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# RELATIONSHIP BETWEEN TREES AND THEIR POLLINATION SERVICES THROUGH A COMBINATION OF FIELD-BASED ASSESSMENTS

[1]Km Neha, [2]Dr. Dharma Dev Pandey
[1]Research Scholar, [2]Supervisor
[1-2] Department of Botany, Malwanchal University, Indore, Madhya Pradesh, India

## ABSTRACT

This study investigates the intricate relationship between trees and pollination services across varied land-use and land-cover (LULC) types, highlighting their critical role in maintaining biodiversity and ecosystem stability. Conducted across eight distinct sites with diverse LULC characteristics, the research examines species diversity, density, and flowering phenology of trees and shrubs to understand their contributions to pollinator support systems. Quantitative metrics, including species richness and diversity indices, were used to assess ecological patterns, while seasonal variations in floral resources and pollinator activity were analyzed to capture dynamic ecological interactions. The findings reveal that forested landscapes harbor higher species richness and density, providing optimal habitats and floral resources for pollinators, whereas agricultural and barren lands exhibit reduced biodiversity. Seasonal data further demonstrate shifts in flowering patterns and pollinator behaviors, emphasizing the need for year-round resource availability. The study underscores the importance of conserving forested areas and integrating agroforestry practices to enhance pollination services in modified landscapes. This research offers valuable insights into tree-pollinator dynamics, providing a foundation for biodiversity conservation and sustainable ecosystem management.

Keywords: Land, Use, Ecological, Pollinator, Flowering, Agroforestry

## INTRODUCTION

Trees are foundational to terrestrial ecosystems, serving as keystone species in supporting pollination services, which are critical for maintaining biodiversity, agricultural productivity, and ecosystem health. They provide essential resources such as nectar, pollen, and habitat for a wide variety of pollinators, including insects, birds, and mammals. The mutualistic relationships between trees and their pollinators not only ensure reproductive success for trees but also contribute to the broader stability of ecosystems (Kremen et al., 2007).

Tree species offer a diverse array of floral resources that sustain pollinators year-round. Unlike herbaceous plants, trees often exhibit extended flowering periods or staggered blooming times, which align with the activity patterns of their pollinators (Ollerton et al., 2011). For instance, tropical trees such as *Mangifera indica* (mango) and *Theobroma cacao* (cacao) rely heavily on specific insect pollinators to achieve successful fruit set. These trees often produce flowers in large quantities, creating a reliable resource for pollinators such as bees and flies, which in turn enhance the reproductive success of the trees (Klein et al., 2008).

Beyond providing food, trees also offer critical nesting and roosting habitats for pollinators. Many bees, bats, and birds rely on tree cavities, crevices, and branches for nesting. For example, tree species such as oaks (*Quercus spp.*) and pines (*Pinus spp.*) support cavity-nesting pollinators like carpenter bees and certain bat species. These habitats are vital for sustaining pollinator populations, especially in fragmented or urban landscapes where natural habitats are scarce (Winfree et al., 2009). Trees also act as ecological corridors, facilitating the movement of pollinators across landscapes, thus enhancing genetic exchange among plant populations (Garibaldi et al., 2013).

In agroforestry systems, trees contribute significantly to crop pollination by attracting and sustaining pollinator populations. Shade trees in coffee (*Coffea arabica*) plantations, for example, create microclimates that support a diverse array of pollinators, resulting in improved fruit set and higher yields compared to monoculture systems (Jha & Dick, 2010). Similarly, trees in mixed farming systems provide refuge and alternative food sources for pollinators, ensuring their persistence even during periods when crop flowers are unavailable.

The interplay between trees and pollinators is increasingly threatened by climate change, which disrupts the flowering phenology of trees and the activity patterns of pollinators. Rising temperatures and altered precipitation regimes can lead to phenological mismatches, where tree flowering no longer aligns with pollinator availability (Forrest, 2015). For example, studies in temperate regions have shown that warmer springs cause earlier flowering in trees like apple (*Malus domestica*), potentially reducing fruit set if pollinators fail to emerge in time (Thomson, 2010).

