Sokoine University of Agriculture

MSc Dissertation

Population Ecology and Distribution Pattern of Honey Bee Plants in Aghondi National Bee Reserve Central, Tanzania

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POPULATION ECOLOGY AND DISTRIBUTION PATTERN OF HONEY BEE PLANTS IN AGHONDI NATIONAL BEE RESERVE, MANYONI DISTRICT, TANZANIA

A dissertation submitted in partial fulfillment of the requirements for the Degree of Master of Science in Forestry of Sokoine University of Agriculture, Morogoro Tanzania

By

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EXTENDED ABSTRACT

The contribution of bee plants in the form of floral rewards for beekeeping development depends on plant species diversity, distribution, flowering phenology, and honey bee visitations. Unfortunately, such information is still lacking for many potentially good sites for honey production. Honey bee plants are being threatened by unsustainable human development activities, and thwart rural development initiatives that depend on honey production as an additional income activity. To address this information gap and to improve honey productivity, this study provides a better understanding of honey bee plants within the Aghondi National Bee Reserve in Central Tanzania. Specifically, the study aimed to address two primary research questions related to respective objectives: what is the diversity, density, and distribution status of honey bee plants? This objective involved assessing honey bee plant diversity, density, and distribution of honey bee plants and (ii) when is the flowering period of honey bee plants and what honey bee visitation patterns of key honey bee plants? This objective was to determine flowering phenology and honey bee visitation rates on selected honey bee plants. Data collection utilized different methods and sampling approaches. For the first objective, a systematic sampling design was used to sample vegetation in 85 square plots in three vegetation types. For the third and fourth objectives, five honey bee plants were selected based on the abundance in three vegetation types and monitored to profile their flowering and phenology, and 34 plants were studied for honey bee visitation rate for 20 weeks.

For the first and second objectives, a total of 79 honey bee plant species were recorded, belonging to 28 families and 5 genera. The distribution of species was relatively even, resulting in the identification of three distinct plant communities. Furthermore, the study indicated that the plant density was generally higher for the shrubs, notably *Vepris nobilis* than for trees and climbers. Moreover, for the second objective, honey bee plants exhibit continuous flower

openings throughout the day, with a notably higher number of flowers opening during the morning (P= 0.0013). The flowering distribution period was longer, lasting for one two to three months with; *Julbernadia globiflora* going for 88 days, *Combretum obovatum* for 72 days, *Combretum celastroides* for 62 days, *Pseudoprosopis fischeri* for 32 days, *Baphia massaiensis* for 53 days. Furthermore, the results revealed that the highest mean number of visits of honey bees was observed in *Albizia petersiana* (115± 36) and *Commiphora mollis* (99±30) while the lowest was observed in *Pseudoprosopis fischeri* (0.818±1.3) and *Dichrostachys cinerea* (0.0818±0.75). The honey bee visitation rate increased with floral rewards (r^2 = 0.128) and the number of flowers (r^2 = 0.157). In addition, temperature (r^2 = 0.001) and humidity (r^2 = 0.004) had no significant effect (P> 0.005) on the honey bee visitation rate for the selected plants.

These results suggest that the reserve contributes substantially to the honey bee forages which are a prerequisite for honey bee productivity and that the bee foraging is modulated by both biophysical and environmental factors. This information is useful for improving honey production strategies such as establishing many apiaries and conserving honey bee plants in Tanzania and elsewhere where bee honey production is a growing priority to develop a beekeeping calendar to maximize honey production within the reserve.

Keywords: Honey bee plant, diversity, honey bees, flowering phenology, honey bee visitation, Aghondi bee reserve.

