BIODIVERSITAS ISSN: 1412-033X
Volume 26, Number 4, April 2025 E-ISSN: 2085-4722
Pages: 1553-1564 DOI: 10.13057/biodiv/d260407

Arboreal insects and mangrove vegetation pollinators in Bunaken National Park, North Sulawesi, Indonesia

RONI KONERI[1,♥], PARLUHUTAN SIAHAAN[1], SAROYO[1], MEIS JACINTA NANGOY[2], WAKHID[3]
[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Sam Ratulangi. Jl. Kampus Bahu, Manado 95115, North Sulawesi, Indonesia. Tel.: +62-431-864386, Fax.: +62-431-85371, ♥email: ronicaniago@unsrat.ac.id
[2]Department of Animal Production, Faculty of Animal Science, Universitas Sam Ratulangi. Jl. Kampus Bahu, Manado 95115, North Sulawesi, Indonesia
[3]Department of Agrotechnology, Faculty of Agriculture, Universitas Tribhuwana Tunggadewi. Jl. Telaga Warna, Malang 65144, East Java, Indonesia

Manuscript received: 13 January 2025. Revision accepted: 24 March 2025.

Abstract. *Koneri R, Siahaan P, Saroyo, Nangoy MJ, Wakhid. 2025. Arboreal insects and mangrove vegetation pollinators in Bunaken National Park, North Sulawesi, Indonesia. Biodiversitas 26: 1553-1564.* The diversity of mangrove species is predominantly composed of animals and plants, where insects have not been fully explored. Therefore, this study aimed to analyze the diversity of arboreal insects and mangrove vegetation pollinators on the Coast of Bunaken Sub-district, Manado City, North Sulawesi, Indonesia. Sampling was conducted at 3 observation stations in mangrove vegetation using the beating-tray method to obtain arboreal insects. Scan sampling and insect nets were used for mangrove vegetation pollinators. The results showed that arboreal insects and mangrove vegetation pollinators comprised 1,028 individuals covering 45 species in 17 families and 6 orders. The order with the highest abundance was Hymenoptera, while the largest number of species was Lepidoptera. Based on the relative abundance of species, *Oecophylla smaragdina, Tetrigona apicalis,* and *Dolichoderus thoracicus* were ranked as 1, 2, and 3, respectively. The average index of dominance, richness, and diversity of arboreal insects and the highest mangrove vegetation pollinators were found at Meras station. The similarity analysis indicated that the composition of arboreal insects and mangrove vegetation pollinators did not show significant differences. Environmental factors such as air temperature, air humidity, wind speed, and light intensity at the 3 observation stations were different. The highest air temperature and wind speed were found at the Tongkaina, while Meras had the lowest. The common species distribution pattern found was aggregate, suggesting that the mangrove vegetation area on the coast of Bunaken could support the abundance, richness, and diversity of arboreal insects as well as mangrove vegetation pollinators. At all observation stations, approximately the same species of insect composition was found. These results provided valuable information, serving as a database and consideration in formulating conservation strategies for arboreal insects and mangrove vegetation pollinators in the mangrove forest area on the Coast of Bunaken Sub-district.

Keywords: Arboreal, diversity, Hymenoptera, insects, mangrove

INTRODUCTION

Insects are a diverse group of animals with abundant numbers on Earth, playing a crucial role in the mangrove ecosystem (Anneboina and Kavi 2017; Ritter et al. 2019). Based on previous studies, the existence of insects in mangrove forests is essential for ecologists and entomologists (Alafia et al. 2023). Gbarakoro and Okene (2020) observed a strong relationship between insects and the mangrove ecosystem. Specifically, insects contribute to diversity and sustainability through their feeding activities, while mangroves provide suitable habitats for insects (Gbarakoro and Okene 2020). This group of animals contributes to ecological dynamics and plays a substantial role in the sustainability of life on Earth (Schowalter 2022).

Insects, including bees, butterflies, and beetles, often facilitate the pollination of mangrove plants, serving as a biodiversity component and a supporter of ecosystem processes. According to Chen et al. (2018), plants rely on insects for pollen transfer, which facilitates the reproduction and regeneration of mangrove ecosystems. Beetle larvae and termites also play a role in the decomposition of leaf litter, which decomposes organic matter into nutrients that plants can reabsorb (Setyawan et al. 2020; Yeo et al. 2021).

Insects are an important food source for various predators in the mangrove ecosystem, including birds, fish, and amphibians. The presence of insects supports complex food webs and ecosystem balance (Sari et al. 2022; Schowalter 2022), playing a crucial role as biological control agents, including predators and parasitoids such as dragonflies and parasitoid wasps, which help control pest populations. These animals maintain the balance of other insect populations that have the potential to damage vegetation (Sembiring et al. 2024). Some insects, including ants, contribute to seed dispersal by carrying small seeds to their nests, thereby facilitating the spread and regeneration of mangrove plants (Bakra et al. 2022).

The decline in insect populations worldwide has gained significant attention due to fragmentation, habitat change, loss, and increased pesticide use (Powney et al. 2019; Zattara and Aizen 2021). The threat of insect extinction occurs not only in lowland, highland forests, and plantation lands but also in mangrove forests that grow abundantly on the coast. Some efforts to anticipate insect extinction in coastal areas include mangrove forest conservation.

Mangrove forest conservation, in addition to preserving trees and restoring their economic-ecological functions, also supports the fauna life. Various efforts are made to conserve mangroves due to the significant contribution to social life and functional benefits for the ecosystem (Kusmana 2018; Konoyima 2020). Mangroves can occupy intertidal areas and interact with aquatic and terrestrial ecosystems, thereby supporting the diversity of flora and fauna (Romanach et al. 2018; Martin et al. 2019).

Bunaken National Park (TNB) belongs to the National Park Management Section (SPTN) Region I Meras (Tabba et al. 2015). This area is in direct contact with the activities of the surrounding community, such as a pier, fishing, and boat mooring. There is also an ecotourism area; thereby, high human activity in an ecotourism area will impact the mangrove ecosystem.

In mangrove vegetation, there are insects associated with trees, both arboreal insects and mangrove vegetation pollinators. Several orders of insects are found in mangrove ecosystems, such as Coleoptera, Diptera, Embiidina, Odonata, Hymenoptera, Lepidoptera, Orthoptera, Blattaria, and Homoptera (Sembiring et al. 2024). Arboreal insects and mangrove vegetation pollinators are unique compared to other ecosystems. The uniqueness of the insect community in mangrove vegetation is due to unusual environmental conditions characterized by extreme daily fluctuations in salinity, temperature, and waterlogging. Several studies on insects in mangrove forests have been studied and published (Semium et al. 2020; Setyawan et al. 2020; Hasan and Nurmiati 2022; Paliana et al. 2022; Rante et al. 2023; Sembiring et al. 2024). Further investigation is needed to provide the necessary information regarding the diversity of arboreal insects and mangrove vegetation pollinators in the Coast of Bunaken Sub-district. Therefore, this study aimed to explore the diversity and distribution of arboreal insects as well as mangrove vegetation pollinators and their relationship with environmental factors. The results are expected to be used to evaluate and consider insect conservation strategies in mangrove vegetation on the Coast of Bunaken Sub-district, the Bunaken Marine National Park area.

MATERIALS AND METHODS

Study area

This study was conducted from April to November 2024 at 3 mangrove forest observation stations on the Coast of Bunaken Sub-district, Manado City, North Sulawesi, Indonesia (Figure 1). Identification of insect samples was carried out at the Advanced Biology Laboratory of the Faculty of Mathematics and Natural Sciences, Universitas Sam Ratulangi. Observation Station 1 is located in the Bahowo mangrove ecotourism area, which is predominantly composed of mangrove species from the genera *Rhizophora* and *Sonneratia* (124°49'13.06"E, 01°34'54.91"N). Observation Station 2 is situated in Tongkaina Village, where the mangrove forest is dominated by species from the genera *Sonneratia* and *Rhizophora* (124°48'28.05"E, 01°34'24.42"N). This mangrove area also features a pier serving as a crossing point to Bunaken Island. Observation Station 3 is located in the mangrove forest of Meras Subdistrict, where the dominant mangrove species belong to the genera *Sonneratia* and *Avicennia* (124°48'54.40"E, 01°34'03.96"N). At each station, 3 transect lines were made with a length of 200 m.