To safeguard pollination services, it is essential to conserve tree diversity and promote sustainable land-use practices. Strategies such as planting native trees, restoring forest habitats, and integrating trees into agricultural landscapes can help maintain pollinator populations and their ecological roles (Potts et al., 2010). Additionally, research into tree-pollinator interactions under changing climatic conditions can provide insights into adaptive management practices to ensure the resilience of these systems.

Trees are integral to pollination services, providing essential resources and habitats that sustain diverse pollinator species. Their role extends beyond individual reproductive success to influencing broader ecosystem stability and agricultural productivity. However, climate change and habitat loss pose significant challenges to these interactions. Conservation and sustainable management of tree species are therefore crucial for ensuring the continuity of pollination services, which are indispensable for ecological and human well-being.

## LITERATURE REVIEW

Aguilar et al. (2023) conducted a comprehensive meta-analysis examining how habitat fragmentation affects pollination and plant reproduction. Their findings indicate that the reduction in habitat size leads to decreased pollinator populations, adversely impacting both male and female reproductive success in trees. This underscores the importance of preserving contiguous habitats to maintain effective pollination services.

Duque-Trujillo et al. (2021) reviewed strategies to attract and conserve natural pollinators within agricultural landscapes. They identified that proximity to natural habitats and the presence of floral resources are pivotal in enhancing pollinator density and diversity. This research emphasizes the necessity of integrating trees into agricultural systems to support pollinator populations.

Nowak et al. (2021) quantified the ecosystem services provided by trees, including their role in supporting pollination. The research highlights that trees contribute significantly to ecosystem functions by offering habitat and resources for pollinators, thereby sustaining biodiversity and agricultural productivity.

Guerra et al. (2021) evaluated existing biodiversity indicators and proposed the inclusion of pollinator-focused metrics. Their work suggests that assessing tree-related pollination services is essential for comprehensive biodiversity evaluations, as trees are integral to the habitats of many pollinator species.

Feller et al. (2023) explored the ecological roles of key functional groups in mangrove ecosystems, including pollinators. They found that trees in these environments are crucial for maintaining pollinator networks, which are vital for the reproduction of both mangrove and adjacent terrestrial plant species. This study underscores the importance of conserving tree species to preserve pollination services in coastal ecosystems.

## RESEARCH METHODOLOGY

The research was conducted across eight selected locations with varying LULC classifications, such as forested areas, agricultural land, and barren land. Each site had a radius of one kilometer, allowing for a detailed examination of the local ecosystem. Field surveys were conducted to gather data on species richness, density, and diversity. Observations were categorized into different strata, including seedlings, saplings, trees, shrubs, and herbs. Blooming phases were tracked seasonally to evaluate temporal fluctuations in the availability of floral resources. The study also recorded pollinator activity during specific blooming periods. Species diversity indices (Shannon-Weaver Index) and density metrics (individuals per hectare) were calculated for various strata to assess ecological diversity and distribution. Statistical analyses were performed to identify variations in species richness and density across the eight sites. Hierarchical cluster analyses grouped locations based on their tree and shrub density, emphasizing patterns in vegetation composition and habitat structure.

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**CHANGES IN LAND COVER AND USE AT VARIOUS SELECTED LOCATIONS**

Table 1 provides information for the area within a 1 km radius (3.14 km2) of each site for various LULC classifications. Most of the locations (5 out of 10; 61.04% orchards) had forest area as their primary land use. For these locations, woods made up anywhere from 69% (Satkhol) to almost 50% (Dukkhar). In contrast, between 45 and 53 percent of the land in the other three locations was used for agricultural purposes. Out of all the locations, the Darima site had the most percentage of unusable land at 11.5%.

