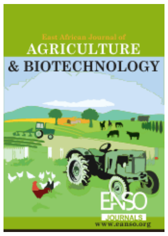

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Original Article

Bee species composition, richness, diversity and distribution along elevation and Temperature Gradients in Mkingu Forest Nature Reserve Tanzania

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Bee species, Elevation, Richness, Diversity, Temperature.

ABSTRACT

Bee species are performing a crucial role in ecosystem services that support human well-being and planet's life support system. Complex interactions of elevation and other environmental variables like temperature affect the population of bee species in the Mkingu Forest Nature Reserve (MFNR). There is however a limited research and knowledge on the influence of environmental gradients especially elevation and temperature on bee species composition in Forest Nature Reserves in eastern Tanzania, to enable the conservation of bees and their important functions in forest ecosystem dynamics. The aim of this study is to assess bee species composition richness and diversity along elevation and temperature gradients in the MFNR. Bee species were collected in elevation strata across high, middle, and low elevations. Pan traps and sweep nets were used for data collection across different locations/plots established in elevation bands in the MFNR. Temperature was recorded at each sampling point using the Thermochron iButton data logger (DS1921G; ± 0.50C resolution; Maximum Integrated Products, USA) mounted 2 meters above the ground on each sampling point, continuously monitoring temperature at 60 minutes' interval for 3 months. The Mean Annual Temperature was calculated as the average of all recorded values. Data were organized in Microsoft Excel and analyzed by R software version (2024.09.0+375). The study collected 1,125 bee individuals identified into 53 bee species, belonging to 23 genera and 3 families. There was a differential bee species richness along the elevation gradient with high elevations having higher species richness (46 bee species), followed by the middle elevation (32 bee species). The lower elevations had the lowest bee species richness (20). Further the there was a higher bee species diversity in the higher elevation (Shannon Weiner Diversity Index 3.371) followed by the middle elevation (Shannon Wiener Index of 2.623). The lower elevations had the lowest diversity of bee species with Shannon-Wiener Index of 2.59. Both elevation and temperature had a significant influence on bee species richness, with elevation (β=0.133, p<0.000) being more significant than temperature (β=0.064, P=0.030). Therefore, the study has shown richness and diversity also relationship between elevation in Mkingu Nature Forest Reserve. With higher species richness and diversity observed at higher elevations, it is evident that these areas are crucial for maintaining bee species.

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INTRODUCTION

Bee species perform important ecosystem services as pollinators that add value to the well-being of people while maintaining the planet's life support systems (Dorey & Schiestl, 2024). They provide an ecosystem services that contribute to achieving some of the sustainable development targets like target 2.5 zero hunger,11.7 sustainable city communities,12.2 responsible consumption and production, target 13.2 climate action, and target 15.5 life on land, thus contributing to food security and biodiversity (Braat & De Groot, 2012; Moyer & Hedden, 2020). However, their richness and diversity is expected to change along different environmental gradients especially elevation due to the differences in daily temperature across elevation variations(Conrad *et al.*., 2021; Forrest & Chisholm, 2017; Gonzalez *et al.*., 2022; Peters *et al.*., 2016; Pyke *et al.*., 2016). Although there are different kinds of bee species belonging to different families, namely Andrenidae, Colletidae, Stenotritidae, Mellitadae, Apidae, and Megachilidae, they differ in morphology, the type of environment, and the physiographic features in which they are found (Peters *et al.*., 2016). Each bee species adapts uniquely to the climatic conditions and ecological conditions at various elevations, which can significantly affect species richness and diversity (Hoiss *et al.*., 2012). Understanding bee species richness and diversity along different environmental gradients such as elevation, is essential for predicting climate change impact on their distribution and the sustainability of global food production through pollination services.

