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Research Paper

Species Composition, Relative Abundance and Diversity of Forager Honey Bees in and around Gishwati-Mukura National Park, Rwanda

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Abstract

This study examined the influence of habitat type, seasonality, temperature, and humidity on forager bee abundance, species richness, and diversity in and around Gishwati–Mukura National Park (GMNP). Bees were sampled using pan traps across three habitat types, namely primary, restored, and disturbed forests, over a 13-month period covering both dry and rainy seasons. A total of 179 forager bee specimens were recorded, representing seven species from Apidae and Halictidae families. Significant differences in bee abundance were observed among habitat types. In disturbed forests, bee abundance was higher during the rainy season, whereas in restored and primary forests, abundance was greater during the dry season. These results indicate that seasonal variation significantly affects forager bee abundance in GMNP, although seasonal trends were generally consistent across habitat types. Overall, species richness was low. Temperature and humidity exhibited a significant negative effect on bee abundance, suggesting that forager bee populations increased under cooler and drier conditions and declined under warmer and more humid conditions. Although the findings suggest that bees are thriving within GMNP, the study was limited to a single year; therefore, future research should incorporate multi-year sampling to capture longer-term trends. The study contributes to existing knowledge on bee ecology and pollination services and underscores the potential of beekeeping as a sustainable livelihood option for communities surrounding GMNP, which may help reduce encroachment, poaching, and habitat degradation. The findings also provide valuable insights for park management and conservation policymakers.

1. Introduction

Bees are widely distributed, occurring on every continent except Antarctica, and inhabit ecosystems that support insect-pollinated flowering plants. Taxonomically, bees belong to the superfamily Apoidea, which comprises numerous families, subfamilies, and tribes, with approximately 25,000 species worldwide and about 3,000 species recorded in sub-Saharan Africa (Eardley et al., 2009; Amsalu et al., 2020). As members of the order Hymenoptera, bees are of considerable ecological, agricultural, cultural, and economic importance (Combey & Kwapong, 2016; Habtamu & Oljira, 2024).

Bees are globally recognized as primary providers of pollination services, a vital ecological function that supports biodiversity in both natural and agricultural systems (Tarakini et al., 2021). Pollination services are strongly linked to biodiversity because many plant species depend on specific pollinators, while numerous bee species exhibit floral specialization. Consequently, bees are widely used in managed agricultural pollination

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to enhance crop productivity (Lagace et al., 2025; Tesfa & Hayat, 2023). Forager bees are worker bees that play a critical role in pollination and honey production.

Studies from East Africa have documented considerable variation in bee abundance, richness, and diversity across habitat types. For example, research in western Kenya reported 82 bee species from three families foraging on hedgerow plants, with Apidae showing the highest species richness (Mwangi et al., 2012). Similarly, 992 bee visitors from nine species and two families were recorded on bean crops in the same region (Nyanumba et al., 2021). Other studies from Kenya and Tanzania have shown higher bee richness, diversity, and plant-pollinator interactions in semi-natural habitats compared with disturbed landscapes (Mwangi et al., 2012; Ojija & Silabi, 2024).

Bee abundance and diversity are shaped by both biotic and abiotic factors. Anthropogenic pressures have contributed to global declines in bee populations, with implications for food security (Munyuli et al., 2011; Nyanumba et al., 2021). Climatic variables, particularly temperature and humidity, also exert strong influences. Bee abundance tends to increase with temperature up to an optimal threshold (approximately 28.5°C) and declines beyond this level (Murray et al., 2012; Tarakini et al., 2021). Along elevational gradients such as Mount Kilimanjaro, temperature has been shown to have a stronger effect on species richness than floral resource availability, with richness declining at higher elevations (Classen et al., 2015). Other factors, including wind speed, flower availability, and habitat type, further influence bee communities (Levenson & Tarpy, 2023; Schwarz et al., 2024; Tarakini et al., 2021).

