

**DIVERSITY, STATUS AND THREATS TO STINGLESS BEES
(APIDAE: MELIPONINI) OF IPEMBAMPAZI FOREST RESERVE,
TABORA - TANZANIA**

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**A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE
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ABSTRACT

This study presents the stingless bees (Meliponini) of Ipembampazi Forest Reserve (IFR) in Sikonge, Tabora Tanzania. Stingless bees were systematically sampled from linear transects from which 80 plots of 20 x 40 m² (0.08ha) were established. A total of 60 nests were found, representing two stingless bee species, *Meliponula ferruginea* Lepeletier and *Hypotrigona ruspalii* Magretti. The third species, *Plebeina hildebrandti* Friese was opportunistically collected at water hole. Relatively low species richness and nest density (9.53 nests ha⁻¹) were found. Most species were unevenly distributed. Cluster spatial distribution was observed exhibited by one species of *H. ruspalii*. The most abundant stingless bee was *Meliponula ferruginea* (52%). Most species were found nesting in trees, except for *P. hildebrandti* which is reported to nest in the ground in termite mounds. Seven tree species were found hosting stingless bees. The primary tree species used by bees for nesting were *Pericopsis angolensis* (46.7%), *Erythrophleum africanum* (23.3%) and *Julbernardia globiflora* (18.3%). Various nesting patterns and architecture were also observed in stingless bees. The different patterns served as an adaptation to varying nest microclimates and response to environmental threats. Most of the threats recorded were mainly human induced. Forest fire (63%), honey hunting (26%) and logging for timber (10%) were the dominant threats to stingless bees in IFR. Together with other factors, may collectively negatively contributed to the low species diversity and nests abundances observed. It was concluded that, more studies on stingless bees is required. The effects due to climate change on stingless bees should not be overlooked. The findings provide important information for the future development of Meliponiculture industry and conservation of the stingless bees of Tanzania.

DECLARATION

I, **ISSA HAMISI** do hereby declare to the Senate of the Sokoine University of Agriculture (SUA) that this dissertation is my own original work and that it has never been submitted to any other University for a degree award.

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.....

Date

The above declaration is confirmed by:

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(Supervisor)

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LIST OF ABBREVIATIONS AND ACRONYMS

ARC	Agricultural Research Council
FAO	Food and Agriculture Organization of the United Nations
FR	Forest Reserve
GPS	Global Positioning System
IFR	Ipembampazi Forest Reserve
MNRT	Ministry of Natural Resources and Tourism

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Stingless bees are honey bees which are divided into two tribes: Meliponini and Trigonini (Arias *et al.*, 2006; Eardley, 2004; Moretto and Arias, 2005; Sommeijer, 1999). The tribes belongs to a large insect order Hymenoptera in the family Apidae (Arias *et al.*,2006). Today, the number of stingless bee species is still controversial, however, estimated to be about 400 to 600 species (Cortopassi-Laurino *et al.*, 2006; FAO, 2009; Michener, 2000). They dominate the tropical and subtropical areas of the world (Slaa *et al.*, 2006; Sommeijer, 1999), mainly in the Central and South America, Africa, South Asia and Australia (Eardley *et al.*, 2010; Souza *et al.*, 2006).

Trigonini is a tribe that has the largest number of genera and sub-genera (Danaraddi *et al.*, 2012; Michener, 2000). The stingless bees in the genus *Trigona* have about 150 species, mostly restricted in the Neotropical and Indo-Australian regions (Danaraddi *et al.*, 2012; Michener, 2000). Six genera of stingless bees; *Meliponula*, *Hypotrigona*, *Dactylurina*, *Liotrigona*, *Cleptotrigona* and *Plebeina* occur in Africa (Eardley, 2004; Eardley *et al.*, 2010). Although, currently there is little understanding of the stingless bee genera and species of Tanzania, many species have been reported in various studies (Eardley, 2004; Mpuya, 2009; Pauly and Vereecken, 2013). A list of stingless bee genera and their respective species in Tanzania is summarized in Table 1.

Table 1: Stingless bee species of Tanzania

S/N	Genus	Species	References
1	<i>Axestotrigona</i>	<i>A. erythra</i> Schletterer	(Eardley, 2004; Mpuya, 2009)
2	<i>Cleptotrigona</i>	<i>C. cubiceps</i> Friese	(Eardley, 2004; Eardley <i>et al.</i> , 2010)
3	<i>Dactylurina</i>	<i>D. schmidti</i> Stadelmann	(Eardley, 2004; Pauly and Vereecken, 2013)
4	<i>Hypotrigona</i>	<i>H. araujo</i> Michener	(Eardley, 2004)
		<i>H. gribodoi</i> Magretti	(Eardley, 2004)
		<i>H. ruspolii</i> Magretti	(Eardley, 2004; Pauly and Vereecken, 2013)
5	<i>Liotrigona</i>	<i>L. bottegoi</i> Magretti	(Eardley, 2004; Pauly and Vereecken, 2013)
6	<i>Meliponula</i>	<i>M. ferruginea</i> Lepeletier	(Eardley, 2004; Pauly and Vereecken, 2013)
		<i>M. ogouensis</i> Vichal	(Eardley, 2004; Pauly and Vereecken, 2013)
		<i>M. landiliana</i> Friese	(Eardley, 2004; Pauly and Vereecken, 2013)
		<i>M. beccarii</i> Gribodo	(Eardley <i>et al.</i> , 2004; Pauly and Vereecken, 2013)
		<i>M. bocandei</i> Spinola	(Mpuya, 2009; Pauly and Vereecken, 2013)
		<i>M. junodi</i> Cockerell	(Mpuya, 2009)
7	<i>Plebeina</i>	<i>P. armata</i> Magretti	(Pauly and Vereecken, 2013)
		<i>P. hildebrandti</i> Friese	(Eardley, 2004; Pauly and Vereecken, 2013)
8	<i>Trigona</i>	<i>T. denoiti</i> Vichal	(Mpuya, 2009; Pauly and Vereecken, 2013)
		<i>T. spinipes</i> Fabr	(Mpuya, 2009)

The stingless bees are widely exploited for their products (honey, propolis and pollen) as an important source of food and for providing a useful component of household income (Hilmi *et al.*, 2011; MNRT, 1998; Salim *et al.*, 2012). Ecologically, the stingless bees are well recognized as potential providers of pollination services on wild plants and agricultural flowering crops (Kajobe, 2013; MNRT, 1998; Sommeijer, 1999).

1.2 Problem statement and justification

Few farmers keep stingless bees in Tanzania (FAO, 2009). However, most of stingless bee products are destructively harvested from feral colonies by honey hunters (Eardley, 2004; Eltz *et al.*, 2003; FAO, 2009). In spite of the socio-economic and ecological roles played by stingless bees in Tanzania, they have been poorly studied (Arias *et al.*, 2006; Eardley, 2004). There is scarce information about the stingless bee species of Tanzania, their distribution and abundances, nesting habits and habitats, honey productivity, and their potential threats to their population. This research, therefore, aimed at filling this information gap by studying the stingless bees of Ipembampazi Forest Reserve (IFR) in Sikonge District. The information gained from this study will be used to establish a database for future studies of stingless bees of Tanzania and promoting keeping of stingless bees and their conservation.

1.3 Objectives

1.3.1 General objective

The general objective of the study was to assess the diversity, status and threats of stingless bees of Ipembampazi Forest Reserve in Sikonge District, Tanzania.

1.3.2 Specific objectives

The specific objectives of this study were to:

- i. Identify the stingless bee species of Ipembampazi Forest Reserve.
- ii. Map the distribution pattern of stingless bees.
- iii. Assess the abundance of stingless bee nests.
- iv. Assess the nesting behaviour of stingless bees.
- v. Identify threats of the stingless bees.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 An overview of the stingless bees classification

Stingless bees are by far the most diverse, morphologically and behaviourally, of the eusocial corbiculate bees (Apini, Bombini and Meliponini) (Michener, 2000). They belong to the family Apidae grouped with the common honey bees, carpenter bees, orchid bees and bumble bees. The stingless bees differ from the common honey bee *Apis mellifera*, in that, the sting in stingless bees is atrophied and does not sting (Roubik, 2006). Stingless bees (Sub family Meliponinae) are classified into two tribes: Meliponini and Trigonini (Michener, 2000). The tribe Meliponini comprises 23 genera and 18 Sub-genera, which consist of 374 recognized species (Michener, 2000). The *Trigona* is the largest and most wide spread genera of the stingless bees. Meliponini are found extensively in the tropical and subtropical regions of the World (Eardley, 2004; Michener, 2000). The most recent account of stingless bee species of Tanzania was given by Eardley (2004), through his study could not represent a wide geographical coverage and vegetation types.

2.2 Stingless bee species diversity

Species diversity is a parameter of community structure which involves species richness and abundance for taxa. A number stingless bee species has been reported across the world. More than 400 stingless bee species have been described, and perhaps more to be identified (Michener, 2000). Cortopassi-Laurino *et al* (2006) reported about 45 species of stingless bees in Asia, while Eardley (2004) reported 19

species of stingless bees are found in Africa. The African stingless bee species comprising six genera: *Cleptotrigona*, *Liotrigona*, *Hypotrigona*, *Dactylurina*, *Meliponula* and *Plebeina* (Eardley, 2004). And more species are likely to be identified in the Sub-Sahara African countries (Eardley, 2004; Munyuli, 2012; Pauly and Vereecken, 2013). The highest species diversity of African stingless bees has been reported on the genus *Meliponula* with 9 species (Eardley, 2004). However, the stingless bee population and their diversity are declining worldwide mainly as a result of habitat loss for nesting and forage for food (Brosi *et al.*, 2008; Dietemann *et al.*, 2009; Eltz *et al.*, 2003; Goulson *et al.*, 2008; Liow *et al.*, 2001; Njoya, 2010; Roubik, 2006)

2.3 Stingless bee species distribution and abundances

Stingless bees are reported to occupy most of the tropical and sub-tropical regions of the world (Michener, 2000). The review of the distribution of the stingless bees in Africa (Figure 1) has recently been documented by Pauly and Vereecken (2013). Although many species have been described highly diverse, stingless bees are not equally distributed within the tropics. Their distribution is highly limited by availability of nesting sites (Roubik, 2006; Potts *et al.*, 2005) and food resources for foraging (Araujo *et al.*, 2004; Biesmeijer *et al.*, 2005; Eltz *et al.*, 2002; Liow *et al.*, 2001; Roubik, 2006). Availability of bee forage accounts for the critical factor limiting their diversity, nests abundance and spatial arrangements across varying habitat types (Biesmeijer *et al.*, 2005; Roubik, 2006). Due to their short flight capabilities among species and their dispersion across fragmented habitats, stingless bees have been greatly affected (Araujo *et al.*, 2004).

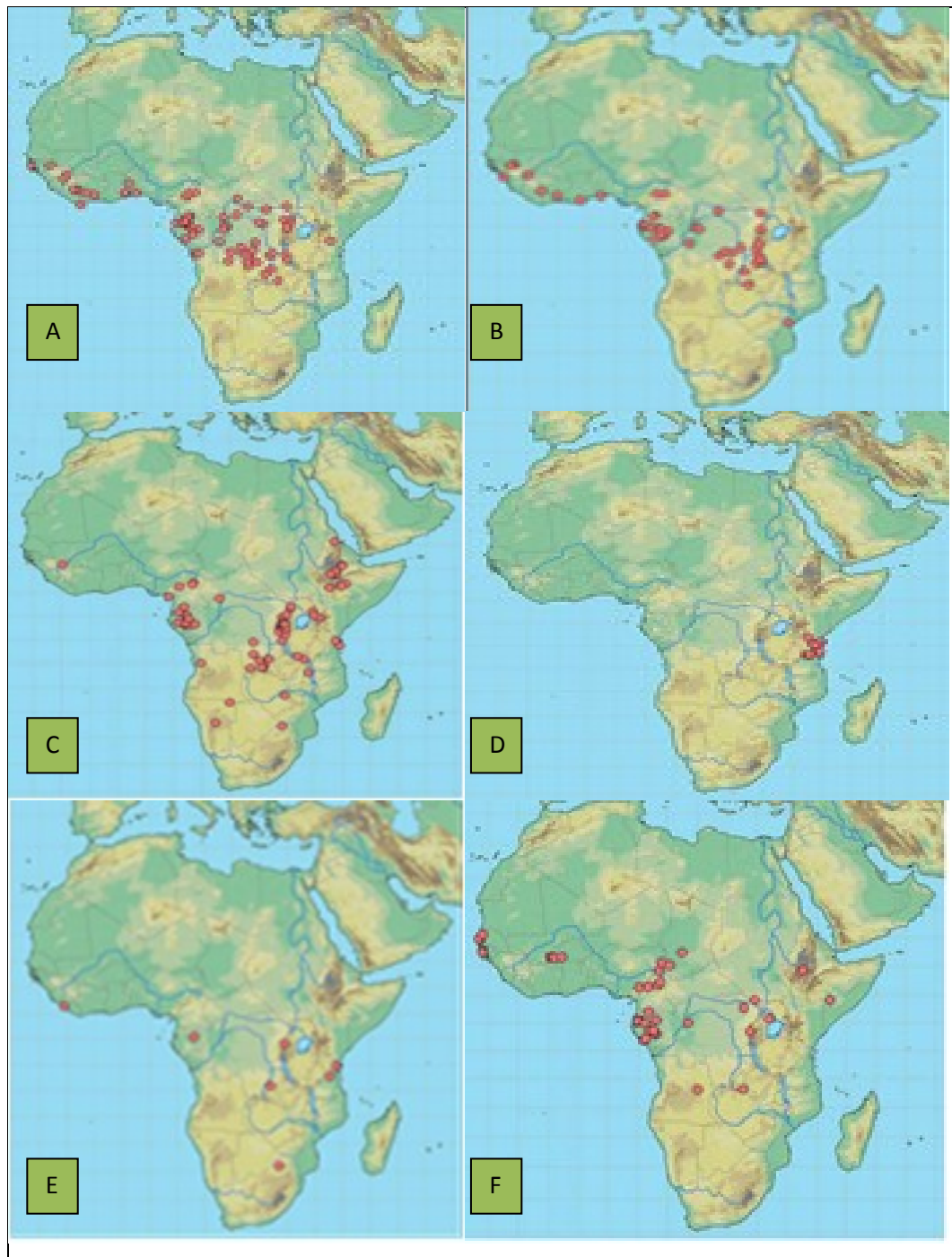


Figure 1: Distribution of some of the stingless bees of Africa.

