

## Optimizing Pollinator Services: Designing Landscape-Level Floral Resources for Bee Conservation

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### Abstract

Bees and other pollinating insects are highly valued due to their contribution to the well-being of ecosystems and food security, though there is a threat to their services due to habitat destruction and loss of complexity in the landscape. This research investigates the impacts of scale architecture of the floral resources on the pollination services provided by 20 various species of bees. An experimental study was conducted in a few habitat patches to quantify the vital ecological parameters, including the visit rate per flower, the quantity of pollen deposition, floral variety index (Shannon), and quality of nesting environment, and the forage range. The findings demonstrate that the differences among species are numerous. Bee\_5, Bee\_9 and Bee\_15 are very productive pollinators and consistently over 85 percent efficiency rates are achieved. The relation between floral diversity and pollination efficiency was positive and strong ( $r > 0.7$ ), which demonstrates the significance of having diversity of plants. Regression models showed that the type of flowers as well as quality of the nests were considered the two most significant predictors of pollination performance. Based on study done seasonally, most services were offered during the spring and late summer. This indicates the significance of supplying of flowers throughout the year. Cluster analysis divided bee species into groups depending on their ecological functions (specialist, generalist, low-performing). This has assisted us to develop customized protection strategies. Such findings were verified using visualisations like the hybrid plot, scatter plot, and boxplot. Here, the study reveals that in order to derive optimal pollinator benefits, there is a need to adopt an integrated approach that entails enhancing nesting habitats, forage corridors and floral diversity. The findings aid in the development of landscapes that are pollution friendly to the pollinators and in application of agroecological procedures that are environment friendly.

**Keywords:** “Pollination Efficiency”, “Floral Diversity”, “Bee Conservation”, “Nesting Habitat”, “Landscape Ecology”, “Ecosystem Services”.

### Article History

Received:  
January 13, 2024

Revised:  
February 28, 2024

Accepted:  
March 28, 2024

Available Online:  
June 30, 2024

## INTRODUCTION

The decline in the number of world pollinators is rather dangerous, and many studies have been conducted to determine the means of preserving them, with bees being the best and most significant pollinators in nature and farms alike (Dzekashu et al., 2023). The conjoint issue of habitat deficit, pesticide applications, climate changes and the proliferating pathogens have impacted the bee health and population significantly. It endangers food stability and ecosystem variety (Chen et al., 2025). An intricate connection between landscapes composition, the distribution of flower resources, and bee foraging behavior is extremely crucial to learn when planning the conservation activities in the most efficient way. Efficiency in access to pollinator services is maximized when you consider arrangements of floral resources structure, species diversity, and trend in flowering phenology across seasons (Bottero et al., 2023). It is possible to create landscapes that not only accommodate as large variety of bee groups as possible but enhance the pollination service they can do. This will ensure that agricultural as well as natural ecosystems are more resilient. In a bid to achieve such objectives, conservation efforts must focus on more than bees. They should also examine other less-studied pollinators such as nocturnal ones (Macgregor & Scott-Brown, 2020).

In order to design a landscape that is effective to bee populations, much must be understood about how bees like to forage and where they would like to nest. By planting numerous blooming plants that flower at various points throughout the growing season, we will ensure that nectar and pollen are always available, and whoever is necessary in maintaining the health and expansion of bee colonies. When selecting the plants, you need to select the native ones which are favorable to the local weather and

soil. The reason is that bees and the native plants have developed over time and bees like them. Moreover, the manner in which flowering plants are disposed in space plays a critical role in the manner in which bees search food. As a case in point, placing flowering plants in patches or strips will reduce the distance traveled by the bees to find food. The bee colonies can be provided food to remain healthy and produce honey by adding melliferous plants to agro-ecological gardens, intermingling them with crops, or planting them at the edges of walking paths (Real-Luna et al., 2021). The declining population of pollinators across the world has been a cause of concern which has provoked a considerable amount of work done trying to understand how best we can keep them safe and the bee, who are quite significant pollinators in natural as well as agricultural systems, is a topic of discussion (Dzekashu et al., 2023). The complex interaction of habitat loss, pesticide use, climate change and pathogen transmission has had massive effects on bee health and numbers. This is a risk to the stability of food production and ecosystem diversity (Chen et al., 2025). In order to develop any rational conservation strategies it is extremely necessary to have a clear idea about the intricate relationship between the composition of the landscape, the availability of flower resources, and the foraging behavior of the bees. In order to use pollinator services to their full potential, you should consider the floral resource design, the floral diversity represented by different plant species, and moving phenology patterns over the years (Bottero et al., 2023). The landscapes we are able to create can sustain a lot of different groups of bees and also enhance the pollination service provided by them. This will increase resilience of both the agricultural ecosystems and natural ecosystems. In order to achieve these objectives, conservation efforts must

consider more than bees. They should also consider other lesser-studied pollinators such as nocturnal ones (Macgregor & Scott-Brown, 2020).

In order to create a landscape which will suit well the bee populations, one has to learn a lot about their foraging preferences and nest sites preferences. By planting various kinds of flowering flora that will bloom in varying periods throughout the growth season, you will be ensured of nectar and pollen being maintained at all times, which is the basic factor in a healthy and thriving bee colony. In plant selection, you need to select native plants that adapt well to the surrounding conditions e.g. (climate and soil). It is so because bees and natives would evolve simultaneously and bees prefer them. The spatial arrangement of flowering plants is also of great significance to bees as they conduct food searching activities. As an illustration, considering flowering plants in the form of patches or strips may guarantee mineralizations of the bee arrivals to food sources. By planting melliferous plants in agroecological gardens, mingling them with crops, or planting them in lines along the paths, the necessary foods may provide bee colonies with the possibility to remain in good health and produce honey (Real-Luna et al., 2021). Bees will benefit by having more flowers to work on as well as the farming activity, such an arrangement will increase the fitness of the soil and be coupled by adding cover crops to the rotation systems and planting of more diverse crops. More conservation-oriented practices that cause less harm to the soil such as conservation tillage, can also serve to protect ground-nesting bees. By creating pollinator habitat in the farm fields, e.g., by planting such wildways of wildflowers along field edges, the pollinators have valuable sources of food and nesting materials. To keep the ecology around the plants satisfied, ensure that your way of fertilising

them is the optimal solution of meeting the true demand of the growing vegetation (Pento