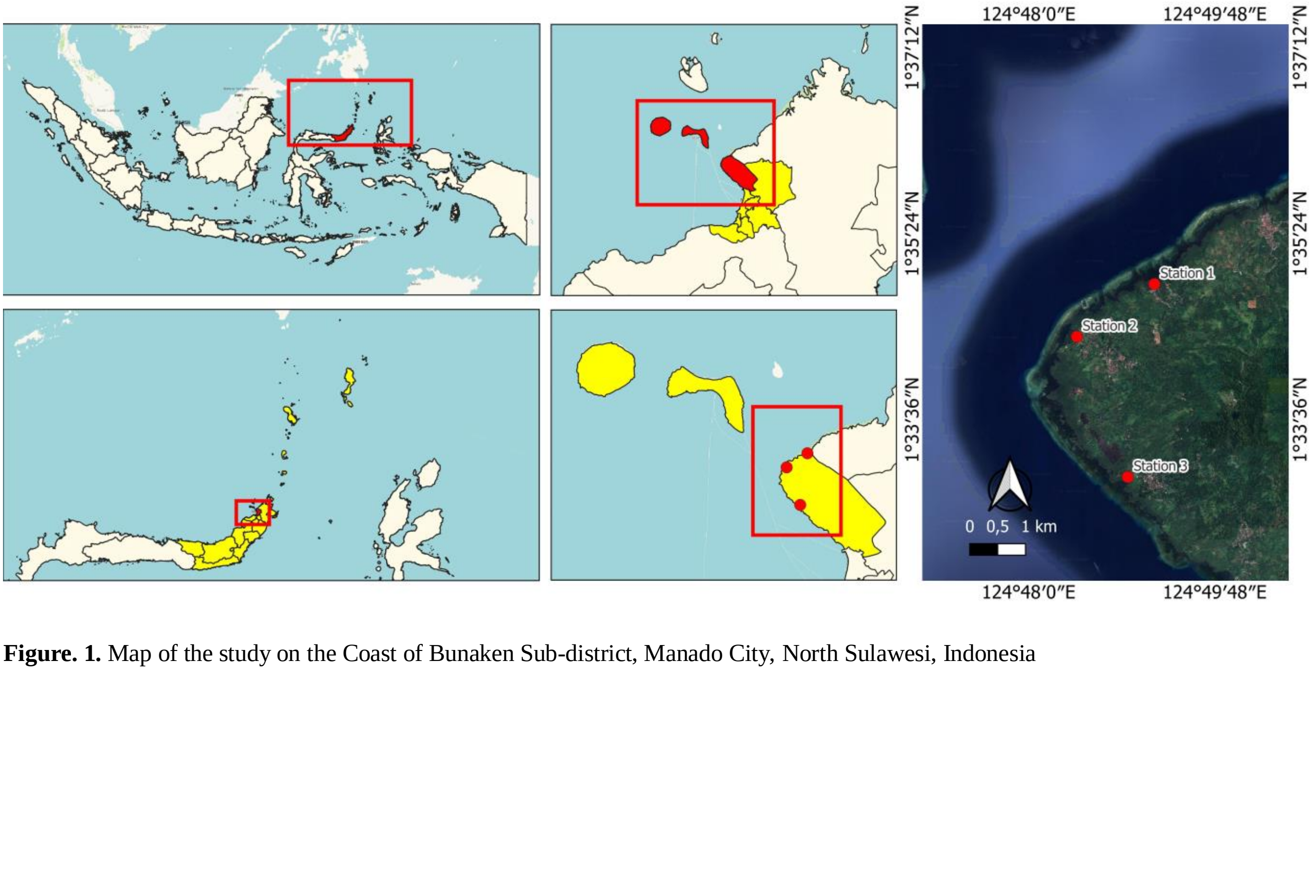

Figure. 1. Map of the study on the Coast of Bunaken Sub-district, Manado City, North Sulawesi, Indonesia

Procedures sampling technique

This study used the purposive random sampling method. Arboreal insects or inhabitants of mangrove tree canopies were captured using the beating-tray method. The beating tray was made of a container in the form of a white cloth measuring 1.5 m^2, placed under the desired mangrove vegetation. Insect collection was carried out by shaking the mangrove branches 30 times for 5 minutes and collecting the insects that fell into the cloth container. A total of 10 net trays were on each transect line, and insect collection was carried out immediately after the tree branches were beaten/shaken (Sembiring et al. 2024).

The scan sampling method, according to Koneri et al. (2024), was used to observe mangrove vegetation pollinators. Both collection and observation were performed on sunny days from 08.00 am-03.00 pm. Observation was performed at each station for 3 days monthly within 3 months by walking along the transect line and recording the species and number of pollinating insects. Mangrove vegetation pollinators were caught with the sweep net for identification.

Species of arboreal insects that were unknown and mangrove vegetation pollinators were captured and collected for identification. This process was carried out using an identification book from Sakagami et al. (1990), Tsukada (1991), Otsuka (1991), and Michener (2000) followed by classification Measurement of environmental factors such as air temperature with a thermometer, air humidity using a hygrometer, wind speed through anemometer, and light intensity using a lux meter. Height above sea level was measured, and the Global Positioning System (GPS) was used to determine coordinates.

Data analysis

The richness and abundance of arboreal insect pollinators associated with mangrove vegetation at each station were systematically compiled using Microsoft Excel. Community structure metrics including species abundance, species richness, the Shannon-Wiener diversity index ($H' = -\Sigma pi \ln pi$), and Pielou's evenness index ($J = H'/\ln S$) were calculated for each observation station (Bashir et al. 2019). Significant inter-habitat differences in individual abundance, species richness, Shannon diversity, and evenness were evaluated using one-way ANOVA followed by Tukey's post hoc test at a 95% confidence level via Statistica software version 6 (Bashir et al. 2019). To assess variations in species composition across stations, an Analysis of Similarity (ANOSIM) was performed, while differences in insect community structure among stations were examined using non-metric multidimensional scaling (NMDS) based on the Bray-Curtis dissimilarity index. Subsequently, principal component analysis (PCA) was employed to elucidate the relationships between environmental factors (independent variables) and the sampling stations (dependent variables). The PCA, ANOSIM, and NMDS analyses were conducted using Paleontological Statistics software (PAST software 3.10) (Cuartas-Hernández and Gómez-Murillo 2015; Wakhid et al. 2021).

Insect diversity was calculated using the Morisita index formula according to Purnama et al. (2024):

$$\text{Morisita Index (Id)} = n\left(\frac{\sum X^2 - N}{N\,(N-1)}\right)$$

Where, Id represents the Morisita dispersion index, n denotes the number of plots, x corresponds to the number of individuals per plot, $\sum X^2$ signifies the sum of squares of all species for each plot, and N is the total number of individuals. Accordingly, an Id value of 1 indicates a random distribution pattern, values exceeding 1 suggest aggregate distribution, and values below 1 reflect a regular or uniform distribution pattern.

RESULTS AND DISCUSSION

Insect species composition

The results on arboreal insects and mangrove vegetation pollinators obtained 6 orders covering 17 families, 45 species, and 1,028 individuals, as shown in Table 1. Based on species abundance, the Hymenoptera order had the highest abundance (730 individuals or 71.01%), followed by Lepidoptera with 195 individuals or 18.97% (Figure 2.A). The order with the highest number of species was Lepidoptera (17 species or 37.38%), followed by Hymenoptera (14 species or 31.11%). Meanwhile, the order with the lowest number of species was Diptera, which only found 1 species (2.22%) (Figure 2.B). The Meras observation station had the highest number of individuals (353) and species (34) compared to the other 2 stations. In comparison, the Tongkaina station has the lowest at 330 individuals and 24 species (Table 1).

The overall ranking of 45 insect species found in the study area based on the relative abundance of 28.60%, 19.46%, and 5.64% showed that *Oecophylla smaragdina*, *Tetrigona apicalis*, and *Dolichoderus thoracicus* were ranked 1, 2, and 3, respectively (Figure 3). The high steepness of the curve from the 1st to the 2nd ranked species showed that the *Oecophylla smaragdina* species was quite abundant in the habitat around the mangrove forest. Furthermore, from the 2nd to the 45th-ranked species, the curve's steepness was low, indicating that the evenness of species in the mangrove forest on the coast of Bunaken was quite good (Figure 3).

The percentage of butterfly composition at each station based on individual abundance showed that the Hymenoptera order had the highest at the 3 stations observed. Hymenoptera of 72.42% was found at Tongkaina station, followed by Bahowo and Meras at 71.59% and 69.12%, respectively. Furthermore, the 2nd highest abundance was the Lepidoptera order, with a percentage of abundance of 21.52% at Tongkaina station, followed by Meras (18.13%) and Bahowo (17.39%) (Figure 4).