Gishwati–Mukura National Park (GMNP) is a recently established protected area in western Rwanda, designated to conserve its rich biodiversity. Although several ecological studies have focused on various faunal groups within GMNP, research on bee fauna remains notably limited, despite their ecological and economic importance (Banerjee et al., 2018). Given the critical role of pollinators in ecosystem functioning, there is a clear need to investigate bee communities within the park. Due to logistical constraints, the present study focuses on forager honey bees as key pollinators contributing to ecosystem health in GMNP.

This study aims to provide baseline data on forager honey bees in and around GMNP and to generate insights that can support research, education, and conservation practice. Specifically, the study seeks to: (i) survey and identify bee fauna; (ii) assess seasonal variation in relative abundance, species richness, and diversity across primary, restored, and disturbed forests; and (iii) evaluate the effects of temperature and humidity on bee abundance and diversity within and around GMNP.

2. Materials and Methods

2.1 Study area

The study was conducted in Gishwati-Mukura National Park (GMNP), located in western Rwanda. GMNP is a tropical rainforest composed of two fragmented forest blocks, Gishwati and Mukura, which together form part of the wider Gishwati-Mukura landscape. The park spans Rutsiro and Ngororero districts in Rwanda’s Western Province and covers an area of 35.58 km² with geographical coordinate location of 1°49′ S and 29°22′ E (Figure 1). Its elevation ranges from 2,000 to 3,000 m above sea level, with mean annual rainfall between 1,200 and 1,500 mm. GMNP lies within a UNESCO-designated region recognized for its conservation and cultural significance and is noted for its high biodiversity (Humphrey, 2015). Established in 2015 and formally designated as a national park in 2016, GMNP supports tourism, biodiversity conservation, and scientific research. Its designation aims to promote habitat restoration, protect endangered species, and conserve the unique biological diversity of the forest ecosystem. A scientific survey conducted in 2020 documented a wide range of plant and animal species within the park (Micomyiza et al., 2021).

2.2 Field survey

Pan trapping was conducted along a 500 m line transect established within three habitat types in and around GMNP: primary forest, restored forest, and disturbed forest. The primary forest, located within the national park, is largely undisturbed. The restored forest, also within the park, experienced historical logging and other disturbances prior to park designation but has undergone substantial recovery following years of protection. The disturbed forest comprised adjacent farmland outside the park boundary.