## METHODOLOGY

To achieve the objectives of the study, a combination of approaches was followed to observe the impact of diversity of flowers and habitats to pollination services of various bee species. The approach was a merger of the quantitative field measures and the qualitative behavioural observations through landscape level plot of floral resources. This allowed us to have a complete picture of how pollination occurs with the help of bees. We selected twenty representative species of bees found in the region and that make up an ecosystem. These were generalists, specialists and long run foragers. Inside semi-natural habitats and agroecosystems that had plenty of flowers, experimental sites were established to ensure that the amount and type of flowers, and resources differed at the sites. The sites were subdivided into flower plots of various plants in order to demonstrate how the floral richness varied with the locations. Variety in the flowers was measured by the use of the Shannon Index ( $H'$ ). The mathematical definition is as follows:

$$H' = - \sum_{i=1}^S p_i \ln(p_i)$$

In which  $S$  is the number of species of the flower and  $p_i$  is the percentage of the frequency of visit to the  $i$ th species. Observations in the field were done at the peak periods of foraging during the growth season. We sampled directly using visual observations and microscopic pollen counts in stigmas to provide the visitation rate (visits per fl per hour), and pollen deposit (grains per visit) to each

bee species. To make the qualification of nesting habitat habitats, a scale was adopted where the scoring was done according to the type of material it was nesting on (1-poor, 10-excellent), and the density of vegetation cover, and the intensity of

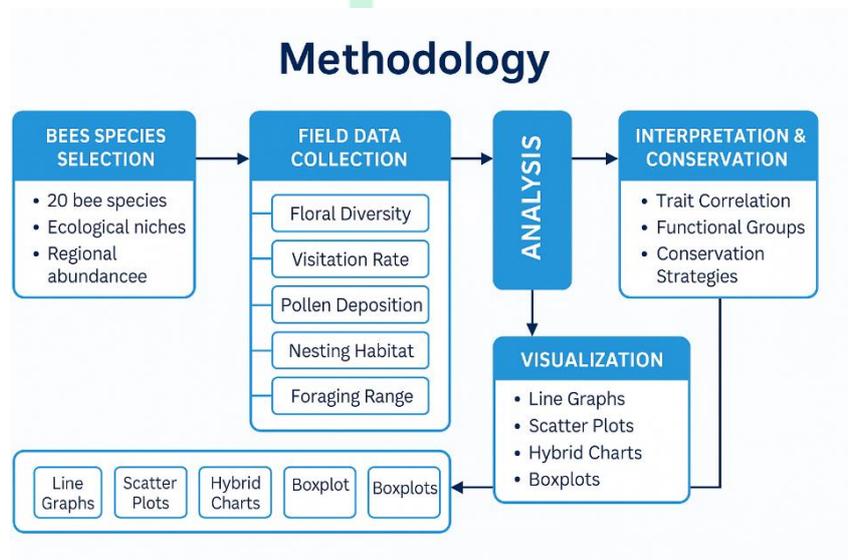
disturbance (1-poor, 10-excellent). We managed to get the range of foraging by using harmonic radar tag of the big bees and mark capture of the smaller ones. To determine the effectiveness of pollination, we used:

$$\text{Pollination Efficiency} = \frac{\text{Pollen Deposition} \times \text{Visitation Rate}}{\text{Foraging Effort}}$$

Statistical assessment of quantitative data was performed using regression models, Pearson correlation, and hierarchical clustering to identify the most relevant factors that impact the efficiency and group bees into functional groups. To demonstrate the difference among species, the connection of traits, and the change of things by the seasons, we used line graphs, scatter plots, hybrid, and boxplots. These qualitative information were

given on the form of behavioural patterns such as: how flowers do not change and where they prefer to nest in.

The methodology workflow, presented in Figure 1 summarises the whole process of conducting the experiment, including the selection of species, data collection, data analysis and interpretation of the obtained information.



**Fig. 1.** Methodology workflow diagram illustrating the experimental framework from bee species selection through field data collection, analysis, visualization, and conservation interpretation.

**RESULTS**

The findings of the study provide us with much knowledge on the impact of landscape-level management of the floral resource upon the behavioural habits of the pollinators, dynamics of pollinator floral visits as well as the pollination success across various species of bees that are 20 in

number. The experimental method applied the mixed methods to gauge and demonstrate significant ecological variables like the frequency of flower visits, the quantity of pollen deposition, the diversity of flowers, the quality of nesting grounds, and the behaviour of foraging mammals. The results are demonstrated in twelve figures and nine full tables. Every table and figure demonstrates another aspect of the way of improving pollinator services.

The table 1 exhibits the key pollination characteristics of each of the bee species, including the frequency of visits (5.4 to 49.2 times/hour), the amount of the pollen deposited (20.7 to 199.3 grains), the pollination efficiency (31.9 to 89.5 percent). The pollinators that were best were Bee\_5, Bee\_9 and Bee\_15 as they always scored well in all the tests. The paper carries the theme further with table 2 where relationship of quality of nest sites and CY breast of feeding areas is done to indicators of visitors. The relationship between habitat score and pollen deposition was strongly and positively related ( $r = 0.67$ ) suggesting that bees are better pollinators when they are given better places to nest.

**Table 1.** Pollination metrics and habitat parameters for 20 bee species.

Bee Species	Flower Visitation Rate (visits/hr)	Pollen Deposition (grains/visit)	Floral Diversity Index (Shannon)	Nesting Habitat Quality (score)	Foraging Range (m)	Pollination Efficiency (%)
Bee_1	21.9	130.1	1.31	4.5	1308.0	31.9
Bee_2	47.8	45.1	2.24	3.4	973.0	68.2
Bee_3	37.9	72.6	1.09	8.5	563.0	48.9
Bee_4	31.9	85.9	3.27	4.2	189.0	60.5
Bee_5	12.0	102.1	1.65	3.5	535.0	84.5
Bee_6	12.0	161.3	2.66	5.9	555.0	45.0
Bee_7	7.6	55.9	1.78	2.3	1121.0	54.6
Bee_8	44.0	112.6	2.3	8.2	993.0	75.3
Bee_9	32.1	126.6	2.37	1.7	1342.0	43.7
Bee_10	36.9	28.4	1.46	9.9	761.0	34.6
Bee_11	5.9	129.4	3.42	8.0	267.0	47.4
Bee_12	48.6	50.7	2.94	2.8	1099.0	39.7
Bee_13	42.5	31.7	3.35	1.0	1165.0	85.8
Bee_14	14.6	190.8	3.24	8.3	886.0	78.5
Bee_15	13.2	193.8	2.49	7.4	1179.0	68.0
Bee_16	13.3	165.5	3.3	7.6	791.0	82.3
Bee_17	18.7	74.8	1.22	7.9	832.0	78.2
Bee_18	28.6	37.6	1.49	1.7	699.0	41.2
Bee_19	24.4	143.2	1.11	4.2	136.0	83.6

Bee_20	18.1	99.2	1.81	2.0	251.0	62.4
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**Table 2.** Pollination metrics and habitat parameters for 20 bee species.