Key: **A:** *Meliponula ferruginea*; **B:** *Meliponula (Axestotrigona) ogouensis*; **C:** *Meliponula beccarii*; **D:** *Dactylurina schmidti*; **E:** *Cleptotrigona cubiceps*; **F:** *Liotrigona bottegoi*

Source: (Pauly and Vereecken, 2013)

Such biological trait significantly influences their distribution, abundances and possible distinction of some species, hence limiting their spatial distribution by swarming, as the new colonies strongly dependent on the parental nest to establish (Araujo *et al.*, 2004; Roubik, 2006). Eltz *et al.* (2003) reported that, nests aggregation appears common among stingless bee species. Also, the clumps distribution of nests in some stingless bee species is a result of restricted nest sites distribution in the area (Eltz *et al.*, 2002). The highest nest density of 16.2 nests ha⁻¹ in stingless bees was reported by Eltz *et al.* (2002) in lowland dipterocarp forests of Sabah, in Malaysia, far exceeding the meliponinae density reported in other tropical countries.

According to Samejima *et al.* (2004), disturbances by human in natural habitats may have serious effects on both nests and species composition. But also, different species differs in their adaptation to human disturbances, hence influencing both nests and hence species distribution in stingless bees. Most stingless bee species occupy the tropical woody areas of Africa (Eardley *et al.*, 2010). Many fragmented habitats have limited stingless bees nests abundances and distribution due to limited flight distances on stingless bees to nesting sites and food (Siqueira *et al.*, 2012). Hence, degraded landscape connectivity tends to affect stingless bees nesting opportunity (Munyuli, 2011).

Stingless bee species abundances have also been described by many other factors. Some stingless bees have specialized nesting habitats hence, more affected by nesting substrate availability (Torné-Noguera *et al.*, 2014) than species that occupy

any immediate environments (Eardley *et al.*, 2010; Roubik, 2006). Therefore different bee species have differed ecological requirements to maintain their survival (Barbosa *et al.*, 2013; Eardley, 2004). Short flight distances (Siqueira *et al.*, 2012) and inability for their queens to fly (Cairns *et al.*, 2005), makes stingless bees highly susceptible to fire. Villanueva-g *et al.* (2005) also reported that, optimal cavity sizes are often selected by stingless bees to nest, though these kinds of cavities are not always abundant in an ecosystem. But, also, the effects due to error in the detecting stingless bee nests in natural habitats may account for the low nest abundances observed in natural habitats (Dorazio and Connor 2014).

2.4 Stingless bees nesting behaviour

2.4.1 Nest architecture of stingless bees

Nests of stingless bees provide an important role to the life of social insects by protecting bees against environmental perturbations and other nests maintain microclimate that provide relative stable temperature (Pavithra *et al.*, 2013). Several hundreds of stingless bee species existing on earth differ considerably in colony size, body size and colour (Michener, 2000). These features greatly affect the bees nesting characteristics. Hence, stingless bee species have shown considerable variation in their nest architecture, which ranges in design from brood cells arrangement in horizontal combs or clusters, cavities from where nests area constructed (some within crevices in trees or in other nesting substrates or in the open (Roubik, 2006). The attributes of the nests are therefore considered useful information in taxonomic studies (Kajobe, 2007; Njoya, 2010; Roubik, 2006). The main nest construction materials is cerumen, “a mixture of beeswax and plant resins” was the main nest building materials (Sommeijer, (1999).

High variations occurred in the arrangement of the broods occur among stingless bees. They have broods that are arranged in horizontal or vertical combs, semi combs or in cluster cells (Njoya, 2010). However, the nest architecture in stingless bees can be modified to various kinds of cavities depending on the nest condition (Njoya, 2010). The bees have evolved adaptive nest constructions strategies which have resulted in sophisticated nest architecture in many species while others lack certain structural components. The clusters of brood cells is common in *Hypotrigona* species (Barbosa *et al.*, 2013). Some stingless bees such as *M. ferruginea* and *P. hildebrandti* have their broods arranged in either horizontal or vertical combs separated from the storage pots by an Involucrum layer which serves to protect the brood cells and control microclimate within the brood chamber (Njoya, 2010). The Involucrum layer is however not found in *Hypotrigona species* (Barbosa *et al.*, 2013). Most of the brood combs have connective pillars that separate adjacent broods, very common in *M. ferruginea* and occasionally found or absent in some *Hypotrigona* species. Stingless bee pillars allowing stingless bees to move easily between adjacent combs, but also support food storage pots and connect nests to the walls of the cavities (Roubik, 2006; Sommeijer, 1999).

Their nest connects to their external environment through the open external entrance tube. The entrance tube vary greatly in the size, shape, camouflage and firmness of the entrance tube indicated an adaptive behaviour to defense (Njoya, 2010). The gluing resin droplets on and around the entrance tubes also acts as a defensive strategy by stingless bee species. It is reported by Njoya, (2010), the resin deposits act as a barrier to intruders. It is used to immobilize them. The amount of propolis/

resins to be used may also be influenced by the colony requirements and availability in natural habitats Pavithra *et al.*, (2013).

Nests aggregation in stingless bees is common, but the underlying reasons for such behaviour in stingless bees is poorly understood (Eltz *et al.*, 2003). Limited availability of suitable nesting sites in degraded areas (Eltz *et al.*, 2003; Siqueira *et al.*, 2012), as a result of chemical cues released by scout bees of stingless bees. Also, an aggregation might be related to how new nests are located by scouts bees. According to Eltz *et al.* (2003) nests allocation can be guided by specific odor of bee broods or nest material (resin) showing suitability of a particular nest tree or by cues that are provided by colonies of other species. The kind of behaviour favour colony aggregation in bees.

2.4.2 Nesting substrates used by stingless bees

The nests of stingless bees are immobile fixtures, potentially long-lived, where the bees live and reproduce (Roubik, 2006). The nesting sites provide fundamental conditions for stingless bee survival. Their absence severely impacts their reproductive division of colonies and dispersion (Siqueira *et al.*, 2012). The stingless bees are highly diverse, and use different types of substrates for nesting in a diverse habitats (Eardley *et al.*, 2010; Roubik, 2006; Venturieri, 2009). For example, nests of some species have been reported in cavities such as walls of mud houses, window frames, door frames, roofing timber, electric sockets, dry drainage pipes, electric and telephone poles, and cavities in trees (Njoya, 2010). Also, stingless bees have been found in underground hollows in termite mounds and opportunistically nest in any

immediate environment (Eardley *et al.*, 2010; Eltz *et al.*, 2003; Roubik, 2006). Most prefer nesting in existing cavities of living woody plants to build their nests (Barbosa *et al.*, 2013; Carvalho-zilse and Nunes-silva, 2012; Cortopassi-Laurino *et al.*, 2006; Eardley *et al.*, 2010; Martins *et al.*, 2004). Some stingless bee species such as *Dactylurina* species often nest in the fork between tree branches in exposed positions (Eardley, 2004; Eardley *et al.*, 2010; Sommeijer, 1999). Also, Some *Meliponula* species also known to have nests in the ground (Eardley *et al.*, 2010; Roubik, 2006) as the case of *Plebeina hildebrandti* which prefer nesting in termite mounds (Eardley *et al.*, 2010). According to Barbosa *et al.* (2013), underground nests are relatively rare among stingless bees.

The *Hypotrigona* species and *Liotrigona* species have been found to nest in small tree cavities or more common in walls of buildings. Most stingless bee nests are found in cavities of large varieties of trees at varying heights from the ground (Eltz *et al.*, 2003). Most prefer cavities in trees with large volumes preferably over 50cm in diameter sizes for nesting (Eltz *et al.*, 2003; Venturieri, 2009).

2.5 Threats to stingless bees

It is crucial to understand how land use changes are affecting the bee communities. The current changes in diversity worldwide is partly driven by anthropogenic factors (Boontop *et al.*, 2008; Coll *et al.*, 2010; Eardley *et al.*, 2009; Potts *et al.*, 2005) and other natural forces (Coll *et al.*, 2010) including climate changes. The loss of habitats is a major source of reported declining bee species diversity (Coll *et al.*, 2010; Boontop *et al.*, 2008; Eardley *et al.*, 2009; Potts *et al.* 2005; Villanueva-g *et*

al., 2005). Timber logging (Cairns *et al.*, 2005; Eltz *et al.*, 2002), wild fire and grazing cattle (Black *et al.*, 2009), beekeeping practices and honey hunting (Cortopassi-Laurino *et al.*, 2006; Eardley, 2004; Reyes-gonzález *et al.*, 2014; Roubik, 2006; Villanueva-g *et al.*, 2005) are important factors contributing to habitat loss and forest fragmentation.

According to Black *et al.* (2009), grazing has been used as a valuable tool for managing shrubs and tree succession to encourage growth of nectar rich plants and creating potential nesting habitats. Grazing in IFR is not allowed. On the other hand, ecologically, grazing can be destructive, destroying many bee nest sites and reduce forage by stingless bees and other pollinators (Black *et al.*, 2009). Such alternation that can be caused by grazing animals negatively affects the entire ecosystem for both plants and stingless bees (Munyuli, 2011).

As the case of many countries in Africa, honey extraction from stingless bees is mostly destructive (Eardley, 2004; Reyes-gonzález *et al.*, 2014; Roubik, 2006; Sommeijer, 1999). Many stingless bee nests are destroyed and thus loss of many bee colonies in natural forests (Cortopassi-Laurino *et al.*, 2006; Villanueva-g *et al.*, 2005). The effect on nested trees is considered selective, where only few species of trees are affected by hunting (Cairns *et al.*, 2005; Potts *et al.*, 2005). Removal of potential nesting substrates affect stingless bees nest density and abundance in the natural habitats (Carvalho-zilse and Nunes-silva, 2012, Roubik, 2006). Similarly, Liow *et al.* (2001) found low species diversity in disturbed areas. Unprotected nests due to honey hunting suffered considerable threat from other animals including honey badgers (*Mellivora capensis*) and birds (Eltz *et al.*, 2001; Roubik, 2006).

Selective logging affects several important nesting tree species used by stingless bees (Cairns *et al.*, 2005; Eltz *et al.*, 2002; Ranius *et al.*, 2009). In natural habitats, many of the commercially logged trees are also important nesting substrates for stingless bees and other pollinator insects. Therefore, nests are frequently destroyed when trees are felled down for timber, though fewer studies have quantified the loss caused by logging (Eltz *et al.*, 2002). Many stingless bees nests in nature are in danger of depletion by logging practices (Cortopassi-Laurino *et al.*, 2006), of which their removal particularly of large trees seriously endanger the survival of stingless bees. Unique habitats for nesting and bee forage not provided by the young trees are also declining (Samejima *et al.*, 2004). In the in the Amazonian stingless bees of South America, commercialization of wood for timber resulted into reduction in stingless bee nesting cavities (Venturieri 2009). This findings has been in agreement by others (Eltz *et al.*, 2003; Ranius *et al.*, 2009; Samejima *et al.*, 2004; Siqueira *et al.*, 2012), that logging significantly contribute to habitat loss. It also have been found to affect reproductive division of colonies, colonies dispersion as a result of habitat fragmentation, and loss of suitable habitats for nesting (Samejima *et al.*, 2004; Siqueira *et al.*, 2012; Villanueva-g *et al.*, 2005). Samejima *et al.* (2004) found that human disturbances positively affected tree density of large trees and hence the stingless bee densities in tropical rainforest, in Malaysia.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

The study was conducted in Ipembampazi Forest Reserve (IFR). IFR is in Sikonge District, Tabora Region. It is located between 5°48" and 6°21" S latitude, and 32°48" and 33°18" E longitude. It covers an area of about 133,120 hectares bordered by Swangala FR in the West, Itulu Hill FR in the South and Nyahua Mbuga FR in the East, all in Sikonge District (Figure 2). The district has a total forest reserve area of about 1,984,560 hectares, about 95% of the District total area [<http://sikongedistrictcouncil.go.tz/?q=node/9>].

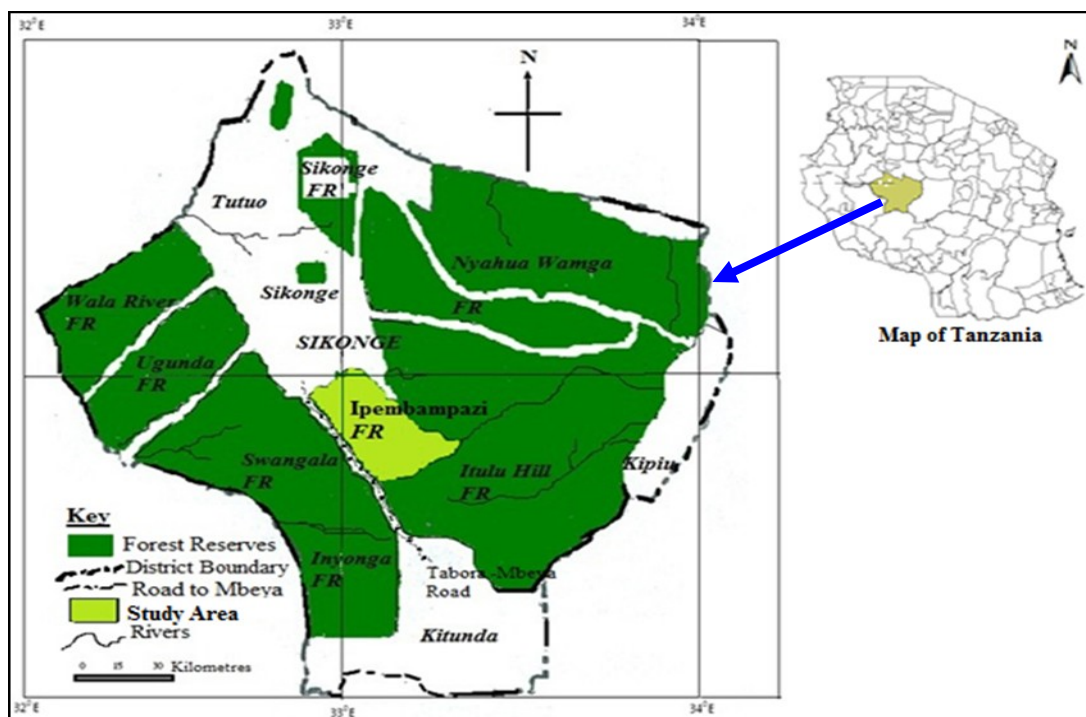


Figure 2: Map of Sikonge District showing the study area.