The bee species richness and diversity within a high mountain ecosystem are influenced by complex interactions between site factors and topographic variables, such as elevation (Dyderski & Pawlik, 2020). The presence of honey bee species in the ecosystem can have significant effects on native bee species due to the competition for floral resources, resulting in population structure in bees (Prendergast *et al.*., 2022). Of recently, there has been a decrease in bee species, mostly caused by human activities and global warming. Human population growth and activities may cause anthropogenic disturbance, causing habitat changes and skewing biodiversity (Morris, 2010). Additionally, the National Beekeeping Policy Implementation Strategy has raised issues of uncontrolled land use practices and application of pesticides around reserve and apiaries , further emphasizing the pressing need for this research on the influence of anthropogenic activities on bee populations (URT, 2021). With global warming, bee populations may tend to expand their range or

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could experience reduction due to warming temperatures (Johnson *et al*.., 2023). The change in pollinator communities along elevation could drive shifts in floral communities as well (Johnson *et al*.., 2023).

Although there is a relationship between elevation and bee species composition across different ecosystems in Tanzania little has been done to document how the composition changes across different physical and anthropogenic disturbance gradients., Understanding the environmental correlates of bee species composition, richness diversity and distribution along physical and anthropogenic gradients is crucial for assessing trait composition and functional diversity within pollinator communities (Adedoja *et al*.., 2020; McCabe & Cobb, 2021, 2021; Orr *et al*.., 2021). The elevation gradient is crucial for species conservation in the changing environment and can impact species richness, and patterns of distribution across the different gradients and especially elevation (McCabe & Cobb, 2021).

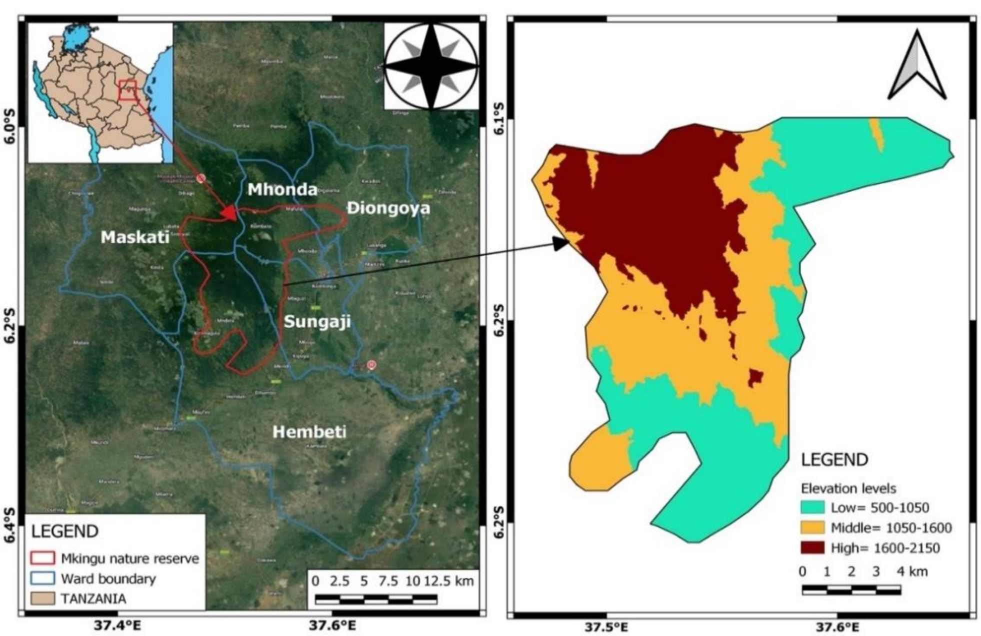
This study aims to assess bee species composition, richness, diversity and distribution across habitat types along elevation and temperature gradients in the Mkingu nature forest reserve. The study will enhance the understanding of ecosystem dynamics, help predict and mitigate the impacts of environmental changes, guide conservation efforts, ensure pollination services, advance scientific knowledge, and foster greater appreciation of the biodiversity of bee species as influenced by environmental change.