Table 1. The composition of arboreal insects and mangrove vegetation pollinators

Order	Family/Species	Station/Individuals			∑	%
		Bahowo	Meras	Tongkaina		
Anisoptera	Libellulidae					
	Orthetrum pruinosum	2	4	1	7	0.68
	Celebothemis delecollei	1	2	0	3	0.29
	Neurothemis ramburii	3	0	0	3	0.29
Coleoptera	Cerambycidae					
	Xystrocera festiva	2	1	0	3	0.29
	Chrysomelidae					
	Pagria signata	0	3	2	5	0.49
	Adoxia benallae	1	1	0	2	0.19
	Monolepta signata	1	1	0	2	0.19
	Coccinellidae					
	Chilocorus circumdatus	0	2	0	2	0.19
	Neda norrisi	2	0	0	2	0.19
	Scarabaeidae					
	Anomala minahassae	2	8	11	21	2.04
Diptera	Syrphidae					
	Eristalinus arvorum	24	5	6	35	3.40
Hymenoptera	Apidae					
	Tetrigona apicalis	69	57	74	200	19.46
	Xylocopa confusa	9	4	3	16	1.56
	Xylocopa latipes	0	6	2	8	0.78
	Thyreus nitidulus	0	5	0	5	0.49
	Eumenidae					
	Delta pyriforme	0	0	12	12	1.17
	Polistes dorsalis	8	3	0	11	1.07
	Formicidae					
	Oecophylla smaragdina	94	107	93	294	28.60
	Dolichoderus thoracicus	24	15	19	58	5.64
	Solenopsis geminata	26	11	7	44	4.28
	Halictidae					
	Nomia strigata	0	12	0	12	1.17
	Ceratina nigrolateralis	0	9	0	9	0.88
	Sphecidae					
	Sphex muticus	4	0	6	10	0.97
	Vespidae					
	Vespa tropica	6	10	18	34	3.31
	Ropalidia stigma	7	5	5	17	1.65
Lepidoptera	Lycaenidae					
	Hypolycaena erylus	6	28	9	43	4.18
	Lampides boeticus	4	4	0	8	0.78
	Arhopala acetes	1	3	0	4	0.39
	Nymphalidae					
	Ideopsis juventa	6	2	10	18	1.75
	Danaus ismare	12	0	4	16	1.56
	Junonia hedonia	5	0	8	13	1.26
	Euploea eupator	0	4	4	8	0.78
	Hypolimnas bolina	6	0	0	6	0.58
	Parantica cleona	2	0	2	4	0.39
	Parthenos sylvia	1	0	0	1	0.10
	Papilionidae					
	Papilio ascalaphus	10	4	0	14	1.36
	Papilio polytes	0	6	0	6	0.58
	Troides helena	0	0	4	4	0.39
	Graphium agamemnon	2	0	0	2	0.19
	Pieridae					
	Catopsilia pomona	4	4	16	24	2.33
	Catopsilia scylla	1	5	9	15	1.46
	Hebomoia glaucippe	0	4	5	9	0.88
Orthoptera	Acrididae					
	Valanga nigricornis	0	8	0	8	0.78
	Stenocatantops splendens	0	5	0	5	0.49
	Valanga irregularis	0	5	0	5	0.49
	Number of individuals	345	353	330	1,028	100.00

Number of spesies	31	34	24	45

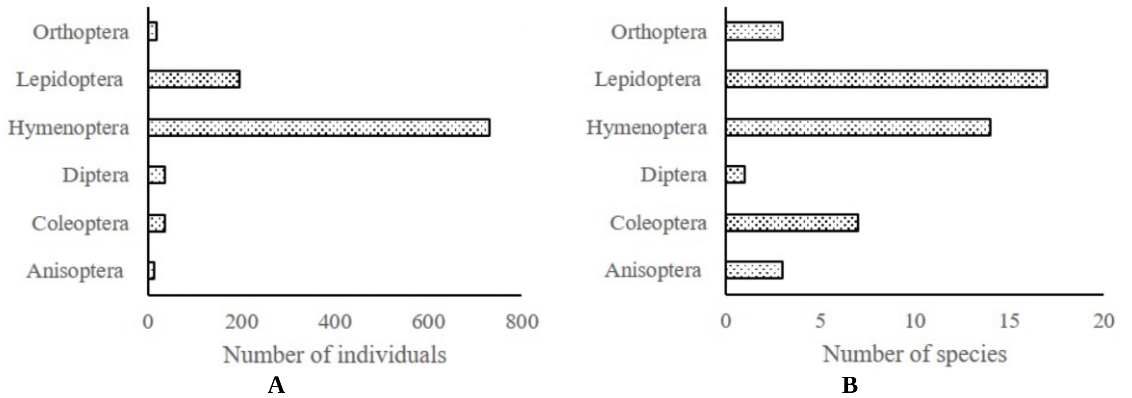

Figure 2. The composition of insect orders on mangrove vegetation based on individual abundance (A) and species count (B)

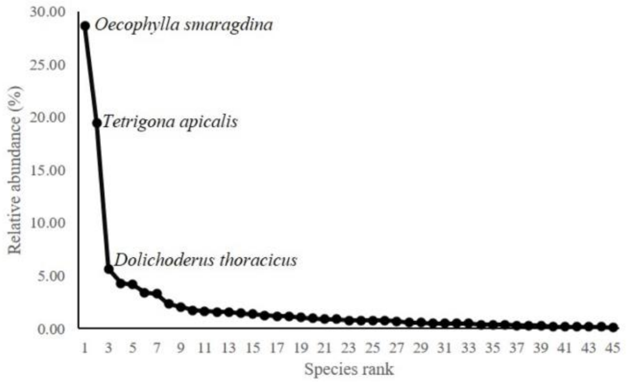

Figure 3. The rank-abundance curve of arboreal insects and mangrove vegetation pollinators

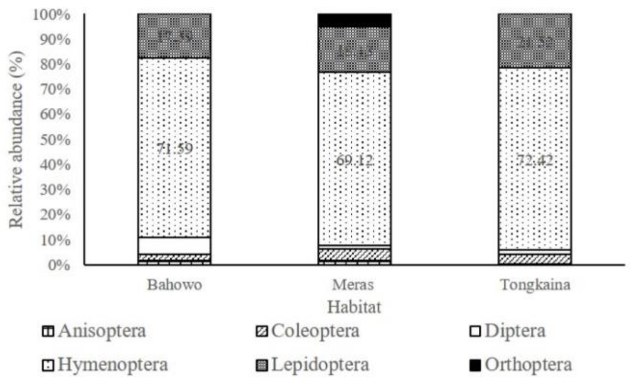

Figure 4. The relative abundance of arboreal insects and mangrove vegetation pollinators by order at three observation stations

Diversity of insect species

The rarefaction interpolation-extrapolation curves of mangrove vegetation pollinators at each station showed a rapid increase at the start of sampling and slowly reached an asymptote point. The curves at the 3 sampling stations overlapped, showing the presence of approximately the same species diversity. Based on the rarefaction extrapolation curve, the number of species in mangrove vegetation found at the 3 observation stations has reached an asymptote point (Figure 5).

The highest average insect species richness and diversity in mangrove habitats quantified by the Margalef and Shannon indices were recorded at Meras, with values of 4.40 and 2.38, respectively. In contrast, the Bahowo station exhibited the lowest indices, at 3.37 and 2.19. Across all stations, the dominance index was approximately 0.16, while the species evenness index ranged between 0.77 and 0.79, indicating an absence of highly dominant taxa. Moreover, one-way ANOVA revealed no significant differences among stations in terms of dominance (F2,8: 0.019; P: 0.981), diversity (F2,8: 0.939; P: 0.442), species richness (F2,8: 3.467; P: 0.099), or evenness (F2,8: 0.412; P: 0.679) (Figure 6).

ANOSIM based on the Bray-Curtis index showed that the composition of mangrove habitat insect species in the 3 stations did not differ significantly (R: 0.09877; P: 0.223). The insignificant differences in species composition were also observed in the results of (NMDS), which showed overlapping ordination points between the 3 stations (Figure 7).