KISIRI KUU

Mchango wa mimea nyuki inayo toa chavua na mbochi kwenye uzalishaji wa mazao ya nyuki unategemea uwingi, matwanyiko, mtindo wa unachanuaji wa maua na ukusanyaji wa chavua na mbochi wa nyuki. Taarifa hizi muhimu katika uzalishaji mazao ya nyuki hazi patikani katika maeneo mengi ya nchi hivyo kupelekea upungufu wa uzalishaji wa mazao ya nyuki. Kufanikisha uzalishaji endelevu wa bidhaa za nyuki kunategemea kwa kiasi kikubwa uelewa aina za mimea ya hasa kipindi cha kuchanua maua, tabia za kuvuna za nyuki, na uhifadhi wa mimea hiyo. Kwa bahati mbaya, taarifa hizi hazipatikani katika maeneo mengi yanayoweza kuwa na uzalishaji mzuri wa asali, na hivyo kuweka mimea ya nyuki wa asali katika hatari kutokana na shughuli za maendeleo yasiyo endelevu ya binadamu, na kuathiri jitihada za maendeleo vijijini zinazotegemea uzalishaji wa asali kama shughuli ya kipato. Ili kukabiliana na pengo hili taarifa za kuboresha uzalishaji wa asali, utafiti ulilenga kutoa uelewa bora wa mimea ya nyuki iliyopo ndani ya Hifadhi ya Taitaifa ya Nyuki ya Aghondi katika Tanzania ya Kati. Utafiti huu ulilenga kujibu maswali mawili makuu, ni aina ngapi za mimea ya nyuki, na ni kwa kiasi gani mimea hiyo imelundikana na kutawanyika? Hili lengo lilijumuisha kutathmini aina, idadi na mtawanyiko wa mimea ya nyuki wa asali. Na pili, lini mimea ya nyuki wa asali inachanua na ni wakati gani nyuki hutembelea maua ya mimea hiyo na pia mimea ipi inapedelewa na nyuki? Lengo hili lilikuwa kutambua jinsi mimea ya nyuki wa asali inavyochanua na idadi ya nyuki wa asali inayotembelea kwenye mimea ya nyuki wa asali iliyochaguliwa kipindi imechanua maua yake. Ukusanyaji wa data ulitumia njia na mikakati tofauti.

Katika lengo la kwanza, iligunduwa aina nyingi za mimea ya nyuki wa asali. Jumla ya aina 79 za mimea ya nyuki wa asali zilitambuliwa, zikijumlisha koo 28. Usambazaji wa mimea ulikuwa mzuri kwenye aina zote tatu za uoto uliopo kwenye hifadhi. Zaidi ya hayo, utafiti ulionyesha kuwa msongamano wa mimea kwa ujumla ulikuwa wa juu zaidi kwa mimea vichaka vya Itigi kuliko aina nyingine za mimea.

Aidha, kwa lengo la pili, niligundua kuwa mimea ya nyuki wa asali ilionyesha kuwa na maua yanayofunguka kwa muda wote wa siku, na idadi kubwa ya maua yalifunguka hasa wakati wa asubuhi (P = 0.0013). Kwa kuongezea, tathmini ya kipindi cha kuchanua maua kilikuwa kirefu kwa aina zote za miti ; *Julbernadia globiflora* ilikuwa kwa siku 88, *Combretum obovatum* kwa siku 72, *Combretum celastroides* kwa siku 62, *Pseudoprosopis fischeri* kwa siku 32, na *Baphia massaiensis* kwa siku 53. Zaidi ya hayo, matokeo yalionyesha kwamba idadi kubwa ya nyuki wa asali walitua sana kwenye mti aina ya *Albizia petersiana* (115± 36) na kufuatiwa na *Commiphora mollis* (99±30), wakati idadi ndogo zaidi nyuki walitua kwenye mti aina ya *Pseudoprosopis fischeri* (0.818±1.3) na *Dichrostachys cinerea* (0.0818±0.75). Viwango vya nyuki wa asali viliongezeka kulingana aina ya chakula cha nyuki (r^2 = 0.128) na idadi ya maua kwenye mti husika (r^2 = 0.157). Kuongezea kwa joto (r^2 = 0.001) na unyevunyevu (r^2 = 0.004) havikuwa na athari kubwa (P > 0.005) kwa nyuki wanaotembelea maua kwenye miti.

Matokeo haya yanaonyesha kwamba hifadhi inachangia kwa kiasi kikubwa malisho ya nyuki ambayo ni sharti la lazima kwa nyuki wa asali ili waweze kuishi na kuzalisha asali. Taarifa hizi ni muhimu katika kuboresha mikakati ya uzalishaji wa asali kama vile kuanzisha maeneo mengi ya kuhifadhia nyuki pamoja na mimea ya nyuki nchini Tanzania na kwingineko ambapo uzalishaji wa asali ni kipaumbele cha kuendeleza ufugaji nyuki ili kuongeza uzalishaji wa asali ndani ya hifadhi.

Maneno muhimu: mimea nyuki, biyoanuai ya mimea nyuki, fenolojia ya maua miti nyuki, Hifadhi ya nyuki Aghondi.

DECLARATION

I, WILSON EDWARD PIKOLOTI, thereby affirm to the Senate of the Sokoine University of Agriculture that this dissertation is entirely my work done during the registration period. It has not been submitted for consideration for any degree at any other institution before.

Wilson E. Pikoloti Date
(MSc. Candidate)

The above declaration is confirmed by;

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LIST OF MANUSCRIPTS

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DEDICATION

The dissertation is dedicated to my beloved family, Fr. Joseph Ntandu. Their resolute support, player, and courage have been a continuous source of inspiration in academic pursuit. With deep gratitude and endless love, I declare myself to construct a brighter future through the pursuit of knowledge, personal growth and love that puts us together all the time.

