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Pollinator insects in the Mount Tumpa Forest Park, Manado, North Sulawesi, Indonesia

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Abstract. *Koneri R, Langoy MD, Nangoy MJ, Wakhid. 2024. Pollinator insects in the Mount Tumpa Forest Park, Manado, North Sulawesi, Indonesia. Biodiversitas 25: 2415-2426.* This study aimed to analyze the diversity and distribution of pollinator insects in forest, forest edge, shrub, and agricultural land around the Mount Tumpa Forest Park, Manado, North Sulawesi, Indonesia, using the scan sampling method. Data analysis included species abundance, species dominance, richness index, diversity index, species evenness index, correlation between environmental factors, species diversity, and composition of pollinator insect species among habitats. Therefore, 17 families were reported, comprising 103 species and 3,665 individuals. The family with the highest number and most frequently encountered was Nymphalidae (25 species). Furthermore, the highest species richness and diversity indices were found in the forest edge habitat. Environmental factor analysis indicated that agricultural land habitat was characterized by high air temperature and low humidity. The species distribution found three patterns: clustered, regular, and random. The results showed that the forest edge habitat had the highest diversity due to complex vegetation structure and environmental factors supporting the survival of pollinator insects.

Keywords: *Apis cerana,* clustering, distribution, forest edge, pollinator

INTRODUCTION

Mount Tumpa Forest Park, Manado, North Sulawesi, Indonesia, is one of the conservation areas in tropical rainforests. This area is located on the Wallace Line, a hypothetical line that demarcates the zoogeographic regions of Asia and Australia, known for high biodiversity and endemism. The area is inhabited by various flora and fauna, including pollinator insects (Suryawan et al. 2015), which play an important role in transferring pollen from the anthers to the stigmas of flowers. Without the facilitation, many interrelated species and ecosystem processes would fail. Approximately 80% of all flowering plant species are dedicated to pollination by arthropods, specifically insects (Wei et al. 2021). In tropical regions, the dependence of plants on these insects is higher than in other parts of the world. Approximately 97% of all lowland tropical rainforest plants rely on insects for pollination (Bashir et al. 2019).

The main pollinator insects belong to the orders Hymenoptera (ants and bees), Coleoptera (beetles), Lepidoptera (butterflies and moths), and Diptera (flies) (Clarisa and Kasmara 2016; Davis et al. 2023). The major insects visiting flowers are from the Hymenoptera and Diptera orders, with about 56.5% being pollinated by bees, 19% by flies, 5% by wasps, 5% by beetles, and 4% by butterflies and moths. Different bee species vary in morphology, behavior, and physiology, leading to differences in pollinated plants (Shaheen et al. 2017).

These insects contribute to the pollination of wild and agricultural flowering plants. The role includes increased agricultural production and the conservation of plants in nature (Katumo et al. 2022). Pollination by insects can increase crop yields of cranberries, blueberries, tomatoes, strawberries, and cotton (Gaines-Day and Gratton 2016; Stein et al. 2017; Abrol et al. 2019; Zhang et al. 2022; Cortés-Rivas et al. 2023). In mustard (*Brassica rapa* L.), visits from pollinating insects can increase the number of pods per plant, seeds per pod, the weight of seeds per plant, and germinated seeds (Asmini et al. 2022).

Visiting flowering plants is to procure sustenance, specifically from nectar flowers, serving as a vital food source. The presence of pollinator insects is influenced by several factors, including flower color, aroma, pollen, nectar, shape, size, the number of flowers, and the suitability of flower characteristics with the body of pollinator insects, as well as environmental factors (Zariman et al. 2022). However, the most influential factor is the flower color since the insects can recognize this feature. The availability of nectar and pollen, food sources for pollinator insects, is also a significant factor in visiting flowers.

The presence of pollinator insects is greatly influenced by the availability of flowering plants in an ecosystem. Forest damage also disrupts the mutualistic interaction between plants and insects (Chiawo et al. 2017). About 95% of all extinct animals are invertebrates, with a large portion being insects. Another factor in reducing pollinator insects is the excessive use of pesticides to control pests in agricultural land (Sánchez-Bayo 2021).

The land outside the Mount Tumpa Forest Park area has various cultivated plants. Pollinator insects around this area are crucial in pollination, increasing crop production. The use of pesticides by farmers to control pests on plants reduces the population of pollinator insects. A survey on pesticide use on food crops conducted in 1990 showed that most farmers in North Sulawesi used insecticides with treatment quantities exceeding the requirements (Koneri et al. 2021). This affects the diversity of pollinator insects in the agricultural land, and several related studies have been conducted in Indonesia and abroad (Bashir et al. 2015; Choi and Jung 2015; Mattu and Nirala 2015; Siregar et al. 2016; Widhiono et al. 2016; Chiawo et al. 2017; Davis et al. 2023; Miyashita et al. 2023). Generally, previous results only considered pollinators of cultivated plant species (Latif et al. 2014; Masawet et al. 2019). There is reduced evidence of the diversity and abundance of pollinator insects in forest habitats. Therefore, this study focused on native wild pollinator insects around the Mount Tumpa Forest Park area contributing to the natural ecosystem. A study on pollinator insects in various habitat types has not been conducted and published. Hence, the impact of pesticide use and forest land conversion on the diversity of pollinator insects should be evaluated. This study aimed to analyze the diversity and distribution of pollinator insects in various habitats around Mount Tumpa Forest Park, Manado, North Sulawesi, Indonesia.

MATERIALS AND METHODS

Study area

This study was conducted on various habitats inside and outside Tumpa Forest Park, Manado, North Sulawesi, Indonesia. The purposive random sampling method was used, and the points were selected based on survey results. Habitats within the Mount Tumpa Forest Park area included forest and forest edge habitats, while those outside were plantation and shrubland habitats (Figure 1). The inside of Mount Tumpa Forest Park consists of two habitats, forest and forest edge. Furthermore, the outside Tumpa Forest Park area consists of two habitats, agricultural land and shrubs. This study was conducted for 4 months, from April to July 2023, around the Mount Tumpa Forest Park area. Meanwhile, the sample identification was performed at the advanced biology laboratory of the Faculty of Mathematics and Natural Sciences, Universitas Sam Ratulangi, Indonesia.