3.1.2 Topography and climate of the study area

The reserve is characterized by flat terrain which covers most of the area. The noticeable hills within the forest reserve in some areas lie at an elevation ranging from 1100m to 1300m [<http://sikongedistrictcouncil.go.tz/?q=node/9>]. The characteristic prominent seasonal swampy known as “Mbuga” in the southern parts of the reserve is very common. Annual maximum rainfall is about 900 mm and minimum at 600 mm. Rainfall starts in October and ends up in April with its peak in December. The daily temperature of the area ranges between 22° - 32° C.

3.1.3 Vegetation types

The vegetation of the Ipembampazi Forest Reserve is primarily dry miombo woodland. The most dominant species were from the family Caesalpiniaceae, with the genera *Brachystegia* and *Julbernardia* dominating (Munishi *et al.*, 2011). *Brachystegia spiciformis* and *Julbernardia globiflora* are the most dominant trees. Other trees found in the reserve include *Pericopsis angolensis*, *Erythrophleum africanum*, *Diospyros mespiliformis*, *Acacia royumae*, *Mimusops densiflora*, *Terminalia sericea*, *Burkea africana*, *Pterocarpus angolensis*, *Pseudolachnostylis maprouneifolia*, *Hymenocardia ulmoides* and *Commiphora* species. In the South, the forest landscape is also characterized by scattered species of *Acacia* and *Combretum* dominating the lowland areas which experience annual water logging conditions when it rains and layers of tall *Hyparrhenia* grass.

3.1.4 Human activities

The miombo woodland in IFR provides different types of ecosystem goods and services as an important source of livelihood for the people in the surrounding areas.

Goods such as timber, traditional hives and honey hunting are among common activities in the reserve. The services accrued from the reserve include game hunting in hunting quotas, grazing grounds for wild animals and occasionally illegal domestication of cattle by livestock keepers. Despite the fact that, it is illegal to establishing human settlement or livestock grazing in protected areas, such activities are still common in IFR.

3.1.5 Research materials and equipment used during the study

Various equipment and materials were used for data collection. Tape measures were used in setting plots along transects. Global Positioning Systems [GPS] was used to geo-reference study plots. Data collection forms (Appendix 1), notebook and pencils were used to take data on stingless bees. Card boards for pinning sample specimens of stingless bees and vials containing 70% ethyl alcohol were used to preserve sample specimens. A ruler and tape measure were used to measure stingless bee nest features (entrance tube length and width size) and nest height from the ground. Digital Camera was used for taking photographs of nest architecture, nesting tree species, environmental disturbances and other features to supplement information captured through other methods.

3.2 Methods

3.2.1 Sampling design

There is no standard protocol for sampling bee communities (Brosi *et al.*, 2008). In this study, systematic sampling was employed alongside opportunistic sampling to capture information relevant to this study.

3.2.2 Systematic sampling

Eight sampling transects of approximately 9 kilometers long were used for stingless bees study at IFR. Transects were laid parallel to each other approximately five kilometers apart. In each transect, ten rectangular plots of 20x40 m (0.08ha) were established, spaced 1 kilometer apart lying eastwards from the forest edge striding along the Tabora – Mbeya road. A total of 80 sample plots were used representing a sampling intensity of 0.003% of the IFR.

3.2.3 Data collection methods

In this study, direct observation was employed for data collection (Njau *et al.*, 2009; Pavithra *et al.*, 2013). The stingless bee nests were visually searched with the help of experienced indigenous honey hunters (Plate 1), a method adopted from Kajobe (2007; 2013). A work force of two honey hunters was employed to aid detection of stingless bee nests. A time scale of at least 25 minutes was spent in each plot to observe and search for stingless bee nests. However, additional time was spent when samples of bees were to be collected. A tree-to-tree searches within each plot and from other potential nesting substrates was employed, a method used by Njau *et al.* (2009) studying on *Apis mellifera* bees in Tanzania. The records of observations were taken and specimens of stingless bees encountered collected. In each plot and along the transect, data on the stingless bee species was collected from different variables such as nest distribution, abundances, nesting sites and nest attributes, and threats on them and their habitats.



Plate 1: Searching for stingless bee nests.

3.2.3.1 Stingless bee species diversity

The stingless bee nests for live and destroyed colonies were recorded in each plot. The stingless bee species were identified using local names with the help honey hunters at the site. Sample specimens of bees were collected from colony sited before they were pinned and sent to Agricultural Research Council (ARC) in Queenswood, Pretoria, South Africa for identification.

3.2.3.2 Stingless bee species distribution and abundances

Geographical locations of the sampled plots and plots with destroyed nests and observed live stingless bee colonies were recorded with Global Positioning System (GPS). The coordinates were used to map the bee species distribution pattern in the study area. The nests for each stingless bee species encountered were counted and recorded.

3.2.3.3 Stingless bees nesting behaviour

To assess the stingless bees nesting behaviour, direct observation was used (Pavithra *et al.*, 2013). The information such as nest sites and their attributes, nest architecture and nest or colony height from the ground were recorded. A height from the ground was measured by using measuring tape. Further, the stingless bee external nest architectures records were attributed to entrance length, entrance diameter and shape while the nests internal features based on nest colour, nest enclosure, storage pots, pots and brood arrangement patterns and construction materials used.

3.2.3.4 Threats to stingless bees

Data on potential threats to the bees and their habitats was collected by direct observation. Various factors that threaten bee resources (bee colonies, nest sites and forage) were recorded.

3.2.4 Data analysis

3.2.4.1 Stingless bee species

The bee species were identified to scientific names by Dr. Connal Eardley, a bee taxonomist from Agricultural Research Council (ARC) in Queenswood, Pretoria, South Africa. The species diversity indices: Shannon and Weiner's Diversity Index (H') and Simpson's Index (D) were calculated and rank species abundance using R-software in VEGAN package for biodiversity. The indices are ideal to obtain species richness and dominance or evenness. Diversity Simpson's Index was expressed as $(1-D)$, as a measure of the variance of the species abundances distribution (Magurran, 2004). The stingless bee species richness estimation were expressed as

numerical species richness which is the number of species per specified number of individuals (Magurran, 2004). The Shannon index was calculated from the equation:

$$H' = \sum_{i=1}^S - (P_i * \ln P_i) \quad \text{Whereas;}$$

H' = The Shannon diversity index is the diversity of the total population of individuals, P_i = the proportion of the entire population made up of the i^{th} species, S = numbers of species encountered, \sum = sum from species 1 to species S and (\ln) = the natural logarithm of the number.

The Simpson's Index (D) was calculated from the equation:

$$D = \sum (P_i)^2 \quad \text{Whereas;}$$

D is a measure of dominance, and as D increases, diversity (in the sense of evenness) decreases. The index is therefore usually expressed as the reciprocal $1-D$ or $1/D$. $1-D$ provides an intuitive proportional measure of diversity.

3.2.4.2 Species distribution patterns

The precise location of each plots nested by stingless bee species (for living colonies) and destroyed nests were mapped to determine patterns of species dispersion a method used by Siqueira *et al.* (2012). The nests position registered as geographical coordinate with Global Positioning System (GPS) from observations were then mapped with ArcView GIS to determine stingless bee spatial patterns of nests in the study area.

3.2.4.3 Stingless bee species abundances

Stingless bee nests abundance for each species was counted. The percentages of plots occupied by stingless bee species were calculated to obtain an index of abundance (Buckland *et al.*, 2005; Magurran, 2004). The analysis considered that species abundance comes in discrete units called individuals. The species abundances though can be visualized in a number of ways, but rank abundance plot for individual species is considered most informative method. However, to provide comparison between different data sets, percentage abundances were often used (Buckland *et al.*, 2005; Magurran, 2004). The dominant species in each habitat was based on the species that its relative nest abundance numerically predominates (Boontop *et al.*, 2008).

3.2.4.4 Nesting behaviour of stingless bees

The type of nesting was cross tabulated. Information on the nesting substrate, nests location, nest architecture, and materials used was summarized using cross tabulation.

3.2.4.5 Threats to stingless bees

Threats to stingless bees were summed up and tabulated. The information was supplemented by photographs.

CHAPTER FOUR

4.0 RESULTS

4.1 Diversity of stingless bees

Three stingless bee species were recorded in Ipembampazi Forest Reserve (Table 2). The species include *Meliponula ferruginea* Lepeletier, *Hypotrigona ruspalii* Magretti and *Plebeina hildebrandti* Friese belonging to three genera: *Meliponula*, *Hypotrigona* and *Plebeina* respectively. The Shannon-Wiener diversity index showed low species diversity ($H' = 0.78$) and richness for stingless bees in IFR. *Meliponula ferruginea* was the most abundant (n=31, 51.7%), followed by *Hypotrigona ruspalii* (n=29, 48.3%) as presented in Table 2 and Appendix 2.

Table 2: Stingless bee species

S/N	Species	Vernacular name (Nyamwezi)	Nest abundance (N, %)	Nests density N/ha
1	<i>Meliponula ferruginea</i>	Upula	31 (51.7%)	4.8 ha ⁻¹
2	<i>Hypotrigona ruspalii</i>	Pula punze/ Mpunze	29 (48.3%)	4.5 ha ⁻¹
3	<i>Plebeina hildebrandti</i> *	Upula	*	*
	Total		60 (100%)	9.3 ha⁻¹
	H' (Diversity Index)		0.78	
	D (Diversity index)		0.48	

* Nests not observed, bee samples were collected at a water hole

The *Plebeina hildebrandti* species was the least abundant of all the three species identified. The higher nest density was observed on *Meliponula ferruginea* (4.8 nests

ha⁻¹) and *H. ruspilii* (4.5 nests ha⁻¹) as presented in Table 2. The species richness for all the three species is as indicated by the species accumulation curve in Figure 3. The species diversity cumulative curve showed no signs of leveling off, (haven't reached an asymptote), indicating that more species are likely to be identified in the studied area (Figure 3).

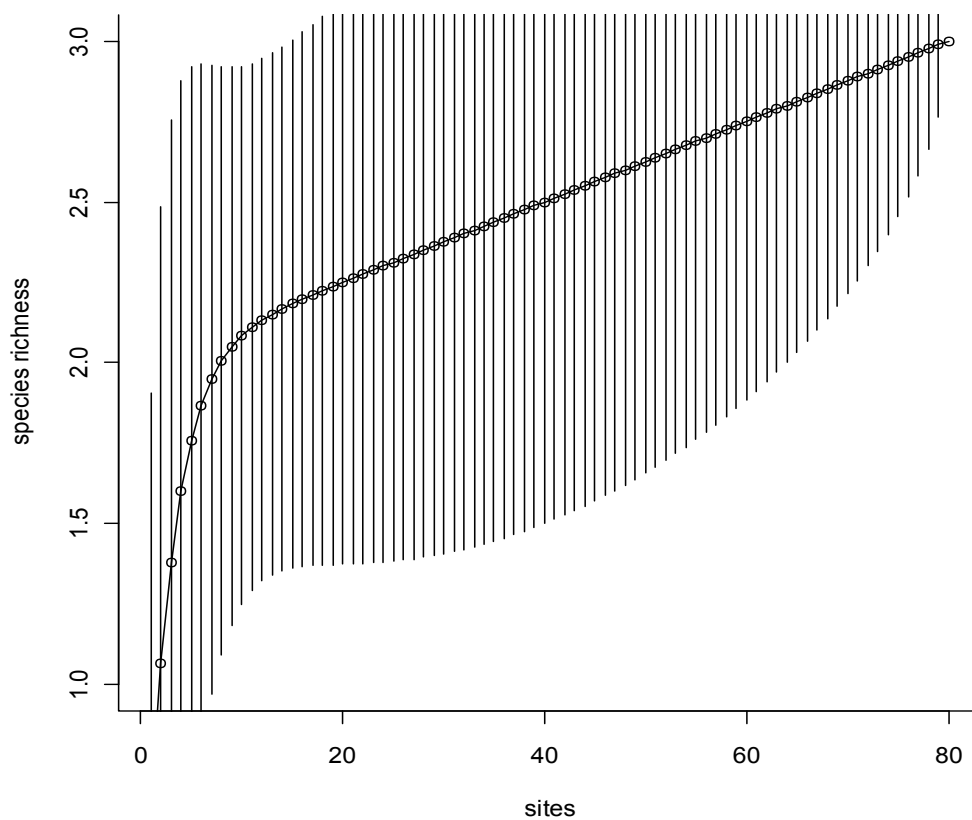


Figure 3: Species diversity cumulative curve showing the total number of species richness in IFR.

4.2 Distribution of stingless bee species in IFR

Only nests of stingless bee species *M. ferruginea* and *H. ruspilii* were observed within the reserve (Appendix 2). *Plebeina hildebrandti* species was observed only on one locality, in a water hole. Overall, the stingless bee nests and their respective species were unevenly distributed (Figure 4). *M. ferruginea* and *H. ruspilii* were widely distributed as compared to *P. hildebrandti*. A distribution map indicates the

occurrence of living stingless bee colonies and destroyed nests of all species recorded in studied area (Figure 4). About 67.7% (n=21) of all *M. ferruginea* colonies (n=31) with only few living undestroyed nests.