The highest air temperature was at the Tongkaina, and the lowest was at Meras station. Meanwhile, the highest air humidity was at the Meras, and the lowest was in Tongkaina. The highest wind speed was at the Tongkaina station and the lowest was in Bahowo. The results also showed that the highest light intensity was at Bahowo and the lowest in Meras. Based on the ANOVA results, environmental factors such as air humidity (ANOVA: F2,8: 3.851; P: 0.084), air temperature (ANOVA: F2,8: 1.401; P: 0.317), light intensity (ANOVA: F2,8: 0.824; P: 0.483) and wind speed (ANOVA: F2,8: 1.129; P: 0.384) did not differ at the 3 observation stations (Figure 8).

The principal component analysis (PCA) of environmental parameters across the three observation stations revealed that the Tongkaina station was distinctly associated with elevated air temperatures and wind speeds, alongside reduced air humidity. In contrast, the Bahowo and Meras stations were predominantly characterized by high air humidity, lower air temperatures, and marked light intensity (Figure 9).

Distribution of insects

The distribution pattern of mangrove vegetation pollinators found based on the Morisita index obtained 3 patterns of species, namely aggregate (clustered), uniform (regular), and random. The distribution pattern of species commonly found was aggregated in 34 species. Random distribution patterns were found in 7 species, while uniform distribution was only found in 4 species. Based on the insect order, the distribution patterns of the Hymenoptera and Coleoptera were included in random patterns, while Diptera and Orthoptera showed aggregate patterns. The Anisoptera Order had a uniform distribution pattern (Table 2).

Discussion

A total of 17 insect families were found at all stations, which was different from other studies in the mangrove ecosystem. Some studies reported lower numbers; for example, Mitra et al. (2016) recorded 15 insect families from the mangrove ecosystem in Diu, India. Hasan and Nurmiati (2022) recorded 4 families in Polewali Mandar, West Sulawesi Province, Indonesia. Semiun et al. (2019) reported 11 insect families in the mangrove ecosystem in Menipo Nature Tourism Park, East Nusa Tenggara, Indonesia. Panda et al. (2019) reported 25 families, and Itumo et al. (2024) recorded 23 families in the mangrove forest in Bundu-Ama, Niger Delta. Meanwhile, Setyawan et al. (2020) found 31 insects in the mangrove forest in Trenggalek, East Java, Indonesia. According to Membere et al. (2021), the differences in abundance of insect families were due to climatic and geographical factors, sampling methods, and variation in the spectrum of mangrove species.

In this study, the abundance of arboreal insects and mangrove vegetation pollinators was mostly found in the Hymenoptera Order. Hymenoptera, with its diverse species from families such as Apidae, Eumenidae, Formicidae, Halictidae, Sphecidae, and Vespidae, is abundant in the mangrove ecosystem. Hymenoptera is among 4 diverse insect orders, consisting of more than 153,000 described and approximately 1 million undescribed species. In an ecosystem, this order acts as parasitoids, predators, and pollinators, playing essential roles in all terrestrial ecosystems with great economic value (Bashir et al. 2019). Several studies have reported that the dominant pollinating insects found are the Hymenoptera order (Choi and Jung 2015). The majority of mangrove forests experience cross-pollination, which is primarily facilitated by insects belonging to the orders Hymenoptera, Diptera, Lepidoptera, and Coleoptera (Mitra et al. 2015; Tomlinson 2016).

Within the study area, across all habitat types, Lepidoptera emerged as the pollinating insect order exhibiting the highest species richness. This predominance is attributable to its role as an ecologically functional group with superior pollination efficiency, enhanced color recognition, and inherent color preferences, thereby facilitating extensive involvement in the pollination of flowering plants. Moreover, the abundance of Lepidoptera was closely linked to the availability of floral resources and prevailing environmental conditions (Koneri et al. 2024). In addition, variations in food type and floral abundance significantly influence pollinator population density and diversity, as increased food availability is a critical determinant of these parameters (Umami et al. 2024).

Table 2. Distribution pattern of arboreal insects and mangrove vegetation pollinators

Family/Species	Morisita index	Distribution pattern
Libellulidae	1.15	Aggregate
Celebothemis delecollei	1.00	Random
Neurothemis ramburii	3.00	Aggregate
Orthetrum pruinosum	1.00	Random
Cerambycidae	1.00	Random
Xystrocera festiva	1.00	Random
Chrysomelidae	1.00	Random
Adoxia benallae	0.00	Uniform
Monolepta signata	0.00	Uniform
Pagria signata	1.20	Aggregate
Coccinellidae	1.00	Random
Chilocorus circumdatus	3.00	Aggregate
Neda norrisi	3.00	Aggregate
Scarabaeidae	1.20	Aggregate
Anomala minahassae	1.20	Aggregate
Syrphidae	1.52	Aggregate
Eristalinus arvorum	1.52	Aggregate
Apidae	0.99	Random
Tetrigona apicalis	1.00	Random
Thyreus nitidulus	3.00	Aggregate
Xylocopa confusa	1.13	Aggregate
Xylocopa latipes	1.71	Aggregate
Eumenidae	1.15	Aggregate
Delta pyriforme	3.00	Aggregate
Polistes dorsalis	1.69	Aggregate
Formicidae	1.00	Random
Dolichoderus thoracicus	1.00	Random
Oecophylla smaragdina	1.00	Random
Solenopsis geminata	1.27	Aggregate
Halictidae	3.00	Aggregate
Ceratina nigrolateralis	3.00	Aggregate
Nomia strigata	3.00	Aggregate
Sphecidae	1.40	Aggregate
Sphex muticus	1.40	Aggregate
Vespidae	1.03	Random
Ropalidia stigma	0.90	Uniform
Vespa tropica	1.14	Aggregate
Lycaenidae	1.39	Aggregate
Arhopala acetes	1.50	Aggregate
Hypolycaena erylus	1.43	Aggregate
Lampides boeticus	1.29	Aggregate
Nymphalidae	1.24	Aggregate
Danaus ismare	1.80	Aggregate
Euploea eupator	1.29	Aggregate
Hypolimnas bolina	3.00	Aggregate
Ideopsis juventa	1.20	Aggregate
Junonia hedonia	1.46	Aggregate
Parantica cleona	1.00	Random
Parthenos sylvia	0.00	Uniform
Papilionidae	1.08	Aggregate
Graphium agamemnon	3.00	Aggregate
Papilio ascalaphus	1.68	Aggregate
Papilio polytes	3.00	Aggregate
Troides helena	3.00	Aggregate
Pieridae	1.39	Aggregate
Catopsilia pomona	1.43	Aggregate
Catopsilia scylla	1.31	Aggregate
Hebomoia glaucippe	1.33	Aggregate
Acrididae	3.00	Aggregate

Stenocatantops splendens	3.00	Aggregate
Valanga irregularis	3.00	Aggregate
Valanga nigricornis	3.00	Aggregate

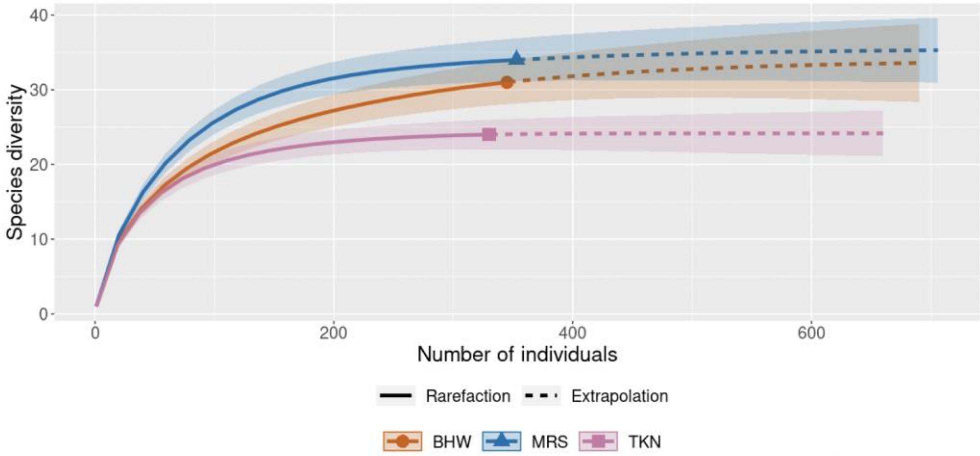

Figure 5. Rarefaction curves of individual arboreal insects and mangrove vegetation pollinators at three observation stations (BHW: Bahowo; MRS: Meras; TKN: Tongkaina)