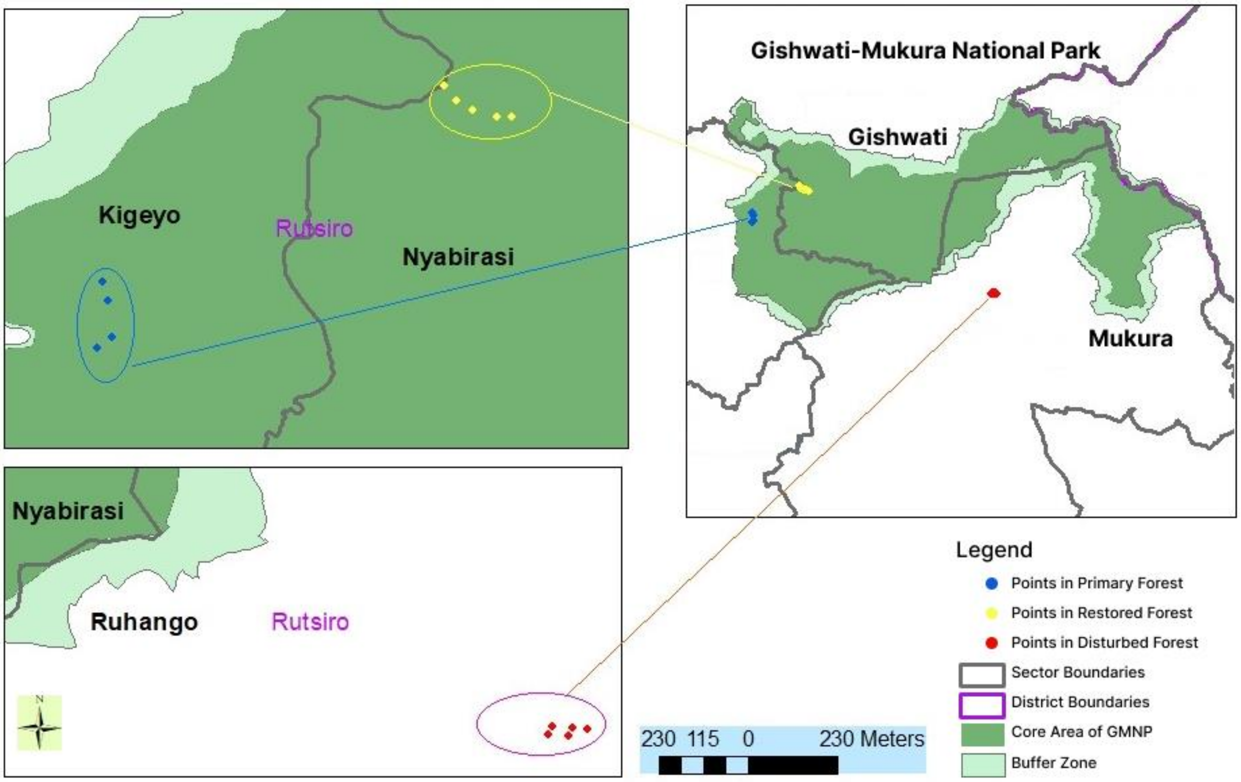


Figure 1: Map of the study area showing some the transect sampling points

At each transect, three pan traps of different colours (blue, white, and yellow) were used as sampling units and placed at 100 m intervals, starting 150 m from each transect edge. These colours were selected because insects, particularly bees, exhibit differential attraction to them (Combey & Kwapong, 2016). In total, nine pan traps (3 colours × 3 points) were deployed per transect, with three replicated transects, resulting in 27 sampling units overall and nine sampling units per habitat type.

Sampling was conducted monthly over a 13-month period from August 2023 to August 2024, covering four seasons: major rainy, minor dry, minor rainy, and major dry seasons. This resulted in a total of 351 sampling events. Pan traps (15 cm in diameter and 10 cm deep) were half-filled with water, and a few drops of detergent were added to reduce surface tension. Collected insects were retrieved after 48 hours, sorted, and preserved in 70% ethanol for later identification. Each specimen was labelled with the site name, date, time, and collector's name.

Temperature and humidity were recorded immediately after each sampling event using a portable digital weather station, and geographic coordinates were obtained using a Garmin 73 GPS unit. Traps were consistently deployed in the morning and retrieved after a fixed 48-hour interval to ensure standardized sampling effort.

2.3 Species identification

The collected insect specimens were shipped to Ghana for sorting, identification, and counting at the Entomology Museum, where they were prepared and preserved in insect boxes. Bee abundance per site, pan trap, and month was calculated by summing the number of bees recorded at sampling points across the three landscape types and averaging the values over the 13-month sampling period. Specimens were identified to family, genus, or species level using available taxonomic keys. For each site and season, bee abundance, genus-level species richness, and diversity were quantified using Margalef's diversity index (Margalef, 1973). This index was selected because it provides a simple and robust measure of species richness, allowing reliable comparisons across sites and seasons despite differences in sample size or sampling effort.

Margalef index (d) was calculated as:

$$d = \frac{S-1}{In(N)}$$

where *s* is the number of species in the community, and *N* is the number of individuals in the community. It was calculated using the vegan package in R, as it incorporates both the abundance and evenness of the bee genera present.