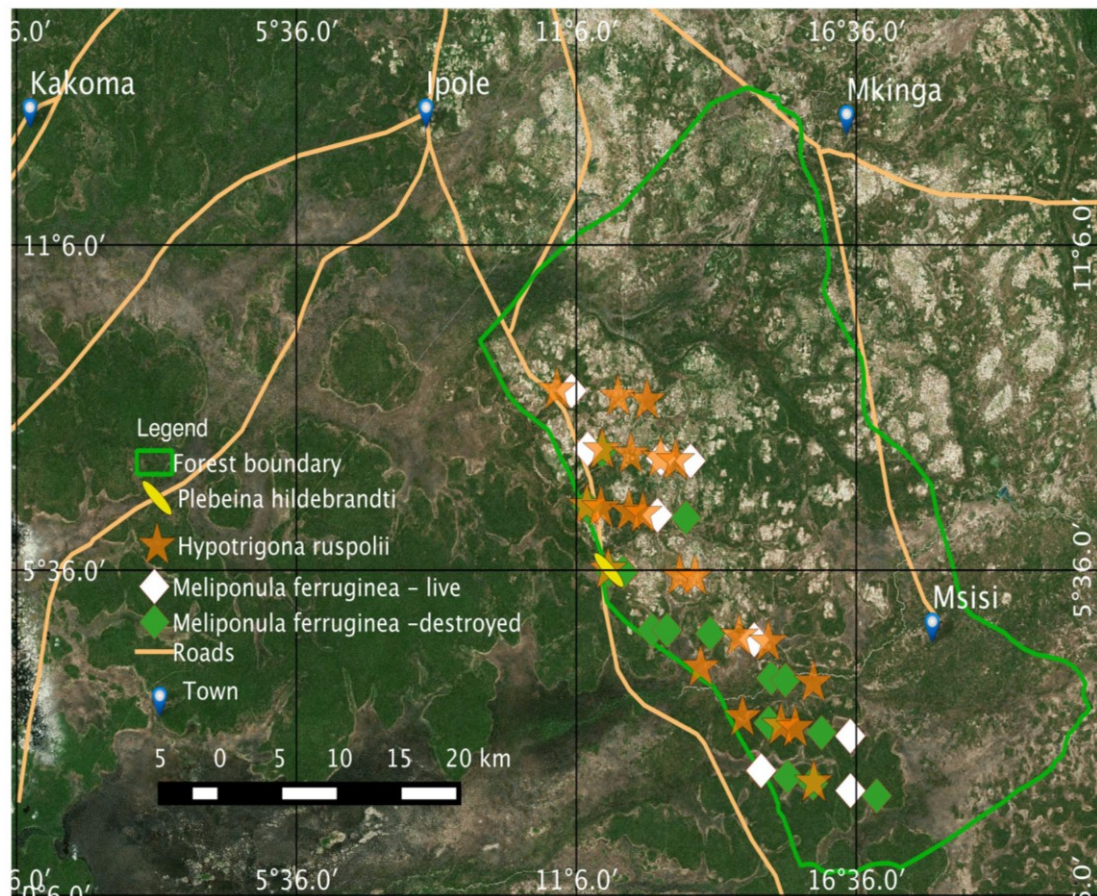


Figure 4: Map showing the distribution of stingless bees in Ipembampazi Forest Reserve.

4.3 Stingless bee species abundances

The relative abundances of stingless bee species of IFR are shown in Table 3. *Meliponula ferruginea* was the most abundant species with the highest frequency of occurrence 26 (52%), followed by *Hypotrigona ruspilii* which was ranked second in abundance 23 (46%). The *Plebeina hildebrandti* though its nest was not seen in this

study, but the bee samples were opportunistically collected in the study area, occurring only once (2%) of all stingless bees encounters.

Table 3: Stingless bee species abundance in Ipembampazi Forest Reserve

S/N	Taxon	Species relative abundance	Rank	Proportions
1	<i>Meliponula ferruginea</i>	26	1	52.0%
2	<i>Hypotrigona ruspalii</i>	23	2	46.0%
3	<i>Plebeina hildebrandti</i>	1	3	2.0%
	Total	50		100%

The nests and colony abundances for all species examined during the survey were rather low but relatively higher species abundances were observed near the forest edges as compared to interior forests (Fig. 5a-c, Appendix 3).

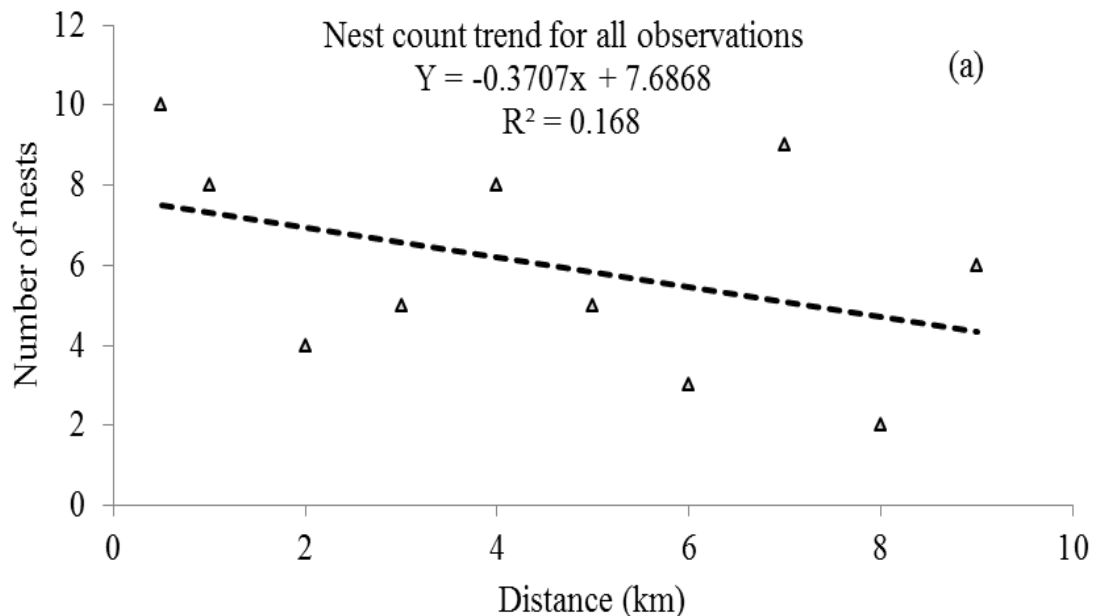


Figure 5a: Relationship between the frequency of encountered stingless bee species (*M. ferruginea*, *H. ruspalii* and *P. hildebrandti*) and the distance from the road.

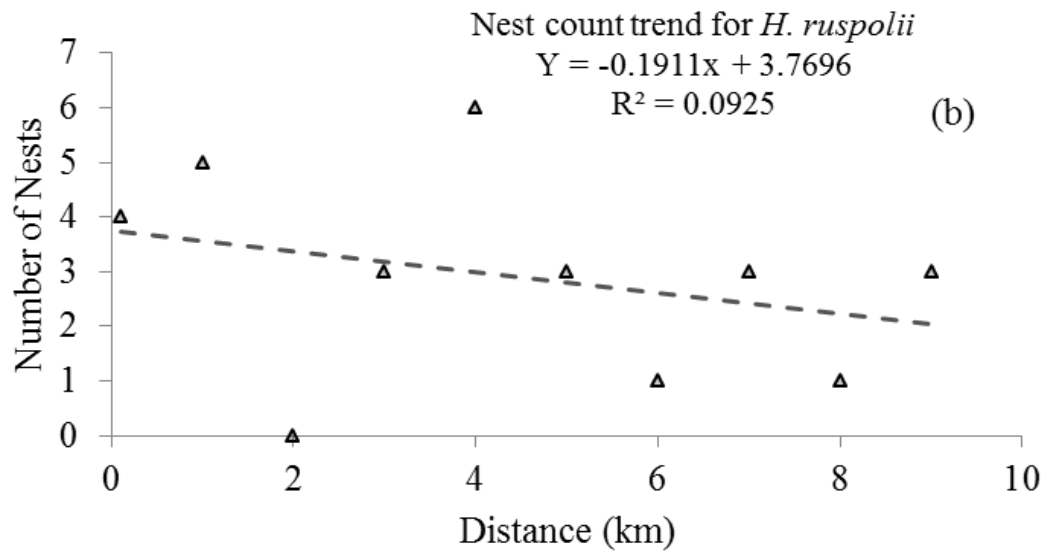


Figure 5b: Relationship between the abundances of *Hypotrigona ruspalii* nests and distance from the road.

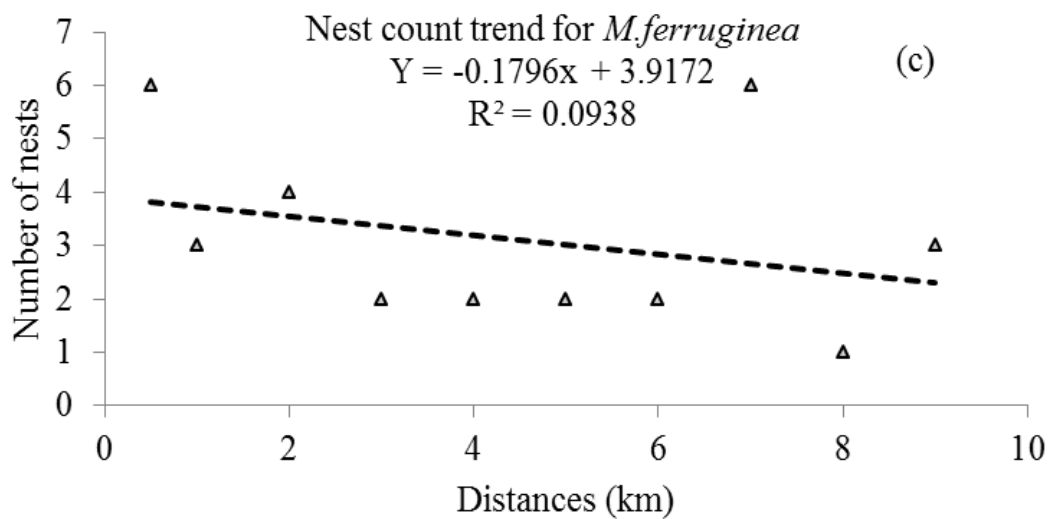


Figure 5c: Relationship between the abundances of *M. ferruginea* nests (live and destroyed colonies) and distance from the road.

4.4 Stingless bee nesting behaviour

4.4.1 Nest architecture

The nest characteristics of *H. ruspalii*, *M. ferruginea* and *P. hildebrandti* are presented in Table 4 and as Plate 2. The nest for individual species of *H. ruspalii* and

M. ferruginea differ in various ways from the external and internal nest architecture as in Table 4 and Plate 2. Since the nest of *P. hildebrandti* was not observed in the field, the described features of nest architecture were based on literature reviewed.

Table 4a: Nest attributes of *Hypotrigona ruspolii*

Nesting attributes	Observations
Nest colour	Brown or yellow
Nest enclosure	Involucrum to enclose broods not present
Storage pots shape	Round
Brood cells	Constructed in a loosely placed cluster rather than in layers Brood cells have similar size and shape
Connecting pillars	Present, but were absent in some. Where present was holding brood nest, connecting brood cells or food storage pots.
Propolis deposit	Present
Entrance shape	Funnel, or Circular
Entrance tube length	1.8 to 25.2mm, average: 11.6mm
Entrance size (diameter)	Average: 3mm

Table 4b: Nest attributes of *Meliponula ferruginea*

Nest attributes	Observations
Nest colour	Brown to dark brown
Nest enclosure	Broods enclosed in a multilayer Involucrum sheath
Storage pots	Food storage pots placed besides broods, but never mixed up Most had round shape
Brood cells	Most Broods consists of many horizontal layers (combs), with open cells facing upwards Queen broods isolated from other brood cells
Connecting pillars	Present separating adjacent brood combs
Propolis deposit	Present at varying amount at the entrance and inside the nest
Entrance shape	Most had circular, some asymmetrical shape
Entrance tube length	Range: 1 to 10mm, average:1.1mm
Entrance size (diameter)	Average: 11mm

Table 4c: Nest attributes of *Plebeina hildebrandti*

Nesting attributes	Observations
Nest enclosure	Broods enclosed in a multilayer Involucrum sheath and batumen
Food storage pots	Food storage pots placed besides broods, but never mixed up
Entrance tube length	Variable
Connecting pillars	Present, connect nest to the cavity and brood combs

Source: (Njoya, 2010)



Plate 2: Nest architecture of the stingless bee *H. ruspolii*. A-F: External nest architecture showing Entrance opening (in White arrow), Entrance tube (Blue arrow); G-H: Internal architecture Cluster broods (Red arrow), food storage pots (Green arrow).

