Sokoine University of Agriculture

MSc Dissertation

Population Ecology and Threats of Bee Species Across Vegetation Types in Mgori Forest Reserve, Singida District, Tanzania

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May 2024

POPULATION ECOLOGY AND THREATS OF BEE SPECIES ACROSS VEGETATION TYPES IN MGORI FOREST RESERVE, SINGIDA DISTRICT TANZANIA

This dissertation is submitted to Sokoine University of Agriculture in fulfilment of the requirements for the Master of Science Degree in Ecosystem Sciences and Management

By

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EXTENDED ABSTRACT

Bees are among pollinator groups of importance in promoting and maintaining biodiversity and food production through provision of pollination services. This makes identifying and monitoring communities of bee species, a crucial step in the process of conservation. Forest vegetation types are among determinant of bee species composition and diversity. With the continued loss of suitable habitats for bees, conservation of bee species should begin with information on their presence. Mgori forest reserve is surrounded by villages with farms planted with crops such as sunflower, which is pollinator dependent, hence they benefit from pollination services from bees inhabiting the forest. To ensure inclusive conservation for the survival of bee species this study aimed at determining the composition, diversity and threats of bee species in Mgori forest reserve, across the vegetation types namely open woodland, thickets and the mosaic of open woodland and thickets, which are found within the forest reserve.

Systematic sampling was used in the study, whereby plots were established in the forest. To collect bees on each plot, pan traps and sweep nets were used.Threats to bees were also observed and recorded on each plot, thereafter plots with observed threats were characterised as disturbed plots and those with no observed threats were characterised as undisturbed sites. Additionally, coordinates and elevation point of the sites were also recorded. Bee species composition was the list of bees identified. Bee species richness and abundance were the number of species recorded and the number of individuals per species respectively. Shannon-Wiener diversity index was used to calculate the diversity of bees in the forest for disturbed and undisturbed sites. Kruskal-Wallis test was used to compare Richness and Abundance of bee species, across open woodland, thickets and the mosaic of thickets and open woodland and the Duncan post hoc was performed for both species richness and abundance. Detrended correspondence analysis was used to find the relationship between species composition and environmental variables and generalized linear mixed effect models were used to find the relationship between environmental conditions and bee species richness and abundance. All data was analysed through the R Software. Threats to bees were described and presented through graphs and tables using SPSS software. And then Chi-Square Test was used for comparison across studied sites to determine the variation of bee species richness and abundance between undisturbed and disturbed sites.

A total of 508 bees were collected from the studies sites in Mgori forest reserve; the Dominant family was the Halictidae family, followed by the Apidae and Megachilidae was the least recorded family. Species composition significantly varied between thickets and open woodland types of vegetation, whereby open woodland had higher composition, richness and abundance than thickets. Environmental conditions were associated with species abundance but not richness; particularly elevation had a significant influence on species abundance.

On the influence of threats on bee species, the human threats recorded were found to be consistent with resource needs in the forest. The threats recorded were debarking, grazing, trails, logging, fire scars and agricultural encroachment. The most consistent evidence was the presence of trails in the forest and grazing across all three vegetation types. The comparison of bee species richness, abundance and diversity showed that, there was significant difference in bees across the disturbed and undisturbed sites. Whereby bees were more present in undisturbed sites than disturbed sites. There was no difference in the calculated Shannon-Wienner diversity index and abundance of bees between the disturbed and undisturbed sites.

The study has revealed the composition of bees in Mgori forest reserve, which can serve as information for future ecological study in the forest. It has also revealed human threats in the forest that

hinder conservation in the forest, as well as influencing the presence of bees in the forest. Particularly their richness across space. In the management of the forest, it is important to consider thickets and open woodland vegetation types found within the forest, since they serve as separate supplementary habitats to these forest species. The apparent human threats in the forest threaten its conservation. As a result, there is a need for the forest patrons and the communities living adjacent to the forest, to work on improving the guarding and conservation of the forest. This is because of the benefits such as pollination services that can be obtained from Mgori forest.

IKISIRI KUU

Nyuki ni miongoni mwa makundi ya uchavushaji muhimu katika kukuza na kudumisha bayoanuwai na uzalishaji wa chakula kupitia utoaji wa huduma za uchavushaji. Hii inafanya kutambua na kufuatilia jamii za spishi za nyuki kuwa hatua muhimu katika mchakato wa uhifadhi. Aina za uoto wa misitu ni miongoni mwa viashiria vya muundo na utofauti wa spishi za nyuki. Kwa upotevu unaoendelea wa makazi yanayofaa kwa nyuki, uhifadhi wa spishi hizi unapaswa kuanza na habari juu ya spishi za sasa. Hifadhi ya msitu wa Mgori imezungukwa na vijiji vyenye mashamba ya mazao kama alizeti ambayo ni tegemezi kwa uchavushaji hivyo wananufaika na huduma ya uchavushaji kutokana na nyuki wanaoishi msituni. Ili kuhakikisha uhifadhi unajumuisha maisha ya spishi za nyuki utafiti huu unalenga kubainisha muundo, uanuwai na vitisho vya spishi za nyuki katika hifadhi ya msitu wa Mgori.

Sampuli za vikundi zilitumika katika utafiti, ambapo ploti zilianzishwa msituni. Kukusanya nyuki kwenye kila shamba, mitego ya vibakuli na nyavu zilitumika. Vitisho kwa nyuki pia vilizingatiwa na kurekodiwa kwenye kila ploti, aina ya uoto na sehemu ya mwinuko wa ploti pia vilirekodiwa. Muundo wa spishi za nyuki ulizingatiwa kama orodha ya nyuki waliotambuliwa. Namba na wingi wa spishi za nyuki ulizingatiwa kama idadi ya spishi zilizorekodiwa na idadi ya wadudu kwa kila spishi moja. Faharasa ya anuwai ya Shannon-Wiener ilitumika kukokotoa utofauti wa nyuki msituni kati ya maeneo yenye vitishio na yasiyo na vitishio. Jaribio la Kruskal-Wallis lilitumika kulinganisha Namba na Wingi wa spishi za nyuki katika aina ya uoto. Kikokotoo cha Duncan kilifanywa kwa namba na wingi wa spishi. Uchanganuzi wa mawasiliano uliozuiliwa ulitumika kutafuta mahusiano kati ya hali Tabia za kimazingira na Muundo wa Spishi za Nyuki na miundo ya athari mchanganyiko ya jumla ilitumiwa kupata uhusiano kati ya aina za mimea na hali ya mazingira,namba na wingi wa spishi za nyuki. Data zote zilichanganuliwa kupitia Programu ya R. Vitisho kwa nyuki

vilielezewa na kuwasilishwa kupitia grafu na majedwali kwa kutumia programu ya SPSS..

Jumla ya nyuki 508 walikusanywa kutoka katika ploti za utafiti katika hifadhi ya msitu wa Mgori. Familia kubwa ilikuwa familia ya Halictidae ikifuatiwa na Apidae na familia iliyorekodiwa kidogo zaidi ilikuwa Megachilidae. Kutokana na matokeo uwepo wa spishi hutofautiana kwa kiasi kikubwa kati ya vichaka na aina za uoto wa msitu wazi, namba na wingi wa nyuki hutofautiana kwa kiasi kikubwa katika aina mbalimbali za mimea. Hali ya mazingira ilihusishwa na wingi wa spishi badala ya namba; hasa mwinuko ulikuwa na ushawishi mkubwa juu ya wingi wa spishi.

Juu ya athari za matishio kwa spishi za nyuki, matishio ya kibinadamu yaliyorekodiwa yaligundulika kuwa yanaendana na mahitaji ya rasilimali msituni, vitisho vilivyorekodiwa vilikuwa ni Kubandua magome ya miti, malisho ya mifugo, njia, ukataji miti, makovu ya moto na uvamizi wa kilimo. Kubwa zaidi ya yote ilikuwa uwepo wa njia katika msitu na iiliyotokea katika kila aina ya mimea zaidi ilikuwa malisho katika aina zote tatu za mimea. Ulinganisho wa namba wa spishi za nyuki, wingi na utofauti ulionyesha kwamba, kulikuwa na tofauti kubwa katika nyuki katika ploti zanye matishio na zisizo na matishio. Ambapo nyuki walikuwepo zaidi katika ploti zisizo na matishio kuliko ploti zenye matishio. Hakukuwa na tofauti katika faharasa ya utofauti wa Shannon-Wienner na wingi wa nyuki kati ya ploti zenye matishio na zisizo na matishio.

Utafiti umebaini muundo na uwepo wa nyuki katika hifadhi ya msitu wa Mgori. Ambao unaweza kutumika kama taarifa kwa ajili ya utafiti wa kiikolojia katika msitu huo. Pia imefichua vitisho vya kibinadamu katika msitu vinavyozuia uhifadhi katika msitu huo. Pamoja na kuathiri uwepo wa nyuki msituni haswa namba zao.. Katika usimamizi wa msitu, ni muhimu kuzingatia aina za mimea zinazopatikana ndani ya msitu, kwa vile zinatumika kama makazi tofauti ya ziada kwa spishi hizi za misitu. Kutokana na kuwepo kwa vitisho vya kibinadamu katika msitu huo vinavyotishia uhifadhi wake, ipo haja kwa walezi wa msitu huo na jamii zinazoishi jirani kufanya kazi, kwa lengo la kuboresha ulinzi na uhifadhi wa msitu huo, kutokana na faida zinazoweza kupatikana kutokana na msitu wa Mgori. pamoja na kuhakikisha kwamba wachavushaji wa misitu wanaendelea kuishi.