To examine relationships between bee genera and explanatory variables, a dataset was compiled using mean values of weather parameters (temperature and humidity) and the total number of bees recorded for each genus across habitat types and seasons. To assess habitat effects on individual genera, the habitat category with the highest frequency of occurrence for each genus was selected; where equal proportions occurred, the category with the greater absolute abundance was used. The effects of seasonality and habitat type on bee abundance and diversity, as well as the influence of temperature and humidity on bee abundance, were analysed using two-way analysis of variance (ANOVA). Statistical significance was evaluated by comparing mean differences across seasons and habitats. All analyses were conducted using R statistical software.

3. Results and Discussion

3.1 Relative abundance of insect families and bee species across the three habitat types

3.1.1 Relative abundance of insect families

An average of 345 insects belonging to nine families, namely, Apidae, Carabidae, Cetoniidae, Halictidae, Meloidae, Nymphalidae, Sarcophagidae, Scarabeidae and Vespidae were sampled around GMNP (Figure 2). Apidae and Halictidae were the only bee families recorded.

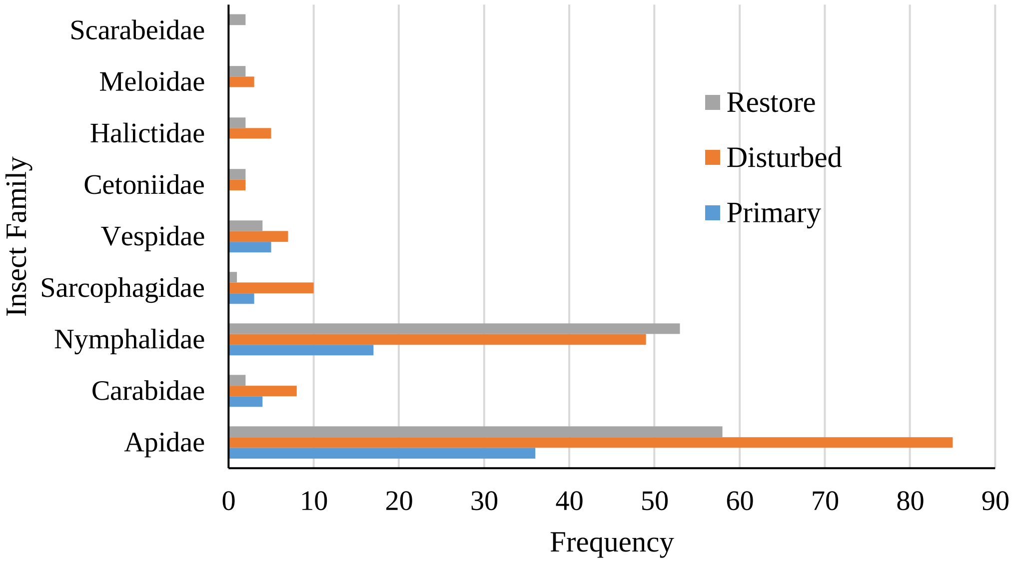


Figure 2: Relative abundance/pan traps/month of insect families across habitat types around GMNP

3.1.2 Relative abundance and diversity of bee species

The study recorded total of 179 individual foraging bees, representing 52% of all insects captured in pan traps across the three habitat types in and around GMNP (Table 1). These bees belong to two families, four genera, and seven species, indicating relatively high abundance and species richness for honey bees within the small park. Data diagnostics confirmed that all models provided a good fit, and there was a significant difference in bee abundance among habitat types ($\chi^2 = 20.19$; df = 2; $p < 0.001$). Disturbed forest exhibited the highest relative abundance per pan trap per month (85), followed by restored forest (58), with primary forest recording the lowest abundance (36). Species richness was also highest in disturbed and restored habitats (five species each) compared to only two species in primary forest. Thus, the Margalef's diversity index of restored and disturbed habitats showed significantly higher diversity (0.99 and 0.90, respectively) than the primary forest (0.28).