MATERIAL AND METHODS

The Study Area

This study was conducted in Mkingu Nature Forest Reserve, located in the Eastern Arc Mountains in the Mvomero district, Morogoro region, and is neighbored by five wards: Maskati, Hembeti, Sungaji, Diongonya, Mhonda. The reserve covers 26,334ha and is composed of former Nguru South and Mkindo Forest Reserves, between latitude 6^{o}01$^{`}$-6 ^{0}13’S and longitude 37^{0}26’-37^{0} 37’E or UTM 9200000-94. The area features a diverse altitudinal range from 380 to 2140 meters above sea level, with its point at Maskati Peak. Rainfall in the reserve varies significantly between 1200-4000mm/annually while mean annual temperatures of 12^{o} – 24^{o} create a cool and moist environment

Figure 1: A Map of the Study Area showing the location of Mkingu Forest Nature Reserve



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Study Design

A stratified sampling design was done accommodating three different sites, namely Semwali, Dibago, and Maskati with different elevation levels, from sampling sites at each elevation. Plots for sampling were set up at various elevations ranging from 500 meters to 2150 meters above sea level. Semwali had the lowest elevation of any site. With elevations ranging from 500 to 1050 meters above sea level, this area is characterized by low rainfall and high temperatures. The intermediate elevation site was located at Dibago. With elevation ranges from 1050 to 1600 meters above sea level. This region is distinguished by mid temperatures and higher mean annual rainfall. The highest elevation site was Maskati, with elevations ranging from 1600 to 2150 meters above sea level. This region has low mean annual temperatures and high mean annual rainfall.

Data Collection

Bee Sampling

The data were collected from 14th March 2024 to 10th May 2024 in three different elevation sites in a stratified manner. In each elevation site, there were 14 plots spaced at 3km, which reflects the foraging radius of bee species. In each study plot, two grid lines of 30m in length, which are spaced 30m from each other, were established. Each grid line consists of three clusters of pan traps made up of different UV-reflecting colours, such as (white, yellow, and blue) spaced 15m apart. Three clusters of pan traps on each transect line were positioned at different heights, one cluster positioned at the surface of the ground and the other two clusters positioned at different heights of herbaceous layer (120cm) and shrub layer (35cm) for the purpose of capturing flying bee species (Millard *et al.*., 2021). The pan traps were filled with a mixture of 70% ethanol solution and soapy water to break the surface tension of water and create a slippery texture, which was necessary for minimizing chances for captured bee species to escape.

In addition to pan trap sampling, a standardized random walk was used to sample bee species. Both sampling methods are effective for catching flying insects. This method involved walking randomly slowly within plots using a sweep net to actively collect bee species from flowers. A random walk was conducted for 2 hours in each study site (one hour per 50 x 50 m study plot), excluding handling and recording time. Bee sampling was conducted from 9:00 am to 5:00 pm time and bee species are expected to be the most active (Lasway *et al*., 2022). This will sum up to 6 hours of active collection per study site and 144 hours for the whole study. Sampling was restricted to days with low wind speed and no or only very little rainfall. The bee species collected were temporarily stored in 70% ethanol, then the samples were sorted, and only bee species were sent to the laboratory for identification.

Mean Annual Temperature

Temperature data at the study site were collected using temperature sensors (iButton) (Lasway et al., 2022). At each study site Thermochron iButton data logger (DS1921G; ± 0.5^0C °C resolution; Maximum Integrated Products, USA) was mounted 2 meters above the ground which continuously monitored temperature throughout the study period (Lasway et al., 2022). The sensor was programmed to record temperature at 60-minute intervals and remained in the field for 3 months (Lasway et al., 2022). The Mean annual temperature was calculated as the average of all recorded values.

RESULT AND DISCUSSION

Bee species composition and abundance across elevation gradient

A total of 1125 bee individuals were encountered, identified into 53 bee species belonging to 23 genera and 3 families (Figure 2). Three bee species (*Apis mellifera ssp monticola - Linnaeus, 1758, Apis mellifera ssp scutellata - Linnaeus, 1758 and Xylocopa nigirita; Fabricus ,1775*) were most abundant, representing 45.4% of the total abundance. The other 6 species *(Lasioglossum(Afrodiactus)sp 5M, Tretraloniella*

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sp 2, Lasioglossum (Afrodiactus) bellulum, Lipotriches pailidicinta, Ceratina sp, and Amegilla sp1) had an abundance of 2 – 3% and represented 13.5% of the total abundance. The remaining species had an abundance of less than 2% distributed evenly across the population (Figure 3). With respect to families, Apidae was the richest and most abundant family with 679 bee individuals and 13 bee species. This was followed by Halictidae with an abundance of 308 bee individuals and 34 bee species. Megachilidae had the lowest bee abundance with 138 individuals and 19 bee species (Figure 3).