The locations included the forest within the Mount Tumpa Forest Park area, forest edges, plantation areas, and shrublands, as shown in Figure 2. The habitat chosen as the sampling location consists of different landscapes because each habitat type has different vegetation structures and compositions. Forests are habitats dominated by trees. The dominant trees are *Spathodea campanulata* Beauverd, *Arenga pinnata* (Wurmb) Merr., *Garcinia* sp., *Dilenia ochreata* (Miq.) Teijsm. & Binn., *Eugenia* sp., *Ficus benjamina* L., *Ficus elastica* Roxb., *Ficus* sp., etc. (Figure 2.A). The forest's edge is a habitat that borders directly on the forests of the Mount Tumpa Forest Park area. This habitat is dominated by trees, shrubs, bushes, and herbs (Figure 2.B).

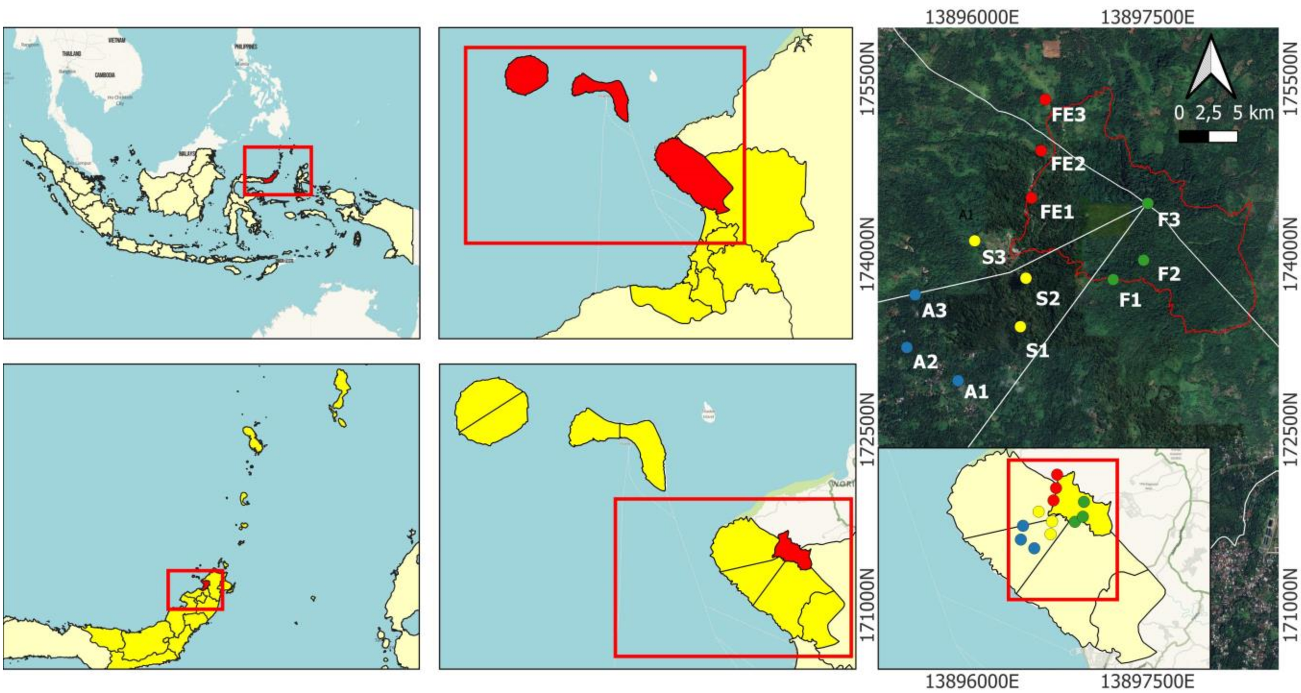

Figure 1. Map of the study around Mount Tumpa Forest Park area, Manado, North Sulawesi, Indonesia. F1, F2, F3: Forest plot-green dots; FE1, FE2, FE3: Forest edge plot-red dots; S1, S2, S3: Shrub plot-yellow dots; A1, A2, A3: Agricultural land plot-blue dots

The trees that grow in this habitat are dominated by *S. campanulata*, *Palaquium obovatum* (Griff.) Engl., *Pinus merkusii* Jungh. & de Vriese, *Cananga odorata* (Lam.) Hook.f. & Thomson, and *A. pinnata*. Other vegetation that grows on the edge of the forest in the form of shrubs and other herbs include *Chromolaena odorata* (L.) R.M.King & H.Rob., *Mikania micrantha* Kunth, *Sphagneticola trilobata* (L.) Pruski, *Spilanthes iabadicensis* A.H.Moore, *Wedellia cinensis* (Osbeck) Merr., *Emilia sonchifolia* (L.) DC. ex Wight, *Borreria laevicaulis* (Miq.) Ridl., *Lantana camara* L., *Oxallis barrelieri* L., *Rubus parviforus* Kük., *Cleome rutidosperma* DC., and *Euphorbia heterophylla* L.

Agricultural land is a habitat that is managed intensively by farmers. The plantation land from which samples were taken was dominated by maize (*Zea mays* L.), banana (*Musa* sp), and coconut (*Cocos nucifera* L.) (Figure 2.C). Landscape changes on agricultural land are very dynamic because there is soil processing, fertilization, use of insecticides and herbicides to control weeds. The shrub habitat is abandoned agricultural land (Figure 2.D); in this habitat, many plants are found in shrubs, bushes, and herbs. *M. micrantha*, *C. odorata*, *S. trilobata*, *Stachytarpheta jamaicensis* (L.) Vahl, *O. barrelieri*, *E. heterophylla*, and *Turnera ulmifolia* L. dominate the vegetation in this habitat.

Procedures sampling technique

In each habitat type, three plots were established, measuring 20×20 m with a distance of 50 m between plots. The observation of pollinator insects used the scan sampling method (Ratti and Garton 1996). The pollinating insects sampled in this study were all insects that fly and are known to function as pollinators in plants. Meanwhile, the observations and collection were conducted on sunny days, from 08:00 to 14:00, for one day per month over 4 months. Pollinator insects were captured using insect nets and placed in ethyl acetate bottles for identification. Subsequently, the specimens were placed in paper envelopes and stored in plastic boxes for identification.

The identification and classification of pollinator insects was done using books (Sakagami et al. 1990; Tsukada 1991; Michener 2000). Unidentified samples based on several identification keys were taken to the BRIN Insect Museum in Cibinong for identification. During the sampling, environmental factors were also measured, including air temperature, humidity, wind speed, and light intensity, using a thermometer, hygrometer, anemometer, and lux meter. The altitude from sea level and coordinates were determined using the Global Positioning System (GPS), and environmental factor measurements were conducted by sampling pollinator insects.