The honey bees *Apis mellifera monticola* and *Apis mellifera scutellata* were the most common species. *A. mellifera scutellata* were the most common species. *A. mellifera monticola* was the only species recorded in primary forest, whereas *A. mellifera scutellata* was more abundant in restored and disturbed habitats. Other bee species were present in much lower numbers.

Table 1: Relative abundance/pan traps/month for forager bee species in the three habitat types

Family	Species	Abundance/pan trap/month		
		Primary	Restored	Disturbed
Apidae	*Apis mellifera monticola*	36	17	27
	Apis mellifera scutellata	-	34	52
	Ceratina spp	-	1	-
	Xylocopa calens	-	4	-
	Xylocopa flavorula	-	-	1
Halictidae	*Lasioglossum lativentre*	-	-	4
	Lasioglossum nitidiusculum	-	2	1
	Total	36	58	85

Notably, *Lasioglossum nitidiusculum* occurred in both restored and disturbed forests, while *Lasioglossum lativentre*, *Xylocopa flavorula*, *Xylocopa calens*, and *Ceratina* spp. were restricted to either restored or disturbed habitats. Picture of some of the bee types is given as Figure 3.

The results indicate a high relative abundance but low species richness of honey bees in the small park, with all three habitat types supporting limited forager bee diversity. Overall species richness was very low, which may be attributed to limited floral resources and habitat fragmentation that restrict the number of species able to persist. In addition, the relatively short sampling period may have constrained the detection of rare species. Long-term surveys spanning multiple years are considered essential for accurately assessing bee biodiversity (Levenson et al., 2024; Oertli et al., 2005). Oertli et al. (2005) reported that more than 25% of species were recorded in only one of two study years, underscoring the importance of extended temporal coverage. Estimates of bee abundance and richness are therefore strongly influenced by study duration, spatial coverage, and sampling methodology (Levenson et al., 2024), although contrasting evidence exists. Winfree et al. (2009), for instance, reported higher bee abundance, richness, and diversity in small habitats compared with more extensive ones.

A relatively richer assemblage of bee species was observed in disturbed habitats compared with the other habitat types, although overall diversity remained lowest. While this pattern is not straightforward to interpret, habitat disturbance may increase the relative abundance of honey bees without necessarily enhancing species richness. Previous findings on the effects of disturbance are mixed. Some studies have documented negative impacts of disturbance on bee abundance and richness (Stanley et al., 2020; Winfree et al., 2009), whereas others have reported higher bee abundance and diversity in moderately disturbed habitats than in undisturbed forests (Dema, 2022). In the present study, the disturbed habitat consisted of farmland, where management practices such as pesticide and herbicide application, slash-and-burn agriculture, and crop rotation may be detrimental to non-dominant bee species, potentially explaining their absence.

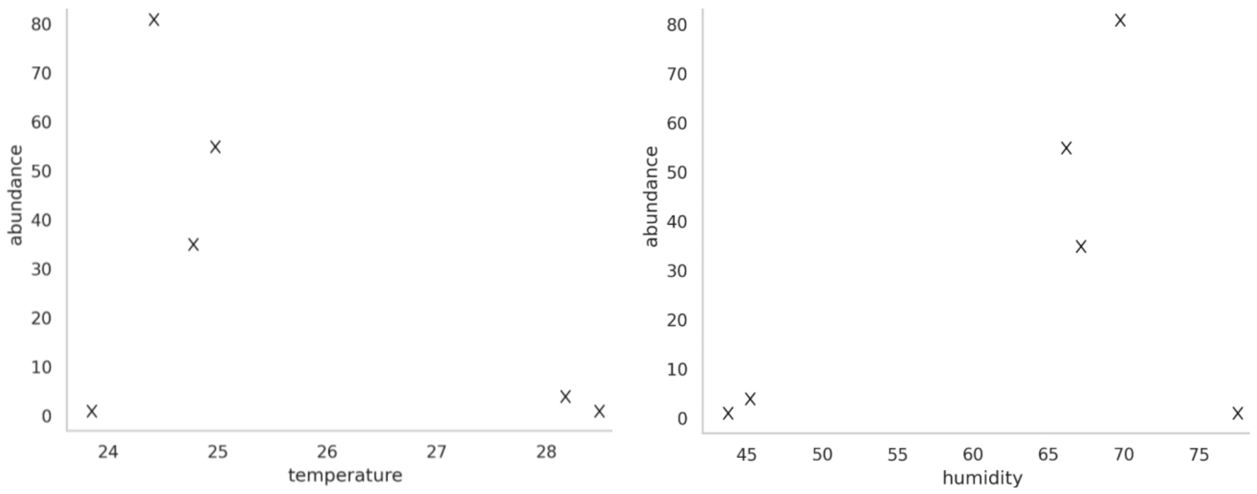
3.2 Effect of temperature and humidity on relative abundance and species richness