DECLARATION

I, **ALPHONCINA EPHRAIM MPONZI**, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

__________________________ ________________________

Alphoncina Ephraim Mponzi Date

(MSc. Candidate)

The above is confirmed by:

__________________________ ________________________

Dr. Paulo J. Lyimo Date

(Supervisor)

__________________________ ________________________

Dr. Thomas Sawe Date

(Supervisor)

LIST OF MANUSCRIPTS

Manuscript 1: Variations in bee diversity patterns across a vegetation gradient in central Tanzania

Manuscript 2: Influence of Human Threats on Diversity of Bee Species in Mgori Forest Reserve

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First and foremost, I give thanks to Almighty God for the blessings throughout my study period and its successful completion.

I would like to express my gratitude to my supervisors, Dr. Paulo J. Lyimo and Dr. Thomas Sawe, for their support and guidance throughout the research project. They helped me complete and present my work clearly. I am honoured to have worked under their guidance and appreciate their constructive feedback and comments and have learned a great deal from them.

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My parents deserve the utmost gratitude for the prayers, support, sacrifices, and encouragement they have provided for my education. I greatly value your being here. I'll always have a soft spot in my heart for you. I'm really grateful to you all.

DEDICATION

I would like to dedicate this work to my Family, Mother, Father, brother Adrian, sister Ancilla. I am here because you have held me, guided me and loved me each in your own way, I couldn’t ask for more Thank you all for your prayers, love, support and wisdom.

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LIST OF ABBREVIATIONS ACRONYMS AND SYMBOLS

AMP	Annual Mean Precipitation
AMT	Annual Mean Temperature
CBFM	Community Based Forest Management
DCA	Detrended Correspondence Analysis
ELEV	Elevation
EVI	Enhanced Vegetation Index
FR	Forest Reserve
PERMANOVA	Permutation Multivariate Analysis of Variance
SPSS	Statistical Package for the Social Sciences

CHAPTER ONE

1.0 General Introduction

1.1 Background Information

Bees are considered as one of the most crucial pollinator groups since they are related to plant diversity in tropical forests as well as food in Agro-ecosystems (Bawa, 1990; Potts *et al.,* 2010; Potts, Imperatriz-Fonsec *et al.,* 2016). Potentially, honeybees have significant contribution to crop production production, due to their reliance on pollen and nectar for their survival (Hung 2018). Approximately, 20,507 species of bees are known worldwide (Orr *et al.*, 2021). Different studies have been conducted in different areas of the world, to record the species present, their abundance and distribution across agro-ecological zones (Michez, Vanderplanck, and Engel 2012). This information helps in the process of conservation of the species to prevent possible loss of unknown species. Coupled with the pollination services they provide; bees have been a focal point of observation in recent years.

Factors that determine bee species composition and diversity in an area, are habitat resources such as food and nesting. Recent studies have shown fast loss of bee habitats, this has ultimately led to significant reduction in bee species richness and abundance (Genung *et al*., 2023; Goulson *et al*., 2015; LeBuhn & Vargas Luna, 2021). Most of the factors causing the recent declines in bees are human mediated. These are such as, agricultural intensification and urbanization (Hall *et al.,* 2019) as well as the use of pesticide, changes in Land uses and predators (Roulston & Goodell, 2011). On the other hand, for many managed forest areas, invasion and harvesting of forest resources, directly causes habitat loss and fragmentation. Bees are affected by this habitat loss and fragmentation, because it alters their dispersal abilities, availability of nesting resources and forage resources (Normandin *et al.,* 2017).

Human threats that result in habitat loss and fragmentation, can increase the isolation of bees individuals, and in turn, affect population dispersion for different bee species as well as their foraging capacity (Boscolo *et al*., 2017a; Ferreira *et al*., 2012). Several studies have shown a decline of bee species in various areas in the world (Jacobson *et al*., 2018; Potts *et al*., 2010, 2016; Powney *et al*., 2019; Zattara and Aizen, 2021).. Due to their importance in food production, especially for pollinator dependent crops, through the process of pollination and other ecosystem services that they provide, bee species monitoring is a crucial activity in conservation. In Tanzania, natural habitats such as forested areas occupy a great part of the country vegetation coverage. This enableprovision of ecosystem services, such as pollination services, , particularly for areas adjacent to forests (Tibesigwa et al. 2019). Studies have shown the benefit of presence of natural habitats adjacent to farms because of pollination by wild bees (Joshi *et al.,* 2016; Maurer *et al.,* 2022). Geographic composition by bees has been covered in many countries, but there are still gaps of coverage especially in Africa (Zattara & Aizen, 2021). But,, bee studies in the country have mostly been conducted in regions of Tabora (Hamisi, 2016) and Manyara, as well as areas in northern Tanzania (Lasway *et al.,* 2021; Pauly et al., 2019) and around Kilombero area (Magesa, 2021) where species other than honeybee *Apis mellifera*, have been identified.. This is still insufficient geographical coverage, and documentation of the primary data on bee species. specifically, the identification of the available bee species, composition, richness and abundance. In order to achieve and maintain inclusive conservation for guaranteed pollination services, especially for pollinator-dependent crops in farms adjacent to forested areas, there is a need to further conduct studies on bee species.

1.2 Problem Statement and Justification

Globally, there have been reports of a decline in the diversity and abundance of bee species (Sánchez-Bayo and and Wyckhuys, 2021; Zattara and Aizen, 2021) mostly as a result of habitat loss and fragmentation. It is well recognized that maintaining pollinator species that would otherwise become extinct is made possible by the landscape having a higher proportion of natural or semi-natural habitats (Viana *et al.,* 2012). Forested areas which are known to be the major habitats for bee species, are under anthropogenic pressure (Hall and Martins 2020). However, in Tanzania the composition of bee species is still unknown in many areas thereby creating a gap in the geographic occurrence of bees, hindering the ability to apply effective conservation measures for bees (Ollerton 2017). In order to prevent the loss of unknown bee species, it is crucial to identify bee species composition and conduct monitoring of bees in forests. These natural habitats for bees are important for ecosystem conservation through pollination.

Mgori Village land Forest Reserve (FR) in Singida region is a forest that provides ecosystem services benefits to adjacent communities. It is also a natural habitat for pollinator species such as bees that are important for pollination of crops like sunflower, a major crop in Singida region, which is also pollinator dependent. However, several studies conducted in Mgori reserve have focused on identifying the vegetation structure and the positive impact of beekeeping toward the conservation of the forest reserve in the area (Augustino, Kashaigili, and Nzunda 2016; Chingonikaya, Munishi, and Luoga 2010). But, Data on bee species found in the forest and the influence of threats on bee diversity is scarce. This information is vital , especially in light of the apparent anthropogenic pressures on forest areas.

This study will provide information on bee species found in the forest reserve, with emphasis on their composition, richness and abundance. It will inform the forest patrons (Tanzania Forest Services Agency)on the existing threats in the forest. This information will facilitate the process of monitoring the status of bee species in the forest; it and enable improvement of the conservation of these species. As well as guide policy improvements. It will demonstrate how disruptions such as human threats, affect the diversity of bee species in their natural environment. The study will also contribute to the primary data on the geographical occurrence of bee species in Tanzania.

1.3 Objectives

1.3.1 Main objective

The main objective of the study was to assess the population ecology and threats of bee species across vegetation types in Mgori forest reserve.

1.3.2 Specific objectives

Specific objectives of the study were:

i. To determine the bee species composition and diversity patterns in
   Mgori Forest Reserve
ii. To assess the influence of human threats on bee diversity in Mgori Forest Reserve.

1.4. Limitation of the study

The encountered limits during the study were:

- Inaccessibility of the forest due to dangerous people who were said to be illegally utilizing the forest
- Riots that were happening because of the change of managing instrument of the forest, from the village to Tanzania Forest Services Agency posed difficulties in collection of Data. This caused some villages to be Dangerous especially those located in the forest Interior
- Limited resources that required minute management in order to ensure they allow for optimum data to be collected

1.5 Dissertation Structure

This dissertation is divided into five chapters and is structured as a series of publishable manuscripts. The first chapter introduces the study, including background information, the problem statement, and study objectives. Chapter two describes the diversity patterns of bees in Mgori Forest Reserve. Chapter three studies the influence of human threats on diversity of bee species in Mgori Forest Reserve. Chapter four is a general discussion of the study's findings, and Chapter five provides a summary of the key contributions, conclusions, and recommendations for future research.

