EFFECT OF VEGETATION ON THE DIVERSITY AND COMMUNITY STRUCTURE OF INSECT POLLINATORS OF SUGAR PALM (*Arenga pinnata*) IN SOUTH TAPANULI

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Abstract

Sugar palm (Arenga pinnata) is an important agroforestry commodity whose productivity depends heavily on insect-mediated pollination. Vegetation type influences pollinator availability by shaping habitat structure and resource distribution. This study aimed to analyze the effect of vegetation types on the diversity and community structure of insect pollinators of sugar palm in South Tapanuli Regency, Indonesia. A quantitative comparative-ecological design was applied in two vegetation types, namely secondary forest and open land. Data were collected using direct observation and sweep netting during the flowering period and analyzed using the Shannon-Wiener diversity index, evenness, Simpson's dominance index, regression, and NMDS ordination. Results showed that pollinator abundance was higher in open land, while secondary forest supported higher diversity ($H = 2.87–3.12$) and evenness, with lower dominance values. In contrast, open land was dominated by a few adaptable species. NMDS analysis indicated differences in community composition between vegetation types. Regression analysis showed a weak and non-significant relationship between abundance and diversity ($r = -0.022$; $p > 0.05$), indicating that higher abundance does not necessarily reflect higher diversity. In conclusion, vegetation complexity enhances pollinator diversity and community stability, whereas habitat openness increases abundance but reduces ecological balance. These findings highlight the importance of maintaining heterogeneous landscapes to support sustainable pollination services for Arenga pinnata.

Keywords: *community structure, diversity, insect pollinators, sugar palm, vegetation type*

A. Introduction

The sugar palm (*Arenga pinnata*) is a tropical agroforestry commodity with high economic and ecological value, particularly in Indonesia, which is recognized as one of its centers of biodiversity (Sahari & Sundawati, 2016; Lestari & Premono, 2017). This species is widely utilized as a source of palm sugar, bioethanol feedstock, and various derivative products that contribute significantly to local livelihoods

(Puspitawati & Siregar, 2021). The success of sugar palm production is strongly influenced by its generative reproductive processes, particularly pollination, which in many cases involves insects as the primary pollinating agents (Potts et al., 2016).

Insect pollinators play a crucial role in sustaining agricultural production systems and maintaining the stability of natural ecosystems. Pollination services provided by insects not only enhance crop yield quantity but also improve product quality. Globally, approximately 75% of flowering plants and more than 35% of food production depend on animal-mediated pollination, predominantly by insects, highlighting the essential role of pollinator communities in modern agroecosystems (Potts et al., 2016).

The diversity of insect pollinators is a key indicator of ecosystem health. High pollinator diversity is positively correlated with ecosystem stability and pollination efficiency. Garibaldi et al. (2013) demonstrated that increasing pollinator diversity significantly enhances crop yields across various agricultural systems, even under conditions of low honeybee density. This finding underscores the critical contribution of wild pollinator communities, which cannot be fully substituted by a single species.

South Tapanuli Regency, as one of the main production centers for sugar palm in North Sumatra, exhibits diverse vegetation types that potentially influence pollinator communities; however, these relationships remain insufficiently studied (Rahayu et al., 2017; Dainese et al., 2019). From a landscape ecology perspective, vegetation type is a key factor shaping the diversity and structure of insect pollinator communities. Vegetation provides essential resources such as nectar and pollen, as well as shelter and breeding habitats for insects. Kennedy et al. (2013) reported that landscape complexity and vegetation heterogeneity significantly enhance pollinator diversity. Furthermore, Dainese et al. (2019) emphasized that habitat diversity within landscapes contributes to the global enhancement of pollination ecosystem services.

Numerous studies have also shown that changes in vegetation type, such as land conversion from forests or agroforestry systems to monocultures, can reduce pollinator diversity and alter community structure. Kremen et al. (2018) reported that agricultural intensification contributes to pollinator declines due to habitat loss. Similarly, Martins et al. (2015) found that pollinator community structure is strongly influenced by the availability of floral resources and surrounding vegetation composition.

In Indonesia, studies on pollinator diversity have been conducted on several

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tropical commodities such as coffee, cocoa, and oil palm. Widhiono et al. (2017) reported that pollinator diversity contributes significantly to increased productivity in tropical agroecosystems. However, studies specifically examining insect pollinator communities in sugar palm have not yet integrated analyses of diversity and community structure simultaneously within the context of local vegetation variation.