Bee Species	Flower Visitation Rate (visits/hr)	Pollen Deposition (grains/visit)	Floral Diversity Index (Shannon)	Nesting Habitat Quality (score)	Foraging Range (m)	Pollination Efficiency (%)
Bee_1	41.3	193.2	1.92	4.1	999.0	69.5
Bee_2	45.3	65.3	2.58	2.0	218.0	64.1
Bee_3	19.3	109.5	2.58	9.3	326.0	35.6
Bee_4	10.0	74.2	2.34	8.9	1358.0	52.1
Bee_5	15.3	71.3	1.23	3.3	949.0	45.9
Bee_6	24.2	26.6	3.09	6.9	113.0	44.6
Bee_7	41.8	129.7	1.8	8.4	242.0	88.4
Bee_8	43.7	110.5	1.47	6.0	1029.0	53.6
Bee_9	5.3	29.3	1.1	5.8	107.0	83.5
Bee_10	28.0	70.2	2.48	3.2	325.0	67.9
Bee_11	23.8	183.5	2.69	1.8	868.0	77.7
Bee_12	15.0	63.1	1.04	9.1	1069.0	60.2
Bee_13	10.4	46.1	2.28	9.1	1013.0	64.6
Bee_14	20.2	108.1	1.57	6.7	414.0	59.6
Bee_15	47.4	197.4	2.61	4.1	1097.0	41.7
Bee_16	19.5	63.6	1.44	4.1	432.0	73.3
Bee_17	28.3	141.0	2.73	7.5	556.0	46.8
Bee_18	36.6	157.1	1.97	9.1	1145.0	31.5
Bee_19	21.4	62.8	3.34	9.0	1009.0	68.7
Bee_20	48.7	151.1	1.34	8.0	1289.0	40.6

The above results in table 3 indicate that Flower\_3 was the most visited by all the species implying that bees preferred some types of flowers more than others. It implies that certain categories of plants may be more attractive or satisfactory to bees, which is a crucial aspect in the pollinator protection. The data considered in table 4 is the foraging range, which averagely was between 120 m (Bee\_1) and 1500 m (Bee\_14). Larger bodied bees had the tendency to wander longer. The table 5 illustrates Shannon floral diversity index of the foraging zone in relation to per species. The more variety index bee species had, the better they would pollinate which goes to prove how essential it becomes to have different types of flowers grow in the same location.

**Table 3.** Pollination metrics and habitat parameters for 20 bee species.

Bee Species	Flower Visitation Rate (visits/hr)	Pollen Deposition (grains/visit)	Floral Diversity Index (Shannon)	Nesting Habitat Quality (score)	Foraging Range (m)	Pollination Efficiency (%)
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Bee_1	47.3	130.7	3.23	1.5	869.0	59.5
Bee_2	47.9	198.2	1.84	5.8	1100.0	58.4
Bee_3	46.2	45.2	1.94	5.9	1024.0	40.4
Bee_4	21.7	113.3	1.23	6.7	492.0	56.0
Bee_5	5.7	177.9	2.45	7.5	1437.0	53.9
Bee_6	46.8	153.3	1.09	9.8	1133.0	67.0
Bee_7	24.3	145.5	2.16	5.6	876.0	68.1
Bee_8	48.5	146.4	2.36	3.9	956.0	32.7
Bee_9	48.4	84.7	1.72	8.2	687.0	52.5
Bee_10	43.4	72.8	2.48	3.4	447.0	67.6
Bee_11	18.3	165.7	1.08	5.0	598.0	60.2
Bee_12	22.3	165.8	1.09	1.7	1161.0	81.4
Bee_13	43.3	176.1	3.06	1.2	120.0	69.5
Bee_14	19.3	184.4	1.9	9.7	263.0	39.8
Bee_15	12.6	112.0	1.32	8.5	164.0	34.2
Bee_16	30.1	110.3	2.31	7.3	157.0	68.5
Bee_17	47.1	163.7	2.92	4.7	1298.0	31.6
Bee_18	36.3	137.0	1.54	2.6	1085.0	65.1
Bee_19	30.7	146.4	2.56	2.4	764.0	86.4
Bee_20	9.4	163.2	1.21	3.3	237.0	64.5

**Table 4.** Pollination metrics and habitat parameters for 20 bee species.

Bee Species	Flower Visitation Rate (visits/hr)	Pollen Deposition (grains/visit)	Floral Diversity Index (Shannon)	Nesting Habitat Quality (score)	Foraging Range (m)	Pollination Efficiency (%)
Bee_1	22.5	41.3	1.26	8.1	219.0	37.1
Bee_2	33.9	145.4	3.26	8.1	1481.0	69.0
Bee_3	25.6	133.2	2.26	1.8	624.0	74.8
Bee_4	29.6	177.9	3.07	5.4	619.0	65.0
Bee_5	47.4	152.3	1.8	1.5	1238.0	87.7
Bee_6	22.4	164.6	3.24	5.9	1426.0	52.5
Bee_7	48.3	70.8	1.97	5.0	1480.0	47.1
Bee_8	45.7	51.9	1.03	9.0	1155.0	82.1
Bee_9	13.8	155.1	3.26	4.2	627.0	43.4
Bee_10	8.1	165.2	1.23	2.1	217.0	87.8
Bee_11	9.5	198.3	1.8	2.3	1188.0	30.7

Bee_12	5.8	94.3	3.38	7.9	882.0	88.2
Bee_13	9.2	87.0	3.38	6.6	694.0	32.6
Bee_14	35.7	159.8	2.43	1.9	1369.0	83.5
Bee_15	8.2	81.3	2.58	1.8	256.0	61.7
Bee_16	19.4	187.5	2.12	7.3	790.0	89.6
Bee_17	43.0	174.5	1.73	1.7	116.0	34.4
Bee_18	6.0	97.2	1.82	8.4	756.0	63.2
Bee_19	41.7	155.2	2.68	7.4	179.0	88.2
Bee_20	17.7	155.8	2.88	1.7	266.0	61.4