CHAPTER TWO

Manuscript One

2.0 Variations in Bee diversity patterns along a vegetation gradient in central Tanzania

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Abstract

Understanding the patterns of bee variety is crucial for the effective conservation and management of bee populations. This is needed because the lack of information on present bee species in various areas poses a risk in possible losses of unknown bee species. To provide valuable information that will help conservationists, researchers, and policymakers better understand and manage bee populations and ecosystems. We aimed to establish a baseline checklist of bee species and assess bee species richness and abundance across vegetation types, as well as understand the response of bee species composition, richness and abundance to selected environmental variables in the then-community forest of Mgori, central Tanzania. We used pan traps to sample bee species in 55 different plots at different vegetation types. We compared species richness, abundance, and community composition of bees in the three vegetation types using Kruskal-Wallis and permutational multivariate analysis of variance tests (PERMANOVA), respectively. We used generalised linear mixed-effects models on species richness and abundance in response to enhanced vegetation index, elevation, and climate. We recorded 46 bee species, of which 36 were from open woodland, 24 were from thickets, and 7 were from a mosaic of thickets and open woodland. PERMANOVA showed that bee community composition differed between vegetation types. Generalised linear mixed effects models showed that bee species richness and abundance all decreased in response to elevation and enhanced vegetation index. The findings of this study reveal a considerable influence that different vegetation types have on the composition of bee communities. This shows that different species of bees have differing preferences for vegetation types; therefore, it is vital to preserve a variety of vegetation types as supplementary habitats to maintain bee diversity. As well as include insect communities in conservation strategies.

Keywords; Pan traps, Bee diversity, Mgori, bee populations, Vegetation, Elevation

2.1 Introduction

Bees with a classification of order Hymenoptera: of super family, Apoidea: Clade Anthophila) are a category of insects that are highly significant to ecology, because they help pollinate both crops and wild plants, preserving natural ecosystems (Lasway *et al.,* 2021; IPBES., 2016). In order to promote biodiversity conservation, pollinators are of utmost importance because through the pollination activities they help to ascertain the provision of other ecosystem services by plants such as carbon sequestration, soil erosion prevention, nitrification and maintaining water tables and many other secondary benefits (Lasway, et al., 2021). According to Ollerton *et al.,* 2011, 94% of plants particularly in the tropics depend on animal pollination, and bees are one among crucial pollinator groups. Despite the importance of bees, many studies have reported a decline in species from this group at local, regional and global scales in terms of both diversity and abundance (Ollerton, 2017) this situation coupled with the fact that information on these species is still insufficient poses a risk in the process of conservation of these species (Lasway, et al., 2021). Without area-specific bee species information, there may be unknown losses of essential bee species and efficient pollinators, which could disrupt pollination services in natural and agricultural ecosystems, which is a global concern (Koh *et al.*, 2016; Potts *et al.*, 2016; Tommasi *et al.*, 2021).

In Tanzania bee ecology studies have gained attention in recent years, but are few, and insufficient in providing information on occurrence of species across the country and is concentrated in the northern, eastern and western part of the country (Classen *et al.,* 2015; Hamisi, 2016; Lasway *et al.,* 2021; Magesa, 2021; Mumbi *et al.*, 2014; Myers-Smith *et al.,* 2019). To provide extra information on the occurrence of bee species from other parts of the country, we analysed bee species richness, abundance, and community composition along a vegetation gradient in central Tanzania to offer data on variety of taxa and provide information for effective planning and management of insect biodiversity. We are aware that bee community composition are determined by environmental conditions as environmental changes have significant influence in the availability of resources for bee species, which in turn determines their richness and abundance across a habitat (Conrad, Peters and Rehan, 2021a). Here, we analyse responses of bee species richness and abundance to different vegetation types and environmental variables. To address our goal of providing relevant information for establishing a baseline checklist and understanding bee diversity patterns in one of the community forests in central Tanzania, the study aimed at answering the following research questions: (i) Does the bee species richness and abundance as well as the community composition differ along a vegetation gradient (characteristic vegetation found in the forest)? And (ii) Which environmental variables influence bee species richness, abundance, and community composition?

2.2 Materials and Methods

2.2.1 Study area

The study was conducted in Mgori Forest Reserve (Figure 2.1) located in Singida region in Tanzania (latitudes 3^0 and 7^0 South and longitudes and 34^0 and 35^0 for two months in dry season (November, January). The forest vegetation mainly consists of the Miombo woodlands. Thickets, grasslands are also scattered across the forest expanse such as *Afzelia quanzensis, Dalbergia melanoxylon*, *Brachystegia* spp., and cultivated areas on the margins of the forest reserve also characterize it. The area receives an average annual rainfall of between 410 and 1070 mm, with an inconsistent pattern throughout the area. The average temperatures in the region range from about 15°C in July to 30°C in October, and elevation vary between 1600 and 1400m above sea level.

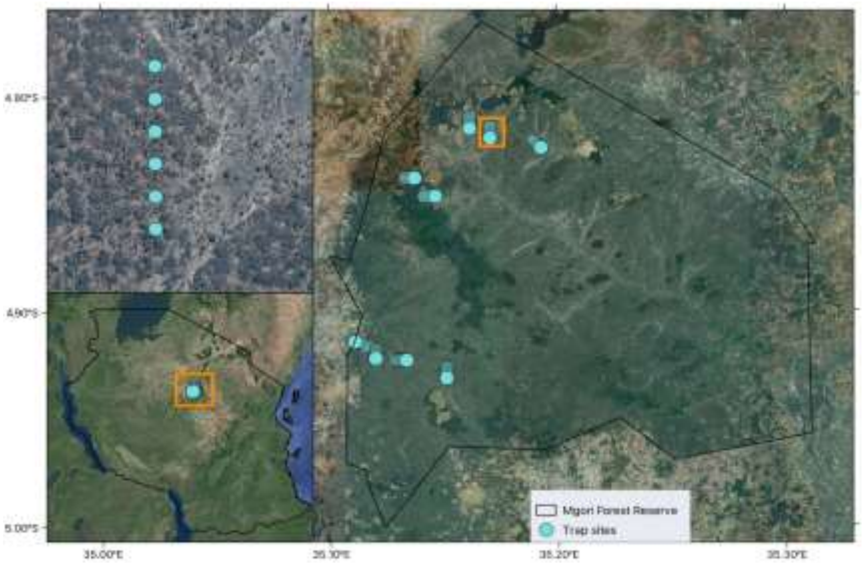

Figure 2.1: Map showing Location of the forest in Tanzania, arrangement and location of bee survey plots across vegetation types within Mgori Forest Reserve, eastern Tanzania.

2.2.2 Sampling design

Cluster sampling with systematic placement of plots was used in the study.55 Plots of size 20m×20m were established in the forest, the distance between plots was a 100m and a total of six plots made one cluster, the first plot was randomly established followed by a systematic approach of 100m. The distance from cluster to cluster was 1000m. The vegetation type where the plot placed was then categorized as open woodland, thickets or a mosaic of open woodland and thickets (these were the vegetation types identified in the forest following vertical structure of the forest).

2.2.2 Bee surveys

Bees were collected using pan traps of white, yellow, blue and red colours in open woodland, thickets and a mosaic of open woodland and thickets, across a total of 55 plots. Each plot had 8 pan traps filled with water and a scentless detergent which was used to break surface tension and collected after 24 hours for two consecutive days, making a total of 48 hours of trapping time, a procedure modified according to a bee survey conducted by O'Connor *et al.* (2019) who laid used pan traps along a transect. The collection was then placed in vials and transferred to Entomology Laboratory at Tanzania Wildlife Research Institute for identification. To understand the influence of environmental variables on bee species richness, bee abundance, and community composition, we used plot specific GPS coordinate to first extract precipitation from WorldClim database (www.worldclim.org; (Fick and Hijmans, 2017), and elevation from SRTM digital elevation model from the U.S. Geological Survey (https://earthexplorer.usgs.gov) using QGIS (QGIS, 2020). Second, to extract primary productivity calculated as enhanced vegetation index (EVI) values from Google Earth Engine - Landsat 8 Collection 1 Tier 1 8-Day EVI Composite (Gorelick *et al.*, 2017).

2.2.3 Data analysis

We used the Kruskal-Wallis to test whether bee species richness and abundance differed between vegetation types, as the data did not follow a normal distribution. Additionally, Dunn's post hoc test was used to assess specifically which vegetation types differed from each other in terms of bee species richness and abundance. We used permutational multivariate analysis of variance (PERMANOVA) to examine variations in species composition across different vegetation types using the adonis function from the vegan package (Stevens and Oksanen, 2020). In addition, we employed the pairwise adonis function from the pairwise-Adonis package, to evaluate disparities among various vegetation types (Arbizu, 2017). Before conducting PERMANOVA, we assessed the presence of homogeneous dispersion among different vegetation types using the betadisp function from the vegan package (Stevens and Oksanen, 2020). We analysed all data in R 4.0.4 (R Core Team, 2023). We performed a detrended correspondence analysis (DCA) for all types of vegetation to evaluate the influence of environmental variables on bee species composition so as to see the environmental variable with influence on species composition. All numerical explanatory variables were scaled to mean zero and unit variance prior to the DCA. To investigate the responses of bee species richness and bee abundance to environmental variables we modelled bee species richness and abundance using a generalised linear mixed effects model with Poisson error distribution in the 'lme4' package of R

(Bates *et al.*, 2014). "Site" was incorporated into the mixed models as a random effect because the plots are nested within the sites. However, prior to modelling we evaluated for over-dispersion before modelling and discovered that the data were not over-dispersed

2.3 Results

We recorded a total of 508 individuals of 45 bee species (36 species were found in open woodland, 24 species in Thickets, and 7 species in mosaic of Thickets and open woodland) belonging to three families (31 Halictidae, 14 Apidae and 3 Megachilidae species). The majority of individuals belonged to the Halictidae family and were caught in open woodland (>400 individuals). Of all the bees, dominant species were *Lasioglossum (Ipomalictus) matopiense, Lasioglossum (Ipomalictus)* sp1*, Lasioglossum (Oxyhalictus) acuiferum, Lasioglosum (Ctenonomia) atricrum,* and *Lasioglossum (Ipomalictus)* sp8*.* Additionally, species *Lasioglossum (Oxyhalictus) acuiferum, Lasioglosum (Ctenonomia) atricrum and Macrogalea candida* occurred in all three vegetation types.