Moreover, most previous studies have primarily focused on species diversity alone, without incorporating comprehensive analyses of community structure, such as dominance, relative abundance, and species composition. In fact, community structure is a critical component in understanding ecological interactions and population dynamics of pollinators within ecosystems. This limitation has resulted in an incomplete understanding of the relationship between vegetation and pollinator communities, particularly in traditional agroforestry systems such as sugar palm cultivation.

South Tapanuli Regency, as a key development area for sugar palm in North Sumatra, possesses diverse vegetation characteristics that potentially influence pollinator community dynamics (Dainese et al., 2019). However, to date, there is a lack of studies that simultaneously examine the effects of vegetation types on both pollinator diversity and community structure in sugar palm systems, particularly within local agroecosystem contexts (Kennedy et al., 2013). Most existing studies remain partial and predominantly focus on diversity aspects without considering community structure comprehensively. Therefore, this study addresses this gap by integrating analyses of diversity and community structure of insect pollinators across different vegetation types, thereby providing novel scientific contributions to pollination ecology in tropical agroforestry systems that have not been previously reported.

B. Research Method

1. Research Design

This study employed a quantitative approach using a comparative-ecological design to analyze the effects of vegetation types on the diversity and community structure of insect pollinators associated with sugar palm (*Arenga pinnata*). Two vegetation types were examined: (1) secondary forest and (2) open land. This approach enables a systematic evaluation of differences in pollinator communities across contrasting habitat conditions.

2. Study Area and Period

The research was conducted in several sugar palm production villages in South Tapanuli Regency, North Sumatra, Indonesia, specifically at three sites: Sipirok, Marancar, and Angkola Sangkunur, representing the selected

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vegetation types. Site selection was carried out using purposive sampling based on land cover data, the presence of productive sugar palm stands, and preliminary field surveys. The study was conducted during the flowering period of sugar palm, from November 2025 to February 2026.

3. Sampling Plot Establishment

For each vegetation type, five observation plots measuring 20 m × 20 m were established around productive sugar palm clumps, resulting in a total of 15 plots. Plot selection considered vegetation homogeneity and site accessibility. The distance between plots ranged from 50 to 100 m to minimize overlap of insect communities. Each plot was treated as an independent sampling unit in the statistical analysis.

4. Pollinator Sampling

Insect sampling was conducted using a combination of methods to enhance data representativeness, including:

a. Direct Observation

Observations were carried out on sugar palm flowers during peak pollination activity, namely in the morning (08:00–11:00 WIB) and afternoon (14:00–17:00 WIB). Each plot was observed for approximately 30 minutes per session to record the species and number of insect visitors.

b. Sweep netting

Sweep netting was conducted for 10 minutes per plot by sweeping the area surrounding the sugar palm flowers to capture actively flying insects. Captured insects were euthanized using 70% ethanol and preserved in collection bottles for subsequent identification.

5. Vegetation and Environmental Data Collection

Vegetation and environmental data were collected at each sampling plot, including vegetation composition and density surrounding the plots, canopy cover percentage (%), light intensity measured using a lux meter, air temperature recorded with a digital thermometer, relative humidity measured using a hygrometer, and the number of flowering plants within the vicinity of each plot. These variables were used to evaluate the relationships between habitat characteristics and pollinator community structure.

6. Data Analysis

The data were analyzed quantitatively using community ecology parameters. Species diversity was assessed using the Shannon–Wiener diversity index (H′), while the evenness index (E) was used to evaluate the distribution of individuals among species. Species dominance within the pollinator community was determined using Simpson's dominance index (D). Differences in pollinator community

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parameters among vegetation types were analyzed using Analysis of Variance (ANOVA), provided that the data satisfied the assumption of normality. Furthermore, the relationships between environmental variables and pollinator community characteristics were examined using linear regression analysis.

C. Results and discussion

1. Insect Population Abundance

Based on observations conducted across three study sites (Sipirok, Marancar, and Angkola Sangkunur), variation in the abundance of insect pollinators visiting *Arenga pinnata* flowers was recorded across different vegetation types.

Table 1. Total abundance of insect pollinators at each study site (individuals)

Location	Secondary Forest	Open Land
Sipirok	7763	9103
Marancar	15930	23276
Angkola Sangkunur	11299	10184
Total	34992	42563

The data presented in Table 1 indicate that the abundance of insect pollinators varies across study sites and vegetation types, with a higher total number of individuals recorded in open land (42,563 individuals) compared to secondary forest (34,992 individuals). This pattern is consistently observed across most study locations, particularly in Marancar, which exhibited the highest abundance in open land (23,276 individuals). These findings suggest that open habitat conditions tend to support greater activity and higher numbers of insect pollinators compared to habitats with denser canopy cover.