Temperature had a significant negative effect on bee abundance in GMNP (Estimate = -4.823 ± 1.7033, p = 0.018; Figure 4 (a)), with each 1 °C increase corresponding to a reduction of 4.823 bees. Thus, bee abundance was higher at lower temperatures. Similarly, humidity negatively affected bee abundance (Estimate = -0.772 ± 0.292, p = 0.025; Figure 4(b)), with each 1% increase in humidity reducing abundance by 0.772 bees, indicating that bees were more abundant under drier conditions. A generalized linear regression model describing the combined effects of temperature and humidity on bee abundance is given by:

$$Abundance = 186.6 - 4.82T - 0.77H,$$

suggesting that bees in GMNP thrive under relatively cool and dry conditions. The effects of temperature and humidity were significant in disturbed habitats (temperature: F(2,10) = 5.687 ± 0.726, p = 0.0081; humidity: F(2,10) = 5.687 ± 0.125, p = 0.019), but not in primary or restored forests. Across all habitats, temperature and humidity had no significant effect on bee diversity, although disturbed and restored forests consistently supported higher bee abundances compared to primary forest.

Figure 3: Some of the recorded bee species around GMNP



(a) **(b)**

Figure 4: The effect of (a) temperature and (b) humidity, on the relative abundance of bees in GMNP

The negative coefficients for temperature and humidity indicate that increasing values of either variable are associated with reduced forager bee abundance. The significant p-value (0.018) suggests that the effect of temperature is unlikely to be due to chance, supporting a negative influence of temperature and/or humidity on forager activity. These findings align with Usha and Devi (2020), who emphasized the role of environmental factors such as temperature and humidity in shaping pollinator activity and population dynamics. Thus, fluctuations in these climatic variables have meaningful ecological implications for bees in and around GMNP. However, other studies have reported a non-linear response, with bee abundance increasing with temperature up to approximately 28.5°C before declining beyond this threshold (Tarakini et al., 2021; Rikohe et al., 2023). The present observation that bee populations increase under cooler and drier conditions, but decline under warmer and more humid conditions, is consistent with findings from Balvino-Olvera et al. (2024), Papanikolaou et al. (2017), and Classen et al. (2015) in both natural and disturbed habitats around Mount Kilimanjaro National Park, Tanzania. These patterns likely reflect physiological and ecological stress associated with altered microclimates, which may affect foraging efficiency, thermoregulation, and nesting behavior. Consequently, bees in disturbed landscapes may be particularly vulnerable to climate variability, highlighting the compounded pressures arising from the interaction between habitat degradation and environmental stressors.