Bee species richness and abundance differed significantly across vegetation types, (Fig.2.2). This was revealed by aA follow-up Dunn's post hoc test which showed that bee species richness and bee abundance in the Open woodland were significantly differed to thickets, and mosaic of woodland and thickets (Fig. 2.2). Between thickets, and mosaic of woodland and thickets, bee species richness and bee abundance did not differ significantly, but we recorded greatest bee species richness and bee abundance (numbers in the thickets compared to mosaic of woodland and thickets (Fig. 2.2).

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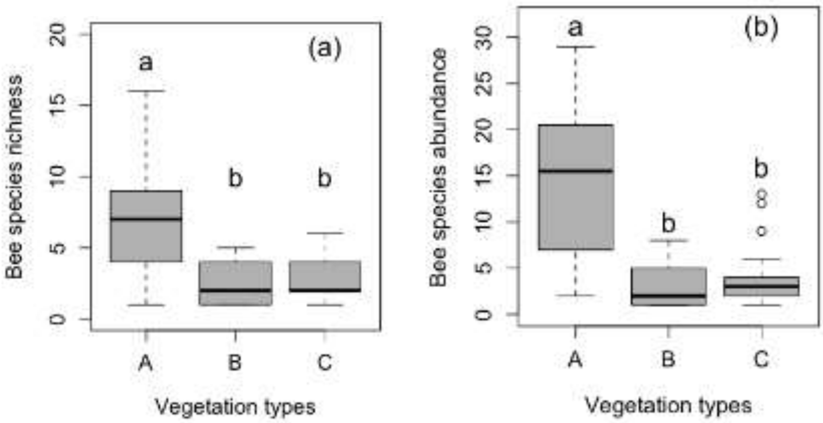

Figure 2.2: Box plot of (a) bee species richness, (b) bee abundance, across vegetation types (A = Open woodland, B = Thickets, C = Mosaic of open woodland and thickets) in the Mgori forest reserve. Different letters above the boxplots indicate significant differences between vegetation types.

Species composition varied across the vegetation types whereby more species were recorded in open woodland, followed by thickets and lastly few species were recorded in the Mosaic of open woodland and thickets (Appendix 1). Although there was an overlap in occurrence of species across the vegetation types, the permutational multivariate analysis revealed that species composition differed across all vegetation types. Whereby, firstly, species composition differed significantly between open woodland and thickets. But species composition did not differ significantly between open woodland and mosaic of open woodland and thickets ($p > 0.05$; Table 2.1), and, between thickets and mosaic of open woodland and thickets ($p > 0.05$; Table 2.1).

Table 2.1: Permutational multivariate analysis of variance (PERMANOVA) of species composition among vegetation types (OW, Open woodland; TH, Thickets; OWT, mosaic of open woodland and thickets) with pairwise comparisons and significance levels indicated by ***P < 0 .001; **P < 0.01; *P < 0.05.

Variable	*F* model	*P* value	Multiple comparisons	*P* value
Vegetation type	2.163	0.004	OW vs OWT	0.164
			OW vs TH	0.004*
			OWT vs TH	0.357

The variability on species composition extracted by Detrended Correspondence Analysis (DCA, Fig.2.3) showed that first axis (Eigenvalue = 0.31) was positively correlated to elevation and annual precipitation and negatively correlated to enhanced vegetation index and annual mean temperature. The second axis (Eigenvalue = 0.25) was positively correlated to enhanced vegetation index and annual mean temperature; and negatively correlated to the elevation and annual precipitation. The variable that exerted the greatest significant influence on the species composition was elevation. Our generalized linear mixed effects model suggested that both bee species richness and bee abundance were positively associated with rainfall and negatively associated with elevation and enhanced vegetation index (Table 2.2). Controlling for these environmental associations, bee species richness and bee abundance were highest in the open woodland and lowest mosaic of open woodland and thickets (Table 2.2).

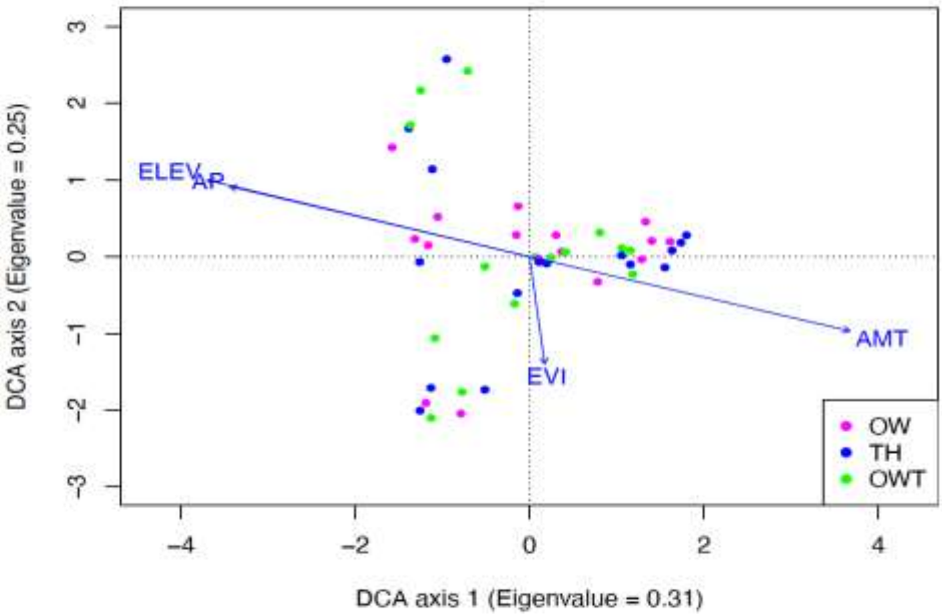

Figure 2.3: Detrended Correspondence Analysis (DCA) of bee species with environmental variables overlaid (Abbreviations: AMP, Annual Mean Precipitation; EVI, Enhance Vegetation Index; AMT, Annual Mean Temperature; ELEV, Elevation).

Table 2.2: Summary statistics of generalized linear mixed effects model explaining association between response and explanatory variables with significance levels indicated by: ***P < 0.001; **P < 0.01; *P < 0.05.

	Bee species richness				Bee abundance			
	Estimate	Std. Error	z value	Pr(>|z|)	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.814	0.093	19.536	< 0.001***	2.479	0.117	21.110	< 0.001***
Thickets	-0.743	0.203	-3.660	< 0.001***	-1.099	0.246	-4.469	< 0.001***
Mosaic of woodland and thickets	-0.595	0.308	-1.929	0.053.	-1.140	0.357	-3.190	0.001**
Precipitation	0.324	0.394	0.822	0.411	0.756	0.466	1.622	0.105
Elevation	-0.612	0.396	-1.546	0.122	-1.050	0.468	-2.241	0.025*
Enhanced vegetation Index	-0.019	0.087	-0.211	0.833	-0.059	0.103	-0.575	0.565

2.4 Discussion

Our analyses revealed that bee species richness and abundance differed significantly between open woodland and thickets as well as open woodland and mosaic of open woodland and thickets. This is because open woodland provide light availability which facilitates floral resources availability in this case, the understory that grows in open woodlands (Joshi *et al.*, 2016; Rappa *et al.*, 2023). Nesting resources also play a role in determining species richness and abundance across vegetation types (Roberts, King and Milam, 2017; Tommasi *et al.*, 2021), thickets do not provide better nesting condition and food resources compared to open woodland hence the low species richness and abundance which is also due to the absence of the herbaceous layer (Sydenham, Moe and Eldegard, 2020) but the vegetation types can still act as supplementary habitat for species in the forest in general.