Data analysis

The abundance and species richness of pollinator insects were tabulated for each habitat using Microsoft Excel. Community structure attributes such as species abundance, Simpson dominance ($D\text{-}1=1/\Sigma pi^2$), species richness, Shannon-Wiener diversity index ($H'=-\Sigma pi \ln pi$), and Pielou's evenness index ($J=H'/\ln S$) were calculated based on each habitat (Bashir et al. 2019). Subsequently, one-way analysis of variance (ANOVA) and Tukey's test at a 95% confidence level were performed using Statistica version 6 software to test significant differences in individual abundance, species richness, Shannon diversity index, and evenness index among habitats (Ajerrar et al. 2020). Species richness was estimated from the abundance data using Chao 1 estimator. Sampling completeness for each land use was assessed by calculating the number of observed species as a percentage of this estimate. Since sample sizes differed, individual-based rarefaction analyses were used to compare the number of species between land-use types.

Figure 2. Photographs of study sites in Mount Tumpa Forest Park, Manado, North Sulawesi, Indonesia. A. Forest; B: Forest edge; C: Agricultural land; D. Shrub

Statistical tests Analysis of Similarity (ANOSIM) was used to assess differences in the composition of pollinator insect species. Furthermore, differences in the composition of communities among habitat types in ecotourism trails were visualized using Non-Metric Dimensional Scaling (NMDS). ANOSIM and NMDS were analyzed based on the Bray-Curtis dissimilarity index. Meanwhile, Principal Component Analysis (PCA) between independent and dependent variables was conducted to determine the relationship between sampling locations and environmental factors. ANOSIM, NMDS, and PCA were analyzed using Paleontological Statistics software (PAST software 3.10) (Hammer et al. 2001). The distribution of pollinator insect species using the index was calculated through the Morisita index formula according to Ginantra et al. (2020):

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

Where:
n : number of plots,
x : number of individuals per plot,
∑ : sum of squares for all species in each plot,
N : total number of individuals,
With the following conditions:
Id = 1, the distribution pattern is random
Id > 1, the distribution pattern is clustered
Id < 1, the distribution pattern is regular/uniform

RESULTS AND DISCUSSION

The pollinator insects in this study amounted to 3,665 individuals, comprising 103 species belonging to 17 families and 4 orders (Table 1). The observed pollinator insects included 66 species from the order Lepidoptera, 29 from the order Hymenoptera, 7 from the order Diptera, and 1 from the order Coleoptera, as shown in Table 1. This study found the highest number of species and abundance of pollinator insects in forest edge habitats (72 species and 1,084 individuals). In comparison, the lowest was agricultural land (65 species and 668 individuals). Flowering plants commonly visited by pollinating insects during sampling were *M. micrantha* (Asteraceae), *C. odorata* (Asteraceae), *S.trilobata* (Asteraceae), *S. jamaicensis* (Verbenaceae), *O. barrelieri* (Oxalidaceae), *E. heterophylla* (Euphorbiaceae), *T. ulmifolia* (Turneraceae), and *Hyptis capitata* Jacq. (Lamiaceae).

The order Lepidoptera consisted of the families Nymphalidae (25 species), Lycaenidae (13 species), Papilionidae (12 species), Pieridae (8 species), Hesperiidae (7 species), and Erebiidae (1 species) (Table 1). Hymenoptera consisted of the families Apidae (9 species), Eumenidae (8 species), Halictidae (5 species), Vespidae (4 species), and Megachilidae (3 species). Diptera included the families Calliphoridae (2 species), Dolichopodidae (2 species), Muscidae (1 species), Sarcophagidae (1 species), and Syrphidae (1 species). Coleoptera was represented by the Chrysomelidae family, with only 1 species found. The Nymphalidae families has the highest abundance in forest edge habitats (30.5%). Furthermore, the Apidae families has the highest abundance in shrub habitats (27.5%). The study also reported the presence of many rare or uncommon species. The species with singleton or doubleton values totaled 14 (14%) out of the 103 found.

The composition of pollinator insects showed that order Lepidoptera had the highest abundance (>50%) in the four observed habitats (Figure 3). This is followed by Hymenoptera and Diptera, with Coleoptera showing the lowest prevalence. Furthermore, Coleoptera was exclusively identified in the forest habitat, represented by *Chrysolina herbaceae* (Chrysomelidae).

The ranking of the 103 species found based on relative abundance indicates that *Apis cerana* (Hymenoptera), *Eurema tominia* (Lepidoptera), *Thyreus nitidulus* (Hymenoptera), *Ideopsis juventa* (Lepidoptera), and *Hebomia glaucippe* (Lepidoptera) occupy ranks 1, 2, 3, 4, and 5, at 9.55%, 8.32%, 5.92%, 4.80%, and 4.07%, respectively. The next four species, ranking 6-12, have relative abundances ranging from 2.13% to 3.79%. The low steepness of the curve shows high species evenness in Mount Tumpa Forest Park, as shown in Figure 4.

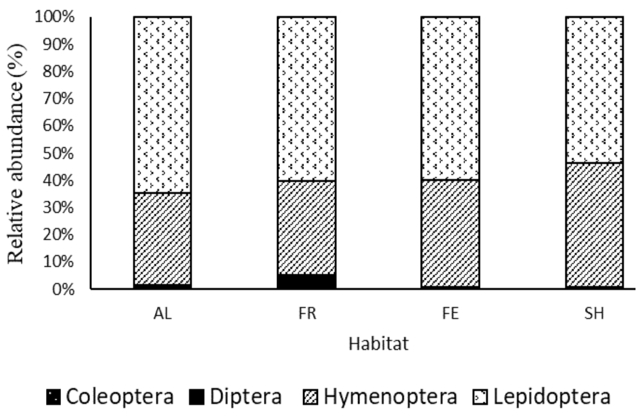

Figure 3. Composition of pollinator insect orders based on individual abundance in four habitats. AL: Agricultural Land; FR: Forest; FE: Forest Edge; SH: Shrub

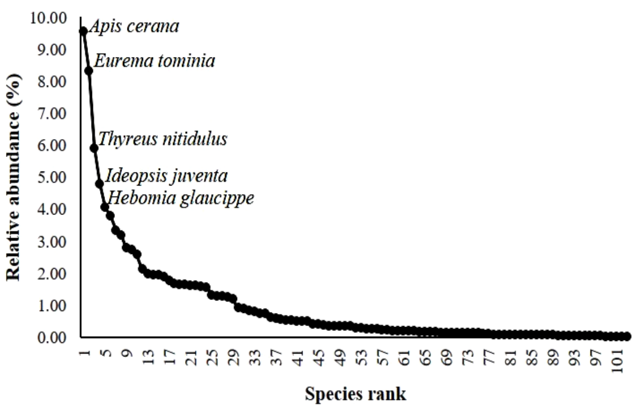

Figure 4. Relative abundance of pollinating insects based on a species in four habitats in the Mount Tumpa Forest Park area, Manado, North Sulawesi, Indonesia