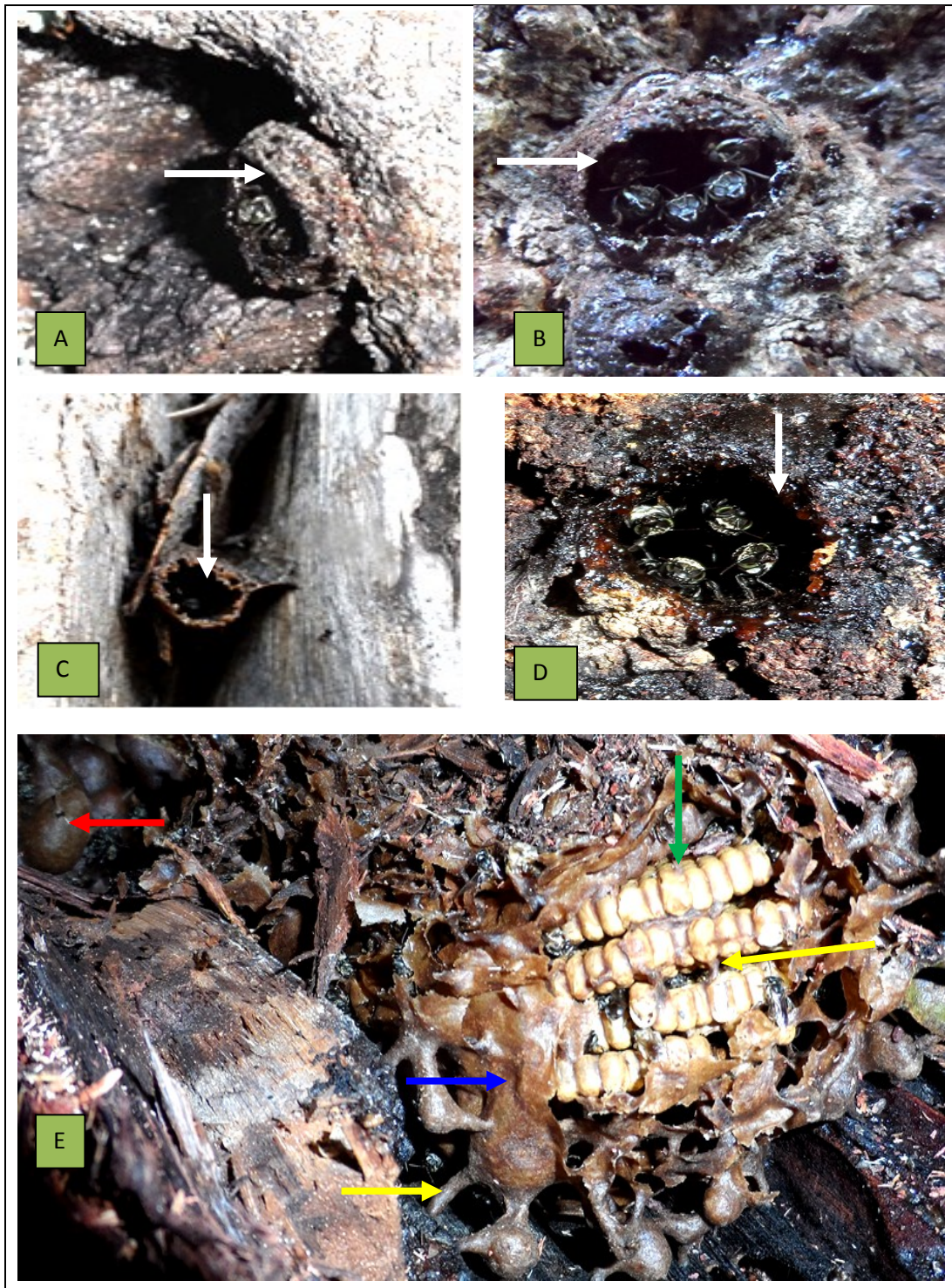


Plate 3: Nest architecture of the stingless bee *M. ferruginea*.

A-D: Nest entrance (White arrow), E: Internal architecture of *M. ferruginea* nest showing Brood combs (Green arrow), brood nest covering sheath (Involucrum) (Blue arrow), food storage pots (Red arrow) and pillars (Yellow arrow).

4.4.2 Nesting substrate for stingless bees

Two species of stingless bees *M. ferruginea* and *H. ruspolii* were recorded nesting in different tree species (Table 5a, Appendix 4). The stingless bee nests were found in seven species of trees (Table 5a). Of these, three species made the majority (about 90% of stingless bee nests, N=60) were in *Pericopsis angolensis* (46.7%), *Erythrophleum africanum* (23.3%) and *Julbernardia globiflora* (18.3%). The bees preferred nesting in living tree trunks (Appendix 5), though many living trees previously occupied by *M. ferruginea* were cut down to extract stingless bee honey rather than tree's natural death (Table 5a and Appendix 5). Other reported nesting trees in IFR are provided in Table 5b. The third species, the *P. hildebrandti* is reported to nests in termites mounds (Eardley, 2004; Njoya, 2010).

Table 5a: Preferred tree species for nesting by stingless bee species

Stingless bee species	Status of tree	Number of nests encountered per tree species							Total Nests (N)
		<i>Pericopsis angolensis</i>	<i>Erythrophleum africanum</i>	<i>Julbernardia globiflora</i>	<i>Diospyros mespiliformis</i>	<i>Combretum molle</i>	<i>Brachystegia boehmii</i>	<i>Combretum zeyheri</i>	
<i>M. ferruginea</i>	Living	2	4	1	0	1	0	0	8
	Dead	9	6	7	1	0	0	0	23
<i>H. ruspolii</i>	Living	6	4	3	1	0	1	2	17
	Dead	11	0	0	1	0	0	0	12
<i>P. hildebrandti</i>	*	*	*	*	*	*	*	*	*
Total Nests		28	14	11	3	1	1	2	60
Percent (%)		46.7	23.3	18.3	5	1.7	1.7	3.3	

* The stingless bee species nests in the ground, in termite mounds (Eardley, 2004)

Table 5b: Other tree species reported to be nested by stingless bees

S/N	Species	Family
1	<i>Commiphora sp</i>	Burseraceae
2	<i>Pseudolachnostylis maprouneifolia</i>	Phyllanthaceae
3	<i>Combretum fragrans</i>	Combretaceae
4	<i>Pterocarpus angolensis</i>	Papilionaceae
5	<i>Burkea africana</i>	Caesalpiaceae
6	<i>Hymenocardia ulmoides</i>	Phyllanthaceae
7	<i>Terminalia sericea</i>	Combretaceae
8	<i>Mimusops densiflora</i>	Sapotaceae
9	<i>Acacia roovumae</i>	Mimosaceae

4.4.3 Height preferences for tree nesting stingless bee species

Stingless bees of IFR were found nesting at varying heights. On average, most nests had nests located at about 3.5m high from the ground (Table 6 and Appendix 2). The highest and the lowest nest position were recorded in *M. ferruginea*, indicating a wider nesting range on a substrate as compared to *H. ruspilii*. The *P. hildebrandti* species is known to have underground nest.

Table 6: Frequency of encounters of nests / or species and heights preferences

Species	Stingless bee nests (N)	Ground nests	Nests in tree cavities	Height of nests cavity (m)		
				Mean	Minimum	Maximum
<i>H. ruspilii</i>	29	-	29	3.2	1.3	7.0
<i>M. Ferruginea</i>	31	-	31	3.8	0.2	7.6
<i>P. hildebrandti</i>	*	1*		*	*	*
Total	60	1	60			

*Stingless bee species that have subterranean nest

4.5 Threats to stingless bees

Five threats to stingless bees of IFR were recorded (Table 7 and Plate 4). Most of the threats were anthropogenic induced.

Table 7: Threats to stingless bees

Threat category	Observations	Number of encounters	Percent (%)	Bee species most affected
Forest fire	Burnt sites	50	63	All
Honey hunting	Destroyed nests	21	26	<i>M. ferruginea</i>
Timber logging	Saw pits	8	10	<i>M. ferruginea</i>
Grazing cattle	Kraal	7	9	All
Tree debarking	Debarked trees	3	4	All

4.5.1 Forest fire and livestock grazing

A total of 50 (63%) of all plots studied were burnt and 7 kraals for keeping cattle (9%) were recorded in the area. The potential and levels of habitat loss due to fires and grazing in the reserve is presented in Table 7 and Plate 4.

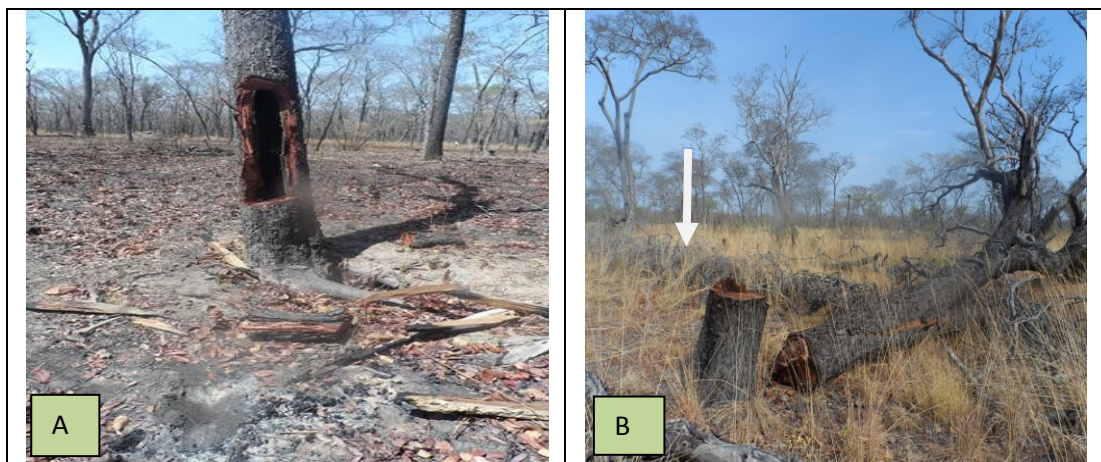


Plate 4: Threats to stingless bees of IFR; (A) Forest fires, (B) Livestock grazing (the arrow shows an abandoned cattle kraal within the reserve).

4.5.2 Honey hunting

Honey hunting for stingless bee honey had severe effects on stingless bees and large living trees (Plate 5). A total of 21 (27.7%) colonies of *Meliponula* species their cavities and nesting trees were destroyed or trees completely cut to exploit stingless bee honey. *M. ferruginea* were the most threatened species. Nests at higher heights from the grounds in tree trunks or branches were accessed by cutting down trees. Trees with colonies at lower heights were partly damaged to extract honey, killing bee colonies and leaving cavities unsuitable to be re-used by stingless bees (Plate 5).



Plate 5: Honey hunting in Ipembampazi Forest Reserve. Nests destruction by hunters from tree nesting stingless bees (A), Chopped *Pericopsis angolensis* (B), *Erythrophleum africanum* (C-D) and *Julbernardia globiflora* trees (E).

4.5.3 Logging and tree debarking

Trees that provide nesting habitats and forage were frequently found cut down or damaged for timber and hives construction (Plate 6). Tree species mostly extracted in the area were *Pericopsis angolensis*, *Pterocarpus angolensis*, *Julbernardia globiflora*, and *Brachystegia spiciformis*. Trees were chopped down or debarked for bark hives (Plate 6). *Julbernardia globiflora* was the most preferred tree for bark hive construction (Plate 6 C-E).

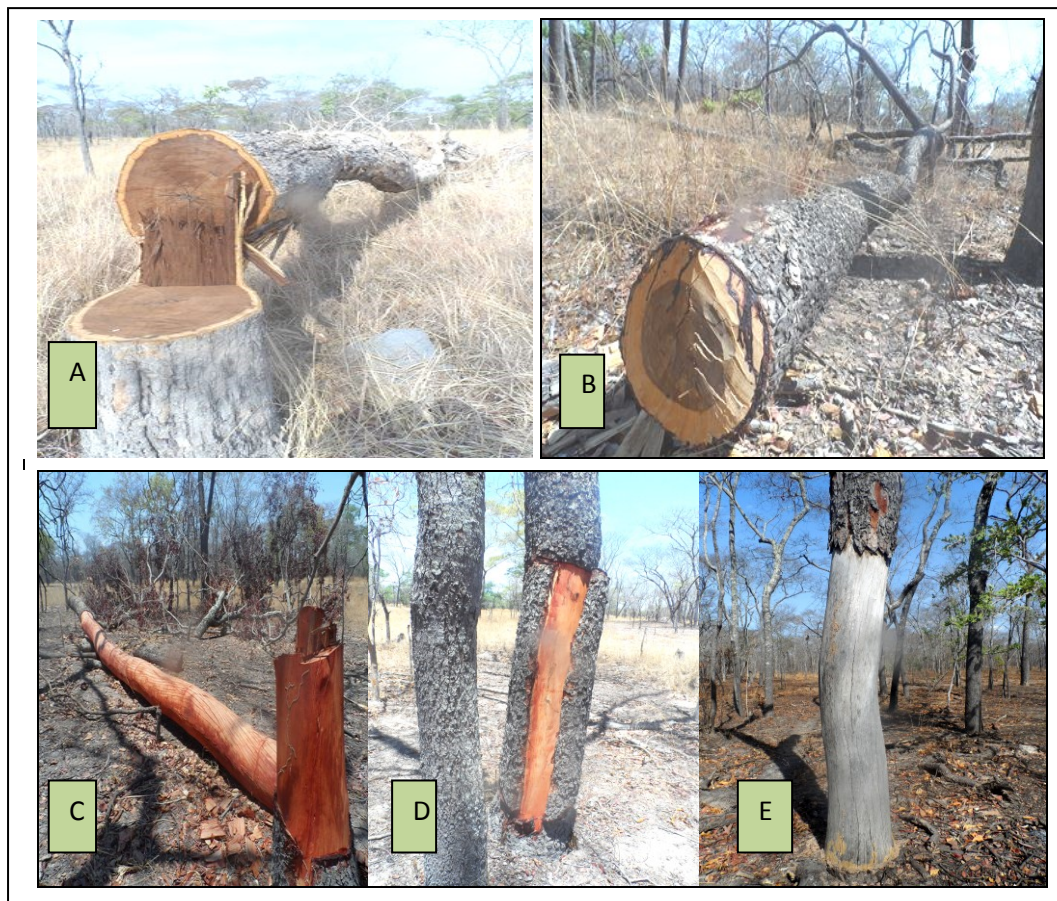


Plate 6: Timber harvesting and tree debarking in IFR; *Pericopsis angolensis* (A) and *Pterocarpus angolensis* (B) chopped down, and debarked *Julbernardia globiflora* (C-E).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Stingless bee species

In this study, three stingless bee species *Meliponula ferruginea*, *Hypotrigona ruspolii* and *Plebeina hildebrandti* were recorded. The three species corresponding to 3 genera: *Meliponula*, *Hypotrigona* and *Plebeina* as provided in Table 2 and Appendix 2. The classification of stingless bees have been fairly done in many parts of the world and many species have been identified and are documented (Cortopassi-Laurino *et al.*, 2006; Eardley, 2004; Michener, 2000). According to Eardley (2004), the three recorded species in IFR represent about 50% of the known African stingless bee genera. The area, represents low species diversity ($H' = 0.78$) and species richness from a total of 60 stingless bee nests (from *M. ferruginea* and *H. ruspolii*) observed and one species, *P. hildebrandti* whose nest was not observed but the bee samples were opportunistically collected from a water hole in the reserve.