3.3 Effect of season on relative abundance and diversity of bees

Forager bee abundance differed significantly between seasons ($F_{1,9}$ = 5.32, p = 0.041) and among habitat types ($F_{2,9}$ = 13.95, p = 0.002). However, the interaction between season and habitat was not significant ($F_{2,9}$ = 0.12, p = 0.889), indicating that seasonal effects were consistent across habitats. Across both seasons, abundance was highest in disturbed forest, followed by restored and primary forests (Figure 5). Bees in disturbed forest were more abundant during the rainy season, whereas in restored and primary forests, abundance was higher in the dry season. These results suggest that seasonal variation influences bee abundance, but the seasonal pattern is similar across habitat types.

Bee diversity was consistently lowest in primary forest and declined from the dry to the rainy season (Figure 6). In restored and disturbed forests, diversity patterns varied: in some cases, indices increased from dry to rainy season, while in others they decreased. Nevertheless, neither the effect of season ($F_{1,9}$ = 0.12, p = 0.93) nor the interaction between season and habitat ($F_{2,9}$ = 1.74, p = 0.21) on bee diversity was statistically significant.

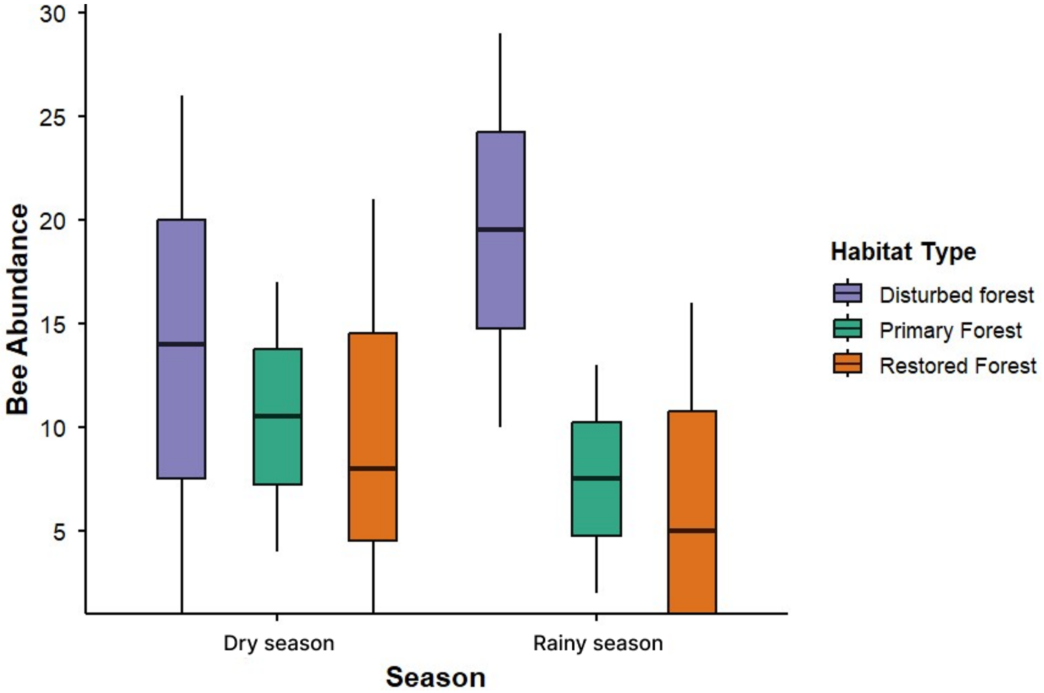


Figure 5: Effect of seasonality on bee abundance across habitat types around GMNP