The bee species richness at the three elevation sites varied significantly, with high elevations registering the highest richness (46 bee species). The middle elevations registered a richness of 32 bee species, relatively lower than the higher elevation, while the lower elevations had the lowest bee species richness (Figure 4). In all elevation sites, the following bee species were common: *Xylocopa nigrita, Apis mellifera, and Lassioglum sp*. Bee species richness increased with the increase in elevation, indicating there were more bee species at high elevations and fewer at low elevations. This pattern suggests that environmental conditions at higher elevations is cooler with unique floral compositions and a higher amount of human activities done at lower elevation sites. These findings contradicts with the result of this study by (Conrad *et al.*., 2021) who conducted study in Costa Rica in Tropical bee species differ with narrow elevations, and (McCabe & Cobb, 2021) conducted study on North America, South America, Europe, and Australia on the global shift in pollinator communities along elevation gradients. These findings highlighted a general decline of bees at higher elevations attributed to cooler temperatures and reduced floral resources. These findings align with the biodiversity hypothesis that has substantial influence on bee species richness and previous researchers like Widhiono *et al.* (2017) who observed 8 species belonging to 3 families (Apidae: *Xylocopa sp*, Apis; Halictidae; *Lasioglossum*) in Indonesia. Similarly, buadu (2017) found variation in bee abundance and diversity across sub-zones in the forest savannah transitional zone of Ghana, with the bee species such as *Apis mellifera, Ceratina sp, Xylocopa nigrita, Lipotriches orientalis, and Megachile sp.* The consistency between these findings and the current study underscores a broader ecological principle, such as environmental gradients, such elevation, which is critical determinants of bee species richness and distribution.

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Figure 2 :Bee species abundance /dominance in Mkingu Nature Forest Reserve