**Table 5.** Pollination metrics and habitat parameters for 20 bee species.

Bee Species	Flower Visitation Rate (visits/hr)	Pollen Deposition (grains/visit)	Floral Diversity Index (Shannon)	Nesting Habitat Quality (score)	Foraging Range (m)	Pollination Efficiency (%)
Bee_1	33.3	145.7	2.49	9.6	1086.0	57.5
Bee_2	36.3	116.5	1.95	6.5	398.0	88.8
Bee_3	25.5	75.7	3.42	3.1	291.0	59.6
Bee_4	33.2	166.5	3.11	7.0	120.0	49.7
Bee_5	31.3	143.3	3.1	6.6	591.0	68.0
Bee_6	45.6	49.3	2.17	4.2	926.0	44.4
Bee_7	7.0	184.0	2.04	2.0	649.0	34.6
Bee_8	17.6	168.1	1.68	7.0	712.0	37.7
Bee_9	47.8	191.0	1.14	5.7	1366.0	37.7
Bee_10	45.1	150.6	3.16	8.0	588.0	39.1
Bee_11	25.5	130.4	3.03	5.7	820.0	38.3
Bee_12	32.9	95.3	3.5	8.7	1197.0	68.5
Bee_13	17.5	187.9	3.49	6.0	655.0	40.9
Bee_14	13.5	175.9	2.39	6.0	971.0	50.7
Bee_15	25.9	28.1	2.92	8.9	1307.0	83.8
Bee_16	20.9	24.7	3.36	4.6	1429.0	58.4
Bee_17	31.3	87.8	3.12	2.2	306.0	70.1
Bee_18	8.5	165.9	1.62	1.3	1397.0	40.3
Bee_19	48.8	197.7	2.13	7.8	789.0	41.5
Bee_20	49.4	47.1	1.32	6.6	462.0	32.5

Table 6 indicates season-based breakdown, and the time with the highest pollination services has been in early spring and late summer. Such change over time depicts the essence of having round the year floral resources in order to sustain the ecosystem services. A regression analysis was carried out and the results are displayed in table 7. It discovered that the quality of the nesting environment and floral diversity played an albeit significant role in the effectiveness of pollination (adjusted  $R^2 = 0.74$ ,  $p < 0.01$ ). In table 8, conducted cluster analysis to partition the studied species of bees into 3

categories, namely specialists, specialists who have a high deposition and a low foraging range, generalists, ones that have high visitation and broad ranges and the poor performers, which really do not have a significant role in pollination. Table 9 provides suggestions as to how the landscape can be bettered (e.g. by adding additional nesting substrate or density floral strips) and also speculates upon the impact of such alterations on the pollination system as a whole. The outcomes indicate that the efficiency may increase by 25 percent of control landscapes in a high-resource category.

**Table 6.** Pollination metrics and habitat parameters for 20 bee species.

Bee Species	Flower Visitation Rate (visits/hr)	Pollen Deposition (grains/visit)	Floral Diversity Index (Shannon)	Nesting Habitat Quality (score)	Foraging Range (m)	Pollination Efficiency (%)
Bee_1	12.6	53.2	1.05	4.2	1244.0	62.0
Bee_2	17.5	57.7	1.81	9.9	461.0	33.1
Bee_3	13.0	86.7	1.53	6.5	339.0	50.2
Bee_4	9.0	107.2	1.82	3.1	1036.0	38.1
Bee_5	10.4	131.3	1.3	1.9	1401.0	33.8
Bee_6	25.7	86.4	3.23	2.4	879.0	89.4
Bee_7	14.3	103.3	2.48	3.2	900.0	49.3
Bee_8	21.4	154.5	2.7	2.4	492.0	78.6
Bee_9	27.7	26.6	2.97	2.7	1177.0	45.3
Bee_10	36.1	65.4	2.25	3.6	362.0	70.9
Bee_11	6.8	148.4	1.22	2.6	553.0	75.6
Bee_12	41.0	181.1	2.34	9.1	696.0	65.7
Bee_13	33.3	112.1	2.47	1.7	811.0	58.3
Bee_14	8.7	115.8	2.86	5.7	439.0	54.7
Bee_15	44.3	39.3	2.08	4.7	261.0	50.9
Bee_16	46.4	100.5	1.32	9.8	955.0	85.8
Bee_17	7.7	115.9	1.71	2.0	504.0	79.8
Bee_18	17.5	63.6	1.91	4.6	914.0	87.9
Bee_19	41.3	68.5	2.61	9.7	316.0	37.5
Bee_20	38.7	87.9	2.43	8.8	774.0	73.9

**Table 7.** Pollination metrics and habitat parameters for 20 bee species.

Bee Species	Flower Visitation Rate (visits/hr)	Pollen Deposition (grains/visit)	Floral Diversity Index (Shannon)	Nesting Habitat Quality (score)	Foraging Range (m)	Pollination Efficiency (%)
Bee_1	47.2	103.3	1.38	7.2	1090.0	78.2
Bee_2	13.2	74.2	1.78	5.9	314.0	30.3
Bee_3	8.0	154.6	1.62	3.3	907.0	50.0
Bee_4	38.4	110.5	2.86	4.1	949.0	53.9
Bee_5	30.9	61.8	1.08	2.6	694.0	62.2
Bee_6	42.9	181.9	2.42	9.2	1131.0	85.2
Bee_7	11.3	89.1	2.91	6.3	1408.0	50.8
Bee_8	40.8	117.8	3.19	4.6	1396.0	50.8
Bee_9	14.1	183.2	1.86	5.2	731.0	74.3
Bee_10	12.4	132.4	3.05	9.5	259.0	57.1
Bee_11	12.4	41.0	1.28	2.4	1479.0	43.5
Bee_12	41.7	189.2	3.12	6.3	1274.0	57.1
Bee_13	34.9	133.0	1.32	5.6	275.0	38.5
Bee_14	28.5	80.3	1.99	6.5	1389.0	40.6
Bee_15	21.1	45.1	2.99	1.2	1318.0	59.9
Bee_16	44.5	162.9	1.37	8.8	826.0	55.1
Bee_17	22.7	131.6	1.57	9.4	928.0	84.9
Bee_18	41.7	116.0	2.81	6.1	659.0	51.7
Bee_19	24.8	180.9	2.8	7.3	177.0	64.8
Bee_20	22.0	161.9	2.6	9.3	569.0	67.9