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

a.s.l	above sea level
ANBR	Aghondi National Bee Reserve
ANOVA	Analysis of Variance
GML	Generalized Linear Model
GPS	Global Positioning Systems
h	Hour
ha	Hectare
IUCN	International Union for Conservation of Nature
m	Meter
MT	Metric Tones
NABERM	National Beekeeping Research Master Plan
Rh	Relative humidity
SE	Standard Mean Error
URT	United Republic of Tanzania

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background Information

Loss of forest cover and shifting land uses in some African countries including Tanzania have significantly impacted the honey bee plants leading to decreased quality and quantity of honey production (Latham, 2016; Onyango *et al*., 2019). Lack of knowledge of plant species foraged by honey bees has also been reported to influence the loss of potential plant forage for honey bees and significantly impacted honey production and loss of honey bee colonies (Kayombo, 2013; Wagner *et al*., 2019; Ara Begum *et al*., 2021; Mossie & Worku, 2023). Apicultural practices have the potential to improve the livelihood of rural communities in many parts of the world including Tanzania, but it has not been unutilized due to poor technology, infrastructures and insufficient information on honey bees and their habitats (Onyango *et al*., 2019; Bareke & Addi, 2020; NABERM 1, 2020). The production of honey and bee wax depends on flowering plants that produce quality and quantity of pollen and nectar. These floral rewards are collected and consumed from a wide variety of flowering plants within their flight range (Hoover & Lynae, 2018; Al-Ghamdi *et al*., 2019; Arega *et al*., 2020).

Nonetheless, due to variations in climatic conditions, ecological conditions, and plant phenological traits not all plants are honey bee plants and not all honey bee plants contribute equally to honey production and survival of honey bee colonies (Al-Ghamdi *et al*., 2017; Arega *et al.*, 2020). It has been reported that other than livestock activities, beekeeping activities entirely depend on the availability of honey bee plants (Al-Ghamdi *et al*., 2019). Identification of plant species foraged honey bees is a basic requirement for apiary site selection and management of honey bee colonies (Arega *et al*., 2020; Addi & Bareke, 2021). The diversity, density, and distribution of honey bee plants, and their flowering phenology period are key factors that determine floral resource availability and foraging behavior of honey bees (Hassan *et al*., 2017; Al-Ghamdi *et al*., 2019; Arega *et al*., 2020).

Knowing and timing of flowering phenology of major and minor honey bee plants determines the honey bee-plant interaction and predicted honey bee behavior which is an essential factor production of honey (Hoover & Ovinge, 2018; Onyango *et al*., 2019; Bareke & Addi, 2020). Flower phenology and flowering period distribution of honey bee plants determine floral resource availability for honey bees and help beekeepers to timely manage honey bee colonies (Hosamani, 2020).

The reproduction cycle of honey bees and their honey production is closely related to the availability of floral honey bee plants at any given time. It has been observed that queen bees lay more eggs, and honey production storage increases significantly during periods of flower blooming *(*Waykar *et al*., 2014; Kumar *et al*., 2013; Demrew, 2019; Al-Ghamdi & Al-Sagheer, 2023). Moreover, honey bee plant, their flowering phenology, and honey bee foraging behavior are important attributes in apiary site selection and colony management and have been shown to increase honey production elsewhere (Ayansola & Adedoyin Davies, 2012; Hassan *et al*., 2017; Adgaba, Al-Ghamdi *et al*., 2017; Addi & Bareke, 2021). Furthermore, the production of honey and other bee products depends on the visitation of honey bees to a wide variety of bee plant species (Essenberg, 2012). Honey bee visitation to a variety of plant species determines the quality, and quantity of bee products (Alqarni, 2015; Polatto *et al*., 2019).

Understanding honey bee plants, their diversity, distribution, flowering period, and honey bee foraging behavior are the basic tools for honey bee colony management at different seasons. Based on these factors, the study was conducted to document the checklist of honey bee plant and their diversity, distribution and flowering phenology in Aghondi National Bee Reserves. Knowing these plant attributes is crucial for conducting sustainable beekeeping activities where beekeeping potential exists.

1.2 Problem Statements and Study Justification

Across tropical countries where bee honey bee plants are abundant, honey production is a growing business that potentially could improve the economies of rural communities. However, increasing honey productivity and its role in poverty reduction of rural communities across tropical developing countries remains limited due to the absence of potential information concerning honey bee plants and the interaction with honey bees for honey production(Gebretsadik, 2016). Several studies have shown that successful beekeeping requires full knowledge of honey bee plants within the flight distance (Ayansola & Davies, 2012; Dukku, 2013; Abou-Shaara, 2014; Adgaba *et al*., 2017; Onyango *et al*., 2019; Ara Begum *et al*., 2021). Furthermore, understanding the relationship between honey bees and honey bee plants from a beekeeping perspective determines the spatial and temporal availability of floral rewards for honey bees to produce bee products.