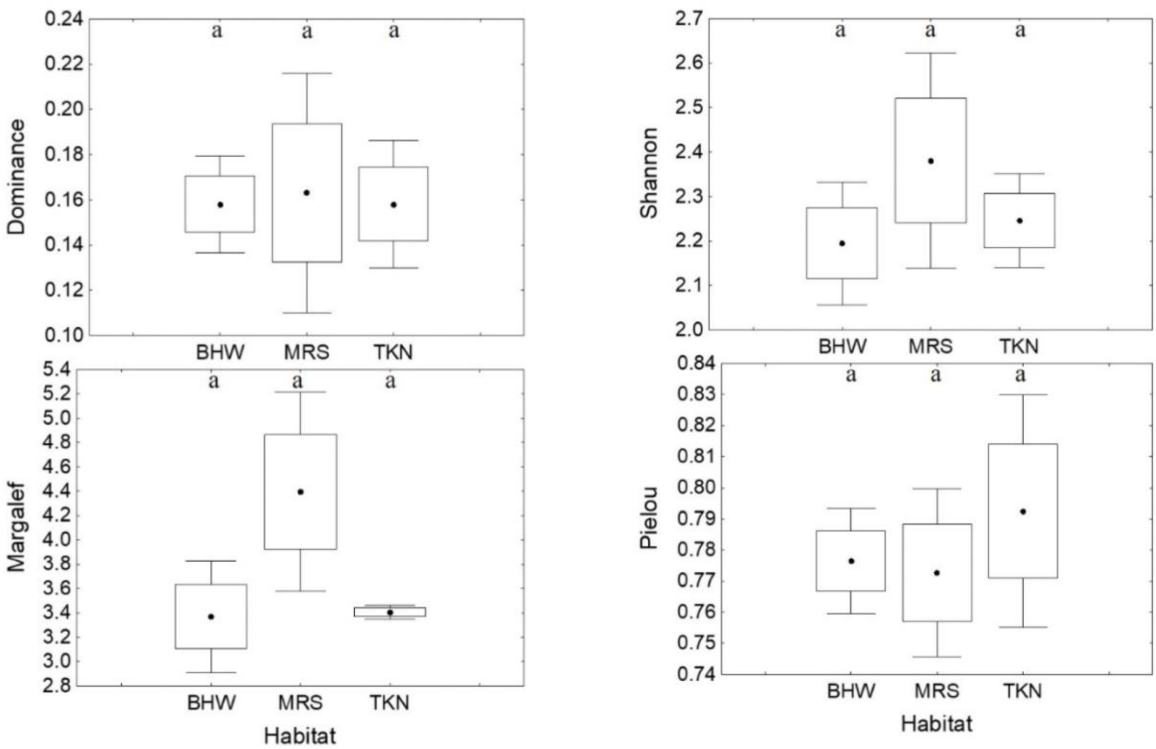

Figure 6. The community structure of arboreal insects and mangrove vegetation pollinators at three observation stations (BHW: Bahowo; MRS: Meras; TKN: Tongkaina)

Conversely, the most abundant family identified in the study area was Formicidae, a trend likely driven by the availability of food sources and conducive environmental conditions (Membere et al. 2021). In contrast, other investigations have reported Apidae as the predominant family in Tanzania (Ojija 2016), while Itumo et al. (2024) documented the dominance of the Tabanidae family in mangrove forests of Bundu-Ama, Niger Delta. These variations underscore that the abundance of insect families is modulated by a complex interplay of factors, including food resource availability, nesting sites, climatic conditions, geographic context, mangrove species composition, and leaf litter availability.

Formicidae and Apidae are the families with the highest abundance in all habitat types. The Formicidae species with the highest abundance is *Oecophylla smaragdina*. Formicidae at all three stations are influenced by the availability of sufficient food, enhancing quick reproduction and environmental conditions that are suitable for their habitat. According to Offenberg (2015), *Oecophylla smaragdina* is an insect that is active on plants (arboreal) and has a wide habitat range but is more commonly found in monoculture systems (high light intensity) than in mixed planting systems (low light intensity). In mangrove vegetation, this insect can act as a predator by eating larvae, small insects, and other organisms. Ants also help maintain the balance of the ecosystem as decomposers, pollinators, and dispersers of mangrove seeds. The genus *Oecophylla* is an arboreal insect that makes nests among the leaves of mangrove vegetation. Ant colonies can have several nests in 1 tree or spread across adjacent trees, playing an important part in the ecosystem and functioning as predators for other insects (Sembiring et al. 2024). Regarding the reports by Gbarakoro and Okene (2020), mangrove seeds do not rot easily due to the presence of ants.

Apidae belong to the Hymenoptera order, including *Tetrigona apicalis*. It is the most effective as well as generalist group of pollinating insects in the pollination process of plants (Siregar et al. 2016). With a shiny black body and transparent wing tips, these bees are small and often fly a few millimeters. In this study, Apidae pollinated several flowers and nested in the cavities of *Avicenna marina* mangrove trees. These bees are effective pollinators, facilitating the transfer of pollen essential for reproduction. Additionally, Apidae is often found on mangrove flowers from the genera *Soneratia* and *Avicenna*.

Hymenoptera insects from the Apidae family are highly adaptable to the environment by thriving in humid conditions and covered by tree canopies. Stingless bees (Apidae) are among the most common and abundant native flower pollinators in various tropical terrestrial ecosystems (Hrncir et al. 2019).

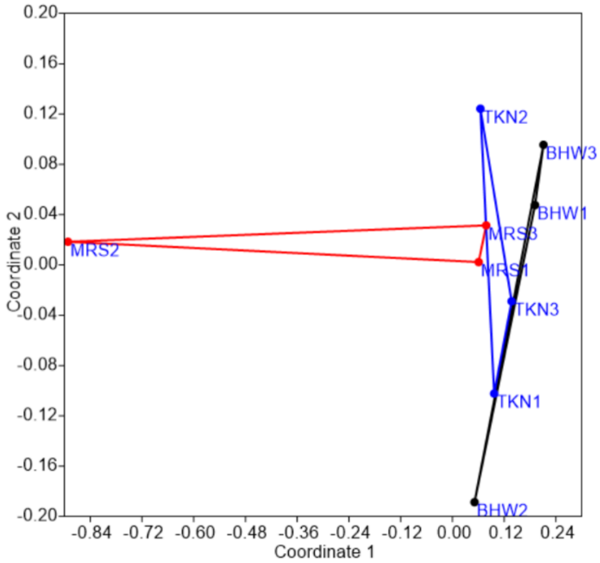

Figure 7. Non-metric dimensional scaling (NMDS) of the composition of arboreal insects and mangrove vegetation pollinators at three stations (BHW: Bahowo; MRS: Meras; TKN: Tongkaina)

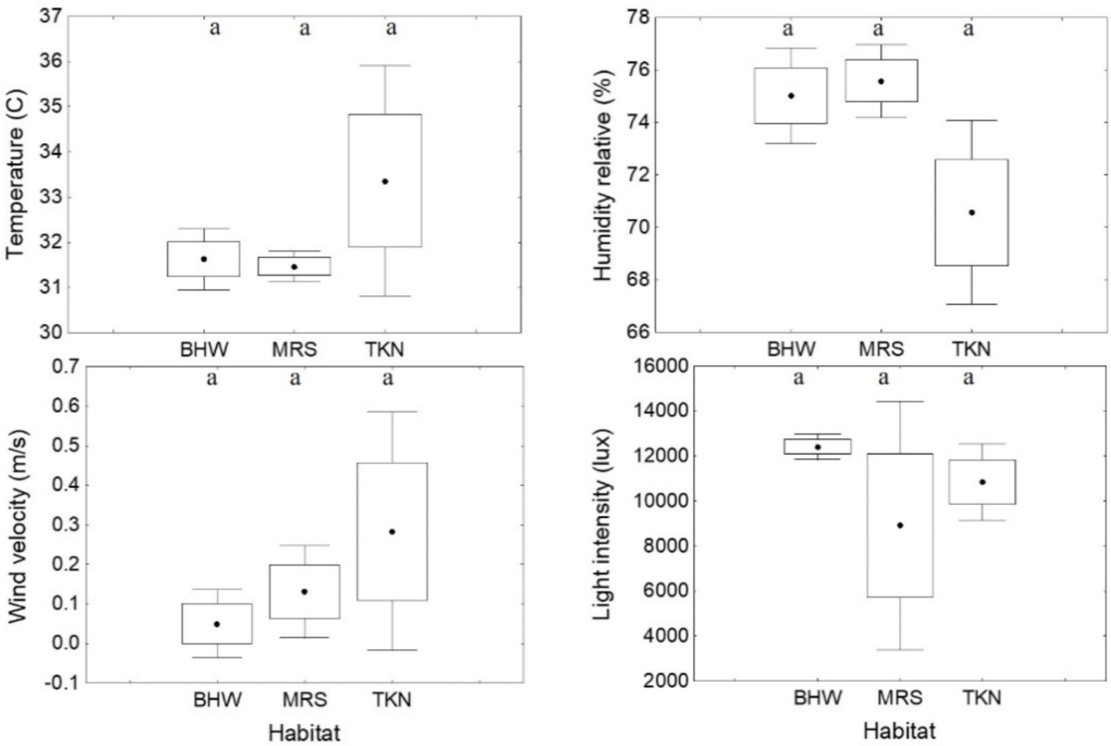

Figure 8. Environmental factors at three observation stations of arboreal insects-mangroves vegetation pollinators on the Bunaken Coastal (BHW: Bahowo; MRS: Meras; TKN: Tongkaina)