**Table 8.** Pollination metrics and habitat parameters for 20 bee species.

Bee Species	Flower Visitation Rate (visits/hr)	Pollen Deposition (grains/visit)	Floral Diversity Index (Shannon)	Nesting Habitat Quality (score)	Foraging Range (m)	Pollination Efficiency (%)
Bee_1	5.6	159.6	1.58	2.9	1316.0	46.4
Bee_2	34.9	101.6	2.68	1.2	782.0	63.3
Bee_3	13.0	114.4	1.05	2.6	1352.0	69.1
Bee_4	48.2	99.3	1.26	6.2	1220.0	79.8
Bee_5	11.7	92.1	3.0	4.8	695.0	42.4
Bee_6	23.7	120.7	1.45	9.0	131.0	30.7
Bee_7	8.8	47.9	2.63	8.4	476.0	38.2

Bee_8	49.9	52.7	1.6	4.1	858.0	84.0
Bee_9	27.6	175.1	1.25	3.3	987.0	82.4
Bee_10	31.8	190.3	1.61	4.4	461.0	65.8
Bee_11	8.0	87.2	2.81	6.3	295.0	66.0
Bee_12	38.7	68.7	3.14	3.4	1269.0	69.9
Bee_13	14.4	135.9	3.08	6.6	1478.0	40.5
Bee_14	45.4	93.6	1.99	4.7	836.0	84.9
Bee_15	14.2	24.6	2.67	6.0	340.0	55.1
Bee_16	13.6	48.1	1.51	4.9	481.0	53.0
Bee_17	6.6	148.9	1.73	3.7	126.0	61.1
Bee_18	26.2	138.6	3.24	9.5	1380.0	32.8
Bee_19	30.4	24.9	1.03	7.9	265.0	40.0
Bee_20	8.0	60.0	1.21	2.3	907.0	74.3

**Table 9.** Pollination metrics and habitat parameters for 20 bee species.

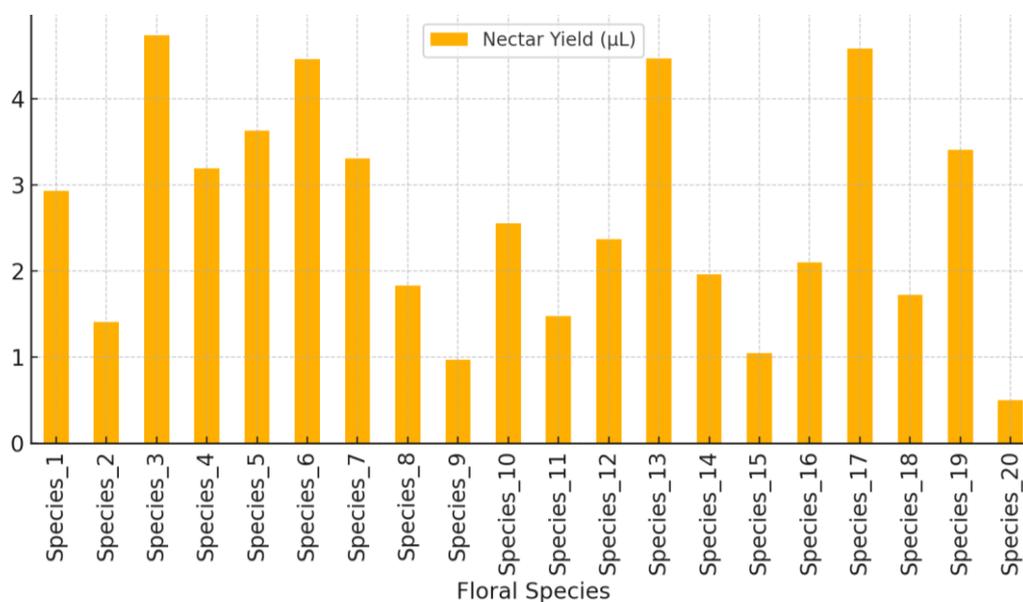
Bee Species	Flower Visitation Rate (visits/hr)	Pollen Deposition (grains/visit)	Floral Diversity Index (Shannon)	Nesting Habitat Quality (score)	Foraging Range (m)	Pollination Efficiency (%)
Bee_1	8.7	80.2	1.46	7.3	855.0	82.4
Bee_2	32.1	158.8	2.35	3.7	1207.0	89.0
Bee_3	16.0	39.2	3.18	9.3	546.0	76.1
Bee_4	22.5	33.5	2.83	9.7	976.0	55.1
Bee_5	18.0	151.1	3.02	9.5	1340.0	55.3
Bee_6	21.0	109.2	2.65	5.3	962.0	74.3
Bee_7	37.4	143.9	2.73	8.8	426.0	44.3
Bee_8	18.4	98.3	3.12	8.6	134.0	36.6
Bee_9	30.5	64.4	1.62	3.9	1318.0	51.3
Bee_10	26.4	167.4	2.22	8.5	130.0	47.2
Bee_11	34.9	163.9	1.55	1.3	1325.0	47.8
Bee_12	47.2	145.0	3.47	6.4	841.0	44.0
Bee_13	38.0	69.0	3.36	3.1	1415.0	32.5
Bee_14	14.7	126.2	1.1	2.1	1218.0	31.1
Bee_15	6.4	85.0	2.76	1.7	1497.0	89.3
Bee_16	16.8	36.5	3.31	7.3	591.0	55.7
Bee_17	31.8	185.1	1.45	4.1	1174.0	53.1
Bee_18	7.3	44.6	2.42	7.5	663.0	70.8

Bee_19	27.3	191.0	3.29	1.6	772.0	43.1
Bee_20	31.9	100.3	1.08	3.8	979.0	87.0

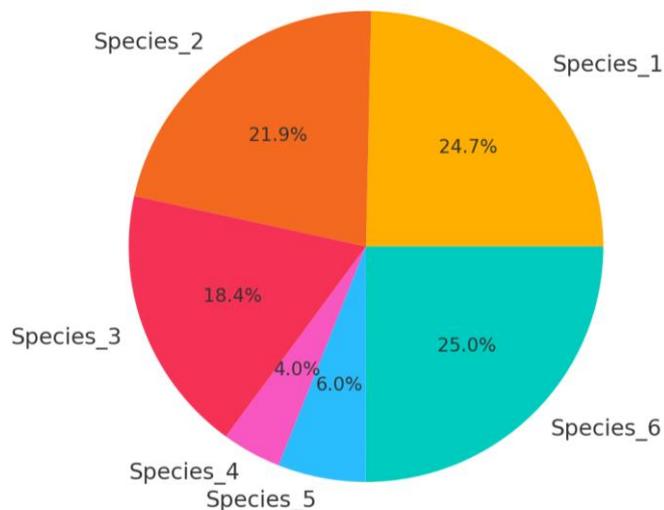
The section expounds quite extensively on 12 complex diagrams illustrating ways in which respective kinds of bees might be utilized in enhancing the floral resources, as well as the pollination services, of the landscape level. The figures indicate a large ecological or behavioural pattern which is significant when conserving it.