Tanzania has a capacity of producing 138000 tons of honey and 9200 tons of beeswax annually, however, only 30400 (22%) tons of honey and 1843(20%) tons of beeswax a produced per year (URT, 1998, 2020, 2021; NABERM 1, 2020). Information on honey bee plants, their diversity, distribution, flowering phenology, and flowering period pattern led to low production of honey, and other bee products in most parts of Tanzania as narrated in beekeeping policy (URT, 1998) and Beekeeping Act No. 15 of 2002 due scarcity of information sons honey bee plants in several aspects. Honey bee plants and floral visitation in several areas have the potential for honey production. Thus, compressive information is required to create the mutual relationships between plant resources available to honey bee and their interactions with ecological and environmental factors in the semi-arid zone.

Further, studies conducted on honey bee plants in different ecosystem regions of Tanzania reported the diverse range of honey bee plants that support honey bees for honey production. For instance, Kayombo *et al*. (2013) identified honey bee plants and their threats in the Mlele Beeking Zone, Latham (2008) identified bee fodders in the southern highland zone, and Ismail *et al*.(2021) passed the richness and distribution of honey bee plants in west Kilimanjaro forest plantation. Moreover, those studies failed to recognize the influence of plant density, honey bee plant community structure, flowering phenology, and honeybee visitation rate as major factors in honey bee product potential. This study aimed to identify honey bee plants, their diversity, density, distribution, flowering phenology, and honey bee visitation rate to specific plants in ANBR.

Aghondi National Bee Reserves is one of the prestigious bee reserves with special vegetation called Itigi thicket dedicated to the conservation of honey bees and their forage resources. However, knowledge of honey bee plants of Aghondi National Bee Reserved as honey bee plants their distribution, diversity, density, pattern of bee visitation, and flowering phenology are limited, therefore this study aims at bridging these research gaps. Given this paucity of information, the findings of this research will contribute to the proper management of the ANBR and the efficient utilization of bee plants for honey production.

The study findings are useful in making informed decisions, policy reviews, and designing management practices and interventions in ANBR. Information from this study is important to the TFS beekeeping projects in designing management practices for beekeeping. Furthermore, the study findings can serve as a reference point for villages willing to adopt sustainable beekeeping management.

1.3 Objectives

1.3.1 General objective

To assess species diversity, distribution pattern, bee visitation and flowering phenology of honey bee plants in the Aghondi National Bee Reserve in Central Tanzania.

3.3.2 Specific objectives

i. To assess the diversity of honey bee plants in the Aghondi National Bee Reserve
ii. To determine honey bee plants' density and distribution in Aghondi National Bee Reserve
iii. To determine the flowering phenology of honey bee plants in the Aghondi National Bee Reserve
iv. To assess the honey bee visitation rate on selected honey bee plants across the day in the Aghondi National Bee Reserve.

1.5 Dissertation Structure

This dissertation is divided into five chapters and is structured as a series of publishable manuscripts. The first chapter provides an introduction to the study, including background information, the problem statement, and study justification and the study objectives. Chapter two is a manuscript on honey bee plant species diversity, density, and distribution across three vegetation types. This chapter has already been submitted to the journal for publication. Chapter three presents flower phenology, the flowering distribution period of five selected honey bee plants, and honey bee visitation rate of 34 selected honey bee plants, and the influence of weather parameters on flowering phenology and honey bee visitations. Chapter four presents a general discussion of the study's findings, and chapter five provides a summary of the major contributions, conclusions, and recommendations moving forward.