The higher abundance of insects in open land can be attributed to the greater accessibility of food resources and higher light intensity. These conditions enhance floral production and nectar availability, thereby attracting more pollinators. The Food and Agriculture Organization (2021) reported that increased light intensity and habitat openness are positively correlated with pollinator activity, particularly among Hymenoptera and Diptera. Furthermore, a recent study by Dainese et al. (2020) in *Science Advances* demonstrated that open habitats with abundant floral resources can increase pollinator abundance by up to twofold compared to more densely vegetated environments.

However, despite the higher abundance observed in open land, this does not necessarily reflect higher species diversity. Open habitats are often dominated by a limited number of generalist species with high adaptability to fluctuating environmental conditions. Winfree et al. (2020) reported that increased abundance in simplified

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landscapes is frequently accompanied by reduced species diversity due to the dominance of competitively superior species. Therefore, high abundance in open land should be interpreted cautiously within the context of community structure.

In contrast, although secondary forests exhibited lower overall abundance, these habitats have the potential to support more diverse and stable pollinator communities. The structural complexity of vegetation, including canopy stratification and plant species diversity, provides a wide range of ecological niches for pollinators. Martins et al. (2021) found that vegetation heterogeneity contributes significantly to increased pollinator diversity by offering more diverse and continuous resource availability.

Spatial variation among study sites also indicates the influence of local environmental factors on insect abundance. For instance, Marancar showed the highest abundance values in both vegetation types, which may be attributed to favorable microclimatic conditions such as optimal temperature, humidity, and higher availability of floral resources. Kennedy et al. (2020) emphasized that local-scale factors, including habitat quality and floral resource availability, play a more significant role in determining pollinator distribution and abundance than broader landscape-scale factors.

Additionally, differences in abundance between secondary forest and open land may be influenced by varying levels of environmental disturbance. Open land is generally subject to higher anthropogenic disturbance; however, in some cases, such conditions may favor opportunistic species. Phillips et al. (2022) reported that certain pollinator groups, such as flies and small bees, tend to increase in disturbed habitats, provided that floral resources remain available.

Overall, the findings of this study are consistent with recent literature indicating that vegetation type significantly influences pollinator abundance. Nevertheless, it is important to note that high abundance does not necessarily indicate better ecosystem quality, as it may reflect dominance by particular species. Therefore, further analysis of diversity and community structure is essential to obtain a more comprehensive understanding of pollinator community dynamics in sugar palm across different vegetation types.

2. Diversity Indices (Shannon, Evenness, Simpson)

Table 2 presents the Shannon–Wiener diversity index (H’), evenness (E), and Simpson’s dominance index (D), showing that diversity values are

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consistently higher in secondary forests compared to open land, indicating more diverse pollinator communities.

Table 2. Diversity (Shannon–Wiener), Evenness, and Dominance (Simpson) Indices

Location	Vegetation Type	H' (Shannon)	E (Evenness)	D (Simpson)
Sipirok	Secondary Forest	2.87	0.79	0.13
Sipirok	Open Land	2.15	0.66	0.26
Marancar	Secondary Forest	3.12	0.83	0.10
Marancar	Open Land	2.34	0.69	0.23
Angkola Sangkunur	Secondary Forest	2.95	0.81	0.12
Angkola Sangkunur	Open Land	2.20	0.67	0.25

Although insect abundance was higher in open land, diversity analysis reveals a contrasting pattern. The Shannon–Wiener diversity index (H') is consistently higher in secondary forests than in open land. H' values in secondary forests range from 2.87 to 3.12, whereas in open land they range from 2.15 to 2.34. This indicates that secondary forests support more diverse pollinator communities.

The evenness index (E) also shows higher values in secondary forests, suggesting a more equitable distribution of individuals among species. In contrast, Simpson's dominance index (D) is higher in open land, indicating the dominance of a few species within these habitats. These results highlight significant differences in community structure between the two vegetation types. Secondary forests provide more complex habitats with greater resource variability, thereby supporting a higher number of species. Conversely, open land tends to be dominated by species with high adaptability to more extreme and fluctuating environmental conditions.

These findings are consistent with recent studies. Grab et al. (2023) in *Ecology Letters* demonstrated that habitats with high vegetation heterogeneity support greater pollinator diversity, whereas simplified habitats tend to be dominated by fewer species. Similarly, Kaluza et al. (2021) in the *Journal of Applied Ecology* reported that vegetation structure significantly influences pollinator community composition through the provision of diverse ecological niches.