**Table 1: use and landcover classifications within a one-kilometer radius of chosen orchards**

| Sites | Agriculture area | | Barren land area | | Built up area | | Forest area | | Road area | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ($Km^2$) | (%) | ($Km^2$) | (%) | ($Km^2$) | (%) | ($Km^2$) | (%) | ($Km^2$) | (%) |
| Darima (S1) | 1.41 | 45.02 | 0.36 | 11.45 | 0.02 | 0.67 | 1.30 | 41.47 | 0.04 | 1.39 |
| Orakhan (S2) | 1.06 | 33.64 | 0.17 | 5.44 | 0.02 | 0.50 | 1.84 | 58.50 | 0.06 | 1.92 |
| Satkhol (S3) | 0.86 | 27.40 | 0.02 | 0.74 | 0.03 | 1.00 | 2.16 | 68.73 | 0.07 | 2.14 |
| Dukkhar (S4) | 1.47 | 46.80 | 0.04 | 1.37 | 0.02 | 0.64 | 1.56 | 49.73 | 0.05 | 1.46 |
| Sheetla (S5) | 1.01 | 32.30 | 0.14 | 4.59 | 0.02 | 0.62 | 1.91 | 60.87 | 0.05 | 1.62 |
| Supi (S6) | 1.49 | 47.40 | 0.20 | 6.45 | 0.01 | 0.46 | 1.41 | 44.84 | 0.03 | 0.85 |
| Dutkaanedhar (S7) | 0.77 | 24.54 | 0.22 | 7.04 | 0.01 | 0.28 | 2.12 | 67.39 | 0.02 | 0.75 |
| Satbunga (S8) | 1.66 | 53.04 | 0.17 | 5.47 | 0.02 | 0.70 | 1.25 | 39.98 | 0.03 | 0.83 |

In Table 2, we can see the specifics of the species richness in various living forms across different strata and locations.

**Table 2 Diversity of plant and animal life in various forest habitats**

| Sites | | Species richness | | | Species richness Herbs | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Seedling | Sapling | Trees | Shrubs | Summer | Rains | Winter | Total | Total of the site (T+S+H) |
| S1 | 8 | 9 | 10 | 10 | 12 | 23 | 2 | 30 | 50 |
| S2 | 5 | 10 | 8 | 9 | 21 | 25 | 6 | 38 | 55 |
| S3 | 9 | 11 | 11 | 9 | 21 | 37 | 5 | 47 | 67 |
| S4 | 7 | 11 | 11 | 9 | 21 | 26 | 3 | 35 | 55 |
| S5 | 8 | 14 | 13 | 7 | 12 | 16 | 3 | 21 | 41 |
| S6 | 10 | 14 | 11 | 8 | 15 | 22 | 2 | 30 | 49 |

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| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| S7 | 4 | 10 | 11 | 8 | 7 | 24 | 1 | 26 | 45 |
| S8 | 6 | 12 | 9 | 8 | 15 | 29 | 2 | 32 | 49 |
| Total | 22 | 17 | 22 | 17 | 35 | 56 | 10 | 73 | 112 |

Taking the diversity index into account, the top three groups for trees were S4 (2.32), S1 (2.15) and S7 (1.73). However, in the sapling layer, S4 (2.27), S6 (2.31), and S5 (2.49) had the highest values. S3 (2.02), S6 (2.23), and S4 (2.27) showed the highest levels of seedling variety. S2 exhibited the least amount of variety among the three tree strata, with values of 0.91 for Tree, 1.17 for Sapling, and 0.83 for Seedling. S6 has the highest shrub diversity index at 1.91, followed by S1 at 1.82, and S8 at 1.78. S7 (0.98), on the other hand, showed very little variety. S3 had the most variety in April's herb layer at 2.88, followed by S4 at 2.85, and S7 had the fewest at 1.31. S8 had the most diversity in August at 3.45 species, followed by S3 at 3.34, and S3 again had the highest diversity in December at 1.47 species, while S7 had only Boenninghausenia albiflora.

Tables 3 and 4 indicate the statistically significant variations ($p<0.05$) across sites with regard to several compositional features.