The species richness of the three stingless bee species is indicated in species accumulative curve in figure 3. The species recorded have also been reported in other studies (Eardley, 2004; Michener, 2000; Munyuli, 2012; Roubik, 2006). *Meliponula ferruginea* was the most dominant species (n=31, 51.7%) of all the three species recorded in this study. Two of these species are common in Tanzania, but all the three have been reported in other studies (Table 1). The species richness within the habitat with only three species as indicated by the species cumulative curve in figure 3, showed that, there is likelihood of finding more stingless bee species in the

area. This results agree with the findings by Eardley (2004), Munyuli (2012) and Pauly and Vereecken (2013) who reported that, more species are to be identified in Africa, particularly in the Sub-Sahara African Countries.

Besides natural distribution ranges by stingless bees, habitat loss for stingless bees to nest and foraging may explain the low species richness observed in the study area. Habitat loss negatively influences the stingless bees diversity and species richness and hence the stingless bee community structure (Dietemann *et al.*, 2009; Eltz *et al.*, 2003; Goulson *et al.*, 2008; Liow *et al.*, 2001; Njoya, 2010; Roubik, 2006). The limitation in the bee forage availability also accounts to define the bee species richness, their distribution and abundances across varying habitats (Roubik, 2006). The presence of more nests of *M. ferruginea* and *H. ruspilii* in the reserve may explain that, they are adapted to nest in a variety of environments including in disturbed forests. These factors, might have influenced the overall nests density and hence species richness of the area. In this study, the stingless bee nests density was lower (9.4 nests ha⁻¹) as compared to 16.2 nests ha⁻¹ being the highest record as by Eltz *et al.* (2002) in lowland dipterocarp forests of Sabah, in Malaysia.

5.2 Stingless bees species distribution

Stingless bees are reported to be widely distributed in the tropical and subtropical regions of the world (Michener, 2000). The review of the distribution of the stingless bees in Africa (Figure 1) has recently been documented by Pauly and Vereecken (2013), while mapping for stingless bees in Tanzania to indicate their exact localities and identities in natural habitats have remained poorly established. In this study,

stingless bee species and their nests were unevenly distributed (Figure 4). Some species occurring in some forest patches than the others. Uneven distribution of stingless bee species in IFR may well be influenced by various factors including the availability of suitable nesting sites (Roubik, 2006; Potts *et al.*, 2005; Samejima *et al.*, 2004), and food resources for bee foraging (Araujo *et al.*, 2004; Biesmeijer *et al.*, 2005; Eltz *et al.*, 2002; Liow *et al.*, 2001; Munyuli, 2011; Roubik, 2006). According to Biesmeijer *et al.* (2005 and Roubik (2006), availability of bee forage accounts for the critical factor limiting stingless bees diversity, nests abundance and spatial arrangements across varying habitat types.

Stingless bee species distribution in IFR indicated greater dominance by two species: *M. ferruginea* and *H. ruspalii* (Figure 4). The nests aggregation in IFR was common in *Hypotrigona ruspalii*. Signifying that, some stingless bees have restricted distribution as a result of preferences to a particular nesting sites or suitable nesting sites that were probably spatially restricted, a similar findings by Samejima *et al.* (2004). On the other hand, their short flight capabilities and dispersion across fragmented habitats (Araujo *et al.*, 2004) and as a common behaviour in some stingless bee species (Eltz *et al.*, 2003) explained the aggregation behaviour observed in some species of IFR. Clumps distribution of some stingless bee species has been caused by restricted nest sites distribution as reported by Eltz *et al.* (2002) studying in Lowland Dipterocarp forests in Sabah, Malaysia. This study also found that, the predominance of few stingless bee species in IFR may be due to variation in their adaptation and responses to different ecological threats among recorded species. Hence, these factors might have contributed in the current stingless bee species abundance and their distribution in the studied area.

Due to high dependence to tropical woody trees for nesting (Eardley *et al.*, 2010), its removal as observed in the study area, have influenced the stingless bees nest distribution pattern. Fragmented habitats limit stingless bees nests abundances and their distribution as stingless bees have limited flight distances to nesting and foraging resources (Siqueira *et al.*, 2012). Therefore, enhanced landscape connectivity tends to increase nesting opportunity in fragmented forests (Munyuli, 2011).

Trees with potential nesting cavities were frequently cut or damaged and hence unsuitable for colonization by new colonies. Such declining qualities of strata most likely have contributed to the current stingless bee distribution in the reserve. Similar findings are reported by others in different place (Biesmeijer *et al.*, 2005; Liow *et al.*, 2001; Potts *et al.*, 2005; Roubik, 2006). Therefore, mapping the bee resources is necessary for designing sustainable utilization and management of the stingless bees in Tanzania.

5.3 Stingless bees species abundances

Nest abundances of each stingless bee species and the ranking order of their nests abundance in this study is presented in Table 3. The nests of two species *M. ferruginea* (52%) and *H. ruspalii* (46%) were most dominant accounting for 98% of the total three stingless bee species recorded. The least abundant species was *P. hildebrandti*; accounting for only 2% of its occurrence, with no nest being observed during the survey. The *P. hildebrandti* was located by chance at a water hole along the study transect. The ranking for occurrence of each species was provided in table 3.

According to Torné-Noguera *et al.* (2014), some bee species have specialized habitats to nest and forage, their absence strongly affects their species and nests abundances. Removal of these habitats, due to human disturbances reduces limits their diversity and nests abundances of some stingless bee species (Samejima *et al.*, 2004).

This study also revealed that the nest abundance for *M. ferruginea* and *H. ruspolti* varied with the change habitats. Similar results were reported by Biesmeijer *et al.* (2005) and Roubik (2006) who observed that the habitats have an important impacts on the stingless bee species composition and nests abundance across varying habitats. Habitat loss which is reported elsewhere, contributed to the declining stingless bee colony densities in natural forests (Araujo *et al.*, 2004; Biesmeijer *et al.*, 2005; Eltz *et al.*, 2002; Liow *et al.*, 2001; Potts *et al.*, 2005). However, the three observed stingless bees in the reserve showed contrasting responses to disturbances, possibly due to differences in foraging and nesting requirements as also reported by Brosi *et al.* (2008). Stingless bees with specialized nesting habitats are said to be more affected by nesting substrate availability (Torné-Noguera *et al.*, 2014) than species those occupying any immediate environments (Eardley *et al.*, 2010; Roubik, 2006). The *H. ruspolti* were found in trees with cavities of different size as compared to *M. ferruginea* which prefer nesting in relatively large cavity size. The results of this study however, are in agreement with the findings by Villanueva-g *et al.* (2005) that different bee species select cavities of optimal sizes to nest, thus their absence acts as a limiting factor on their abundances in an ecosystem. Detecting stingless bees in natural habitats is often difficult, hence affecting the overall assessment of their abundances. The *P. hildebrandti* nest was not observed in this study, but the

individual bees were opportunistically collected at a water hole. Therefore, effects due to error in detecting stingless bee species nests in natural habitats may also account for the low species and nest abundances in an area (Dorazio and Connor 2014).

It was also found that, the chances of finding nesting colonies for the three stingless bee species along the study transect from the forest edge across varying habitats varied. Most stingless bee nests were observed near the forest edge, along roadsides (Figure 5a, Appendix 3). Overall, for all the three stingless bee species, the relationship was not statistically significant ($R^2=0.168$, $F_{10}=1.6152$, $P= 0.2395$). A similar trend was revealed on the species abundances of *H. Ruspolii* ($R^2=0.0925$, $F= 0.8151$, $P= 0.3930$, Figure 5b) and *M. ferruginea* ($R^2= 0.0938$, $F= 0.8282$, $P= 0.3894$, Figure 5c). This implies that, multiple factors are affecting the composition of stingless bee species and the nest abundances in IFR rather than the distances away from the forest edge. The findings of this study is therefore supported by other studies (Dorazio and Connor 2014; Eardley *et al.*, 2010; Roubik, 2006; Torné-Noguera *et al.*, 2014; Villanueva-g *et al.*, 2005), that, several factors are contributing to affect the bees population structure. Availability of nesting cavities of optimal cavity sizes (Torné-Noguera *et al.*, 2014; Villanueva-g *et al.* 2005), availability of floral resources (Eardley *et al.*, 2010) and presence of human disturbances (Samejima *et al.*, 2004) and others might be important factors affecting stingless bee abundance in the studied reserve.

5.3.1 Abundances of *M. ferruginea*

Meliponula ferruginea was the most abundant stingless bee species at IFR, followed by *Hypotrigona ruspalii*. The revealed stingless bee species abundances at different areas in this study may have been influenced many factors. These include their ecological requirements and disturbance gradients on individual species (Eltz *et al.*, 2003; Roubik, 2006). *M. ferruginea* were found mainly in cavities of both living and dead tree of relatively large volumes as compared to trees that were often nested by *H. ruspalii*. *M. ferruginea* showed different responses to varying ecological patterns, their nests abundances showed some variation as a function of distance from the forest edge to interior (Figure 5). This finding differs from the other studies (Araujo *et al.*, 2004; Biesmeijer *et al.*, 2005, Liow *et al.*, 2001; Potts *et al.*, 2005; Roubik, 2006) who found higher colony abundances far from the forest edge. The higher nests abundances close to the road may be due to occurrence of abundant trees of large sizes that could offer bees with diverse nesting and food resources as compared to interior parts of the forest that were highly degraded due to human activities. Highly degraded habitats lower the stingless bees nesting qualities especially for species with highly specialized nesting requirements. But also, more nests were destroyed at distances close to the road where hunting pressure was high.

5.3.2 Abundances of *H. ruspalii*

Hypotrigona ruspalii was ranked second in abundance after *M. ferruginea* in IFR. The relative abundance of *H. ruspalii* nest decreased from the edge to interior forest, though the relationship was not statistically significant. Their declining may be due to, in part, habitat loss as a result of human activities. According to findings by Cairns *et al.* (2005), stingless bees were highly susceptible to fire due to inability for their queens to fly.

5.3.3 Abundances of *P. hildebrandti*

In this study, *P. hildebrandti* nests were not observed during the survey, but stingless bee samples were collected at a water hole. This shows that, the species could have low abundances and possibly limited in distribution. Among other factors for low occurrence in the area, is its hidden behaviour which makes it difficult to be detected in natural habitats. According to Eardley (2004) and Barbosa *et al.* (2013), *P. hildebrandti* prefer nesting in the ground and in termite mounds. In addition, their distribution patterns may have been influenced by the ecological requirements for this species (Eardley, 2004).

5.4 Nesting behaviour of stingless bees

5.4.1 Stingless bees nest architecture and nest aggregation

The nests of two observed stingless bee species exhibited diverse nest architecture (Table 4). According to Pavithra *et al.* (2013), nests provide an important role to the life of bee by protecting them against environmental perturbations and other nests maintain microclimate. The three species; *M. ferruginea*, *P. hildebrandti* and *H. ruspolii* differ considerably in body size, supporting the findings by Michener (2000). *M. ferruginea* and *P. hildebrandti* had relatively larger body size as compared to *H. ruspolii* which is considered the smallest stingless bee species in the area. Their nest architecture therefore vary considerably, in design from brood cells arranged in horizontal combs or cluster cells and cavities size where nests were constructed within tree cavities, as reported in a study by Roubik (2006). The observed variations in nest architecture among species may be acting as an adaptive feature by different stingless bee species. Such variations in nest architecture provide useful information in identification of stingless bee species (Kajobe, 2007; Njoya,

2010; Roubik, 2006). A considerable nest construction designs were observed in their food storage pots, brood cell arrangement, nest entrance shape and sizes, nest enclosure (Involucrum) and occurrence of connecting pillars (Table 4). The nest architecture and other attributes of the two species (*M. ferruginea* and *H. ruspolii*) are provided in Table 4 and Plate 2. Cerumen “a mixture of beeswax and plant resins” was the main nest building materials, of all the three stingless bees recorded (Sommeijer, 1999).

In stingless bees, there are two cell types: brood cells and food storage cells for nectar and pollen. Very often, the food storage cells are called food storage pots. The food storage pots in most stingless bee species were larger than the brood cells. The *H. ruspolii* had their broods in clusters of cell arrangements (Plate 2), different from that of *M. ferruginea* with their brood combs horizontally arranged in clear patterns (Plate 3). Such kinds of brood nest arrangement have been reported by others (Barbosa *et al.*, 2013; Njoya, 2010; Roubik, 2006). The nest of *P. hildebrandti*, bear the same brood pattern as that of *M. ferruginea*. The cluster cell arrangement in *H. ruspolii* have also been reported by Barbosa *et al.* (2013). The broods of *H. ruspolii* lacks protective outer layer (the Involucrum) as the case of broods in *M. ferruginea*. The *M. ferruginea* brood combs were enclosed in multilayers of protective sheath ‘the Involucrum’ (Plate 3), the same as for *P. hildebrandti* (Njoya, 2010; Roubik, 2006). The nest of *P. hildebrandti* was not examined in this study, and its nest feature is based on previous studies by Njoya (2010), as presented in Table 4 c.