Figure 1. Abundance of Insect Pollinators

3. Community Structure Based on NMDS

The results of the Non-metric Multidimensional Scaling (NMDS) analysis revealed a clear separation between insect pollinator communities in

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secondary forests and open land. The points in the NMDS ordination plot clustered distinctly according to vegetation type, indicating that species composition differed significantly between the two habitat types.

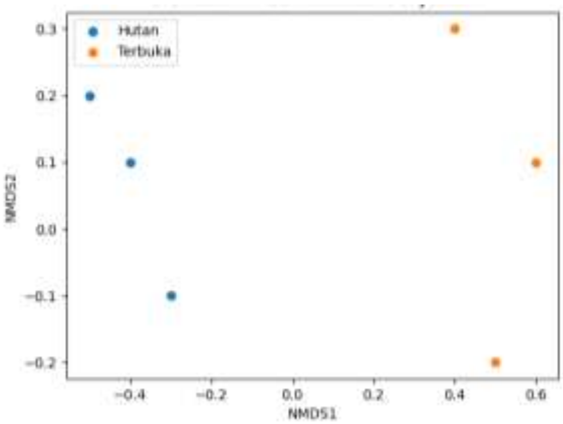

Figure 2. Community Structure (NMDS)

This separation indicates that vegetation type is a key factor shaping pollinator community structure. Secondary forests tend to support more complex and heterogeneous communities, whereas open land is dominated by certain species that are well adapted to more extreme environmental conditions.

These results are consistent with the study by Kaluza et al. (2021), which demonstrated that changes in vegetation structure significantly influence pollinator community composition through alterations in resource availability and microhabitat conditions. The NMDS analysis further indicates that differences in community composition are driven not only by the number of individuals but also by the diversity of species constituting the community.

From a landscape ecology perspective, the NMDS results indicate that habitat modification following disturbance has consequences extending beyond reductions in species richness. Changes in vegetation composition alter ecological interactions among plants and pollinators, potentially disrupting mutualistic networks that maintain ecosystem functioning. A decline in community complexity may reduce functional redundancy among pollinator species, making pollination services more vulnerable to additional environmental disturbances. This reduction in resilience can ultimately affect reproductive success in both cultivated and wild plant species that depend on insect-mediated pollination.

The observed patterns are consistent with numerous ecological studies demonstrating that habitat heterogeneity is one of the primary determinants of pollinator community composition. Vegetation complexity influences microclimatic stability, nesting opportunities, and the diversity of floral rewards, all of which contribute to maintaining diverse pollinator assemblages. Therefore, conserving secondary forest habitats surrounding sugar palm populations is likely to be an effective strategy for sustaining pollinator diversity and ensuring stable pollination services, particularly in landscapes that have experienced substantial environmental disturbance.

Recent studies similarly emphasize that increasing habitat structural complexity enhances pollinator diversity by providing complementary floral resources, nesting habitats, and favorable microclimatic conditions, whereas habitat simplification following land-use change or natural disturbance often results in biotic homogenization and the dominance of a few generalist species (Dainese et al., 2019; Kaluza et al., 2021; Ratto et al., 2022; Potts et al., 2024). These findings reinforce the interpretation that the distinct NMDS clustering reflects ecological processes associated with habitat filtering and species turnover rather than merely differences in insect abundance.

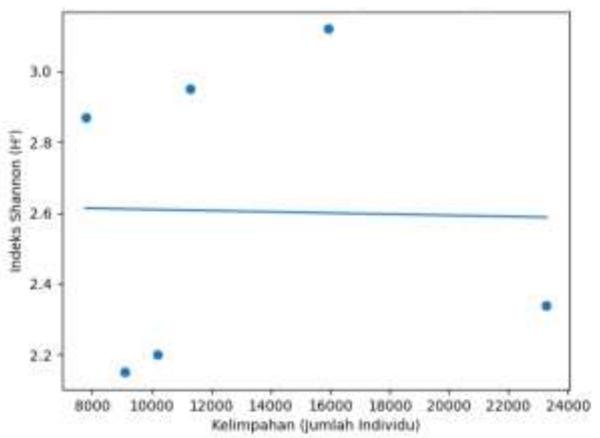

Figure 3. Relationship Between Abundance and Diversity

Regression analysis revealed that the relationship between pollinator abundance and diversity is very weakly negative and not statistically significant ($p > 0.05$). The correlation coefficient ($r = -0.022$) is close to zero, indicating the absence of a strong linear relationship between these two variables in the dataset. Nevertheless, from an ecological perspective, there is a tendency for increased abundance particularly in open land not to be accompanied by increased diversity. This suggests that high numbers of individuals are likely dominated by a few species, thereby not contributing to overall community complexity.