**Table 3 Diversity of living species and their density in various woodland locations**

| Sites | | Species density (ind ha$^{-1}$) | | | | Species density (ind ha$^{-1}$) | |
|---|---|---|---|---|---|---|---|
| | Seedling | Sapling | Tree | Shrub | Herbs (Summer) | Herbs (Rainy) | Herb (Winter) |
| S1 | 707$^{ab}$ | 1720$^{a}$ | 1850$^{b}$ | 7827$^{ab}$ | 42111$^{bc}$ | 81000$^{ab}$ | 3667$^{a}$ |
| S2 | 151$^{a}$ | 1313$^{a}$ | 1073$^{a}$ | 6988$^{ab}$ | 34556$^{abc}$ | 47444$^{ab}$ | 37000$^{a}$ |
| S3 | 560$^{ab}$ | 493$^{a}$ | 1163$^{a}$ | 12672$^{b}$ | 57667$^{c}$ | 149889$^{b}$ | 20000$^{a}$ |
| S4 | 924$^{b}$ | 3710$^{b}$ | 1933$^{bc}$ | 4928$^{a}$ | 32556$^{abc}$ | 77667$^{ab}$ | 4778$^{a}$ |
| S5 | 249$^{ab}$ | 2280$^{ab}$ | 2513$^{cd}$ | 13492$^{b}$ | 6556$^{a}$ | 17778$^{a}$ | 6500$^{a}$ |
| S6 | 489$^{ab}$ | 3913$^{b}$ | 2997$^{d}$ | 8033$^{ab}$ | 26222$^{abc}$ | 93889$^{ab}$ | 4333$^{a}$ |
| S7 | 902$^{ab}$ | 1627$^{a}$ | 4090$^{e}$ | 6928$^{ab}$ | 35000$^{abc}$ | 60556$^{ab}$ | 32556$^{a}$ |
| S8 | 293$^{ab}$ | 3527$^{b}$ | 2483$^{cd}$ | 13028$^{b}$ | 16000$^{ab}$ | 92889$^{ab}$ | 9667$^{a}$ |

**Table 4 Species richness in various forest habitats**

| Sites | | | | | Species Diversity (H') | | |
|---|---|---|---|---|---|---|---|
| | Seedling | Sapling | Tree | Shrub | Herb (Summer) | Herb (Rainy) | Herb (winter) |
| S1 | 1.96$^{cd}$ | 1.92$^{b}$ | 2.15$^{cd}$ | 1.82$^{b}$ | 2.02$^{ab}$ | 2.97$^{a}$ | 0.33$^{ab}$ |
| S2 | 0.83$^{ab}$ | 1.17$^{a}$ | 0.91$^{a}$ | 1.42$^{ab}$ | 2.63$^{b}$ | 2.37$^{a}$ | 0.96$^{bc}$ |
| S3 | 2.02$^{cd}$ | 2.03$^{b}$ | 1.34$^{b}$ | 1.01$^{a}$ | 2.88$^{b}$ | 3.34$^{a}$ | 1.47$^{c}$ |

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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| S4 | 2.27$^{d}$ | 2.27$^{b}$ | 2.32$^{d}$ | 1.24$^{ab}$ | 2.85$^{b}$ | 2.67$^{a}$ | 0.62$^{abc}$ |
| S5 | 1.68$^{cd}$ | 2.49$^{b}$ | 1.72$^{bc}$ | 1.29$^{ab}$ | 2.35$^{b}$ | 2.67$^{a}$ | 1.00$^{bc}$ |
| S6 | 2.23$^{d}$ | 2.31$^{b}$ | 1.53$^{b}$ | 1.91$^{b}$ | 2.29$^{b}$ | 2.81$^{a}$ | 0.66$^{abc}$ |
| S7 | 0.33$^{a}$ | 1.94$^{b}$ | 1.73$^{bc}$ | 0.98$^{a}$ | 1.31$^{a}$ | 2.62$^{a}$ | 0.00$^{a}$ |
| S8 | 1.30$^{bc}$ | 2.10$^{b}$ | 1.67$^{b}$ | 1.78$^{b}$ | 2.12$^{ab}$ | 3.45$^{a}$ | 0.00$^{a}$ |

When comparing the density of trees at different locations, Dutkaanedhar (S7) stands out with a much higher density ($p<0.05$). The tree density was also much greater in the Sheetla (S5), Supi (S6), and Satbunga (S8) locations than at the S1, S2, S3, and S4 sites. Compared to sites S3, S4, S5, and S8, the density at Dukkhar (S4) was much lower in the shrub layer ($p<0.05$). Sites S5 and S8 have an abundance of shrubs. Outside of site S4 (Table4.4), however, there was no statistically significant increase ($p > 0.5$).