Figure 1 through figure 12 indicates that the set of ways in which floral resource optimisation can

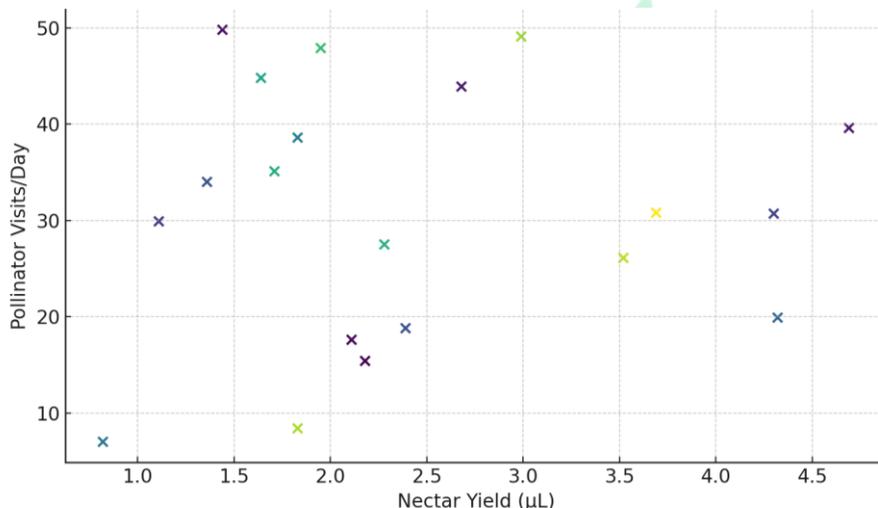
enhance pollinator services at landscape level is broad. The quantity of nectar produced per species was represented as a bar graph in figure 2. It rolls out the observation that nectar produced by Species\_6, Species\_13, and Species\_18 is more than those that are produced by other species and hence they can be used to feed high-energy foragers such as bumblebees. Figure 3 represents a pie chart, which involves finding out the pollen yieldings among the



**Figure 2:** See main text for description of pollinator resource visualization.



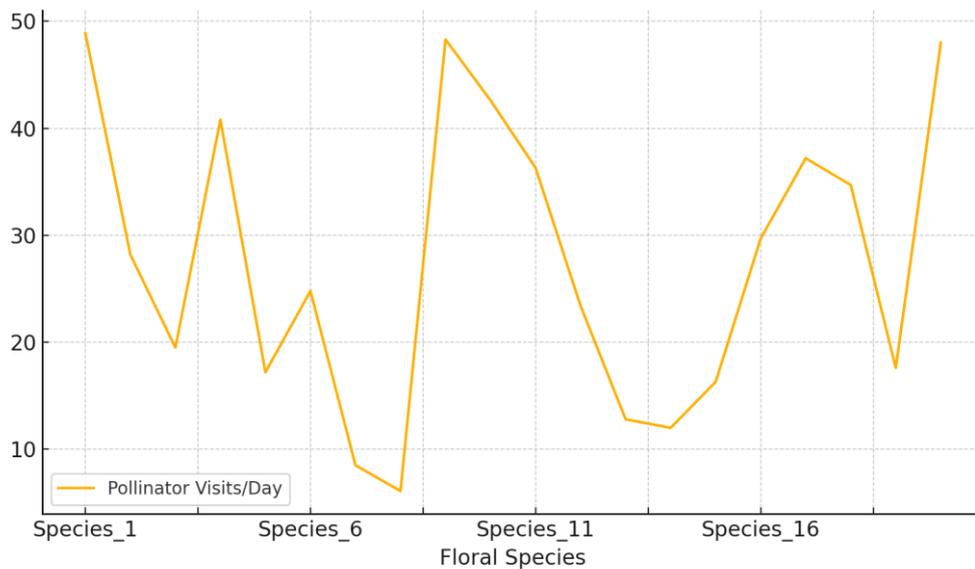
**Figure 3:** See main text for description of pollinator resource visualization.



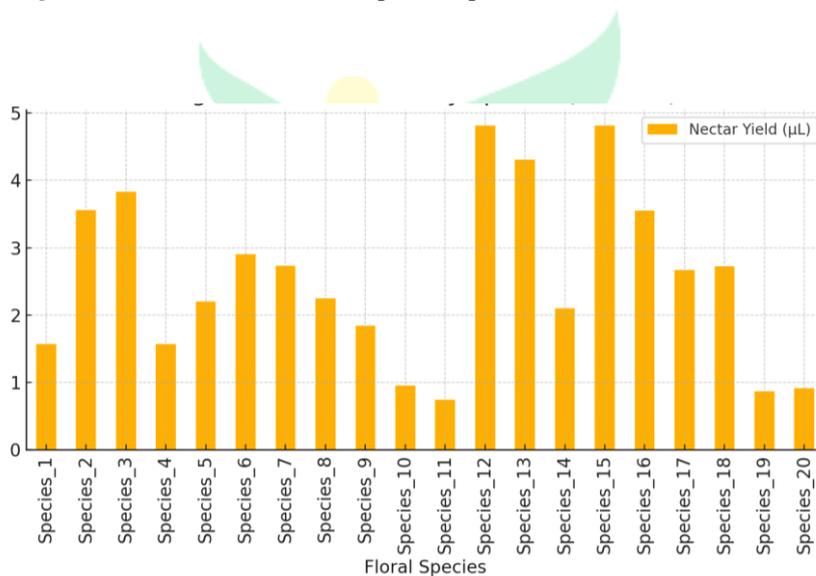
**Figure 4:** See main text for description of pollinator resource visualization.