Table 1. List of pollinator insect species found in four habitats on Mount Tumpa Forest Park area, Manado, North Sulawesi, Indonesia

Ordo/Family/Species	Habitat types/number of individuals				∑	%
	AL	FR	FE	SH		
Coleoptera						
Chrysomelidae						
Chrysolina herbacea (Duftschmid, 1825)	0	3	0	0	3	0.08
Diptera						
Calliphoridae						
Chrysomya megacephala (Fabricius, 1794)	0	4	0	2	6	0.16
Lucilia sericata (Meigen, 1826)	0	9	3	1	13	0.35
Dolichopodidae						
Condylostylus bituberculatus (Macquart, 1842)	0	0	1	0	1	0.03
Psilopus bituberculatus (Macquart, 1842)	0	0	1	0	1	0.03
Muscidae						
Musca sp.	2	28	1	3	34	0.93
Sarcophagidae						
Sarcophaga carnaria (Linnaeus, 1758)	8	1	1	0	10	0.27
Syrphidae						
Episyrphus balteatus (De Geer, 1776)	0	0	0	3	3	0.08
Hymenoptera						
Apidae						
Amegilla zonata (Linnaeus, 1758)	15	10	20	56	101	2.76
Apis cerana (Fabricius, 1793)	59	78	106	107	350	9.55
Apis dorsata (Fabricius, 1793)	4	1	15	3	23	0.63
Apis nigrocincta (Smith, 1860)	0	2	0	0	2	0.05
Apis sp.	7	6	22	11	46	1.26
Ceratina cognata (Smith, 1879)	5	9	9	21	44	1.20
Ceratina nigrolateralis (Cockerell, 1916)	2	0	0	0	2	0.05
Thyreus nitidulus (Fabricius, 1804)	26	67	55	69	217	5.92
Xylocopa confusa (Pérez, 1901)	12	19	19	15	65	1.77
Eumenidae						
Apodynerus troglodytes (de Saussure, 1856)	1	0	0	2	3	0.08
Cyrtolabulus interstitialis (Cameron, 1902)	1	0	2	4	7	0.19
Delta campaniforme (Fabricius, 1775)	2	2	9	6	19	0.52
Delta conoideum (Gmelin, 1790)	2	5	3	3	13	0.35
Delta pyriforme (Fabricius, 1775)	6	1	5	21	33	0.90
Phimenes flavopictus (Blanchard, 1845)	1	0	0	0	1	0.03
Phimenes indosinensis (Vecht, 1959)	10	12	6	2	30	0.82
Polistes dorsalis (Fabricius, 1775)	17	26	15	37	95	2.59
Halictidae						
Augochlora pura (Say, 1837)	0	0	0	3	3	0.08
Lasioglossum malachurum (Kirby, 1802)	0	0	0	4	4	0.11
Nomia melanderi Cockerell, 1906	0	3	2	4	9	0.25
Nomia strigata (Fabricius, 1793)	21	9	61	32	123	3.36
Nomia thoracica (Smith, 1875)	0	0	0	1	1	0.03
Megachilidae						
Megachile centuncularis (Linnaeus, 1758)	3	9	4	4	20	0.55
Megachile latreillii (Spinola, 1806)	0	2	0	0	2	0.05
Megachile relativa (Cresson, 1878)	7	13	24	18	62	1.69
Vespidae						
Ropalidia fasciata (Fabricius, 1804)	9	14	15	22	60	1.64
Ropalidia stigma (Smith, 1858)	0	1	0	2	3	0.08
Vespa affinis (Linnaeus, 1764)	6	0	9	5	20	0.55
Vespa tropica (Linnaeus, 1758)	10	18	28	14	70	1.91
Lepidoptera						
Erebidae						
Amata trigonophora (Turner, 1898)	0	0	3	0	3	0.08
Hesperiidae						
Borbo cinnara (Wallace, 1866)	1	7	0	0	8	0.22
Notocrypta curvifascia (C.Felder & R.Felder, 1862)	0	5	0	0	5	0.14
Parnara bada (Moore, 1878)	2	0	0	0	2	0.05
Potanthus confucius (C.Felder & R.Felder, 1862)	0	0	2	0	2	0.05
Potanthus chloe (Eliot, 1960)	11	0	6	14	31	0.85
Potanthus fettingi (Möschler, 1878)	0	0	3	0	3	0.08
Potanthus omaha (Edwards, 1863)	34	3	24	12	73	1.99