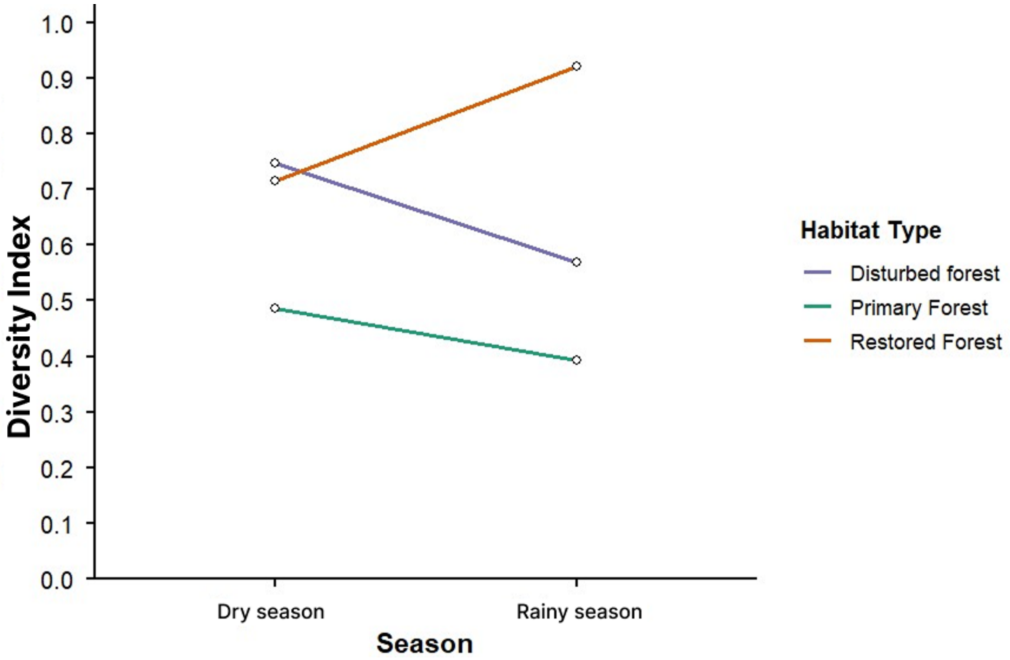


Figure 6: Effect of seasonality on bee diversity across habitat types around GMNP

The results of this section corroborate previous studies demonstrating that seasonal variation significantly influences bee abundance, although seasonal patterns appear relatively consistent across habitats. Oertli et al. (2005) attribute this to the plasticity of bee life cycles, which confers resilience to climatic variability. Bee taxa differ in foraging distances, activity periods, and the number of broods produced per season, traits that buffer populations against seasonal fluctuations in floral resource availability. Consistent with Mramba (2025), floral resource availability in preceding months was an important predictor of bee activity when other factors were not limiting. This suggests that forager bee abundance, richness, and diversity may increase in subsequent years if favorable conditions persist. Overall, the findings support previous evidence that seasonality strongly shapes bee assemblage structure (Oertli et al., 2005) and demonstrate that surveys conducted over a single season or partial seasonal window are likely to underestimate bee diversity and the relative representation of ecological groups.

4. Conclusion

At Gishwati–Mukura National Park, this study revealed a complex interplay between habitat types, bee assemblage characteristics (species richness, diversity, and relative abundance), and climatic factors, particularly temperature and humidity, all of which are critical for sustaining ecosystem health and services. Forager bee populations increased under cooler and drier conditions but declined under warmer and more humid conditions, suggesting that altered microclimates impose physiological and ecological stress on bee foraging, thermoregulation, and nesting. These findings indicate that bees at GMNP are especially vulnerable when habitat degradation coincides with climatic stressors.

Although honey bees appeared relatively successful across habitats, long-term availability of floral resources may provide resilience against climate-related stress. Consequently, future research should prioritize multi-year sampling to better capture temporal variability and adaptive responses, rather than relying on single-year surveys. Further investigation into the mechanisms by which bees cope with interacting environmental stressors would also be valuable.

Overall, the findings contribute to the growing body of knowledge on bee ecology and pollination, with implications for enhancing forest health and ecosystem services in GMNP. Maintaining robust bee populations within and around the park could also support beekeeping as a sustainable livelihood option, potentially reducing pressures from encroachment, poaching, and other forms of environmental degradation. These results therefore underscore the importance of targeted conservation and informed policy interventions to ensure the long-term protection and management of GMNP.

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