Our PERMANOVA results revealed that species composition differed across the vegetation types; specifically, between open woodland and thickets, whereas there was no significant difference between open woodland and mosaic of open woodland and thickets, as well as thickets and mosaic of open woodland and thickets. The significant difference in species composition between open woodland and thickets, can be explained by a habitat use preference by the bees, whereby more species use open woodland than thickets for resource acquisition as evidenced by the higher number of species recorded in open woodland (36) more than thickets (24). These findings suggest that the type of vegetation can be utilized to indicate the bee composition within it, and that taller trees which are a characteristic of open woodland support a higher diversity of species because of the availability of nesting sites (Gonçalves and Araújo, 2021). The result also show that bee species assemblage in the forest is divided; this can be seen by the fact that Mosaic of woodland and thickets did not record a considerable number of species. Because bees are central place foragers and are often found to use one habitat (Maurer *et al.*, 2022), in this case either open woodland or thickets, and not the mosaic of the two structures. It also likely explains the reduced number of species recorded in the Mosaic of woodland and thickets.

Floral resources is one of the most important determinant factors of bee species abundance, and in terms of forested areas this means presence of understory, (Zou *et al.*, 2017; Maurer *et al.*, 2022) this can explain why we found open woodland vegetation type had the highest abundance of the recorded species, since it supports understory growth. Additionally the findings also aligns with several studies that highlight the importance of floral resources in supporting diverse bee communities (Rader *et al.*, 2016; Klein *et al.*, 2018). In general, it seems any forest management technique that increases light penetration and temperature near the forest floor is likely to have a positive effect on bee species richness and abundance (Dormann *et al.*, 2020). The variation in species composition between the two vegetation types in the forest also suggests that the different vegetation types can act as supplementary habitats for different bee communities within the same forest, hence allowing bees to have access to resources and easy pollinator movement with dependence on the more preferred habitat (Roberts, King and Milam, 2017). This has further been explained by Eckerter *et al.*, (2022) that the presence of canopy openness such as that of open woodlands increases suitability of habitat for wild bees and help further improve their presence and survival.

Our DCA results revealed that elevation is the most influential variable on species composition; this suggests that, elevation is a strong determinant that influence bee species composition in the forest (Dzekashu *et al.*, 2022). High-altitude regions are often characterized by conditions that do not support a higher diversity of bees, although Mgori forest reserve is located between 1400m to 1600m a.s.l. Noticeably elevation was found to influence species composition. So, despite not being located at very high altitude points, the results hold true that changes from low to high altitude cause a reduced number of bee species (Classen *et al.*, 2015b); but it can also be due to species preference to low altitude due to availability of better conditions. The absence of these better conditions can likely limit the suitable habitats and resources available for bees, leading to lower species richness in higher elevations (Osorio-Canadas *et al.*, 2021).

Our generalized linear mixed effect model revealed a negative association between elevation and bee abundance. This suggests that unattractive conditions in higher altitudes for bees in the area influenced a decreased abundance. This can be explained by the inability of bees to endure in higher elevation, due to reduced resources (Conrad, Peters and Rehan, 2021b). The influence of elevation on bee abundance also indicates that bees are sensitive to environmental changes, which also drives their abundance, this can affect the availability of pollination services. Precipitation governs the time available for foraging as well as availability of forage (Ogilvie *et al.*, 2017). The positive relationship between rainfall and species richness and abundance is because increase in rainfall leads to a subsequent increase in floral abundance, which in turn supports survival and abundance of species (Roland and Matter, 2016). The positive response to Mean annual temperature can be attributed to the fact that Warmer temperatures can promote bee activity, foraging efficiency, and reproductive success, resulting in increased population size (Zattara and Aizen, 2021). However, extreme heat events can have detrimental effects on bees. Which emphasizes the need for a balance between temperature conditions and bee conservation efforts. Enhanced vegetation Index showed a negative response to species richness and abundance because thick forest vegetation does not support bee richness and abundance. This is because it lacks canopy openness which positively supports bee abundance (Eckerter *et al.*, 2022). Understanding different contributing factors that influence richness and abundance of bee species in forested landscapes can help in further improving management strategies that are geared towards improving conservation of pollinators.

2.5 Conclusion

Bee communities in forested landscapes are influenced by several factors, and the study has revealed that vegetation types as well as elevation are the factors that to a great extent influence bee diversity. This suggests the need to maintain and manage different vegetation types within the same forest because they can be supplementary habitats. Forest managers in the process of management and protection of forests can use this understanding specifically in the efforts to maintain appropriate habitats for bees. It has also provided a checklist of bee species, which can later on be used for further ecological studies in Mgori forest Reserve.

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Conflict of Interest
The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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CHAPTER THREE

Manuscript Two

3.0 Influence of Human Threats on Conservation of Bee Species in Mgori Forest Reserve

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Abstract

Bee conservation is a crucial action to ensure sustainability for all living things on earth. Because they provide pollination services for plant diversity and crop production. In recent years many areas around the world have faced a rapid decline in bee diversity. This study was conducted with the objectives of identifying human threats in the forest reserve. By determining the extent of their occurrence within each type of vegetation in the forest reserve, and assessing how the occurrence of threats affects the occurrence of bee species in the forest. Cluster sampling was employed with each cluster having 6 plots and data was collected through direct observation and then plots were categorized into disturbed and undisturbed sites. Bees were collected through pan traps in the same plots and they were identified to species level. Data analysis was conducted using SPSS software for the analysis of human threats. And diversity of bee species was calculated through the Shannon-Wiener diversity Index. Chi-Square test was then used to determine the variation in richness and abundance between bees in disturbed and undisturbed sites. The results showed human threats are prevalent in the forest; the threats identified included grazing, human trails, logging, agricultural encroachment and fire. There wasn't a significant relationship between type of vegetation and the human threats ($p>0.05$). The Shannon-Wienner diversity Index was similar for disturbed and undisturbed sites. But variation was found for species richness between disturbed and undisturbed sites ($p<0.05$). Majority of the species were found in undisturbed sites than disturbed sites Dominant species in undisturbed site was *Lassioglossum matopiense* and some species were only found in undisturbed sites (*Megachile* genus) in the forest. The study has revealed the significant difference in species richness between the disturbed and undisturbed sites, which suggest that human threats affect the occurrence of bee species in the forest reserve. It also highlights the need to increase vigilance in protecting the community forests (because of the threats identified in the forest) by increasing focus on providing education to communities surrounding all protected areas on the importance of conservation. Since they are the first communities to benefit from ecosystem services provided by the forest such as pollination services that are crucial for food security and biodiversity conservation.

Key Words: Bees, Conservation, Diversity, Human-threats

3.1 Introduction

Forest areas are important pollinator habitats, and are crucial for pollinator survival due to abundance of resources. In turn pollinators are important in forest areas because they provide pollination services for forest plants and crops grown adjacent to forest, hence promoting plant biodiversity and food security (IPBES, 2016). Gradual loss of forest resources and biodiversity has been a concern for many years and this loss has been attributed to human pressure (IPBES, 2019) with attributed local threats including exploitation of resources, deforestation and agricultural conversion this indicates that Humans have been more involved in the process of reshaping natural habitats (Collado, Sol, and Bartomeus 2019; Prakash and Verma 2022). The resulting effect of habitat loss is decline of species that are sensitive to changes as well as dependent on forest resources such as bees (Chiarucci and Piovesan 2020; Ferreira *et al*. 2015). This is because bees lose favourable habitat, which affects their dispersal ability, nesting habits, and availability of good forage (Jamieson *et al*. 2019). This has also been explained by Carman & Jenkins (2016) that in addition to anthropogenic pressures affecting vegetation, they also, indirectly cause unsuccessful foraging of pollinators such as bees.

Bees are main pollinators of wild and cultivated plants (Winfree *et al*., 2011) , and they depend on natural areas to survive, because these areas provide forage and nesting resources for the bees (Garibaldi *et al*. 2011). Studies in temperate areas on effect of natural areas on bee species richness and abundance have been reported extensively, whereas the information from the tropics is yet to fill the gaps of information (Viana *et al*. 2012). The Information is crucial to ensure that these natural areas such as forests, which are crucial of bee pollinator survival continues to support them because, in the event of pollinator shortage wild as well as food plants that are pollinator dependent will be affected and biodiversity as a whole (Gutiérrez-Chacón, Dormann, and Klein 2018).

Mgori forest reserve, which was upgraded from village land forest, is in Singida region in Singida rural district. The forest is home to wildlife and was also regarded as a mating site for Elephants from the Swaga swaga game reserves. It was placed under community based forest management (Iddi, 2002) and according to Wily, (2001) Mgori village land forest reserve, showed conservation success as a community governed forest reserve, in a way that there was adequate participation by villagers in conservation. This management scheme has been employed and found to be of benefit to the communities surrounding the forest over the years, with the study by Augustino, Kashaigili, and Nzunda (2016) showing a positive use of resources for beekeeping activities for income generation. Over the years there hasn't been documentation on the forest's status but rather the activities being conducted in the surrounding communities and how they affect conservation of the forest. In order to understand the effectiveness of village land reserve management scheme there is a need to investigate the current status of the forest. Particularly the status on the human threats and their influence on bee diversity. This study will provide information without which the deleterious effect of human disturbance on bee species cannot be observed and therefore effectively managed (Gonçalves and Araújo 2021) .