Lycaenidae						
Catochrysops strabo (Fabricius, 1793)	9	3	1	0	13	0.35
Curetis insularis (Horsfield, 1829)	0	0	2	0	2	0.05
Jamides aratus (Cramer, 1782)	9	1	0	0	10	0.27
Jamides pura (Moore, 1886)	0	0	0	10	10	0.27
Jamidesa alecto (Felder, 1860)	0	9	0	0	9	0.25
Jamidesa celeno (Cramer, 1775)	7	0	4	3	14	0.38
Lampides boeticus (Linnaeus, 1767)	0	0	2	6	8	0.22
Megisba malaya (Horsfield, 1828)	6	2	11	0	19	0.52
Pithecops phoenix (Röber, 1886)	0	8	9	5	22	0.60
Rapala dioetas (Hewitson, 1863)	0	0	1	0	1	0.03
Rapala manea (Hewitson, 1863)	0	1	4	0	5	0.14
Zizina otis (Fabricius, 1787)	0	28	0	0	28	0.76
Zyzula hylax (Fabricius, 1775)	0	0	3	12	15	0.41
Nymphalidae						
Charaxes affinis (Butler, 1865)	1	0	0	5	6	0.16
Cyrestis strigata (Felder, 1867)	0	11	4	4	19	0.52
Danaus genutia (Cramer, 1779)	19	9	17	15	60	1.64
Danaus ismare subsp. *alba* (Morishita, 1981)	6	10	33	0	49	1.34
Doleschallia bisaltide (Cramer, 1777)	2	4	1	0	7	0.19
Euploea algea (Godart, 1819)	1	0	0	4	5	0.14
Euploea eupator (Hewitson, 1858)	6	0	8	1	15	0.41
Euploea hewitsonii (C.Felder & R.Felder, 1965)	0	2	0	0	2	0.05
Euploea leucostictos westwoodii (Felder & Felder, 1865)	1	1	5	0	7	0.19
Hypolimnas bolina (Linnaeus, 1758)	9	0	2	0	11	0.30
Hypolimnas misippus Linnaeus, 1764)	3	1	3	1	8	0.22
Idea blanchardii (Marchal, 1845)	3	34	16	19	72	1.96
Ideopsis juventa (Cramer, 1777)	39	40	64	33	176	4.80
Ideopsis vitrea (Blanchard, 1853)	9	56	70	4	139	3.79
Junonia hedonia intermedia (Linnaeus, 1764)	38	13	30	36	117	3.19
Lasippa neriphus (Hewitson, 1868)	3	5	8	5	21	0.57
Moduza lymire (Hewitson, 1859)	0	2	0	6	8	0.22
Mycalesis horsfieldii (Moore, 1858)	0	5	0	1	6	0.16
Mycalesis janadarna (Moore, 1857)	1	2	0	0	3	0.08
Neptis ida (Moore, 1858)	2	7	26	26	61	1.66
Parantica cleona (Stoll, 1782)	10	3	23	12	48	1.31
Parthenos sylvia salentia (Hopffer, 1874)	3	21	15	8	47	1.28
Vindula dejone celebensis (Butler, 1874)	2	0	0	0	2	0.05
Yphtima loryma (Hewitson, 1864)	0	0	3	0	3	0.08
Yptima nynias (Fruhstorfer, 1911)	3	2	3	0	8	0.22
Papilionidae						
Graphium agamemnon (Linnaeus, 1758)	4	40	17	17	78	2.13
Graphium meyeri (Hopffer, 1874)	0	0	3	8	11	0.30
Graphium milon (Felder & Felder, 1864)	0	3	0	1	4	0.11
Pachliopta polyphontes (Boisduval, 1836)	10	9	19	21	59	1.61
Papilio ascalaphus (Boisduval, 1836)	32	12	5	9	58	1.58
Papilio blumei (Boisduval, 1836)	0	0	1	2	3	0.08
Papilio demoleus (Linnaeus, 1758)	5	0	0	0	5	0.14
Papilio gigon (Felder & Felder, 1864)	2	0	1	0	3	0.08
Papilio polytes (Linnaeus, 1758)	0	5	0	8	13	0.35
Papilio sataspes (Felder & Felder, 1864)	3	4	4	2	13	0.35
Troides helena (Linnaeus, 1758)	3	19	7	43	72	1.96
Troides hypolitus (Cramer, 1775)	0	7	0	0	7	0.19
Pieridae						
Appias zarinda (Boisduval, 1836)	2	2	2	0	6	0.16
Catopsilia pomona (Fabricius, 1775)	15	15	44	29	103	2.81
Catopsilia scylla var. *asaema* Staudinger, 1885	47	0	5	9	61	1.66
Cepora celebensis (Rothschild, 1892)	0	2	0	0	2	0.05
Eurema celebensis (Wallace, 1867)	0	0	3	0	3	0.08
Eurema tominia (Snellen van Vollenhoven, 1865)	43	79	82	101	305	8.32
Hebomia glaucippe (Linnaeus, 1758)	21	37	41	50	149	4.07
Pareronia tritaea (Felder & Felder, 1859)	5	7	8	8	28	0.76
Total abundance	668	888	1,084	1,025	3,665	
Total species richness	65	69	72	66	103	
Chao1	67.5	71.5	76.5	68.1	104	

Notes: AL: Agricultural Land; FR: Forest; FE: Forest Edge; SH: Shrub

The rarefaction-extrapolation curve shows a rapid increase at the beginning of sampling, followed by a slow approach to an asymptotic point (Figure 5). The curves for the four habitats overlap, showing that all four habitats have similar species diversity. Based on the rarefaction-extrapolation curve, the number of species found in the four habitats has reached an asymptotic point as the curve levels off. Based on Chao1, the estimates of species of insect pollinators found in the four habitats are forest edge (76.5 species), forest (71.5 species), shrub (68.1 species), and agricultural land (67.5 species) (Table 1).

The highest average species richness and diversity, based on the Margalef and Shannon indices, were found in the forest edge habitat (7.99 and 3.41), while the lowest was in the shrub (7.32 and 3.24) (Figure 6). In this study, the dominance index and species evenness in all four habitats showed values and species evenness close to zero and one, indicating fewer species in the habitats. Additionally, ANOVA analysis showed that the average dominance (ANOVA: F3, 11=1.271; P=0.348), diversity (ANOVA: F3, 11=0.726; P=0.565), species richness (ANOVA: F3, 11=0.361; P=0.783), and evenness (ANOVA: F3, 11=1.38; P=0.317) did not differ significantly among four observed habitats.

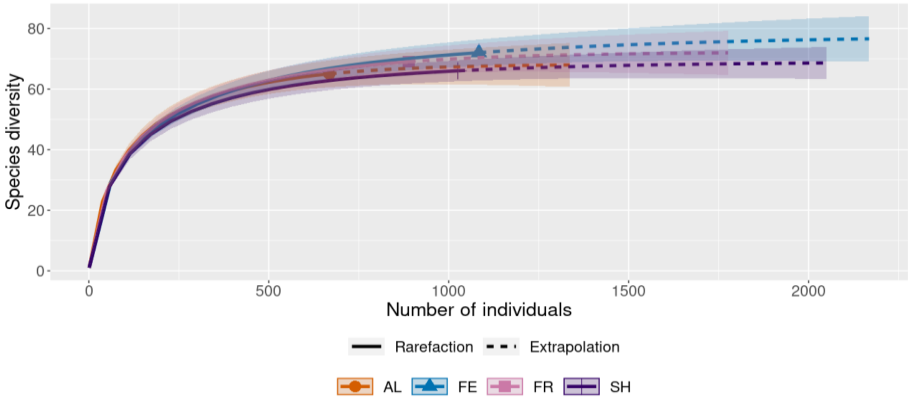

Figure 5. Rarefaction curves of individual pollinating insects in four habitats on Mount Tumpa Forest Park, Manado, North Sulawesi, Indonesia. AL: Agricultural Land; FR: Forest; FE: Forest Edge; SH: Shrub