The internal nest architecture of *H. ruspolii* examined had their brood cells tightly connected by connecting pillars while others were without pillars (Plate 2 G and H). The pillars in *M. ferruginea* are present between brood combs and connects nest to

the cavity walls of the nesting substrate. According to Roubik (2006), stingless bee pillars allowing stingless bees to move easily between adjacent combs, but also support food storage pots and connect nests to the walls of the cavities. Honey storage pots were occasionally mixed with cells contain pollen while in some cases, honey pots grouped at the periphery of the food storage compartment and pollen pots near the brood chamber, also reported by Sommeijer (1999).

The nests entrance occurred in a diverse modification among individual stingless bee colonies of the same and among species (Plate 2- 3). The nest entrance in stingless bees connects the internal part of the nest to that of the environment through the entrance opening (Njoya, 2010). The *H. ruspalii* had slender, long entrance tube (Plate 2) as compared *M. ferruginea* with relatively short entrance tube and wide entrance opening. The entrance tube also occurs in different colour patterns, a behaviour which was also associated with defense behaviour against intruders. The *H. ruspalii* had narrow, long and small sized entrances. The longest nest entrance tube was 25.2 mm recorded in *H. ruspalii* colony while the shortest measured 1mm in *M. ferruginea* Table 4a-3). The narrow, long entrance tube allows the nest to be easily defended by only few guard bees positioning themselves in the mouth of the entrance tube (Plate 2 D, F). Similar finding was reported by Njoya, (2010). The stingless bee species with longer nest entrance had fewer deposits of resin droplets around entrance tubes and vice versa (Plate 2-3). The resin droplets act as a barrier against intruders (Njoya, 2010). Equally, the number of guard bees and amount of resin droplets increases with increasing size of the nest entrance (Plate 3, A, B, D). Pavithra, *et al.* (2013), reported that, the variation on the amount of materials used by stingless bees may also influenced by the propolis availability and colony requirement.

Although nests aggregation in stingless bees of IFR was apparent in all species (*H. ruspolii* and *M. ferruginea*) of the examined colonies (excluding *P. hildebrandti*), nests aggregation was prominent in *H. ruspolii* colonies. Only few cases of nests aggregation were observed on *M. ferruginea*. An aggregation of nests of different stingless bee species has also been reported in other studies (Eltz *et al.*, 2003; Njoya, 2010). The shortest distance between nests aggregates was recorded on *Hypotrigona ruspolii* colonies located 20 cm apart on the same nest tree. A maximum of six nests of *H. ruspolii* was recorded in the same nest tree. The highest nest aggregation observed in *M. ferruginea* was three colonies from two trees of *Pericopsis angolensis*. The trees were only 60 cm apart. This suggests that, nests aggregation is common in stingless bees. But the underlying reasons for nests aggregation in stingless bees are poorly understood (Eltz *et al.*, 2003). Limited availability of suitable nesting sites may be one possible reason especially in degraded areas and that have reduced natural nesting sites (Eltz *et al.*, 2003; Siqueira *et al.*, 2012). Also, an aggregation might be related to how new nests are located by scouts bees of stingless bees. Eltz *et al.* (2003) reported that, stingless bees allocate new nest site by the use of specific odor of bee broods or nest materials (resins) showing suitability of a particular nest tree or by cues that are provided by colonies of other species.

5.4.2 Stingless bee nesting substrata

The stingless bees of IFR used trees as their nesting substrates (Table 5 and Appendix 4). The nesting sites provides conditions to ensure stingless bee colony survival (Roubik, 2006) and reproduction (Siqueira *et al.*, 2012). Being highly diverse, the stingless bees use different types of nesting substrates to nest (Eardley *et al.*, 2010; Roubik, 2006; Venturieri, 2009). Some species of stingless bees have been

found nesting in walls of mud houses, window frames, door frames, roofing timber, electric sockets, dry drainage pipes, electric and telephone poles, and cavities in trees (Njoya, 2010), in the ground in nests of living animals, in termite mounds, or in any in any immediate substrates (Eardley *et al.*, 2010; Eltz *et al.*, 2003; Roubik, 2006). In this study, the two stingless bees *M. ferruginea* and *H. ruspolti* were all found nesting in trunk cavities of living trees (Table 5a, Appendix 2). Similar results were reported by Barbosa *et al.*, 2013; Carvalho-zilse and Nunes-silva, 2012; Cortopassi-Laurino *et al.*, 2006; Eardley *et al.*, 2010; Martins *et al.*, 2004) who observed more stingless bee nests in cavities of living woody plants. Many of the recorded dead trees that were nested by *M. ferruginea* were indicated dead, mostly because of being intentionally cut by hunters to extract stingless bee honey rather than death by natural phenomena, because of maturity.

Two species *M. ferruginea* and *H. ruspolti* were found nesting in seven species of trees (Table 5a). The finding of this study was in agreement with Eltz *et al.*(2003), Martins *et al.* (2004) and Roubik (2006) that, stingless bees are opportunists, and choose any tree species for nesting. However, it was found that, some tree species were highly selected for nesting. The three species of trees, *Pericopsis angolensis* (46.7%), *Erythrophleum africanum* (23.3%) and *Julbernardia globiflora* (18.3%) made the majority of the tree species used for nesting in the study area (Table 5a). The likely factors influencing stingless bees choice to a particular substrate to nest has remained uncertain (Pavithra *et al.*, 2013). Though, the stingless bees tend to use and nest in any tree species provides it offers suitable cavity of the right size (Eltz *et al.*, 2003; Roubik, 2006). According to Siqueira *et al.* (2012), trees with larger volumes are mostly used by stingless bees to nest. In a study by Njoya (2010),

stingless bees of Bamenda in Afromontane Forests in Cameroon, the *Hypotrigena* spp, due to their relatively smaller body size, their nests were found in tree branches with 20 and 28cm thick. Unlike, the *M. ferruginea* which prefer mostly large trees with relatively large cavities in tree trunk and *H. ruspalii* which were found nesting cavities of variable sizes. The *Dactylurina* species that construct nests in an exposed position (Eardley, 2004; Eardley *et al.*, 2010; Sommeijer, 1999), were not recorded in this study.

Honey hunters reported nine tree species that are also nested by stingless bees (Table 5b and Appendix 4). According to honey hunters (Personal comm), *Commiphora* species, *Mimusops densiflora*, *Burkea africana*, *Pterocarpus angolensis*, *Terminalia sericea*, *Pseudolachnostylis maprouneifolia* and *Combretum* species were among nesting tree species by stingless bees in the study area that was dominated by miombo woodland.

Roubik (2006) found that, trees are closely linked to stingless bees for food requirements and nesting site, their absence negatively influences their population in natural habitats. Therefore, in a productive forest like IFR, where harvesting for forest resources including timber, continuous removal of nesting trees due to human activities may account for their future population decline. Majority of the tree species nested by stingless bees in IFR, were also potential trees for timber. The knowledge of nesting habitats for stingless bees remains to be important to provide ultimate information for their future conservation and protection of stingless bees. Many of these trees are also exploited by human being for various uses, hence threatening the future of many tree nesting stingless bees and their ecology.

According to Barbosa *et al.* (2013), underground nests are relatively rare among stingless bees. Hence they are difficult to detect in natural habitats. The occurrence of *P. hildebrandti* in IFR adds up to two nesting substrates (the trees and ground soil) to be used and nested by stingless bees in the study area from a variety of recorded nesting substrates as reported by others (Eardley *et al.*, 2010; Roubik, 2006). The findings of this study calls for more investigations on stingless bees nesting behaviour to determine whether tree selection by tree nesting stingless bees is influenced by some tree characteristics rather than nesting cavities availability.

5.4.3 Nesting heights by stingless bees

Most of the stingless bee nests were found within tree cavities in tree trunks of woody trees. Nests in trees with large sizes were particularly highly selected by *M. ferruginea* and *H. ruspolti* to nest. The stingless bee nests were found at varying heights from the ground (Table 6), in tree trunks. A similar relation was found by Eltz *et al.* (2003) in Sabah, Malaysia, that stingless bee nest cavities could be at any height of the tree trunk. In this study, most nests were observed at an average height, 3.5m from the ground. However, a study by Venturieri (2009) on the Amazonian stingless bees of Brazil, found that stingless bees prefer nesting in cavities in the base of tree hollows. Trees with relatively larger cavities were highly selected by *M. ferruginea* species for nesting as compared to cavities used by *H. ruspolti* species. According to Eltz *et al.* (2003) and Venturieri (2009), tree cavities with volumes over 50 cm diameters size are highly selected for nesting. Therefore, on a positive note, reduced forest cover with large old trees negatively influences the number of *M. ferruginea* as compared to *H. ruspolti*.

5.5 Threats to stingless bees

Attributes of stingless bee threats and vulnerability were evaluated based on the observed quantitative and qualitative incidences of ecological features that degrade the bee habitats. The results show that, the stingless bees habitats in IFR have been greatly degraded and destroyed. Nesting sites and nests of *M. ferruginea* species were destroyed, and possibly their colonies were killed as a result of many threats as presented in Table 7 and Plate 4 – 6. Five major threats to stingless bees of IFR were identified: forest fires (63%), honey hunting (26%), timber logging (10%), livestock grazing (9%) and tree debarking for hives construction (4%), that are ranked according to their relative frequency of occurrences during this study. The many threats recorded on stingless bees were partly driven by anthropogenic factors (Table 7) (Boontop *et al.*, 2008; Coll *et al.*, 2010; Eardley *et al.*, 2009; Potts *et al.*, 2005) and other natural forces (Coll *et al.*, 2010). However, the mechanism at which each stingless bee species is affected requires further investigation.

It was found that, habitat loss due to human activities negatively impacts plants and stingless bees. The loss reported worldwide is a major concern to the current decline on bee species (Coll *et al.*, 2010; Boontop *et al.*, 2008; Eardley *et al.*, 2009; Potts *et al.* 2005). Some of the indicators of its effects on bee populations may include (a) habitat loss for nesting sites and forage (Boontop *et al.*, 2008; Eardley *et al.*, 2009; Potts *et al.* 2005; Villanueva-g *et al.*, 2005), (b) low species diversity; and (c) damage on nests and nesting cavities by honey hunters (Reyes-gonzález *et al.*, 2014; Roubik, 2006; Sommeijer, 1999). Though East Africa considered still have the largest stingless bee diversity in Africa (Eardley, 2014, Personal comm.), substantial

evidence from this study revealed significant losses in stingless bee populations is taking place in IFR (Plate 4 - 6). This research work possibly represents only a fraction of the actual status of the stingless bee losses in protected areas in Tanzania.

5.5.1 Forest fire and livestock grazing

Forest fires and grazing cattle were among common threats to stingless bees of IFR (Table 7, plate 4). Of the total plots sampled, 63% were burnt and 9% of all sites surveyed had signs of livestock grazing. According to Black *et al.* (2009), the impact of forest fire and grazing are mixed. Fire and grazing cattle can have damaging impacts but when carefully managed they can be beneficial on bees and other pollinators. In many ecosystems, controlled burning have increasingly been used as a management tool (Black *et al.*, 2009).

This study found that, fire may be more damaging in respect to stingless bees. Hence, frequent fire in natural forests as the case of IFR, might have significant negative effects by removing bees nesting and foraging resources. The dominance of fire as an ecological perturbation in bee resources was reported by Potts *et al.* (2005) in a Mediterranean landscape where fire caused a large shift in the relative proportions of nesting guilds. The losses due to fire may be either directly, causing mortality to bee colonies during fire or indirect due to reduction in resources for nesting and foraging (Black *et al.*, 2009; Potts *et al.*, 2005). The poor absconding ability in response to disturbances (Eltz *et al.*, 2003) as compared to *Apis mellifera* bees makes stingless bees highly susceptible to the effects of fire. Frequent forest burns remove floral, nesting resources and the bees. This reduces nesting materials

for stingless bees and can have detrimental effects to many insects including stingless bee colonies which cannot fly longer to safer areas at the time of burn.

Though, grazing can be a valuable tool for managing shrubs and tree succession, encouraging the growth of nectar rich plants and creating potential nesting habitats (Black *et al.*, 2009), grazing in IFR is lawfully banned. Grazing destroy nest sites and remove bee forage (Black *et al.*, 2009). Removal of understory herbs and shrubs layers by grazers changes the diversity and vegetation composition in natural forests. Consequently, removal of this layer due to fires and livestock grazing might have contributed to the observed low stingless bee diversity and nests abundances in IFR. Such alterations to suitable habitats for stingless bees negatively affect the entire ecosystem and increases vulnerability to bees and plants for forage and nesting. According to Munyuli (2011), grazed habitats by cattle are considerably fragile and unstable nesting habitats for pollinators. Yet the magnitude on the effects of fire and livestock grazing could not be quantified in this study, despite the visible secondary effects on total decline in forest health, stingless bee nests abundances and low stingless bee species diversity in the area.

5.5.2 Honey hunting

The traditional practice in obtaining stingless bee honey from natural cavities may be the most common threat to stingless bees of IFR. Apart from declining habitats, stingless bee losses in IFR were highly driven by stingless bee honey hunting (Table 7, Plate 5). However, nests from destroyed cavities could not be easily identified and were all treated as from *M. ferruginea*, as also supported by honey hunters. Stingless

bees honey extraction by hunters is destructively done (Eardley, 2004; Reyes-gonzález *et al.*, (2014); Roubik, 2006; Sommeijer, 1999). Therefore, of the three stingless bees identified, *M. ferruginea* was the most vulnerable stingless bee species for hunting, (i.e. 67.7%, 21 nests of all *M. ferruginea* nests (n=31) were destroyed), possibly causing mortality to their bee colonies. The increasing demand and values for stingless bee honey in local markets accelerate more losses on stingless bees by hunters. Local people reported that, wild colonies of *M. ferruginea* were once very abundant in the area, but their abundances have greatly reduced. However, the overall mortality rate caused by the honey hunters and the surviving bee colonies after honey extraction needs to be studied, also reported by (Roubik, 2006). Honey hunters (Personal comm.) reported that, *Hypotrigena rufipolii* are rarely hunted because of low honey yield they can produce. This might account for the observed higher abundances of living colonies in the area (Appendix 2). The *Plebeina hildebrandti* species is well known for its hiding behaviour in natural habitats, very difficult to locate its nest, hence less hunted. Such behaviour may have provided low exposure to hunting threats.