CHAPTER TWO

MANUSCRIPT I

2.0 Diversity, Distribution and Density of Honey Bee Plants in Aghondi National Bee Reserve, Central Tanzania

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Abstract

The contribution of a honey bee plant species to survival and honey production by honey bee Apis mellifera depends on the plant's diversity, distribution, and density. However, the knowledge of plant species foraged by honey bees is still far from reach partly due to insufficient information about honey bee plants, service productivity, and their conservation. We assessed the diversity, distribution, and density of honey bee (*Apis mellifera*) plant species within the Aghondi National Bee Reserve in central Tanzania to enhance informed decisions on improving the beekeeping sector. Data were collected from October 2022 to April 2023, from 85 plots (10×10 m) in three vegetation types, recording all plant species visited by *Apis mellifera*. We analyzed the data using the Shannon diversity index, the density of the honey bee plant was computed by the quadrat method, and hierarchical cluster analysis was used to determine the distribution of honey bee plans. A total of 79 honey bee plant species, belonging to 28 families and 58 genera, were distributed in the reserve. Shannon diversity index was high (H' = 3.73) overall, and showed substantial variation across vegetation types, with the acacia woodland having the highest diversity. Species distribution was grouped distinctly into three plant communities with various growth forms. Furthermore, plant density was overall higher for *Vepris nobilis* and *Pseudoprosopis fischeri*. This information is useful for informing the improvement of honey production strategies and the conservation of honey bee plants in Tanzania and elsewhere where bee honey production is a growing priority to develop a beekeeping calendar to maximize honey production within the reserve.

Keywords: Bee resources; growth form; community structure; floral reward; honey production

2.1 INTRODUCTION

Pollinators play a crucial role in the pollination process of flowering plants, aiding in their reproduction and contributing to ecosystem stability. While there are various types of pollinators, bees have emerged as one of the most significant and efficient contributors to this vital ecological function (Hristov *et al.,* 2020). To ensure the sustainability of honey bee populations and their important role as pollinators, it is crucial to focus on the sustainable management of plant resources for bee foraging. This includes promoting the planting and maintenance of diverse floral habitats that provide a continuous supply of nectar and pollen throughout the growing season. By increasing the availability of diverse flowering plants, we can support the nutritional needs of bees and enhance their foraging opportunities. The availability of bee forage limits honeybee productivity and is very important for beekeepers to maximize productivity (Adgaba *et al*., 2017; Onyango *et al.*, 2019; Al-Ghamdi., 2019; Ara Begum *et al*., 2021; Hosamani, 2020; Al-Ghamdi & Al-Sagheer, 2023). The foraging behavior of honey bees, the overall health of their colony, and honey production of honey are determined by the availability of honey bee plants in a given area (Plascencia & Philpott, 2017; Al-Ghamdi *et al.,* 2019; Al-Ghamdi & Al-Sagheer, 2023).

Across African countries including Tanzania where forests are abundant, honey production is a growing business that potentially could improve the economies of rural communities through selling non-timber products including bee products such as honey, and bee wax (Lowore *et al.,* 2018; Gebretsadik, 2016; Harianja *et al.,* 2023; Dukku, 2013; Kayombo *et al.,* 2013; URT, 2020). However, increasing honey productivity and its role in poverty alleviation of rural communities across tropical developing countries is still curtailed by the lack of information on the honey bee plant species. Such information, if available could help improve the strategies for managing and conservation of the honey bee plants to boost honey productivity. Knowledge of the honey bee plant species in specific areas could help improve the health of bee colonies through for example improved conservation strategies and thereby potentially improve honey productivity. Furthermore, across most tropical countries, honey bee plants are under mounting threats from anthropogenic activities. For example, shifting cultivation, fire, charcoal mining, road construction, and pesticide application are recurring threats (Latham, 2016; Jackson *et al.*, 2018; Al-Ghamdi & Al-Sagheer, 2023).

In Tanzania, beekeeping is one of the emerging sectors of economic importance to rural communities. Tanzania has a capacity of producing 9200 tons of beeswax and 138 000 tons of honey annually, however, only 30 400 (22%) tons of honey and 1830(20%) tons of beeswax are produced per year URT, 1998; FAO,2018; NABERM 1, 2020; URT, 2020; URT, 2021). One reason for underperformance in productivity is the scarce information about bee forage resources, particularly the bee plants, and the threats they face. As is rightly put in the National Beekeeping regulations (i.e., Act No. 15 of 2002) and Beekeeping policy and strategy of Tanzania for 2020-2030, beekeeping is envisaged to drive several rural communities out of the poverty trap. Further, supporting this envision is the establishment of beekeeping in forest reserves, targeted to trigger socio-economic growth and prosperity among rural communities URT's (1998), the Beekeeping Regulations of 2005, and the National Beekeeping Research Master plan, have been placed on identifying and conserving plant species that honey bees forage on within all areas dedicated to beekeeping activities, aiming for effective management of honey bee colonies and honey bee. However, insufficient knowledge of the honey bee plants across these designated bee reserves hinders the targeting of such resources especially on hive installation and the conservation of the bee forage resources against potentially mounting threats (i.e., deforestation and wildfires) in most rural landscapes (Wagner *et al.*, 2019). Honey bee plants and honey production have been extensively studied in some Sub-Saharan Africa as revealed by the study conducted for example, Johannsmeier and Mostert (2001), Nguemo *et al*., (2016); Otim *et al.*(2019); Onyango *et al.* (2019); Arega *et al*. (2020); Mossie and Worku (2023) identified honey bee plants with the focus of understanding how these honey bee plants play a vital role in managing honey bee colonies for honey production.