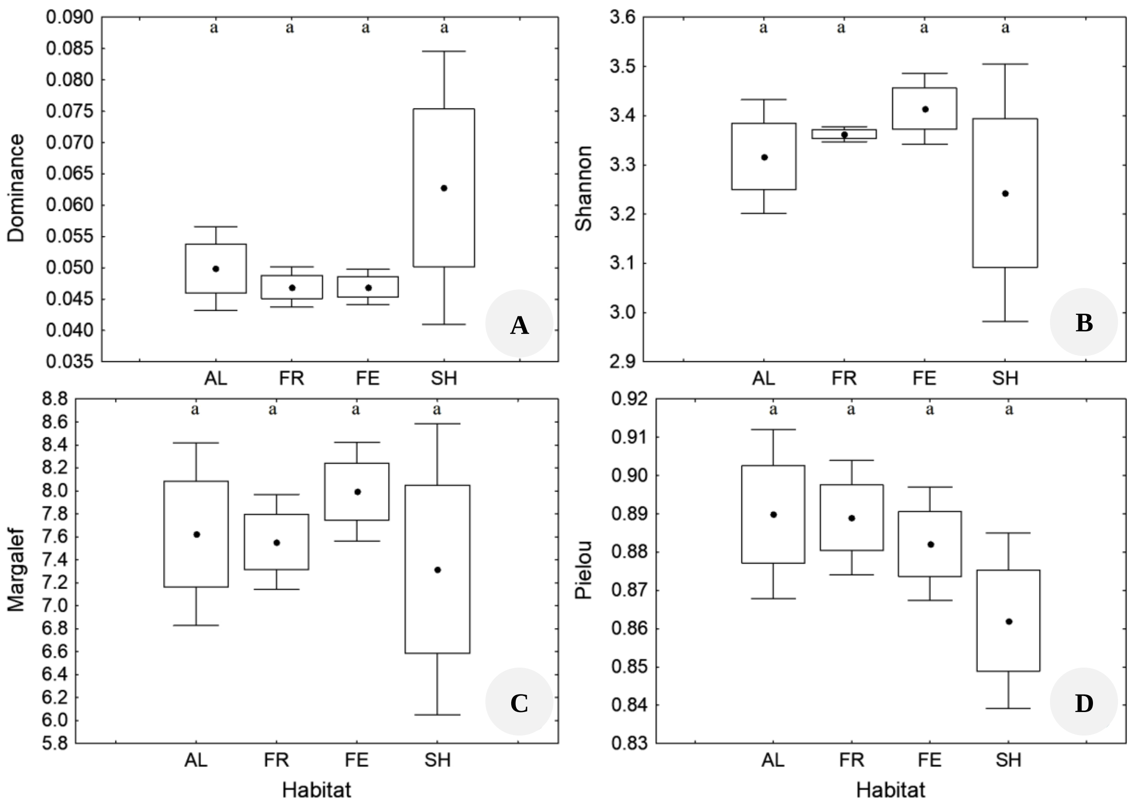

Figure 6. Pollinator insect community structure (A: Dominance index; B: Shannon diversity index; C: Margelef index; Pielou index) in four habitats on Mount Tumpa Forest Park, Manado, North Sulawesi, Indonesia. AL: Agricultural Land; FR: Forest; FE: Forest Edge; SH: Shrub

Analysis of Similarity (ANOSIM) based on the Bray-Curtis index reports a significant difference in the composition among the four habitats (R: 0.5123; P: 0.0009). Significant differences in species composition are also evident in Non-Metric Dimensional Scaling (NMDS) ordination results, which show separate and non-overlapping ordination points for the four habitats (Figure 7).

Environmental factors such as humidity (ANOVA: F3, 35 = 4.389; P= 0.0107), temperature (ANOVA: F3, 35 = 17.06; P= 8.48e-07), light intensity (ANOVA: F3, 35 = 4.74; P= 0.00758), and wind speed (ANOVA: F3, 35 = 3.793; P= 0.0196) varied among the four observed habitats. The highest and lowest humidity was found in forest and shrub habitats (Figure 8). The highest and lowest temperature was found in the agricultural and forest habitats. Conversely, the highest light intensity and wind speed were reported in the shrub habitat.

The Principal Component Analysis (PCA) coordination of environmental factors across the four observed habitats shows that agricultural land is characterized by high temperature and low humidity (Figure 9). In contrast, the Forest habitat is characterized by low temperature, light intensity, and high humidity. Furthermore, the Shrub habitat is characterized by high wind speed and light intensity.

The distribution in the four habitat types, based on the Morisita index, showed three species distribution patterns: Aggregate, Uniform, and Random. The most common distribution pattern is Aggregate, which has been reported in 92 species. The Uniform and Random patterns are present in 8 and 4 species. Based on the order, the species of Coleoptera order show the Aggregate pattern, while Diptera reports Aggregate and Uniform patterns. Hymenoptera and Lepidoptera orders indicate distribution patterns, including Aggregate, Uniform, and Random, as shown in Table 1.

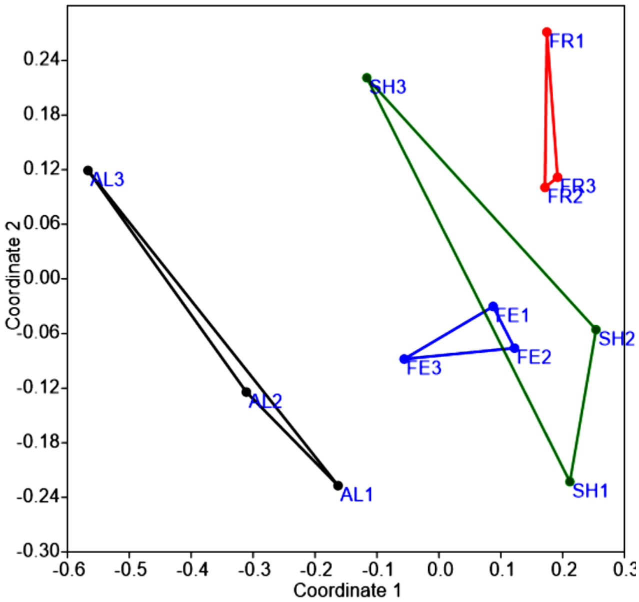

Figure 7. Non-Metric Dimensional Scaling (NMDS) of pollinator insect composition in four habitats on Mount Tumpa Forest Park, Manado, North Sulawesi, Indonesia (stress value: 0.1779). AL: Agricultural Land; FR: Forest; FE: Forest Edge; SH: Shrub