The continued loss of habitat for bees due to human exploitation in forest reserves, necessitates the importance of continuing assessment of status of Human activities in forests. And how they affect ecosystem components such as bee species. Specifically for this study we conducted a collection of bees in the Mgori forest which was previously a community forest. In the study, plots where human activities occurred were categorized as disturbed sites and undisturbed sites were plots with no human activities. The aim was i) To assess the human threats in the forest this, and (ii) To Assess the variation in bee richness and abundance between disturbed and undisturbed sites, where we hypothesized that bee richness and abundance will significantly differ between disturbed and undisturbed sites in the forest. This information is important to the authority under which Mgori forest reserve is managed, since it will help to plan areas of focus in order to ensure the forest regenerates to its better conditions and increased ability to support bee species.

3.2 Materials and Methods

3.2.1 Study area

The study was conducted in Mgori Forest Reserve. The forest lies between latitudes $3^0$and 7^0 South and longitudes and 34 ^{0}and 35 ^{0} East in Singida Rural district in Singida Region, The five villages that surround the forest are; i) Unyampanda; ii) Mughunga; iii)

Nduamughanga; iv) Pohama and; v) Ngimu(Majule et al. 2014). The Forest covers an area of 38698.8 Ha.

The area receives an average annual rainfall of between 410 milliliters and 1070 milliliters, with an inconsistency throughout the area. The average temperatures in the region vary according to altitude, but generally range from about 15°C in July to 30°C in October (Gilbert, 2017). The major vegetation type of Mgori is the miombo woodlands. Also, Thickets, and grasslands vegetations are also scattered across the forest expanse. The surrounding farmlands are characterized by small-scale farming of crops such as, sunflower, maize and beekeeping activities as well as livestock keeping (Augustino *et al*. 2016a; Chingonikaya *et al*. 2010)

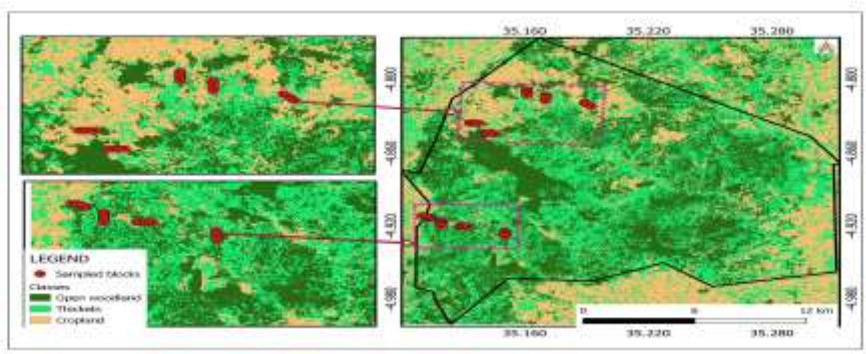

Figure 3.1: Map of Mgori Forest reserve showing plots studied

3.2.2 Sampling Design

In the study cluster sampling design was employed, where a total of 9 clusters were established in the forest. The first cluster was randomly chosen (with consideration of village entrance to forest) and other clusters followed at 1000m distances from one cluster to the next. In each cluster 6 plots each of size 20m × 20m were established and distance between the plots was 100m. The plots in the cluster followed one direction. A total of 55 plots were studied.

3.2.3 Data Collection Method

Direct observation was the main method used for data collection. Whereby in a plot looking at signs of presence of threats or disturbance (human activities and forest disturbances) we visually identified various threats. The threats identified and their indicators were as follows; Forest fire (Fire scars), Logging (tree stumps, clustered fresh firewood), Debarking (Debarked tree scars), Grazing (defecation, cattle), Encroachment (left over land from agriculture) and Human/Animal trails (footpaths). GPS coordinates were also recorded at the centre of each plot.

3.2.4 Collection of bees,

Pan traps were used to collect bees, they were placed in plots for 48 hours, and they were identified to species level at an entomology laboratory. The bees were categorized into those occurring in disturbed sites and undisturbed sites.

3.2.5 Data Analysis

3.2.5.1 Data on threats

Data across plots was pooled and tabulated, and the frequency and percentage count of occurrence of each threat was determined. Cross tabulation was used to examine the relationship between threats and vegetation types to determine the distribution of threats per type of vegetation. The Obtained data was analysed through SPSS statistical package version 25.

3.2.5.2 Data on bees

Data on bee occurrence was pooled for all plots and categorized into disturbed sites and undisturbed sites, Shannon Wienner diversity Index was calculated for bees that occurred in disturbed and undisturbed sites to find out if there is a difference in diversity. Bee richness and abundance were calculated for the two categories through Chi-Square test, to test for variation in richness and abundance between the two categories. All the work was conducted in R software.

3.3 Results

3.3.1 Bee diversity, richness and abundance in disturbed and undisturbed habitats

We recorded more species in undisturbed sites (36) than disturbed sites (33). We found that *Lasioglossum (*oxyhalictus*) acuiferum* was the dominant species in the disturbed habitat (35) and the undisturbed habitat was dominated by *Lasioglossum (*Ipomalictus*) matopiense*. Most Species with a total of individuals less than three

occurred in Undisturbed sites such as all species of the Genus *Megachile* occurred in undisturbed sites, interestingly most bees that occurred in undisturbed sites are
solitary bees.

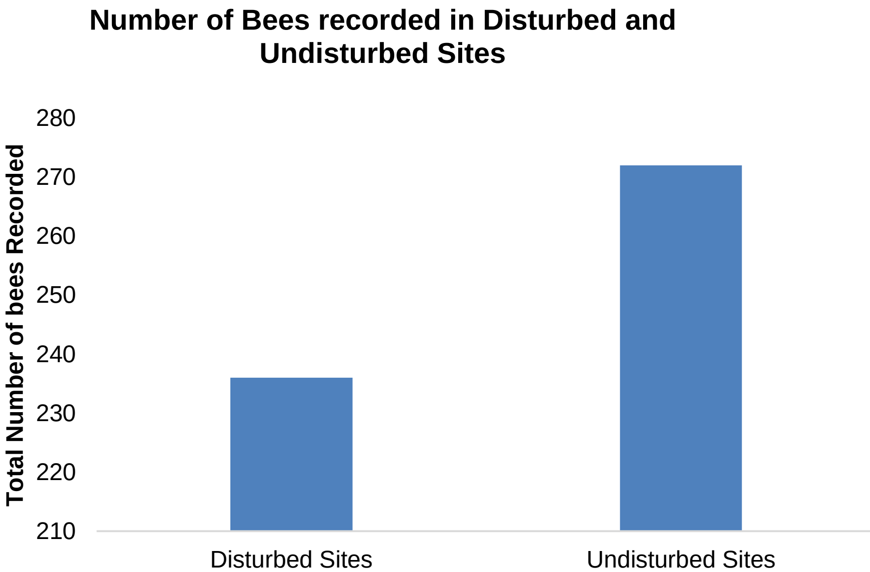

Figure 3.2: Total number of bees recorded in Disturbed and Undisturbed Sites

Shannon-Wienner diversity index was found to be similar in both disturbed sites (H'= 2.8476) and undisturbed sites (H'= 2.81366). And the analysis of variation of bee species richness and abundance between disturbed and undisturbed sites the revealed a significant difference in bee species richness between disturbed and undisturbed habitat while bee species abundance showed no significant differences between disturbed and undisturbed sites. Table 3.1.

Table 3.1: Variation in bee species richness and abundance in disturbed and undisturbed habitat

Category	Richness	Abundance
Disturbed habitat	3.776 ± 2.3a	2.088 ± 2.3a
Undisturbed habitat	6.4 ± 3.9b	2.125 ± 2.1a

Site-specific species richness revealed that more species were present in sites that were undisturbed than disturbed sites. Most sites that were undisturbed maintained higher numbers of species whereas disturbed sites had consistently lower numbers of species indicating that the bad conditions offered by disturbed sites hindered species availability (Figure 3.3).

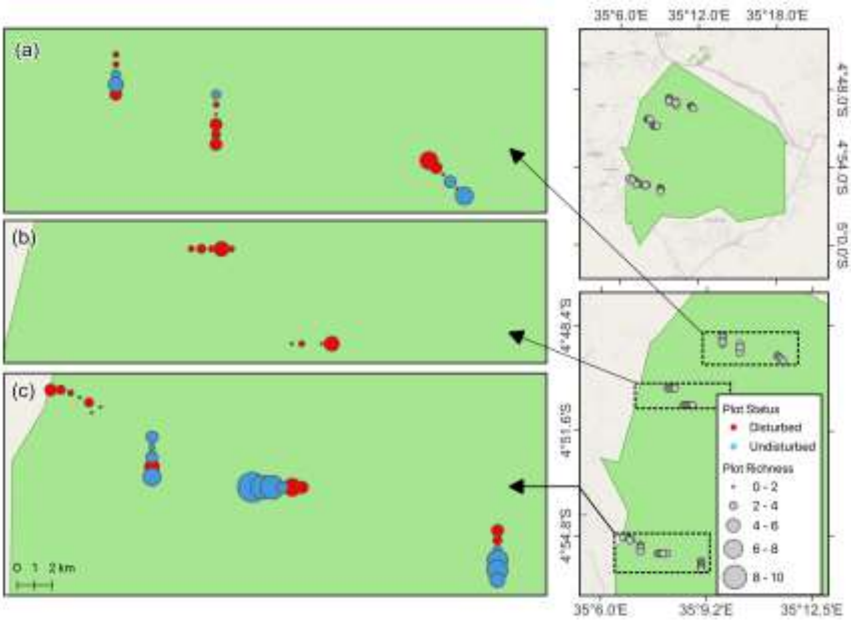

Figure 3.3: Map of Mgori forest reserve showing site-specific species richness in disturbed and undisturbed sites.