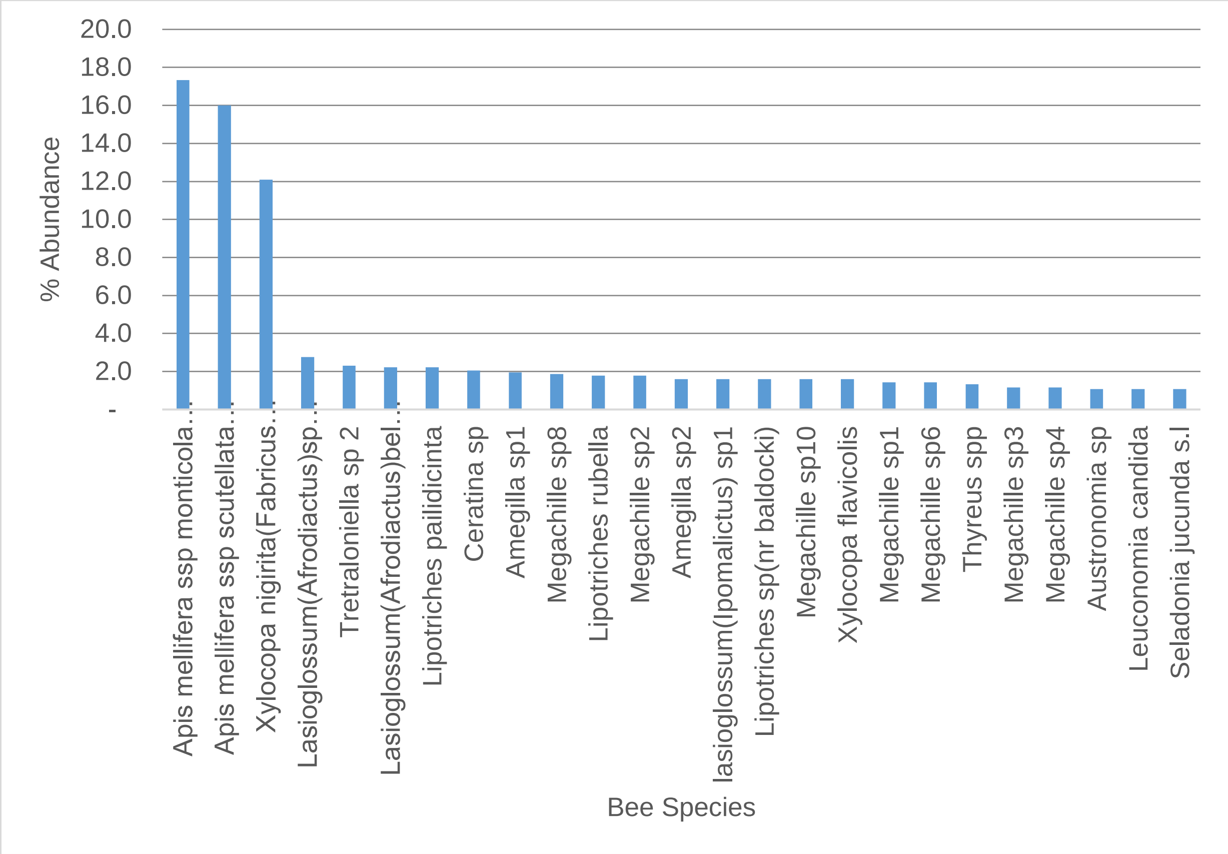

Figure 3: Species Richness in Different Families at Mkingu Nature Forest Reserve

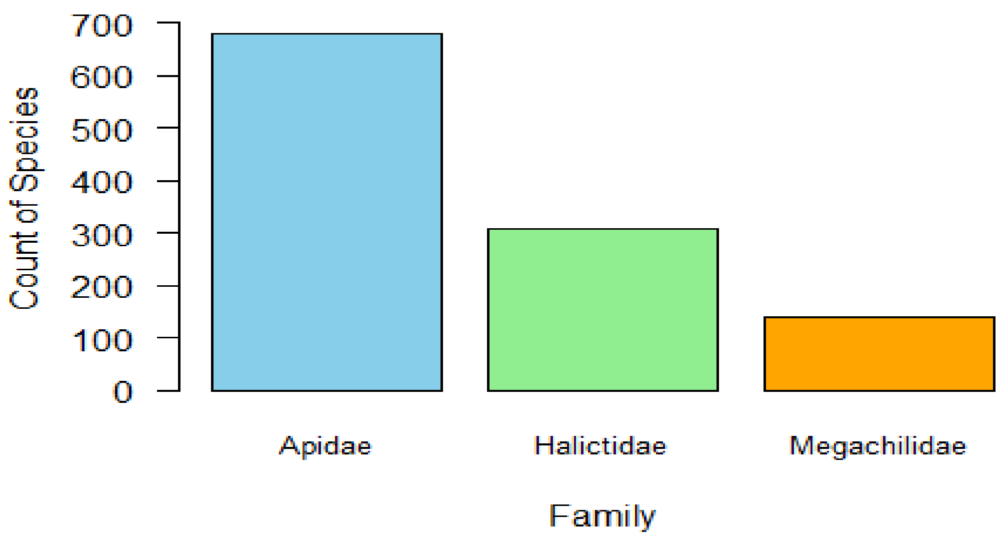

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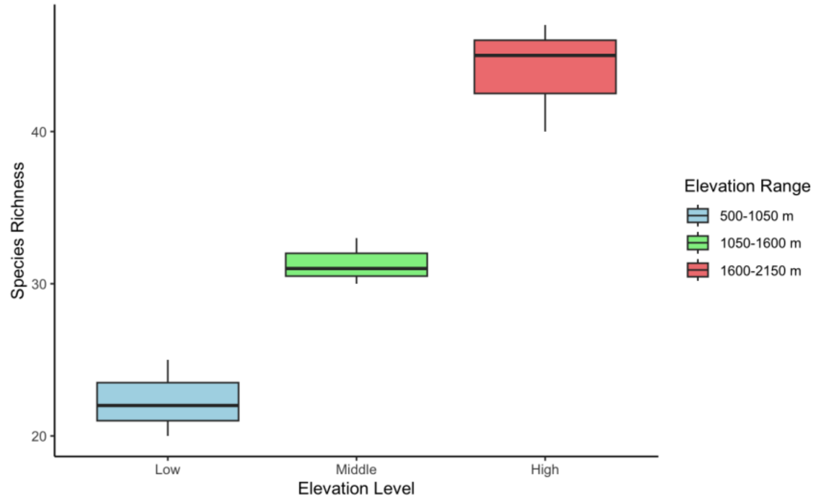
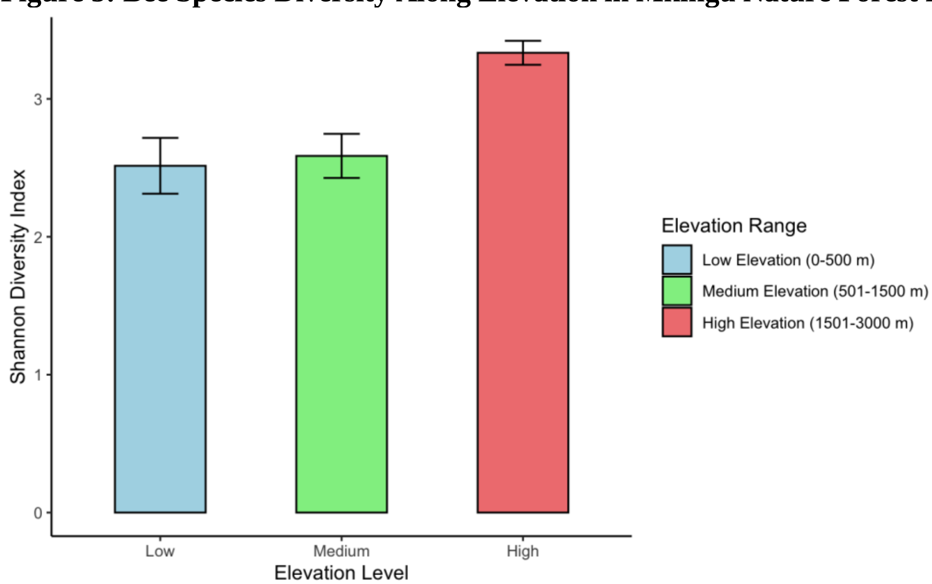
Figure 4: Bee Species Abundance Along Elevation at Mkingu Nature Forest Reserve



Bee species diversity across elevation gradient

Kruskal Wallis test show a significant difference in the diversity of bee species across elevations (Kruskal Wallis test): x^2=4.828 df=57.93 p=0.0115<0.005) with the high elevations registering the highest diversity as indicated by the high Shannon Wiener index (H') of 3.371) which suggests the ecosystem in higher elevations supports a greater variety of bee species with relatively low variability in the diversity of bees within the high elevation sites. The middle elevations support moderate species diversity (Shannon Weiner index (H') of 2.623). The diversity in the middle elevation shows a slight increase in within-strata variability in this range, which might be an effect of environmental factors. The low-elevation site shows the lowest diversity of bee species (Shannon Wiener index (H') of 2.59). Based on the error bars, the low elevation shows some within-strata variability, though not substantial, indicating relatively consistent diversity across the elevation gradient. The lower diversity in the lower elevation suggests factors that may limit bee species richness, such as human activities (Figure 5).

Figure 5: Bee Species Diversity Along Elevation in Mkingu Nature Forest Reserve



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The combined influence of temperature and elevation on bee species richness and diversity.

The Elevation has a significant positive effect on bee species richness, with higher elevations supporting greater species diversity (β=0.26, p<0.021). An increase in temperature negatively affects the bee species by a reduction in number (β=0.05, P=0.032). The high R^2 value (0.723) indicates temperature and elevation importance in influencing bee species richness.