In Tanzania, in the Umalila southern highland (Latham, 2008) engrossed on cultivated crops as a major bee fodder, (Kayombo, 2013) in the Mlele beekeeping zone in the western part identified 90% of trees being bee fodders, and more recently in the West Kilimanjaro forest plantation (Ismail *et al.,* 2021) revealed diverse plant species foraged by honey bees. However, previous studies have focused primarily on zones with varying vegetation types and climatic conditions, leaving the central zone with huge potential that can be utilized by beekeepers. Moreover, those studies overlooked the influence of plant density, honey bee plant community structure, and floral rewards as a major factor in honey bee product potential. Therefore, this study sought to fill a knowledge gap by assessing the diversity and richness of honey plant species and their distribution in the Aghondi National Bee Reserve in central Tanzania. Specifically, the study sought to determine the value and importance of honey plant species for honey bees and improve honey productivity strategies and conservation of honey bees' plants.

2.2 MATERIALS AND METHODS

2.2.1 Study area

The study was conducted between October 2022 and April 2023 in Aghondi National Bee Reserve (ANBR) located in central Tanzania between 3°S to 7°S and 34°E to 35°E (Fig.1). The reserve covers an area of 2161 hectares laying at 1500 above the sea level. The vegetation cover in the area is mostly thickets and savanna (Luvanda & Lyimo, 2018). The average annual rainfall ranges from 500 to 700 mm per year, with temperatures ranging from 20°C in July to 30°C in

October (Jackson *et al*., 2018). ANBR was established as a National Bee Reserve on October 19, 2005, and is maintained by the Tanzania Forest Services Agency for the conservation of bee resources and beekeeping activities. The reserve comprises three vegetation types: thicket, acacia woodland, and miombo woodland, with Itigi thicket covering a larger area. Village communities that surround the Aghondi National Bee Reserves engage in a variety of human activities, such as the construction of unauthorized footpaths, grazing and the illegal extraction of resources from the reserve and its buffer zone, including timber and non-timber products, to meet their daily needs. Additionally, the reserve is home to a large number of elephants, which forage honey bee plants as part of their diet. These threats threaten the abundance and quality of the potential bee forage resources available in the Manyoni district including ANBR (Makero *et al*., 2016; Godfrey, 2018).

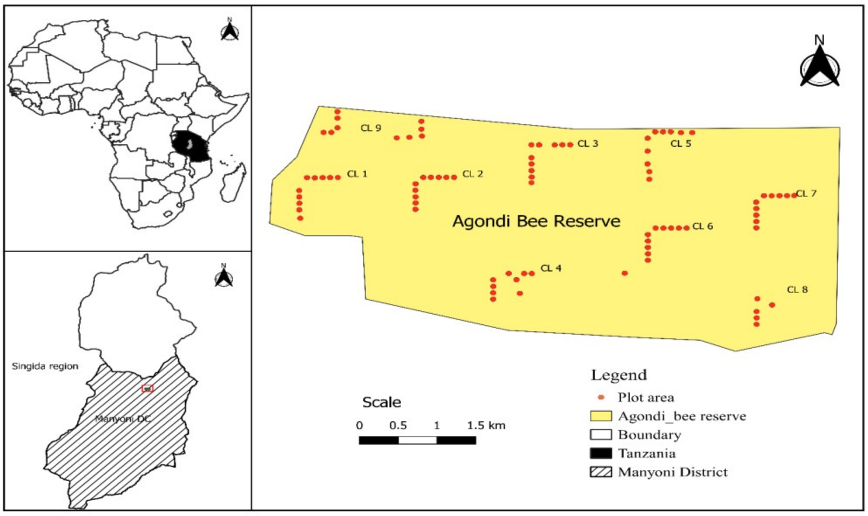

Figure 2.1: Location of Aghondi National Bee Reserve (ANBR) where this study was conducted indicating the distribution of sampling plots for the honey bee plant species across the reserve

2.2.2 Study Design and Data Collection

A double sampling for stratification design was used to sample the vegetation and to record data between October 2022 and April 2023. Woody honey bee plants were sampled from a total of 85 plots measuring (10 m x 10 m) superimposed with (1m x1 m) for herbaceous species following (Wubie *et al.*, 2014; Ismail *et al*., 2021 and Al-Ghamdi & Al-Sagheer, 2023). The sampling plots were aligned in ‘L’ format following the vegetation type of a particular cluster to capture existing vegetation heterogeneity (URT, 2015). The first plot was chosen randomly and the subsequent plots were established at 100 m intervals along the transect lines. Each plot was geo-referenced using a hand-held Garmin GPSMAP 78s and elevation of the plot center was recorded. Within each plot, honey bee plant species were recorded as family, growth, and floral rewards. In this study, we utilized direct observation of honey bees foraging on the flowers of various plant species as a method for identifying the plants visited by the bees described by (Ayansola & Adedoyin Davies, 2012; Dukku, 2013).