3.3.2 Threats

Threats were observed in 34 sites, which is equal to 61.8% of all the studied plots. The threats observed in the forest were: Forest fire, Logging, Debarking, Grazing, Agricultural encroachment and Human/Animal Trails. Also, we observed persistence in the threats observed across vegetation types. Whereby Among the recorded threats human and animal trails have a high occurrence compared to the rest of the threats, this is followed by Grazing, Logging and Encroachment as shown in Figure 3.4.

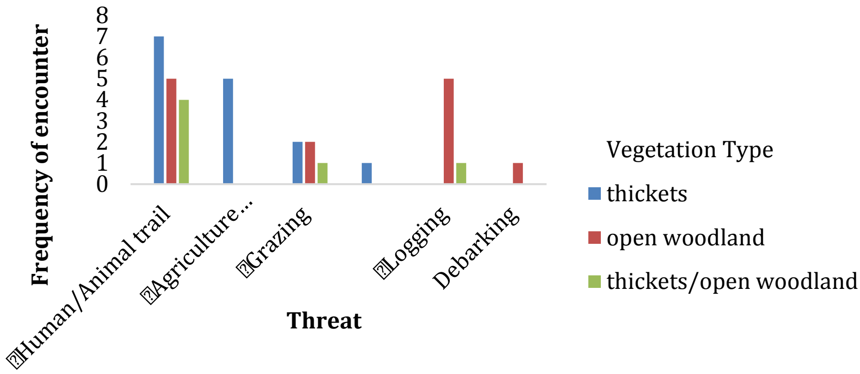

Figure 3.4: Occurrence of threats for each vegetation type in Mgori Forest Reserve

There wasn't a significant relationship between vegetation types and occurrence of threats ($p>0.05$). But rather the occurrence of threats in vegetation types showed that there were more threats in thickets than open woodland. And we found that the threats observed reflected the type of function that could be utilized from the vegetation type. That is to mean, in thickets there were more Human trails and agricultural encroachment, and in Open woodland there was more logging and noticeable debarking. Grazing was found to be consistent in all three vegetation types showing that in the forest grazing was a more spread-out activity.

3.4 Discussion

Major drivers of loss of bee diversity are those that are associated with Human activities that cause occurrence of habitat loss and fragmentation, which then bring about a chain reaction of events that result in loss of biodiversity (Hazwan *et al.* 2022). Apart from that it is difficult to balance people's need for ecosystem services with conservation of forest resources (Sayer, Elliott, and Maginnis 2003). Studies on human mediated changes on Landscapes, have revealed significant impacts of these changes on ecosystem functioning, such as the provision of pollination services in these landscapes (Ferreira *et al.* 2015; González-Varo *et al*. 2013; Isbell *et al.* 2013; Kumar and Verma 2017; Prakash and Verma 2022) as a result forest ecosystems, biodiversity and food production suffer as a result.

Undisturbed sites had significantly more species than the disturbed sites despite the absence of difference in abundance these findings partially confirm the hypothesis tested that more species will occur in undisturbed sites than disturbed sites. Although partial the results indicate that favourable conditions in undisturbed sites can favour more bee occurrence. The difference in richness but not abundance of bee species between disturbed and undisturbed sites was also reported by (Enríquez-Espinosa *et al*. 2022) whose study also reported similar findings with mostly solitary bees occurring in undisturbed sites, with the explanation that quality of the physical habitat can affect bee survival in disturbed area (Brosi 2009). Human threats affect areas by causing fragmentation; this affects the habitat by reducing connectivity, which supports movement of bees in search of forage and nesting sites (Török, Gallé, and Batáry 2022). In the study a lower composition of species was found in disturbed sites than in undisturbed sites, this has also been indicated by Gonçalves and Araújo, (2021) who explained that anthropized areas (areas with anthropogenic presence) affect the presence of species especially those sensitive to landscape changes such as bees. The variation of richness between the disturbed and undisturbed sites shows that, the human threats in the forest have effect on the occurrence of bee species, since they affect the microhabitat (Beche *et al.* 2022b). As explained by LeBuhn and Vargas Luna, (2021) that degradation of an area due to Land use changes, as is the case of human threats in Mgori affect the foraging and nesting sites for bees, which alters the bee species composition of the area. Site-specific species richness showed a consistent higher number of species occurrence because of resource availability in the area. The resources available ensure presence of species particularly those sensitive to site-specific environmental perturbations (Jamieson *et al*. 2019). Majority of the bees collected were solitary bees, whose dispersal ability is over small distances, (Janovský *et al.* 2013) this supports the pattern of distribution observed in the forest where more species could be found in undisturbed sites, with reduced numbers of the same species in disturbed sites. Generally the noteworthy lower numbers of species, majorly consisting of solitary species that were found in disturbed sites in the forest indicate the sensitivity and the need of available resources for species survival (Gonçalves and Araújo 2021).

The assessment of the Mgori forest revealed that, the forest reserve is not immune to human activities due to the frequency of occurrence of these activities in the forest (Figure 3.2). Data pooled across the sites indicated that the forest is accessible for utilization by surrounding communities. This enabled other activities to easily be conducted in the forest. For instance, grazing and agricultural activities were found to be conducted inside the forest, this is in contrast with the ban placed on natural forests utilization. The consistency of occurrence of these activities across protected areas in Tanzania has also been reported by Mwabumba, (2015) who found similar activities in the study on human disturbances which was conducted in Magamba nature reserve, as well as the general study by Mbeyale *et al.* (2021) which showed the decreased vigilance over community forest. One of the major management themes in community-based forest management, refers to the involvement of communities in forest management. One of the categories identified is the Village based forest management that gives rise to village land forest reserves (Nzunda, Luoga, and Mahuve 2011) like Mgori forest reserve. With the observed changes over times, such as population increase, and consequently increase in human activities it was important to examine how this indirectly impacts the capacity of the continued use of previously established conservation scheme. Despite the fact that studies have shown added benefits of community based forest management, through ecosystem services provision and beekeeping activities for income generation, in the past years in Mgori forest reserve (Augustino *et al.* 2016), it is clear from the results that there are anthropogenic activities still persisting in the forest. Such threats could also be more severe where human settlements are in very close proximity to the protected areas (Giliba *et al*. 2022). The observed pattern in the type of activity within a vegetation type, whereby thickets were observed to be more vulnerable to agricultural activities and woodlands more vulnerable to logging, but both vegetation types were not without grazing activities, has also been pointed out by other studies that found that that the pattern of occurrence of human activities were driven by how humans use the landscape (Beche *et al*. 2022a). This indicates that for communities it is more convenient to clear Thickets for agricultural activities, since they can also be used for firewood. Grazing activities in the forest have been reported to be detrimental to forest growth because it affects ecosystem functioning, land productivity as well as soil stability (Lulandala *et al*.

2022). This will ultimately hinder the ability of the forest to successfully regrow unless measures are taken to ensure that grazing is controlled in the forest. Therefore, any effort that tends to identify and measure the severity of human effects within protected areas such as the information gathered in this study, would not only save species but may also arm management with useful tools. That can be used for enlightenment and enforcement to ensure continued survival of species within the protected areas (Chaskda and Fandip 2017)

3.5 Conclusion

The study findings revealed a prevalence of human threats in Mgori forest reserve; it also showed the possibility of convenience in the use of forest resources. The study also partially corroborated the hypothesis that disturbed habitats will differ significantly in richness and abundance of bee species from undisturbed habitat. Human threats are still prevalent in Mgori forest reserve, and their presence affect the presence of bee species in the forest particularly bee richness. These occurrences show that despite restrictions communities still find ways to invade and encroach the forests and hence destroy habitat of bees. As such there is a need to conduct extensive and periodic monitoring of human threats in the forest reserves, because they cause gradual but extensive effects on forest thereby impacting its biodiversity. In addition to that, there is a need to educate communities on impacts of continued destruction of forest resources.

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Conflict of Interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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CHAPTER FOUR

4.0 General Discussion

Bees are known to be among the major pollinator groups, with their diversified feeding requirement, which is of advantage in both agricultural and natural settings. This feeding requirement also fulfils pollination services, which is important for food security and conservation of plant biodiversity. Recent research has reported an alarming decline of bees (Potts et al., 2016), which has called to attention the need for more research into the distribution of bees across different settings and habitats as well as better presentation of bees in conservation schemes (Hall & Martins, 2020). In order to better study and understand bee ecology and achieve their conservation, data on their primary data is important, but recent studies have shown a wide gap in the knowledge on bee occurrence around the world including Africa (Zattara & Aizen, 2021a), a problem which impedes further attempts at achieving conservation of species before their disappearance.