Density changes seasonally in the plant layer. In comparison to Sheetla (S5) and Satbunga (S8) sites, the Satkhol (S3) site had a considerably higher density throughout summer ($p<0.05$). The significance level of this difference was less than 0.05 in other instances. With the exception of the Sheetla (S5) location, where the herb density was much lower ($p<0.05$) than Satkhol (S3), most differences across sites remained non-significant after it rained. All of the locations had about the same plant density in the winter (Table 4).

When looking at the diversity index, it was clear that there were noticeable differences in the tree layer across the several sites. The Orakhan (S2) site had the lowest tree diversity compared to the others. The tree diversity was much higher ($p<0.05$) in Darima (S1) and Dukkhar (S4) sites compared to the majority of the other sites. When it came to shrub density, sites S1 (Darima), S6 (Supi), and S8 (Satbunga) displayed much more than sites S3 and S7. For the others, the difference was negligible. When it came to herbs, seasonal differences were most noticeable in the summer and winter. Table 4.5 shows that plant species diversity was unaffected by rainfall.

**HIERARCHICAL CLUSTER ANALYSIS**

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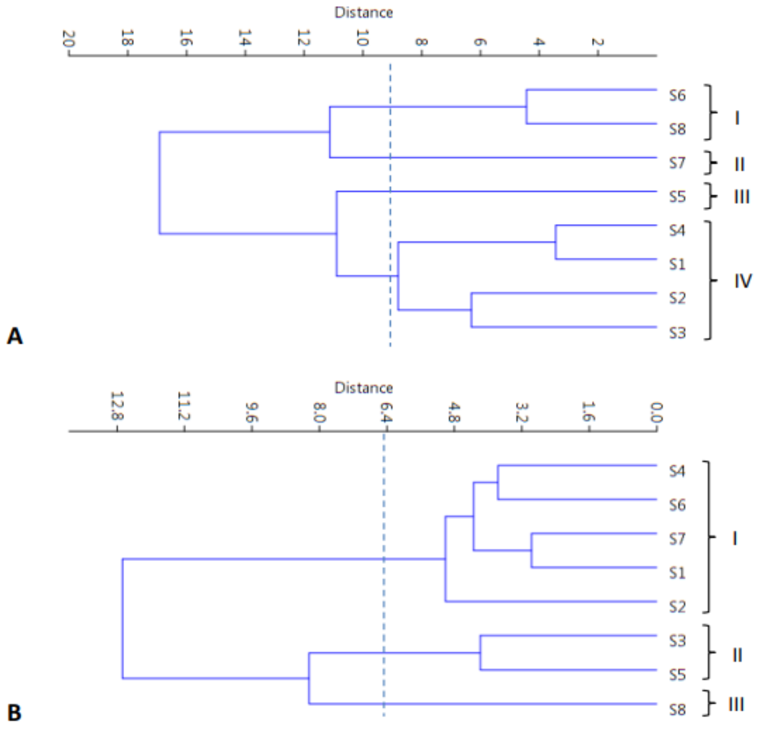
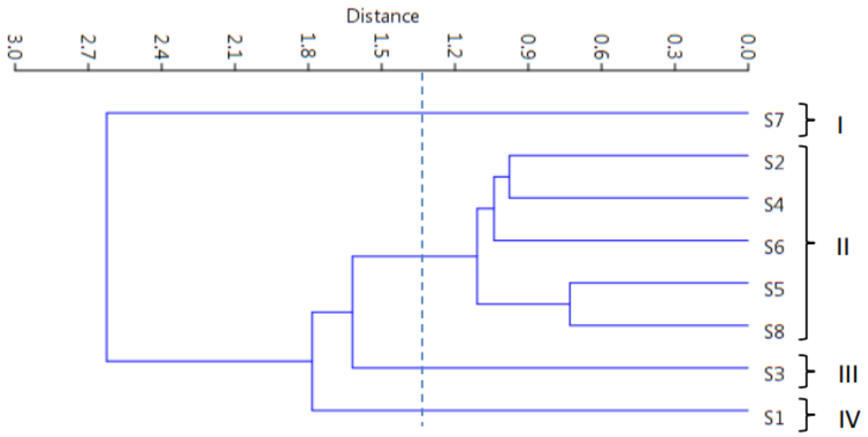