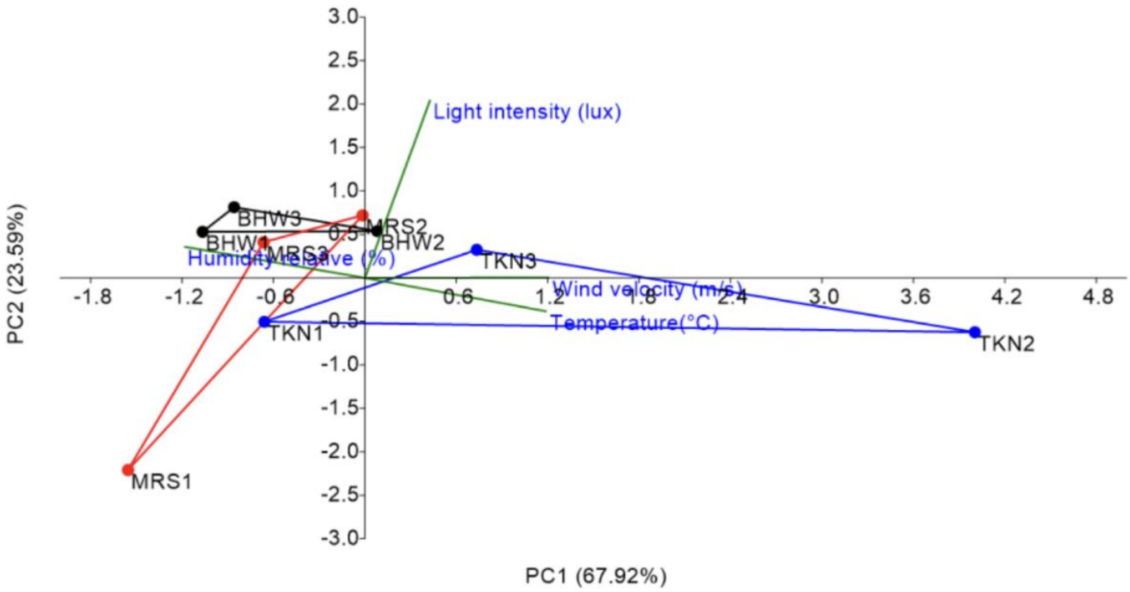

Figure 9. PCA ordination of three observation stations in Bunaken Coastal (BHW: Bahowo; MRS: Meras; TKN: Tongkaina)

In Meras mangrove vegetation, there was the highest species richness and diversity index. The results showed more diversity compared to Tongkaina and Bahowo dominated by *Soneratia* and *Brugreria*, respectively. The mangrove vegetation during the study consisted of flowering plants such as *Soneratia alba* and *Avicenna marina*, which several insects pollinated. Environmental conditions and the type of mangrove ecosystem could cause variation in diversity. Rante et al. (2023) reported that the composition of mangrove stands, the quality and quantity of food, including the number of suitable host plants, and the density influenced the diversity of insect species.

Flowering wild plants at the edge of Meras mangrove vegetation is significantly caused by pollinating insects. The edge of the mangrove forest is a transition zone between open habitats and mangrove vegetation. According to Darsono et al. (2020), there is significant variability in the 3-dimensional structure, such as tree trunks' width, shape, and density. Generally, the edge of the mangrove forest is rarely disturbed by humans, providing numerous nesting areas for pollinating insects. This is because habitats with low human disturbance characteristics, such as forests and edges, have higher richness and diversity of pollinating insect species compared to intensively managed agricultural lands (Sheffield et al. 2013).

According to Ellis et al. (2017) and Welti et al. (2017), the diversity of pollinators associated with mangrove vegetation is closely linked to habitat quality. This encompasses not only the presence of flowering plants and the year-round availability of floral resources as food sources, but also the provision of suitable nesting sites. Given that pollinating insects typically forage close to their nests, a greater diversity and abundance of flowering plants is likely to foster a richer pollinator community. Insect diversity within a habitat is thus modulated by a suite of factors, including environmental conditions, the density of flowers (which supply essential pollen and nectar), and the structural characteristics of the vegetation. Additionally, the inherent attributes of flowers such as color, shape, fragrance, and the availability of nectar and pollen play a critical role in attracting pollinators, thereby further influencing the overall diversity of pollinating insects.

Human activities significantly influence the presence of mangrove vegetation pollinators. The mangrove stations in Tongkaina and Bahowo are ship docks to Bunaken Island. Ship activities can cause noise, thereby impacting the presence of mangrove vegetation pollinators. According to Hasan and Nurmiati (2022), noise caused by human activities harms the communication process of insects, which impacts the low number of individuals. Long-term noise can have an impact on decreasing orientation, courage, escape ability, short-term memory, and parenting behavior of ant with exposure to sounds of 42-200 beats per minute (Cammaerts and Cammaerts 2018).

The average values of air humidity, temperature, wind speed, and light intensity exhibited minimal variability across the three stations. These environmental parameters including rainfall are known to modulate insect flight activity. Notably, the Meras mangrove area was characterized by comparatively lower temperatures and elevated humidity, likely due to the buffering effect of the tree canopy cover.

Temperature, as a critical environmental variable, significantly influences the diversity of pollinating insects, which, as poikilothermic organisms, are inherently dependent on ambient thermal conditions. Each species requires a specific temperature range for optimal survival typically between 15°C and 45°C, with an optimum near 25°C while foraging activity declines sharply (to below 21%) at temperatures under 12°C (Withaningsih et al. 2024). In this study, the mean temperatures across the four habitats ranged from 28.60°C to 34.70°C, indicating conditions that are conducive to sustained foraging activity. Widhiono and Sudiana (2015) further elucidate that air temperature critically affects the energetic dynamics of pollinators, whereby decreases in ambient temperature reduce energy acquisition, thereby increasing the energetic cost per pollinated flower.

Furthermore, air humidity emerges as a pivotal climatic factor influencing the diversity of mangrove pollinators. Forested habitats, characterized by high humidity levels, inherently support the reproductive, developmental, and behavioral processes of insects. Xiong et al. (2017) affirm that both temperature and humidity are essential in shaping local biodiversity, while Koneri et al. (2020) note that humidity also indirectly affects insect diversity by influencing host plant growth.Wind speed impacts the diversity of insect species that pollinate mangroves. The results of wind speed measurements at the 3 observation stations were not significantly different. According to Widhiono and Sudiana (2015), wind speed impacts the foraging activity of pollinating insects. Wind speed between 24-34 km/hour harms the activity of pollinating insects in foraging.

Insects in mangrove vegetation indirectly need sunlight, but it can be used as a marker for certain activities. Insects use sunlight for foraging, molting, reproduction, or events related to their life history. Sunlight also impacts the local distribution of insects, thereby enhancing activeness based on the response to signals received. According to Perks and Goodenough (2020), light intensity is an abiotic factor that can impact insects' activity. Insects in mangroves will use the optimal light intensity for sunbathing and foraging. However, when the light intensity is low or excessively high, it is used for resting and shelter. High light intensity also causes the volume of nectar secretion in flowers to decrease. Sunlight will affect air temperature and light intensity, which play an important role in pollinating insects' flying and foraging activities (Bharti et al. 2015).

The distribution of arboreal insects and mangrove vegetation pollinators generally has a clustered distribution pattern (Aggregate). This shows that the individuals consisted in the population respond to differences locally (in groups). The clustered distribution pattern occurs when there is strong competition for nutrients between individuals in the population. Diversity (heterogeneity) exists in environmental conditions, food availability, mating, defense, social behavior, and competition factors. According to Meléndez-Jaramillo et al. (2019), the factors causing insects to spread in a clustered pattern included biotic and abiotic factors, which affected their distribution patterns. These factors include temperature, relative humidity, as well as the presence and abundance of host plants, creating certain microclimatic conditions that attract insect species.