The primary driver of distribution and changes in bees (pollinator) communities is Land cover which in turn is influenced by human land use, therefore land management can also be regarded as a factor that drives pollinator distribution in a landscape(LeBuhn & Vargas Luna, 2021). Improper land use land management causes fragmentation of bees' habitat. Fragmentation results in increased decline of bees and affects ecosystem functioning because of the changes in abundance of bees (Chase et al., 2020). Studies have revealed that the changes of ecosystem functioning because habitat functioning can also affect provision of ecosystem services such as pollination services (Liu et al., 2018) this trend in the ever-changing ecosystem functioning and services makes it important to study the species that are sensitive to these changes such as the bees especially in their natural habitats.

Tanzania is among countries that have placed strategies in land management that would maximize conservation, for instance forest reserves. Conducting bee studies in agricultural landscapes has revealed that bee availability in these areas consist of species poor communities, suggesting a need to maintain natural habitats where bees can survive and provide pollination to adjacent areas especially were natural and agricultural landscapes are closely connected allowing species movement but also allowing the ability to maintain nesting substrates that are not available in agricultural landscapes (Joshi et al., 2016; Roulston & Goodell, 2011; Wayo et al., 2020; Zou et al., 2017). In addition to that studies show that agriculture areas that are adjacent to forested areas or natural habitats benefit form pollination by wild bees which has been found to be of more advantage in terms of better crops (Garratt et al., 2014; Tibesigwa et al., 2019). Managed forests such as Mgori forest reserve in Singida region benefit the communities surrounding it who practise Sunflower farming, a crop that is pollinator dependent, in order to ensure that they do benefit from wild pollination, awareness of the composition of bees present in the forest is important. This will enable increased attention to bee monitoring to ensure the pointed-out benefits are continuously available and also an ability to further conduct ecology studies in order to ensure the synergy between forest and bee conservation.

Hence the objectives of the study were to:

1. To determine bee diversity patterns along a vegetation gradient in central Tanzania
2. To assess Influence of Human Threats on Diversity of Bee Species In Mgori Forest Reserve

4.1 Composition and Diversity patterns of Bees

The study in Mgori has provided a checklist of bee species that are found in the forest. This will enable further monitoring of changes in bee species population in the forest following a more inclusive management of the forest. It has also revealed that vegetation type also is a factor that determines the richness and abundance of bee species, this is due to the significant in variation found in bee species richness and abundance across the found vegetation types. This has been shown by several studies, which have suggested that species composition is closely related to within habitat heterogeneity, because different species use different aspects of the habitat for their survival (Lane et al., 2020; Ricklefs,1987), Such as nesting substrates and favoured pollen sources. In addition to that bee diversity is expected to vary depending on habitat offering (Torné-Noguera et al., 2014) as was also the case for Mgori forest reserve in which the diversity varied among the vegetation types, which suggests that plant structure and the resulting condition such as openness and light availability may also determine the species communities in it and ultimately the diversity. On the other hand studies have shown that the range of colonization by bees depends largely on the resource and nesting substrates, (Torné-Noguera et al., 2014) for instance for tree cavity nesting bees open woodland would be more preferred to thickets because of the trees with cavities present (Steffan-Dewenter & Westphal, 2007), which suggest why more numbers of bees were recorded in open woodland vegetation type than the thickets and the mosaic of woodland and thickets. But more studies in bee ecology are needed to further delve into characterizing bee behaviour and preferences for bees in Sub Saharan Africa in order to maximize in utilizing wild bees pollination services.

4.2 Anthropogenic Influence on Bee Composition and Abundance

Bee pollinator declines have been at the forefront of conservation in recent years, several studies have been conducted to explore the causes of these declines. The most notable factor in the decline of bee species observed is anthropogenic influence of these changes (Carman & Jenkins, 2016; Decourtye et al., 2019; Hall & Martins, 2020) the major result that occur due to anthropogenic influence that affects bees directly is habitat loss and fragmentation which has been found to be prominent in managed areas such as managed forests (Fischer & Lindenmayer, 2007) also suggested by Senf et al., (2017) that in forested landscapes human disturbances dominate over natural disturbances and are the dominant driver of forest structure and biodiversity.

The study in Mgori revealed the presence of anthropogenic activities that are a threat to bees because of how they affect forest structure. The recorded threats were; logging, grazing, presence of trails, debarking, fire scars, and agricultural encroachment to mention a few which are consistent with several studies that have conducted observation of anthropogenic threats in the forest (Antongiovanni et al., 2020; Beche et al., 2022a).

On the influence of these threats on bee species diversity the study revealed that species richness was significantly influenced by human threats, furthermore, more species were present in undisturbed sites than sites that were disturbed by the presence of human threats. Anthropogenic disturbances in forested landscapes affect bee habitats because they result in the loss of forage, nesting resources as well as limiting their dispersal ability (Normandin et al., 2017), For instance activities such as grazing and agriculture encroachment affect ground nesting bees and logging affects cavity nesting bees due to disruption of their nesting resources, also pointed out by (Geslin et al., 2016).

CHAPTER FIVE

5.0 KEY CONTRIBUTIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter describes the key contributions, conclusion and recommendations obtained from the study conducted in Mgori forest reserve

5.2 Key Contributions

In this study bee species found in Mgori forest reserve were identified and recorded as a contribution to primary data on bee species in Tanzania in different environmental settings.
Generally, the major contributions of the study are:

- It shows the influence of vegetation types on bee diversity patterns in the forest
- It provides information that can be used to conduct further ecosystem studies in Mgori forest reserve,
- It gives an overview of the status of human threats in Mgori forest reserve that can be used in planning of conservation schemes for the forest.

5.3 Conclusion

The study has provided a list of bee species found in Mgori forest reserve and the status of the diversity patterns across the different vegetation types found in the forest. Whereby, the study suggests that vegetation types can be used as a factor in determining species community composition, especially for forested landscapes and studies pertaining to bee ecology.

The data and result on Bee species composition also suggests that for forested areas, surrounded by pollinator dependent crops. There is a need to conduct species monitoring, because it is suitable to indicate forest health condition. As well as its ability to provide suitable habitats for pollinator species. This is in order to ensure successful pollination of adjacent farms.

Forest reserves still harbor significant human threats. They continue to spread gradually, and that type of vegetation can be used to describe possible threats to be encountered in the forest. This will enable easy forest monitoring, and better strategies at mitigating forest destruction by human activities.

5.4 Recommendations

With the provided explanation from the study, it is recommended;

- To further conduct bee species studies in other natural areas, in order to account for the species present and be able to forecast the continued availability of pollination services.
- Incorporation of bee monitoring process in forest conservation schemes so as to ensure their usefulness
- To evaluate the status of conservation in other village land forest reserves to ensure that the system is still effective.
- Further studies to be carried in Mgori forest reserves in order to further characterize its ecosystem

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APPENDICES

Appendix 1: A checklist of Bee species and their Abundance in Mgori Forest Reserve

Species name	Open woodland	Thickets	Thickets/open woodland
Amegilla sp1	2	0	0
Amegilla sp2	4	5	0
Apis mellifera	5	3	1
Austronomia sp1	1	0	0
Austronomia sp2	1	0	0
Austronomia sp3	1	0	0
Braunsapis sp1	1	1	0
Ceratina sp1	6	4	0
Ceratina sp2	0	1	0
Ceratina sp3	1	0	0
Eucara sp1	2	0	0
Hypotrigona sp	2	0	0
Lasioglossum (Afrodialictus) bellulum	0	1	0
Lasioglossum (Ctenonomia) sp5	8	1	0
Lasioglossum (Ctenonomia) sp *AKU2*	1	2	0
Lasioglossum (Ctenonomia) transvaalense	26	0	3
Lasioglossum (Ctenonomia) zanzibaricum	0	1	0
Lasioglossum (Ipomalictus) matopiense	85	2	0
Lasioglossum (Ipomalictus) nairobiense	13	0	0
Lasioglossum (Ipomalictus) sp1	39	10	0
Lasioglossum (Ipomalictus) sp8	63	5	0

Lasioglossum (Oxyhalictus) acuiferum	34	6	6
Lasioglossum (Sellalictus) deceptum	9	0	0
Lasioglossum schubotzi	3	1	0
Lasioglossum scobe	0	1	0
Lasioglossum (Ctenonomia) atricrum	33	10	1
Leuconomia niprociliata	6	0	0
Liotrigona sp	12	0	0
Lipotrichs sp1	0	1	0
Macrogalea canolida	17	9	3
Maynenomia sp1	4	0	0
Maynenomia sp2	12	0	0
Megachile sp1	1	0	0
Megachile sp2	1	0	0
Megachile sp3	1	0	0
Nubenomia reichardia	0	1	0
Pachyhalictus (Dictyohalictus) sp	3	0	0
Pachynomia macrotegula	2	1	0
Patellapis (Chaetalictus) sp1	0	1	0
Patellapis (Chaetalictus) sp2	1	0	0
Seladonia sp	8	0	2
Stictonomia aliceae	9	4	0
Tetralonia sp1	2	0	0
Thrinchostoma sp	0	0	1
Xylocopa senior	0	1	0