**Figure 1 Grouping of forest locations according to tree and shrub density (A): 1. Darima; 2. Orakhan; 3. Satkhol; 4. Dukkhar; 5. Sheetla; 6. Supi; 7. Satbunga; 8. Dutkaanedhar**



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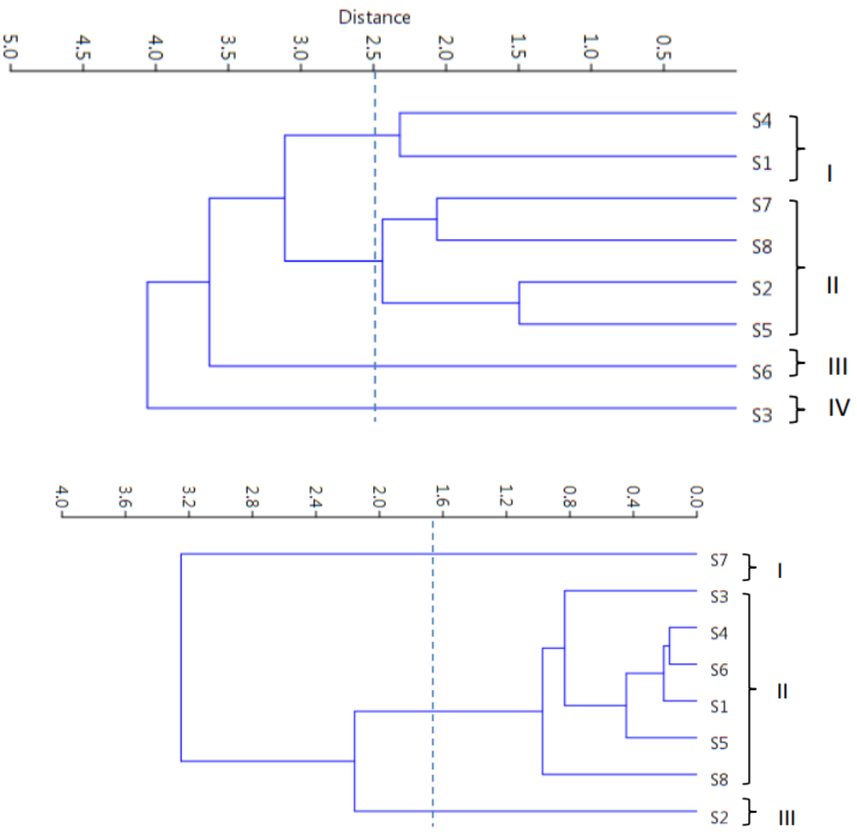


**Figure 2 Grouping Forest locations according to the number of herbaceous species in April (A), August (B), and December (C): 1. Darima; 2. Orakhan; 3. Satkhol; 4. Dukkhar; 5. Sheetla; 6. Supi; 7. Satbunga; 8. Dutkaanedhar**

**Fluctuations in the Variety of Flowers Throughout the Year**

There was an analysis of the species richness throughout the blooming phase throughout the whole season and in particular for each sample month. Tables 5 a and 5 b show that the richness changed with the seasons and the months of sampling, respectively. Over half of the species in the shrub and tree strata bloomed in the summer, but that number dropped down with each passing season. In contrast, the herb layer's richness began to rise in the summer, peaked during the wet season, and then suddenly declined throughout the winter.