Further, to record bee plants based on bee foraging, about 10 minutes of observation were spent within each plot to observe bee visitation and foraging on the plants. A plant was considered a honey bee plant when at least three (3) *Apis mellifera* honey bees were observed visiting flowers and effectively gathering either pollen in their hind legs or nectar through their proboscis from 700h to 1700h (Ayansola & Adedoyin Davies, 2012; Bhalchandra *et al*., 2014). Nectariferous plants were identified when the honey bees extended their proboscis into the flowers for nectar collection, while pollen collection was noted when honey bees carried pollen on their hind legs from the flowers. Plants for which bees were seen displaying both behaviors on the flower, were classified as pollen-nectariferous source plants (Johannsmeier and Mostert, 2001; Ayansola & Adedoyin Davies, 2012; Bhalchandra *et al.*, 2014; Otim *et al*., 2019). Honey bee plant species were identified by local botanists and cross-checked using the National Forestry Resources Monitoring and Assessment of Tanzania (NAFORMA) species list (URT, 2014).

2.2.3 Data Analysis

To understand the composition of the honey bee plant communities in the study area, the plant abundance data were described by categorizing them into plant forms, flower rewards, and taxonomic groups. Sampling completeness was assessed using rarefaction curves (Fig.2.2). Firstly, a normality test was run on the data before using analysis of variance (ANOVA) to conform to the assumptions of ANOVA tested by using the Shapiro-Wilk test ($P<0.05$). Pooled plant abundance data were used to compute species diversity and the analysis of variance was used to explore differences in species diversity between the vegetation types. The Shannon-Weiner index was used to determine species richness and diversity among vegetation types. Furthermore, differences in species richness and diversity between the vegetation types and between floral variables were tested using ANOVA.

In addition, to significant test results, a post-hoc test was performed to detect the variables mostly influencing variations using the Tukey HSD test. Secondly, to understand how honey bee plants are distributed across the surveyed area, cluster analysis based on plant abundance values was performed (Chatanga & Sieben, 2020). PAST Version 4.13 was used for cluster analysis (Hammer *et al*., 2001) with the use of Sørenson's (Bray-Curtis) similarity index and Paired group (UPGMA) method as the linkage method thereby plotting a dendrogram. Thirdly, to describe honey bee plant stocking in the study area, the density of trees, shrubs, and climbers per plot extrapolating to a value per hectare was calculated as the relative abundances of respective plant growth forms. The density of trees, shrubs, and climbers per hectare was computed in a quadrat of 10m×10m (Mossie & Worku, 2023). We excluded herb plant species from the density calculations due to their low abundance, as their presence could potentially affect the interpretation of the results. Lastly, to understand the conservation status of honey bee plants in the study area, each species was assessed to the most recent IUCN Red List of Threatened Species (IUCN, 2021).

2.3 Results

2.3.1 Composition of honey bee plant, species richness and diversity

We found 79 nectar and or pollen-producing honey bee plants from 58 genera and 28 families across the study area (Table 1). Itigi thickets contributed the highest honey bee plant species (n=51), and acacia woodland lowest species richness (n=39) among the three vegetations (Table 2.1). No difference in honey bee plant species was found between the surveyed three vegetation types ($F_{2, 129} = 1.196$, $p > 0.05$). Further, the bee forage comprises four plant forms: trees (44.3%, n=35 species), shrubs (39.2.%, n=31 species), climbers (7.6%, n=6 species, and herbs (8.9%, n=7 species. Species richness was significantly different across these bee plant life forms ($F_{2, 75} = 3.469$, $p < 0.0118$) and the differences were mostly between trees and herbs (Tukey HSD test=0.0004), between shrubs and herbs (Tukey HSD test, p=0.0006), shrubs and climber (Tukey HSD test, p=0.0005) and tree and climber (Tukey HSD test, p=0.0003).

Looking at the family composition of these bee plants, the family Fabaceae with the highest composition in the bee plant pool (22.5% n=18 species), 16 plant families had the lowest richness, with each family consisting of only one species (Fig.2.2). Nevertheless, honey bee plants were categorized into nectar, pollen, and both sources, with nectar source plants having the highest species richness (46.3% n=37 species) (Fig.2.3). Species richness was significantly different across this bee floral reward ($F (2,235) = 37.02$, $p < .005$ and the variation were between pollen and nectar (Tukey HSD test, p=0.017) and both pollen and nectar and nectar (Tukey HSD test, p=0.0068).