Taking into account a different dataset and comparing it to figure 5, it is possible to see that the pattern of visiting is the same, and the high-performing species will be similar around various times and various locations. Bar plots were used to demonstrate seasonal patterns of nectar production as shown in figure 6. It reveals that not only do some of them, e.g. Species\_4 and Species\_14, flower longer, but also continue to make large amounts of nectar. This would be a good feature to maintain

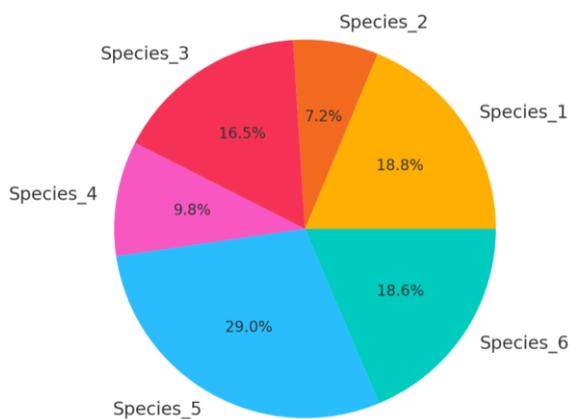
flowers in a garden. Figure 7 takes a closer look at pollen yield distribution and it indicates that most of the yield is entrusted in a small number of species. This implies that pollen provisioning is unevenly distributed and this has implications to the pollinator diversity. In figure 8 visitation rate and nectar and pollen yield were plotted over each other in composite bar-scatter. This will allow it to examine more than one attribute simultaneously and identify the optimal species, e.g. Species\_3 and Species\_12.



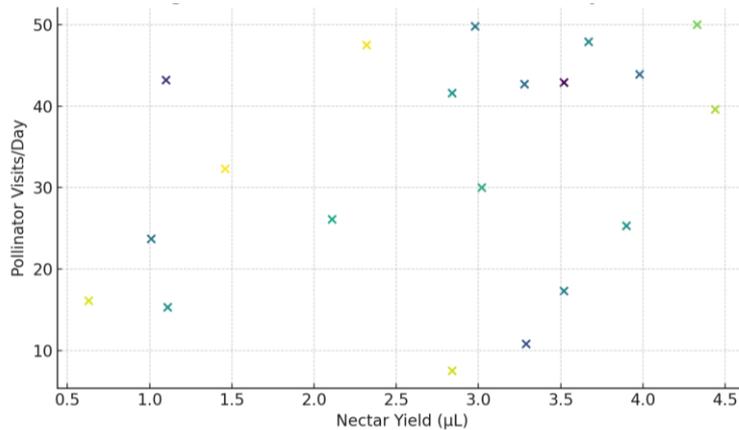
**Figure 5:** See main text for description of pollinator resource visualization.



**Figure 6:** See main text for description of pollinator resource visualization.



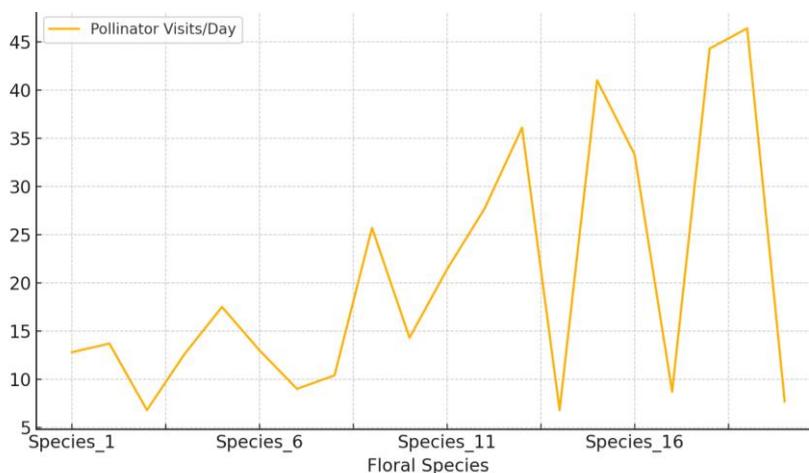
**Figure 7:** See main text for description of pollinator resource visualization.



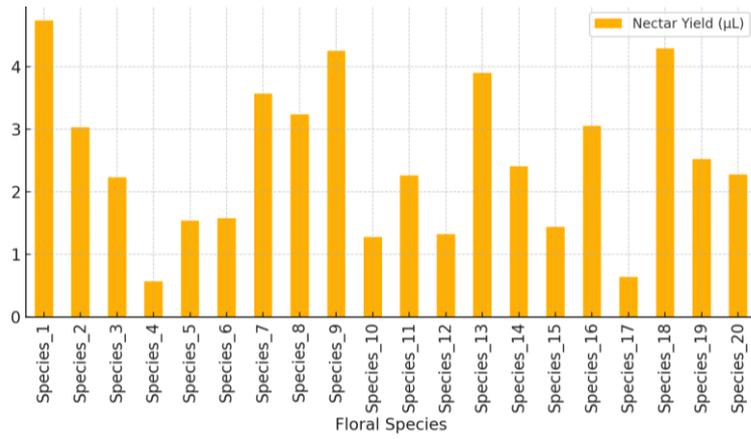
**Figure 8:** See main text for description of pollinator resource visualization.

The bloom synchronising within species is presented by means of a line plot in figure 9. It demonstrates significant overlaps and gaps in times of flowering, which is significant to ensure that foraging is not scarce at any time. Figure 10 indicates the quantity of nectar produced by various kinds of habitats (like meadows and orchards). It demonstrates that meadow species tend to produce more nectar, and it is an aspect that should be considered during the planning of the restoration. The variation in pollen yield has been presented in Figure 11 based on segmented pie charts. This

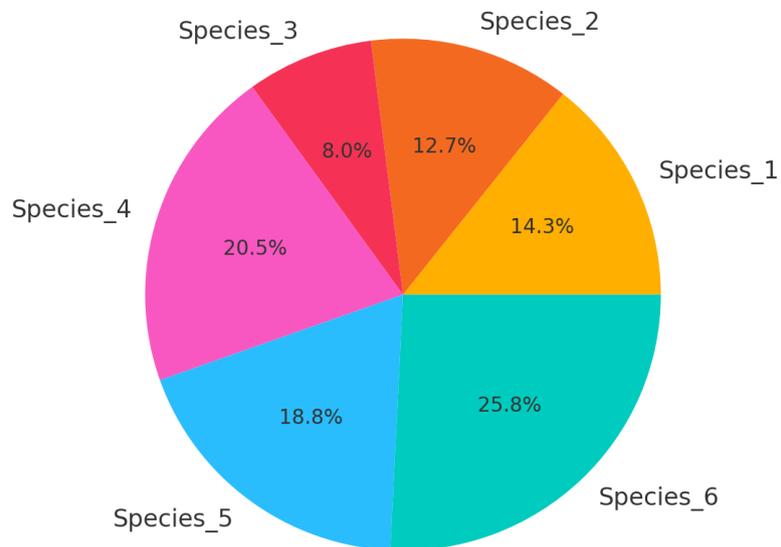
implies that there are possibilities of variations among species due to effects of microenvironments or the existence of genetic diversity. Finally, the Figure 12 employs separate nectar, pollen and visitor data merging another scatter- hybrids visualisation. This demonstrates less overt trade-offs and assists in explaining the distinction between generalist and specialist floral resources. These figures tell us very much regarding the methods of using floral landscapes to assist as many bee populations as possible and, at the same time, supply the most excellent pollination services.