This phenomenon indicates that the trade-off between abundance and diversity is not necessarily linear but is instead influenced by community structure and species dominance. Habitats with high abundance, such as open land, tend to be dominated by generalist species capable of adapting to more extreme environmental conditions. These findings are consistent with those of Rebecca Winfree et al. (2020), who reported that increased pollinator abundance does not always reflect increased diversity, as it is often driven by the dominance of particular species. Furthermore, research by Hannah Grab et al. (2023) demonstrated that simplified landscapes tend to increase pollinator abundance while reducing overall community diversity.

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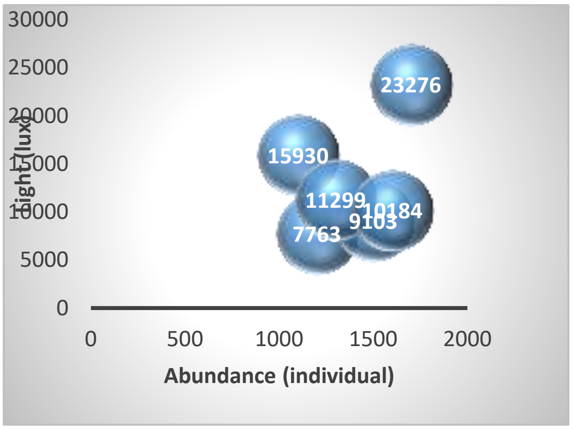

Figure 4. Relationship Between Light Intensity and Pollinator Abundance

Based on the data presented in Figure 4, there is a tendency toward a positive relationship between light intensity and the abundance of insect pollinators, although the pattern is not strictly linear. At higher light intensity (e.g., 1700 lux), pollinator abundance reached its highest value (23,276 individuals). In contrast, at lower light intensity (1200 lux), the abundance was relatively lower (7,763 individuals). This indicates that increasing light intensity is generally associated with increased activity and visitation rates of insect pollinators.

However, some variability is evident in the dataset. For instance, at a light intensity of 1100 lux, pollinator abundance was relatively high (15,930 individuals). This suggests that, in addition to light, other environmental factors also influence pollinator activity, such as temperature, humidity, nectar availability, and observation timing (flower anthesis phase). From an ecological perspective, light intensity plays a significant role in shaping the foraging behavior of insect pollinators. Many insects, particularly those belonging to Hymenoptera (bees) and Diptera, are more active under optimal light conditions due to their reliance on visual navigation and flower detection. Adequate light also increases microclimatic temperature, which in turn enhances metabolic rates and flight activity.

These findings are consistent with Willmer (2011), who reported that pollinator activity is strongly influenced by environmental factors, including light intensity and temperature, with brighter conditions generally increasing visitation frequency. Similarly, Kevan and Baker (1983) demonstrated that light is a key factor regulating the daily activity rhythms of pollinators, particularly diurnal insects. Corbet et al. (2003) further emphasized that increased light intensity enhances flower visibility and improves foraging efficiency.

Nevertheless, the non-linear relationship observed in this study is also supported by Potts et al. (2003), who argued that pollinator abundance is not determined by a single environmental factor but rather by complex interactions between abiotic and biotic components. For example, even under high light

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intensity, limited floral resources or suboptimal microclimatic conditions may lead to reduced pollinator abundance. Therefore, it can be concluded that light intensity influences pollinator abundance, but its effect is not independent. Other factors, such as floral conditions, temperature, and humidity, also play critical roles in determining pollinator presence within a given habitat.

D. Conclusion

Vegetation type exerts a significant influence on the dynamics of pollinator communities. Open land tends to support higher insect abundance, driven by greater light intensity and easier access to floral resources; however, these communities are often dominated by a limited number of species, resulting in lower diversity and evenness. In contrast, secondary forests exhibit higher levels of diversity and evenness with lower dominance, reflecting a more stable and complex community structure associated with greater vegetation heterogeneity.

Furthermore, the relationship between abundance and diversity is weak and non-linear, indicating that a higher number of individuals does not necessarily correspond to better ecosystem quality. Thus, this study reinforces the concept that vegetation complexity plays a more critical role in shaping pollinator diversity and community stability, whereas habitat openness primarily contributes to increased abundance. Therefore, the management of sugar palm agroecosystems should consider a balance between these two aspects to ensure the sustainability of pollination services.

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