Site S4 had the highest concentration of blooming resources (31 species) throughout the summer, whereas site S7 had the lowest concentration (19 species). The overall number of blooming species fluctuated from 17 (S5) to 30 (S3) species throughout the rainy season, with herbs accounting for the majority of these species. However, the total number of blooming species may range from 4 (S6, S7, and S8) to 9 (S1 and S3) species throughout the winter. Variations in various types of life are shown in Table 5 a.

**Table 5 (a) Diversity of flowering plant species by time of year, habitat, and life type**

| | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 |
|---|---|---|---|---|---|---|---|---|
| **Summer** | | | | | | | | |
| Tree | 07 | 04 | 06 | 08 | 08 | 07 | 06 | 06 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Shrub | 08 | 05 | 06 | 07 | 06 | 07 | 07 | 06 |
| Herb | 10 | 15 | 17 | 16 | 08 | 12 | 06 | 11 |
| Total | 25 | 24 | 29 | 31 | 22 | 26 | 19 | 23 |
| **Rainy** | | | | | | | | |
| Tree | 04 | 02 | 04 | 03 | 04 | 02 | 01 | 02 |
| Shrub | 03 | 02 | 02 | 03 | 02 | 02 | 02 | 03 |
| Herb | 16 | 18 | 24 | 19 | 11 | 15 | 19 | 20 |
| Total | 23 | 22 | 30 | 25 | 17 | 19 | 22 | 25 |
| **Winter** | | | | | | | | |
| Tree | 04 | 03 | 04 | 03 | 04 | 02 | 03 | 02 |
| Shrub | 03 | 01 | 01 | 02 | 02 | 01 | 01 | 01 |
| Herb | 02 | 04 | 04 | 01 | 02 | 01 | - | 01 |
| Total | 09 | 08 | 09 | 06 | 08 | 04 | 04 | 04 |

Table 5 b displays the variances among sites when considering the richness of blooming species in particular sample months. Almost without fail, the patterns mirror the broader seasonal changes.

**Table 5 (b) Richness of flowering species across months, lifeforms, and locations of sampling**

| | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 |
|---|---|---|---|---|---|---|---|---|
| **April** | | | | | | | | |
| Tree | 04 | 02 | 04 | 04 | 04 | - | 03 | - |
| Shrub | 07 | 05 | 06 | 06 | 05 | 05 | 07 | 05 |
| Herb | 08 | 12 | 12 | 13 | 07 | 09 | 05 | 09 |
| Total | 19 | 19 | 22 | 23 | 16 | 14 | 15 | 14 |
| **August** | | | | | | | | |
| Tree | 02 | 01 | 01 | 02 | 01 | 01 | - | 01 |
| Shrub | - | 01 | 01 | 01 | - | 01 | 01 | 02 |
| Herb | 15 | 17 | 20 | 18 | 11 | 15 | 18 | 18 |
| Total | 17 | 19 | 22 | 21 | 12 | 17 | 19 | 21 |

| December | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tree | 01 | 01 | 02 | - | 02 | - | - | - |
| Shrub | 01 | 01 | 01 | 01 | 01 | - | - | - |
| Herb | 02 | 02 | 02 | 01 | 02 | 01 | - | 01 |
| Total | 04 | 04 | 05 | 02 | 05 | 01 | - | 01 |

## CONCLUSION

The study underscores the critical role of trees in supporting pollination services and sustaining biodiversity across various land-use and land-cover types. It highlights those forested landscapes, with their higher species richness and density, provide essential floral resources and habitats for pollinators, significantly contributing to ecosystem stability. In contrast, agricultural and barren lands exhibit lower diversity, emphasizing the need for integrating sustainable practices such as agroforestry to mitigate habitat loss. Seasonal variations in flowering phenology and pollinator activity reveal the dynamic interplay between ecological factors and species interactions, illustrating the importance of preserving diverse floral resources throughout the year. The findings emphasize the urgent need for conservation strategies that address habitat fragmentation and promote native vegetation to maintain robust pollination networks. This research provides a foundational understanding of the ecological significance of tree-pollinator relationships, serving as a guide for future studies and policies aimed at enhancing ecosystem services and biodiversity resilience.

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