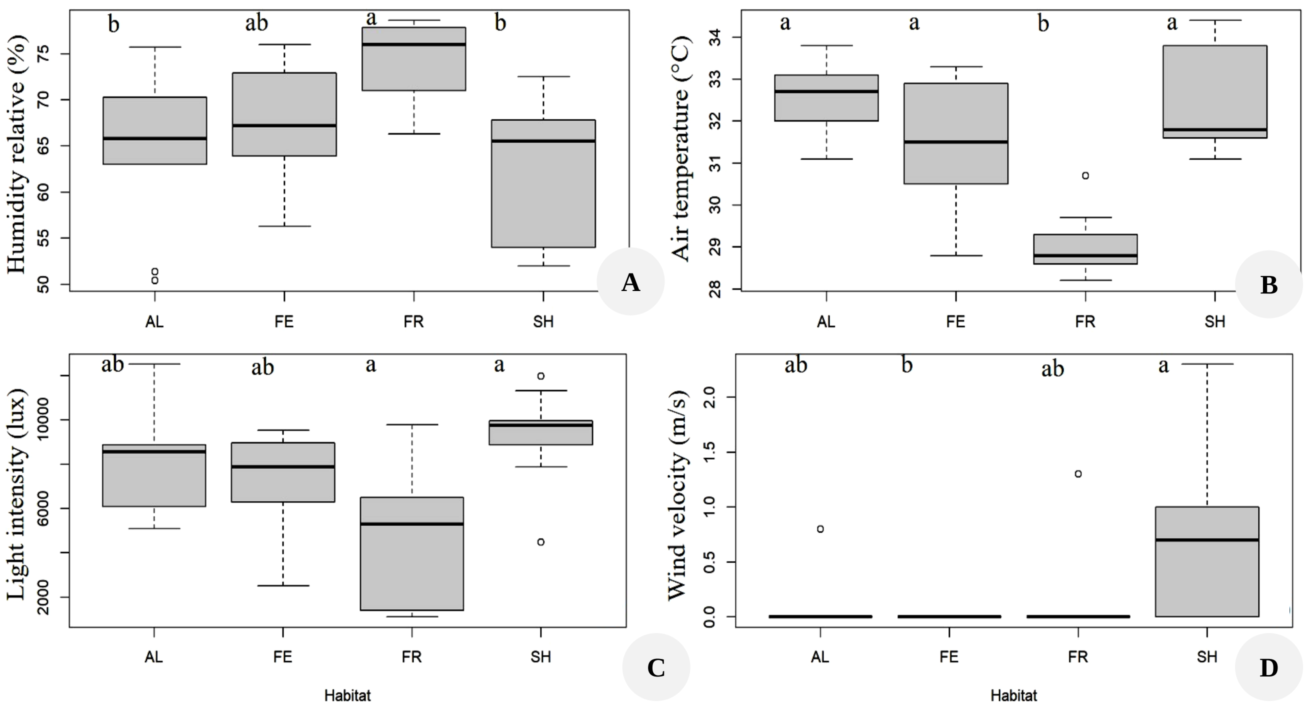

Figure 8. Environmental factors (A: Humidity relative; B: Air temperature; C: Light intensity; D: Wind velocity) in four habitats on Mount Tumpa Forest Park, Manado, North Sulawesi, Indonesia. AL: Agricultural Land; FR: Forest; FE: Forest Edge; SH: Shrub

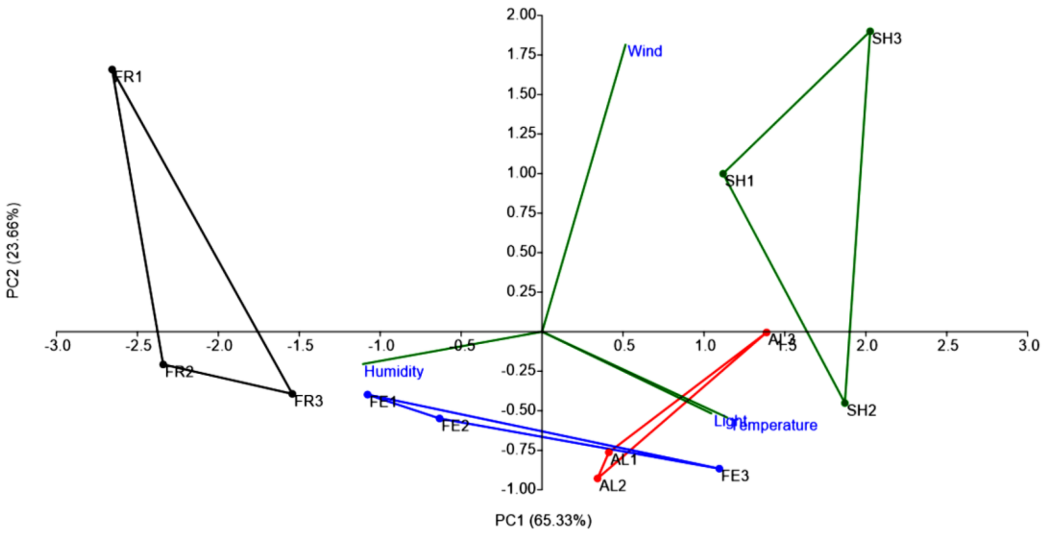

Figure 9. PCA ordination of four habitats on Mount Tumpa Forest Park, Manado, North Sulawesi, Indonesia. AL: Agricultural Land; FR: Forest; FE: Forest Edge; SH: Shrub

Discussion

Based on the number of species and their abundance, Lepidoptera is the most richness and abundant order in the location and is dominant in all habitat types. The dominance is attributed to efficient ecological functional groups in pollination, high color recognition capability, and inherent preference for color. This leads to frequent occurrences in the pollination of flowering plants (Mertens et al. 2021). The abundance of Lepidoptera is closely related to the availability of food plants and environmental conditions (Forbes et al. 2019). The type and quantity of food also significantly influence pollinator insects because the availability is an important factor regulating the activity, population density, and diversity. Fountain (2022) stated that habitat diversification provided nectar for parasitoids and served as a temporary shelter.

The order Hymenoptera is the second most common order found in this study. This is one of the four highly diverse insect orders, comprising more than 153,000 and up to one million described and undescribed species. According to Kataria and Edgaonkar (2023), Hymenoptera, with almost 250,000 described species, is the most important pollinator group. Species of this order play a fundamental role in all terrestrial ecosystems, acting as parasitoids, predators, and pollinators (Bashir et al. 2019). Several studies report that dominant pollinator insects belong to the Hymenoptera order (Choi and Jung 2015; Siregar et al. 2016; Bashir et al. 2019; Senapathi et al. 2021).

