of individuals of each butterfly species is evenly distributed, with no dominant or sub-dominant species (Figure 4). The high evenness recorded indicates that despite these habitat variations, the species composition remains balanced, preventing ecological degradation and maintaining a robust food web. Pertiwi et al. (2020) explain that high evenness in a community indicates the ecosystem is in good condition, while low evenness suggests damage or degradation of ecosystem quality. By calculating the evenness index, it can be determined that Lepidoptera in the Nantu-Boliohuto Wildlife Reserve across various habitat types have an evenly distributed species composition and a healthy ecosystem. This is supported by Baderan et al. (2021) & Rahim et al. (2023), who explain that a community can be categorized as stable or as having evenly distributed species if the evenness index value approaches 1; and conversely, a lower evenness index indicates uneven species distribution. High indices of species diversity and evenness indicate a stable habitat and the availability of resources that support butterfly life. Butterflies have high mobility and adaptive abilities to environmental factors.

The dominance index of Lepidoptera was low at each research station (Figure 4), indicating that there are no dominant Lepidoptera species in the Nantu-Boliohuto Wildlife Reserve. According to Attiwilli et al. (2022), species richness significantly influences dominance values; specifically, lower species richness typically leads to a higher dominance index, whereas high richness tends to yield lower dominance. These results reflect a balanced distribution of individuals among species, which may intensify interspecific competition for limited floral resources, such as nectar, as influenced by the functional traits of the community. Overall, these findings suggest that the Nantu-Boliohuto Wildlife Reserve maintains a stable and diverse habitat that supports a wide array of Lepidoptera without the ecological pressure of a single dominant taxon.

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