Table 2:Generalised Linear Regression Table Showing combined influence of Temperature and Elevation Influence Bee Species Richness

	Bee Richness		
Predictors	Estimates	CI	P-values
Intercept	0.36	-0.41 – 1.53	0.049
Mean temperatures	0.26	-0.08 – 0.60	0.032
Mean Elevation	0.05	-0.01 – 0.09	0.021

Observations 53, R2 / R2 adjusted, 0.723 / 0.588

Temperature and elevation together influence bee species richness. This study shows both elevation and temperature influencing bee species richness, although temperature has a weaker effect compared to elevation (temperature β=0.345, p<0.030) and elevation β=4.069, p<0.001)(Table 1). This may be because bees are ectothermic organisms that rely on ambient temperature for activities such as foraging and reproduction. This result is similar to the previous studies done by Classen *et al.* (2015), which observed that temperature had a strong positive effect on species richness in the mountains. Also, Geppert *et al.* (2023) observed that both wild bee abundance and species richness were driven by temperature, with a positive effect of warmer temperatures. Some bee species are adapted to specific elevations and dominant temperature ranges. For instance, *Amegilla* sp. and *Lasioglossum (Afrodiactus) bellulum* are adapted to high elevations, while *Xylocopa nigrita* is commonly found at mid-elevations. *Apis mellifera*, however, tolerates a wide range of elevations, from low to high, and is resilient across varying daily temperatures.

Bee species diversity, family diversity, and abundance increase significantly with increasing elevation. The positive relationship between elevation and species diversity is similar to Perillo *et al*. (2021), who observed a decrease in both site and mountain diversity of other pollinators, such as butterflies, but only bees increased with elevation in Brazil. Increased bee diversity at higher elevations could be attributed to lower levels of human disturbance, allowing ecosystems to have more specialized bees. Also, Miller-Struttmann & Galen (2014) observed that bee queens and workers increase with elevation, as predicted if the interval of queen foraging activity expands to compensate for temporal restrictions on colony growth. The increase in diversity can be partly attributed to global warming, as climate change drives bee species upwards in search of cooler temperatures and suitable habitats. This represents a range shift among bee populations resulting from the impacts of climate change. Climate change is likely causing significant shifts in bee populations, with many species experiencing range contractions or expansions as they seek suitable habitats, with some bees migrating to higher altitudes or latitudes as temperatures rise (Suzuki-Ohno *et al* 2020; Kuhlmann *et al* 2012; Rihimi *et al* 2021; Dew *et al* 2019; Deborah Magesa 2021 (Conte & Navajas, 2008.; Dew, 2019.; Kuhlmann *et al*., 2012; Magesa, 2021; Rahimi *et al*., 2021; Suzuki-Ohno *et al*., 2020).

A study by Jackson *et al*. (2018) observed that *Bombus bifarus* increased with an increase in elevation, contrary to *Bombus vonsenkii, which* decreased with an increase in elevation. This observation underscores the importance of considering specific habitat requirements and adaptive traits in the conservation efforts, especially as climate shifts may further influence bee diversity.

Despite all the promising results, it is important to acknowledge certain limitations of this study. High elevations have more abundant floral resources, and flowering times at high elevations align better with bee cycles, resulting in bee species concentrated there. Also, human activities at lower elevations can lead to a scarcity of bee species at lower elevations. This indicates that there will be more pollination services conducted in the high elevation rather than in other elevation sites. Human activities can be a major cause of the skewness of bee species in lower elevations, resulting lack of floral resources.

CONCLUSION

Elevation has substantial influence on the composition, richness, abundance, and distribution of bee species, with high elevations harboring higher species richness, diversity, and abundance. This is evident that these high altitude areas, especially montane forest ecosystems, are crucial for maintaining a wide variety of bee species, justifying their role in biodiversity conservation. Temperature has a significant influence on bee species distribution, with a connotation on bee species distribution and range shifts resulting from climate change. The interaction of elevation and temperature plays a major role in shaping bee populations across diversity and richness in the Mkingu Forest Nature Reserve, factors that would be of consideration in conservation planning. Therefore, concerted efforts on further research across montane forest ecosystems are imperative to enhance conservation efforts for bee species as important pollinators contributing to biodiversity conservation, socio-economic development, and livelihoods.

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Data Availability Statement

The data that support the findings of this study are available upon reasonable request from the corresponding author.

Declarations

Ethical approval: The collection of bee species in this study was permitted under the Tanzania Forest Reserve**.**

Conflict of Interests

The authors declare no conflicts of interest.

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