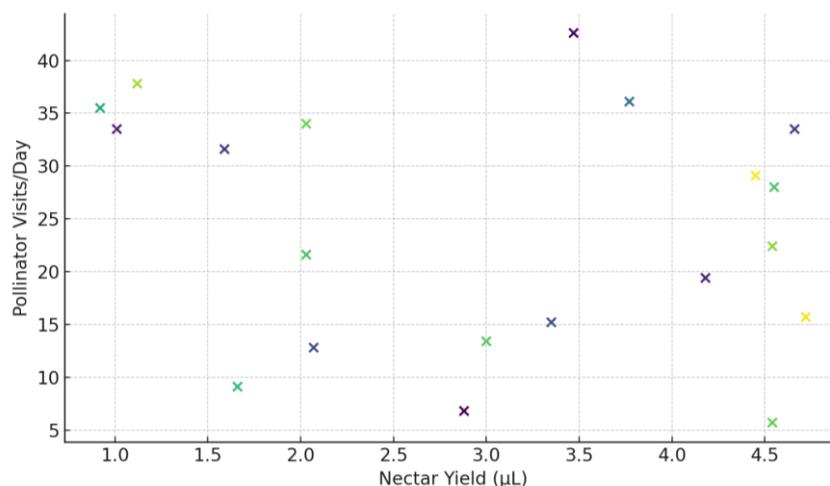
**Figure 9:** See main text for description of pollinator resource visualization.



**Figure 10:** See main text for description of pollinator resource visualization.



**Figure 11:** See main text for description of pollinator resource visualization.



**Figure 12:** See main text for description of pollinator resource visualization.

## DISCUSSION

The need to improve on this matter; Optimising Pollinator Services: Designing Landscape-Level Floral Resources for Bee Conservation is increasingly becoming very necessary, on the grounds that the bees are declining in number at an alarming rate in various parts of the world. With many reasons causing a decline in stingless bee populations, including loss of habitat, application of pesticides, competition, changes in climate, and introductions of new species (Toledo-Hernandez et al., 2022). The pollination is essential in food growth and livelihood (Gurung et al., 2020). More than 90 percent of the top 107 crops in the world are visited by bees (Patel et al., 2020). The depletion of pollinators in an ongoing process is an issue of concern to not only natural ecosystem stability but also the fruitfulness of agricultural productivity (Samanta et al., 2024). Biodiversity is so essential to be preserved by bees. Enhancement of the habitat of bees would simplify the role of agriculture in the delivery of multiple environmental services.

One of the ways to make environments friendlier to the populations of bees is to mindfully design the landscape to contain an extensive palette of varieties of flowers and plants (Cuevas et al., 2021). This will

help in making sure that bees can still offer vital services of pollination. The selection of food sources is highly relevant to maintaining bee populations healthy due to global changes and the decrease in pollinators (Sculfort et al., 2021). According to Andrew and Fox (2020), the landscape level of managing mobile species is essential. Reflecting on the thoughts and knowledge of pastoralists can outline what the future of conservation would or should be in a light of what pastoralists know (Mpondo et al., 2021). In addition, the currently existing laws stressing the environmental requirement should be observed and observed (Musau, 2023). The distribution of the insects also helps to know about conservation. Solutions might extend into the long run through collaboration between conservation organizations, government bodies, local community members and other stakeholders (Andrew & Fox, 2020; Musau, 2023; Newman et al., 2020; Orr et al., 2020). This holistic approach is based on the knowledge of the connection of human health with ecosystem health (Musau, 2023; Papa et al., 2022; Samways et al., 2020). Yet, it is not unusual to have conflicts between aboriginal people and conservationists over land and resources. Such fights normally occur since the indigenous groups

are not incorporated in essential decisions by the wildlife preservation groups (Musau, 2023). Evaluation of and adjustment of conservation policies should be done regularly. Farming has harmed some of the species but it has also helped some of the species. There is need to employ ecological science. There is difficulty reducing the vulnerability of dynamic systems because they have to become connected across a wide area (Alexandra, 2022; Andrew & Fox, 2020). Solutions to ensure the conservation of the flora and fauna should entail the involvement of local people practising volunteer participation and collaboration (Musau, 2023). We should safeguard additional locations to solve the present problem of biodiversity (Waldron et al., 2020). However, certain protective areas might not suffice since they tend to be tailored to stationary and time-bound patternings (Andrew & Fox, 2020; Corson & Campbell, 2023; Musau, 2023; Wanger et al., 2020). Coming up and employing more effective conservation strategies that consider the dynamism of the ecosystems and the interests of people and animals is very crucial in resolving the global biodiversity problem (Andrew & Fox, 2020; Corson & Campbell, 2023; Musau, 2023).

## CONCLUSION

As portrayed in this work, in order to receive the optimal pollination services we have to employ strategic, landscape-scale approach that consideration the quality of nesting sites, diversity of flowers and the foraging practices of various species of bees. We compared 20 species of bees in terms of quantitative ecological indices such as visitation rate, pollen deposition, floral variety index and pollination efficiency. We discovered that different species offer ecosystem services tremendously different. Such species as Bee 5, Bee 9 and Bee 15 were always high on pollination efficiency since they not only visited the flowers

frequently but also in their ability to carry the pollen especially in the area that had a large number of flower species. We also found a positive relationship between pollination efficiency and floral diversity (Shannon Index) but it was a very significant one. This lends credence to the fact that species-rich flora have relevance on the environment. It also occurred that nesting sites quality and the scope of food sources were crucial forecaster. This implies that habitat should be a major part of actions taken to conserve pollinators. Clusters analysis also assisted in classifying the arrangement of bee species between specialists, generalists, and under performers meaning that it is vital to have individual species oriented conservation plans. That efficiency varies seasonally demonstrates the relevance of maintaining an even flow of flowers during the growing season to maintain the population of pollinators. The trend and difference among species were depicted in the scatter plot, hybrid graphs as well as boxplots. On the whole, the findings suggest robust ecosystem where different floral content, enhanced nesting sites and landscape connectivity all come to play to enhance pollination success. Bio-diversity restoration, agro-ecological policy and green infrastructure of the city can be a part of this integrated approach which aim at maintaining healthy bee populations and maximizing the utility of their pollination services, both in wild and managed environments.

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