A clustered (aggregate) distribution pattern is shown by mangrove vegetation pollinators with limited dispersal capabilities. Other biotic factors include nectar-producing plants, whose availability and diversity can attract pollinators to a particular area, causing their distribution to become clustered. Furthermore, roosting trees suggest that the availability of suitable species can contribute to the clustering of insect pollinators (Kass et al. 2020).

Some insect species have random and uniform distributions. Random distribution patterns indicate uniformity (homogeneity) in environmental conditions. Soil insects with random distribution patterns suggest that the environmental factors in the habitat are almost the same. Random distribution patterns are caused by the negative influence of resources among individual population members. However, uniform distribution patterns occur due to competition between individuals in obtaining limited food sources, with even division of habitat space and place (Darmi et al. 2023).

In conclusion, this study showed that the abundance of arboreal insects and mangrove vegetation pollinators was dominated by the Hymenoptera order, followed by Lepidoptera. Based on the relative abundance of species, *O. smaragdina*, *T. apicalis*, and *D. thoracicus* were ranked 1, 2, and 3, respectively. The average dominance index, richness, and diversity of arboreal insects and mangrove vegetation pollinators were highest based on the dominance, Margalef, and Shannon indices found at the mangrove observation station in Meras, followed by Tongkaina and Bahowo. The results showed that the distribution pattern of pollinating insects found was generally aggregate. This suggested that the mangrove area on the coast of Bunaken could support the abundance, richness, and diversity of arboreal insects and mangrove vegetation pollinators at different trophic levels.

ACKNOWLEDGEMENTS

The authors are grateful to the Chancellor of Universitas Sam Ratulangi for funding this study through UNSRAT's Leading Basic Research Cluster 1 with Contract Number: 643/UN12.13/LT/2024 dated 24 April 2024.

REFERENCES

Alafia AO, Ajelara KO, Onyema HE, Reis GA, Ogun ML, Anikwe JC, Denloye AA, Makanjuola WA. 2023. Insect diversity and abundance in three forest areas of Lagos State. Zoologist 22: 40-47. DOI: 10.4314/tzool.v22i1.6.

Anneboina LR, Kavi KKS. 2017. Economic analysis of mangrove and marine fishery linkages in India. Ecosyst Serv 24: 114-123. DOI: 10.1016/ j.ecoser.2017.02.004.

Arvind K, Madhura M. 2015. Insect fauna in mangrove ecosystem of Bhatye estuarine region. Intl J Curr Res Acad Rev 3 (5): 248-251.

Bakra D, Sheela S, Bhattacharyya S. 2022. Diversity and distribution of ants (Hymenoptera: Formicidae) in Sunderbans, West Bengal, India. Intl J Zool Investig 8 (2): 146-154. DOI: 10.33745/ijzi.2022.v08i02.019.

Bashir MA, Saeed S, Sajjad A, Khan KA, Ghramh HA, Shehzad MA, Mubarak H, Mirza N, Mahpara S, Rehmani MIA, Ansari MJ. 2019. Insect pollinator diversity in four forested ecosystems of southern Punjab, Pakistan. Saudi J Biol Sci 26 (7): 1835-1842. DOI: 10.1016/j.sjbs.2018.02.007.

Bharti V, Ahlawat DS, Sharma SK, Singh NV, Jitender J, Singh N. 2015. Diversity, abundance and pollination efficiency of insect pollinators of fennel (*Foeniculum vulgare* Miller) and effect of abiotic factors on insect pollinator activity. J Appl Nat Sci 7 (2): 786-793. DOI: 10.31018/jans.v7i2.684.

Cammaerts MC, Cammaerts D. 2018. Impact of environmental noise on insect ethology - A study on ants as models. Biol Eng Med 3: 1-8. DOI: 10.15761/BEM.1000150.

Chen M, Zhao X-Y, Zuo X. 2018. Pollinator activity and pollination success of *Medicago sativa* L. in a natural and a managed population. Ecol Evol 8 (17): 9007-9016. DOI: 10.1002/ece3.4256.

Choi SW, Jung C. 2015. Diversity of insect pollinator in different agricultural crops and wild flowering plants in Korea. Apiculture 30 (3): 191-201. DOI: 10.17519/apiculture.2015.09.30.3.191.

Cuartas-Hernández SE, Gómez-Murillo L. 2015. Effect of biotic and abiotic factors on diversity patterns of anthophilous insect communities in a tropical mountain forest. Neotrop Entomol 44 (3): 214-223. DOI: 10.1007/s13744-014-0265-2.

Darmi D, Ezatalopa M, Rizwar R. 2023. Community structure of soil Diplopoda at different altitudes in Kabawetan Tea Plantation, Bengkulu. Biosilampari 5 (2): 143-153. DOI: 10.31540/biosilampari.v5i2.2130. [Indonesian]

Darsono, Riwidiharso EDY, Santoso S, Sudiana E, Nasution EK, Aprilliana H, Chasanah T. 2020. Insect diversity in various distances to forest edge in small nature reserve: A case study of Bantarbolang Nature Reserve, Central Java, Indonesia. Biodiversitas 21 (10): 482-4828. DOI: 10.13057/biodiv/d211048.

Ellis CR, Feltham H, Park K, Hanley N, Goulson D. 2017. Seasonal complementary in pollinators of soft-fruit crops. Basic Appl Ecol 19: 45-55. DOI: 10.1016/j.baae.2016.11.007.

Gbarakoro TN, Okene PF. 2020. Assessment of insect functional groups of mangroves parts at Asarama, Andoni, Rivers State, Nigeria. Eur J Agric For Res 8 (2): 18-27. DOI: 10.37745/ejafr.2013.

Hasan PA, Nurmiati N. 2022. Insect diversity of mangrove flower visitors in Gonda Mangrove Park District Polewali Mandar, West Sulawesi Province. Jurnal Entomologi Indonesia 19 (1): 33-33. DOI: 10.5994/jei.19.1.33. [Indonesian]

Hrncir M, Maia-Silva C, da Silva Teixera-Souza VH, Imperatri FVL. 2019. Stingless bees and their adaptations to extreme environments. J Comp Physiol A 205: 415-426. DOI: 10.1007/s00359-019-01327-3.

Itumo M, Onyinye IOAOI, Okeke CPN. 2024. Assessment of the impact of land-use change on the abundance, composition and diversity of Mangrove Insects in Bundu-Ama, Niger Delta. J Environ Earth Sci 14 (4): 1-10. DOI: 10.7176/JEES/14-4-01.

Kass JM, Anderson RP, Espinosa-lucas A, Juárez-jaimes V, Martínez-salas E, Botello F, Tavera G, Flores-martínez JJ, Sánchez-cordero V. 2020. Biotic predictors with phenological information improve range estimates for migrating monarch butterflies in Mexico. Ecography 43: 341-352. DOI: 10.1111/ecog.04886.

Koneri R, Langoy MD, Nangoy MJ, Wakhid W. 2024. Pollinator insects in the Mount Tumpa Forest Park, Manado, North Sulawesi, Indonesia. Biodiversitas 25 (6): 2415-2426. DOI: 10.13057/biodiv/d250610.

Koneri R, Maabuat PV, Nangoy MJ. 2020. The distribution and diversity of butterflies (Lepidoptera: Rhopalocera) in various urban forests in North Minahasa Regency, North Sulawesi Province, Indonesia. Appl Ecol Environ Res 18: 2295-2314. DOI: 10.15666/aeer/1802_22952314.

Konoyima KJ. 2020. Conservation of mangroves: Challenges and prospects in the Scarcies River Estuary, Sierra Leone. SSRG Intl J Hum Soc Sci 7: 7-13. DOI: 10.14445/23942703/IJHSS-V7I6P102.

Kusmana C. 2018. Mangrove plant utilization by local coastal community in Indonesia. IOP Conf Ser Earth Environ 196: 012028. DOI: 10.1088/1755-1315/196/1/012028.

Martin C, Almahasheer H, Duarte C. 2019. Mangrove forests as traps for marine litter. Environ Pollut 247: 499-508. DOI: 10.1016/j.envpol.2019.01.067.

Meléndez-Jaramillo E, Cantú-Ayala C, Sánchez-Reyes UJ, Sandoval-Becerra FM, Herrera-Fernández, B. 2019. Altitudinal and seasonal distribution of butterflies (Lepidoptera, Papilionoidea) in cerro bufa el diente, Tamaulipas, Mexico. ZooKeys 900: 31-68. DOI: 10.3897/zookeys900.36978.