Apidae had the highest abundance in all habitat types belonging to the Hymenoptera order (Siregar et al. 2016). Insects from these families have relatively small body sizes, numerous hairs on the bodies, long proboscis, and pollen baskets on the outer surface of the hind leg tibia, which function as pollen carriers. According to Li et al. (2023), Hymenoptera insects from the Apidae family greatly adapt to the environment. They can thrive in humid conditions and under the canopy of trees and are abundant at the forest edge.

A single bee species from the genus Apis represents half of the recorded Apidae individuals. In this study, *A. cerana* is the most abundant pollinator insect (9.55%), specifically in the forest edge habitat. A previous study on insect pollinator diversity on Mount Slamet Central Java also showed that *A. cerana* had the highest abundance, 33.1% of total pollinator insects (Widhiono et al. 2016). The higher abundance of *A. cerana* observed here is attributed to social behavior, forming colonies with thousands of members working to forage for food. However, these honey bees are generalist pollinators, a characteristic commonly referred to as flower constancy (Urbanowicz et al. 2020).

The richness and diversity indices of species are highest at the forest edge defined as the transition zone between open habitats and forest. There is significant variability in the three-dimensional structure, such as tree stems' width, shape, and density (Darsono et al. 2020). The forest edge is a natural habitat subjected to minimal human disturbance and provides diverse nesting places for pollinator insects. Wood et al. (2020) reported that habitats with low human disturbance, such as forest edges, have higher richness and diversity of pollinator insect species than intensively managed agricultural land. Farmer commonly use the synthetic pesticide on their agricultural land. Synthetic pesticides used are known can reduce the diversity of pollinator insects. Many synthetic pesticides, especially systemic insecticides and other active ingredients, cause lethal and sub-lethal impacts on pollinators (Desneux et al. 2007).

Forests and forest edges have a more diverse flora and fauna than plantations and shrubs. This analysis was consistent with studies by Chiawo et al. (2017), McKechnie et al. (2017), and Darsono et al. (2020) that found higher richness and diversity of pollinator species in forest edge habitats. Threlfall et al. (2015) reported that forests had a very high diversity of pollinator insects compared to other areas, such as plantations and rice fields. Several research results on pollinating insects show that ecosystems close to natural habitats, such as forests, have a higher abundance and diversity of pollinating insects. Widhiono et al. (2016) reported the highest and lowest diversity in forest plantation habitats on Mount Slamet and agricultural land, respectively. This difference occurs because the diversity of flowering plants in agricultural land is lower than in other areas. The more diverse and abundant the flowering plants, the higher the diversity of pollinator insects (Katumo et al. 2022). Bożek et al. (2023) reported a positive correlation between pollinator insects and the richness of flowering plant species.

Another factor contributing to the high diversity of pollinator insects is flowering species as a nectar source. The presence of pollinator insects in a location is influenced by the availability of various flowering plants containing nectar (Threlfall et al. 2015; Majewska and Altizer 2020). According to Lestari et al. (2023), the diversity is influenced by several factors, such as the quantity of flowers serving as food sources, environmental factors, and the surrounding vegetation in the observation area. Observations in the forest edge habitat reported mixed vegetation of tree plants with cultivated crops, creating a habitat that optimally and sustainably uses land by combining forestry and agricultural activities. In the forest edge habitat, vegetation from the Euphorbiaceae, Asteraceae, Mimosaceae, Fabaceae, and Malvaceae families is abundant.

Environmental factors such as humidity, temperature, light intensity, and wind speed vary in each habitat. Environmental factors significantly affect the presence of pollinator insect species. Humidity is crucial for insect activities during flight and high humidity reduces light intensity, which is important for pollinator insects in finding food. According to Rohde and Pilliod (2021), this factor can affect the rate of insect visits, nectar quality, and the balance of nectar within flowers. Koneri et al. (2020) reported that humidity affected host plants and food, indirectly impacting the diversity of pollinator insect species.

The temperature in the forest and edge habitat, averaging 29.2℃ and 31.3℃, is lower than others. This abiotic factor determines richness, and pollinator insects prefer to forage at higher temperatures between 15°C and 40°C. Below 12℃, foraging pollinator insects drop by more than 21%, and the metabolic rate can increase with rising temperatures, changing flight activity. In honeybees, the flight metabolic rate decreases with increasing temperature. Larger, dark-colored bees heat and cool more rapidly than smaller, light-colored bees (Karbassioon et al. 2023).

The amount of light received can influence the phenology of plants and pollinator insects. The reproductive success of species pollinated by insects is highly vulnerable to seasonal changes in light. In some cases, there is a possibility that rainfall is responsible for influencing the abundance of pollinator insects (Keeler et al. 2021). Arnold et al. (2018) reported a positive relationship between the abundance of pollinator insects and rainfall. Light influences the local distribution of insects in response to signals from the sun, and high intensity reduces nectar secretion volume in flowers. According to Majeed et al. (2021), sunlight affects light intensity and temperature, which is crucial in pollinator insects' flight and foraging activities.

Clustered distribution patterns show that individuals in the population respond locally to differences within the habitat. This occurs when strong competition exists among individuals, such as competition for nutrition and space on plants. Environmental heterogeneity, food availability, mating, defense, social behavior, and competitive factors greatly contribute (Ginantra et al. 2020).

The distribution of all species in nature can be categorized into three basic patterns: random, regular, and clustered. These distribution patterns are related to environmental conditions (Hotimah et al. 2022). The findings show that the species distribution pattern is clustered because pollinating insects, such as *Apis* spp. (Family Apidae), are mostly eusocial. This result is consistent with Zairina et al. (2015), where the distribution pattern is clustered, as insects tend to forage together. Some species have a random distribution pattern, showing environmental homogeneity, and this is caused by negative resource influences among individual members (Ginantra et al. 2020).

In conclusion, pollinator insects found in the study belonged to 4 orders and 17 families, comprising 103 species and 3,665 individuals. The family with the most species and individuals was Nymphalidae, while the most commonly found species was *Apis cerana* (Hymenoptera). The highest species richness and diversity indices were found in the forest edge habitat. The composition of pollinator insect species significantly differed between habitats; in this context, agricultural habitats were characterized by high air temperatures and low humidity. The distribution pattern of pollinator insect species was clustered (Aggregate) and the differences in habitat types significantly affect the richness and diversity of pollinator insects. The Mount Tumpa Forest Park area supports pollinating insects' abundance, richness, and diversity in the surrounding habitat. However, when there is a change in landscape type from a forest area to an agricultural area, it is also followed by the composition of pollinating insects change between forest and agricultural areas. The composition of pollinating insects in agricultural areas differs from pollinating insects in the other three habitats. Also, it has the lowest individual abundance and species richness compared to the other three habitats.

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