Table 2.1: List of honey bee plant species, families, growth form, floral rewards, and IUCN status of the HBP of the Aghodi National Bee Reserve

SN	Local name	Species name	Family	Growth form	Floral reward	IUCN Status
1	Msanguo	*Achyranthes aspera*	Amaranthaceae	Herb	Nectar	NE
2	Ntewah	*Aeschynomene mossoensis*	Fabaceae	Shrub	Nectar and Pollen	VU
3	Musimilii	*Albizia petersiana*	Fabaceae	Tree	Nectar and Pollen	LC
4	Mkulurakanga	*Asparagus falcatus*	Asparagaceae	Shrub	Pollen	NE
5	Muhingiri	*Baphia massaiensis*	Fabaceae	Shrub	Pollen	LC
6	(blank)	*Barleria argentea*	Acanthaceae	Herb	Nectar	LC
7	Mhangarara	*Bidens pilosa*	Asterceae	Herb	Nectar and Pollen	NE
8	Mtumba	*Boscia mossambicensis*	Capparaceae	Tree	Nectar	LC
9	Mtundu	*Brachystegia spiciformis*	Fabaceae	Tree	Nectar and Pollen	LC
10	Mkodokodo	*Burttia prunoides*	Connaraceae	Shrub	Pollen	LC
11	Mbefu	*Bussea massaiensis*	Fabaceae	Tree	Nectar and Pollen	LC
12	Mkamu	*Canthium burtii*	Rubiaceae	Shrub	Nectar and Pollen	NE
13	Mja watemi	*Canthium oligocarpum*	Rubiaceae	Tree	Nectar	LC
14	Mtendasaje	*Capparis tomentosa*	Capparaceae	Climber	Nectar	NE
15	Mmulimuli	*Cassia abbreviate*	Fabaceae	Tree	Nectar	LC
16	Mulugala	*Cassipourea mollis*	Rhizophoraceae	Shrub	Nectar and Pollen	LC
17	Mnukanuka	*Clerodendrum myricoides*	Lamiaceae	Shrub	Nectar	NE
18	Mgombwe	*Clerodendrum uncinatum*	Lamiaceae	Shrub	Nectar and Pollen	NE
19	Mnang'ana	*Combretum celastroides*	Combretaceae	Shrub	Nectar	LC
20	Mtundira	*Combretum collinum*	Combretaceae	Tree	Nectar	LC
21	Mgombwe	*Combretum obovatum*	Combretaceae	Climber	Nectar	LC
22	Mgombwe	*Combretum paniculatum*	Combretaceae	Climber	Nectar	NE
23	Mgombwe	*Combretum purpureiflorum*	Combretaceae	Climber	Nectar and Pollen	NE

24	Msana	*Combretum zeyheri*	Combretaceae	Tree	Nectar	LC
25	(blank)	*Commelina benghalensis*	Commelinaceae	Herb	Pollen	LC
26	(blank)	*Commelina latifolia*	Commelinaceae	Herb	Pollen	LC
27	(blank)	*Commiphora caerulea*	Burseraceae	Tree	Nectar	LC
28	Mdonto	*Commiphora mollis*	Burseraceae	Tree	Nectar and Pollen	LC
29	Mdonto	*Commiphora mossambicensis*	Burseraceae	Tree	Nectar and Pollen	NE
30	Mzomvugo	*Commiphora ugogensis*	Burseraceae	Tree	Nectar and Pollen	LC
31	Mpandu	*Craibia brownie*	Fabaceae	Tree	Nectar and Pollen	NE
32	Mtati	*Croton menyharthii*	Euphorbiaceae	Tree	Nectar	LC
33	Utumbu	*Cucumis dipsaceus*	Cucurbitaceae	Climber	Nectar and Pollen	NE
34	Mbibi	*Dalbergia boehmii*	Fabaceae	Tree	Nectar	LC
35	Mtunduru	*Dichrostachys cinerea*	Fabaceae	Shrub	Pollen	LC
36	Mnyondo	*Ekebergia benguelensis*	Meliaceae	Tree	Nectar and Pollen	LC
37	Mdaa	*Euclea divinorum*	Ebeneceae	Shrub	Nectar	LC
38	Mlimbo	*Euphorbia cuneata*	Euphorbiaceae	Shrub	Nectar and Pollen	LC
39	Mkumila kanaga	*Gardenia ternuifolia*	Rubiaceae	Tree	Nectar and Pollen	NE

40

Mpeleme

Grewia forbesii

16