Membere O, Bawo DDS, Onwuteaka J, Ugbomeh AP, Nwosu OR. 2021. Abundance and diversity of insects associated with *Rhizophora mangle* and *Avicennia germinans* in Bundu-Ama mangrove ecosystem of the Niger Delta, Nigeria. Sci Afr 14: e01058. DOI: 10.1016/j.sciaf.2021.e01058.

Michener CD. 2000. The Bees of The World. The Johns Hopkins University Press, Baltimore.

Mitra B, Biswas O, Roy S, Chakraborti U, Panja B. 2016. Insect faunal diversity of the Sunderban Biosphere Reserve, West Bengal, India. Intl J Curr Res Acad Rev 4: 87-98. DOI: 10.20546/ijcrar.2016.409.008.

Mitra B, Biswas O, Roy S, Chakraborti U. 2015. Pollinators of mangroves in the perspective of Indian Sunderbans. ENVIS Newsl 21: 6-11.

Offenberg J. 2015. Review: Ants as tools in sustainable agriculture. J Appl Ecol 52: 1197-1205. DOI: 10.1111/1365-2664.12496.

Ojija F. 2016. Diversity and abundance of arthropods at Mbeya University of Science and Technology, Tanzania. Intl J Sci Technol Res 5 (9): 201-210.

Otsuka K. 1991. Butterflies of Borneo Vol. 2: Lycaenidae, Hesperiidae. Tobishima, Japan.

Panda M, Lele N, Samal RN. 2019. Insect flower visitors and their role in mangrove pollination: A Study from East Coast of India. J Trop For Environ 9 (2): 78-92 DOI: 10.31357/jtfe.v9i2.4470.

Perks SJ, Goodenough AE 2020. Abiotic and spatiotemporal factors influence the activity of European bat species and have implications for acoustic survey detectability. Wildl Biol 2020 (2): 1-8. DOI: 10.2981/wlb.00659.

Powney GD, Carvell C, Edwards M, Morris RKA, Roy HE, Woodcock BA, Isaac NJB. 2019. 2019. Widespread losses of pollinating insects in Britain. Nat Commun 10 (1): 1-6. DOI: 10.1038/s41467-019-08974-9.

Purnama MF, Prayitno SB, Muskananfola MR, Suryanti S. 2024. Red berry snail *Sphaerassiminea miniata* (Gastropoda: Mollusca) and its potential as a bioindicator of environmental health in mangrove ecosystem of Pomalaa, Kolaka District, Indonesia. Biodiversitas 24 (6): 2330-2339. DOI: 10.13057/biodiv/d250601.

Rante FFT, Mokosuli YS, Setyawati I, Tumbel FM, Lawalata HJ. 2023. Insect biodiversity in mangrove area of Tatengesan Village, Pusomaen District in Southeast Minahasa, North Sulawesi. Adv Trop Biodivers Environ Sci 7 (2): 63-69. DOI: 10.24843/ATBES.2023.v07.i02.p04.

Ritter CD, Häggqvist S, Karlsson D, Sääksjärvi IE, Muasya AM, Nilsson RH, Antonelli A. 2019. Biodiversity assessments in the 21st century: The potential of insect traps to complement environmental samples for estimating eukaryotic and prokaryotic diversity using high-throughput DNA metabarcoding. Genome 62 (3): 147-159. DOI: 10.1139/gen-2018-0096.

Romanach S, Deangelis D, Hock LK, Li Y, Su YT, Sulaiman R, Zhai L. 2018. Conservation and restoration of mangroves: Global status, perspectives, and prognosis. Ocean Coast Manag 154: 72-82. DOI: 10.1016/j.ocecoaman.2018.01.009.

Sakagami SF, Inoue T, Salmah S. 1990. Stingless bees of Central Sumatra. In: Sakagami SF, Ohgushi R, Roubik DW (eds). Natural History of Social Wasps and Bees in Equatorial Sumatra. Hokkaido University Press, Sapporo.

Sari A, Tuwo A, Saru A. 2022. Diversity of fauna species in the mangrove ecosystem of Youtefa Bay Tourism Park, Papua, Indonesia. Biodiversitas 23 (9): 4490-4500. DOI: 10.13057/biodiv/d230915.

Schowalter TD. 2022. Insect Ecology: An Ecosystem Approach. Academic press, London.

Sembiring J, Saleky D, Merl SL, Pangaribuan RD, Mendes J. 2024. Insect diversity in mangrove ecosystems in Payum Beach, Merauke Regency, Papua. BioLink: Jurnal Biologi Lingkungan, Industri, Kesehatan 11 (1): 12-23. DOI: 10.31289/biolink.v11i1.12216. [Indonesian].

Semiun CG, Lengur ER, Duhan GUB. 2020. Insect diversity profile of mangrove ecosystem in Menipo Nature Tourism Park, East Amarasi, East Nusa Tenggara. IOP Conf Ser Mater Sci Eng 823: 012050. DOI: 10.1088/1757-899X/823/1/012050.

Setyawan YP, Wakhid, Suhadi. 2020. The denser canopy of mangrove drives the structure of insect communities. Trop Life Sci Res 31 (3): 77-90. DOI: 10.21315/tlsr2020.31.3.6.

Sheffield CS, Pindar A, Packer L, Kevan PG. 2013. The potential of cleptoparasitic bees as indicator taxa for assessing bee communities. Apidologie 44 (5): 501-510. DOI: 10.1007/s13592-013-0200-2.

Siregar EH, Atmowidi T, Kahono S. 2016. Diversity and abundance of insect pollinators in different agricultural lands in Jambi, Sumatera. Hayati 23: 13-17. DOI: 10.1016/j.hjb.2015.11.002.

Tabba T, Wahyuni NI, Mokodompit HS. 2015. Composition and structure of Tiwoho II mangrove vegetation in Bunaken National Park area. Jurnal Wasian 2 (2): 95-103. DOI: 10.62142/n8859p33. [Indonesian]

Tomlinson PB. 2016. The Botany of Mangroves. Cambridge University Press, Cambridge.

Tsukada E. 1991. Butterflies of The South East Asian Island Part 5: Nymphalidae. Azumino Butterflies Research Institute, Japan.

Umami S, Amaliyah NS, Fahlefi AR, Zumar MR, Romzalis AA, Wibisana OR, Susanto, MAD. 2024. Butterflies (Lepidoptera: Papilionoidea) diversity in Kedung Klurak Tourism Area, Mojokerto District, East Java, Indonesia. Intl J Trop Drylands 8 (1): 27-34. DOI: 10.13057/tropdrylands/t080104.

Wakhid W, Rauf A, Krisanti M, Sumertajaya IM, Maryana N. 2021. Aquatic insect communities in headwater streams of Ciliwung River watershed, West Java, Indonesia. Biodiversitas 22 (1): 30-41. DOI: 10.13057/biodiv/d220105.

Welti E, Helzer C, Joern A. 2017. Impacts of plant diversity on arthropod communities and plant-herbivore network architecture. Ecosphere 8 (10): e01983. DOI: 10.1002/ecs2.1983.

Widhiono I, Sudiana E. 2015. The role of wild plants in the conservation of pollinating insects of the order Hymenoptera. Prosiding Seminar Nasional Masyarakat Biodiversitas Indonesia. Bandung, 13 Juni 2015. [Indonesian]
Withaningsih S, Ilmi BF, Parikesit P. 2024. Correlation between flying insect diversity and environmental factors in various land use types in Paseh District, Sumedang Regency, West Java. Diversity 17 (1): 2. DOI: 10.3390/d17010002.
Xiong Y, Meng QS, Jie GAO, Tang XF, Zhang HF. 2017. Effects of relative humidity on animal health and welfare. J Integr Agric 16 (8): 1653-1658. DOI: 10.1016/S2095-3119(16)61532-0.
Yeo D, Srivathsan A, Puniamoorthy J, Maosheng F, Grootaert P, Chan L, Guenard B, Damken C, Wahab RA, Meier R. 2021. Mangroves are an overlooked hotspot of insect diversity despite low plant diversity. BMC Biol 19: 202. DOI: 10.1186/s12915-021-01088-z.
Zattara EE, Aizen MA. 2021. Worldwide occurrence records suggest a global decline in bee species richness. One Earth 4 (1): 114-123. DOI: 10.1016/j.oneear.2020.12.005.