Large trees hosting cavities were damaged or totally cut, possibly causing mortality to many stingless bee colonies (Plate 5). Similar findings from other studies (Eardley 2004; Reyes-gonzález *et al.* 2014; Sommeijer 1999) suggest that, tree nesting species suffered substantial hunting pressures. For this case, only fewer species of trees are affected by hunting (Cairns *et al.*, 2005; Potts *et al.*, 2005). For trees with nests high up on trees were completely felled to extract stingless bees honey (Plate 5), thereby killing the entire tree. In this study, tree species; *Pericopsis angolensis*,

Erythrophleum africanum and *Julbernardia globiflora* were mostly affected. Their removal negatively affect stingless bees nest densities (Carvalho-zilse and Nunes-silva, 2012, Roubik, 2006). Liow *et al.* (2001) reported that, disturbed sites contain adequate numbers of stingless bee colonies and but low species diversity. This supports the results of this study, and that, the area has been significantly degraded.

Many of the cut trees for honey extraction had stingless bee nests high up on trees from the ground. Nests located at relatively lower heights from the ground, in tree trunks, their cavities were directly opened and trees were partly cut to explore and extract stingless bee honey (Plate 5), leaving many destroyed cavities unsuitable to be nested by stingless bees. Timber loggers and the beekeepers, illegally reported to engage themselves in hunting stingless bee honey. In this respect, machines used for timber logging such as chainsaws, were observed to be used for felling down trees and opening the cavities to explore and extract stingless bee honey (Plate 5). Therefore, destructive exploitation of stingless bee honey in IFR contributes to the current habitat loss and declining stingless bees. Exposed nests after hunting operations might have intensified predation risks on individual bees and the bee colonies, mainly from predator mammals and birds that feed on stingless bees (Eltz *et al.*, 2001).

Although honey hunting has greatly reduced the populations of some species of stingless bees in IFR, little attention has been drawn by conservation stakeholders in the country. Schwartz and Caro, (2003) reported that, the responses of the Miombo woodland to most forms of disturbance has received little attention. The damage caused by hunters on stingless bee nests and host trees may have profound long term negative effects on stingless bees and possibly the entire ecosystem.

5.5.3 Logging and tree debarking

Logging for timber and tree debarking for beehives construction were also considered among stingless bee threats in IFR. Tree logging and debarking for hive construction were all found to have severely impacts plants and stingless bee species composition in IFR as presented in Table 7. According to Cairns *et al.* (2004), Eltz *et al.* (2002) and Ranius *et al.* (2009), selective logging for timber negatively affects stingless bees. This study found that, most of the tree species of value for timber logging or debarked were also recorded as nesting tree species for stingless bees in the reserve. Ipembampazi as among few forest reserves in Tanzania where harvesting of forest products is allowed commonly known as “productive forest” access to various forest resources is legally permitted. The most common activities observed in IFR were; timber logging, beekeeping and tourist hunting. In this respect, several tree species have a local economic value. Some tree species such as *Pterocarpus angolensis*, *Pericopsis angolensis*, and *Julbernardia globiflora* are among valuable tree species for timber logging and debarked or timber processed for hives construction. It was realized that most of these commercially logged trees or debarked for hives were also nested by stingless bees (Table 7, Plate 6). According to Cortopassi-Laurino *et al.* (2006), stingless bees nests in nature are in danger of depletion by logging practices. Therefore, removals of large trees at harvesting seriously endanger the survival of many stingless bees. Samejima *et al.* (2004) found that, unique habitats for nesting and bee forage not provided by the young trees are also declining.

In IFR, trees with nesting sites were inefficiently protected under the current management approach despite of the observed effects on bees and the plants. Trees with and that provide potential nesting sites were being removed from the forest (Table 7, Plate 6). In a study by Venturieri (2009) in the Amazonian stingless bees of South America, commercialization of wood for timber resulted into a strong reduction in stingless bee nesting cavities. The effects of habitat loss due to selective harvesting have been reported in many other studies (Eltz *et al.*, 2003; Ranius *et al.*, 2009; Samejima *et al.*, 2004; Siqueira *et al.*, 2012). These includes: effects on reproductive division of colonies, colonies dispersion due to habitat fragmentation, and loss of suitable habitats for nesting (Samejima *et al.*, 2004; Siqueira *et al.*, 2012; Villanueva-g *et al.*, 2005), directly killing bee colonies (Samejima *et al.*, 2004) and possible decline in stingless bees nests density (Venturieri, 2009). Samejima *et al.* (2004) studied the effects of human disturbance on stingless bee community in a tropical rainforest, in Malaysia and found that, nest density was positively related to the density of large trees. Similarly, Villanueva-g *et al.* (2005) studying in Mexico, found low nests density in primary forests as a result of habitat loss for nesting. The findings of this study however, suggest the need for the comparative studies in the productive and protective forest reserves to test the effects of various forest management strategies on the dynamics in the stingless bees and other pollinator insects of Tanzania.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Three stingless bee species are present in Ipembampazi Forest Reserve. These include *M. ferruginea*, *H. ruspolii* and *P. hildebrandti*. Low species richness and diversity were revealed in IFR. Most species were unevenly distributed across the study area. *M. ferruginea* was the most abundant species, followed by *H. ruspolii*. Depending on species, stingless bees exhibited a wide range of nesting behaviour of building nests and nesting characteristics. Their nests showed a wide variety of nest architecture. Usually build their nests in trunk cavities and cavities in tree branches of living trees of only few selective tree species. Observed threats on stingless bees and their habitats were mainly human induced. The most common threats were frequent fires, honey hunting, logging for timber and livestock grazing. The threats observed was associated with habitat loss and observed low stingless bee species diversity and nests abundances in the reserve.

6.2 Recommendations

In view of the above discussions and conclusions, this study recommends the following

- i. The MNRT, through District Executive Director and other forest and beekeeping regulatory authorities should educate forest users on the importance of protecting the natural forests generally in order to conserve habitats of stingless bees and other pollinators.

- ii. Local knowledge to domesticate feral colonies of stingless bee colonies in artificial hives to be promoted to communities living adjacent to protected forests.
- iii. More studies on stingless bees of Tanzania and their ecology in different habitats and forests under different management regimes are required.
- iv. To map stingless bee species distribution and its resources for nesting and forage across the country to guide its conservation and planning for development of meliponiculture industry in the country.
- v. Studies on the effects of climate change and weather variability on stingless bees of Tanzania is also required.

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APPENDICES

Appendix 1: Data collection form for the study

Locality name: -----, **Region:** -----, **District:** -----, **Form Number:** -----
Date: -----, **Name of observer:** -----, -----
Transect number: -----, **Species name:** -----

Plot number	Number of Nest	Colony status	Nesting characteristics					Location	
			Name of nesting substrate	NS	NP	HG	ED	ES	Coordinate

NS = Nesting Substrate (**LT**= Live tree, **DT**= Dead tree, **C**= tree cavity, **G**= Ground); **NP** = Nest Position (**HG** = Height from the ground, **E**= Exposed nest, **FT**= Forked tree); **ED**= Entrance Diameter; **ES** =Entrance shape; **EL** =Entrance Length

Other Information:

Stingless bee threats:

.....

Other observations:

.....

Appendix 2: Stingless bees nest status and nesting position in tree cavities

S/N	Species name	Colony status	Entrance Length (mm)	Entrance Diameter (mm)	Position on a substrate	Height from ground (m)	Number of colonies
1	<i>H. ruspalii</i>	Living	8.5	7	Tree branch	1.3	1
2	<i>H. ruspalii</i>	Living	10	6.5	Tree branch	2.0	1
3	<i>H. ruspalii</i>	Living	20	6	Tree branch	2.5	1
4	<i>H. ruspalii</i>	Living	18.3	5.1	Tree branch	2.7	1
5	<i>H. ruspalii</i>	Living	18	6	Tree branch	2.8	1
6	<i>H. ruspalii</i>	Living	16.1	4.8	Tree branch	3.6	1
7	<i>H. ruspalii</i>	Living	15	5.3	Tree branch	5.0	1
8	<i>H. ruspalii</i>	Living	7	6	Tree branch	6.0	1
9	<i>H. ruspalii</i>	Living	21	4.5	Tree branch	7.0	1
10	<i>H. ruspalii</i>	Living	23	6	Tree trunk	1.0	1
11	<i>H. ruspalii</i>	Living	16	4.5	Tree trunk	1.0	1
12	<i>H. ruspalii</i>	Living	40	4.5	Tree trunk	1.6	1
13	<i>H. ruspalii</i>	Living	20.3	4.5	Tree trunk	1.8	1
14	<i>H. ruspalii</i>	Living	13	4	Tree trunk	1.9	1
15	<i>H. ruspalii</i>	Living	13	3.8	Tree trunk	1.9	1
16	<i>H. ruspalii</i>	Living	21	4	Tree trunk	2.1	1
17	<i>H. ruspalii</i>	Living	3	7	Tree trunk	2.5	1
18	<i>H. ruspalii</i>	Living	50	8	Tree trunk	3.0	1
19	<i>H. ruspalii</i>	Living	21	6.1	Tree trunk	3.0	1

S/N	Species name	Colony status	Entrance Length (mm)	Entrance Diameter (mm)	Position on a substrate	Height from ground (m)	Number of colonies
20	<i>H. ruspolii</i>	Living	6.8	4.7	Tree trunk	3.0	1
21	<i>H. ruspolii</i>	Living	40	5.5	Tree trunk	3.3	1
22	<i>H. ruspolii</i>	Living	15	6	Tree trunk	3.5	1
23	<i>H. ruspolii</i>	Living	25	5.8	Tree trunk	3.6	1
24	<i>H. ruspolii</i>	Living	10	6	Tree trunk	4.0	1
25	<i>H. ruspolii</i>	Living	-	-	Tree trunk	4.0	1
26	<i>H. ruspolii</i>	Living	-	-	Tree trunk	4.0	1
27	<i>H. ruspolii</i>	Living	3	6.3	Tree trunk	4.3	1
28	<i>H. ruspolii</i>	Living	-	-	Tree trunk	5.0	1
29	<i>H. ruspolii</i>	Living	39	5	Tree trunk	6.0	1
30	<i>M. ferruginea</i>	Living	4.3	7.5	Tree branch	2.5	1
31	<i>M. ferruginea</i>	Living	3	8.9	Tree branch	2.5	1
32	<i>M. ferruginea</i>	Living	1.5	15	Tree branch	4.0	1
33	<i>M. ferruginea</i>	Living	2	18	Tree branch	6.0	1
34	<i>M. ferruginea</i>	Living	2.5	8.4	Tree branch	6.0	1
35	<i>M. ferruginea</i>	Living	6	13	Tree branch	6.0	1
36	<i>M. ferruginea</i>	Living	8	13.5	Tree branch	6.8	1
37	<i>M. ferruginea</i>	Living	4.5	12	Tree trunk	4.8	1
38	<i>M. ferruginea</i>	Living	3.5	5.8	Tree trunk	5.3	1
39	<i>M. ferruginea</i>	Living	2.5	7.5	Tree trunk	6.5	1
40	<i>M. ferruginea</i>	Destroyed	-	-	Tree base	0.2	1
41	<i>M. ferruginea</i>	Destroyed	-	-	Tree trunk	0.5	1
42	<i>M. ferruginea</i>	Destroyed	-	-	Tree trunk	1.5	2

S/N	Species name	Colony status	Entrance Length (mm)	Entrance Diameter (mm)	Position on a substrate	Height from ground (m)	Number of colonies
43	<i>M. ferruginea</i>	Destroyed	-	-	Tree trunk	2.0	3
44	<i>M. ferruginea</i>	Destroyed	-	-	Tree trunk	2.5	1
45	<i>M. ferruginea</i>	Destroyed	-	-	Tree trunk	3.0	3
46	<i>M. ferruginea</i>	Destroyed	-	-	Tree trunk	3.5	2
47	<i>M. ferruginea</i>	Destroyed	-	-	Tree trunk	3.8	2
48	<i>M. ferruginea</i>	Destroyed	-	-	Tree trunk	5.4	1
49	<i>M. ferruginea</i>	Destroyed	-	-	Tree trunk	5.6	1
50	<i>M. ferruginea</i>	Destroyed	-	-	Tree trunk	7.1	1
51	<i>M. ferruginea</i>	Destroyed	-	-	Tree branch	2.0	1
51	<i>M. ferruginea</i>	Destroyed	-	-	Tree branch	5.0	1
53	<i>M. ferruginea</i>	Destroyed	-	-	Tree branch	7.0	1
54	<i>P. hildebrandti</i>	*	*	*	*	*	*

Note: * The stingless bees were collected at a water source and their bee colonies or nest was not observed during the survey.

Appendix 3: Stingless bee nests count across the forest from the forest edge

Distance (km)	S ₁	S ₂	S ₃	S ₄	S ₅	S ₆	S ₇	S ₈	Total	(%)
<0.5	3	0	0	0	2	4	0	1	10	16.7
1	2	1	1	2	0	2	0	0	8	13.3
2	0	0	1	0	1	0	1	1	4	6.7
3	0	0	0	1	0	1	2	1	5	8.3
4	0	0	0	1	6	0	0	1	8	13.3
5	1	0	1	1	0	1	1	0	5	8.3
6	1	1	0	0	0	0	0	1	3	5.0
7	0	2	1	1	1	1	2	1	9	15.0
8	0	0	1	0	0	0	1	0	2	3.3
9	0	1	1	1	1	0	1	1	6	10.0
Total	7	5	6	7	11	9	8	7	60	100
(%)	11.7	8.3	10	11.7	18.3	15	13.3	11.7	100	

S₁...S_n= Transect number, Km= Perpendicular distance from the main road crossing the reserve, %= Percentage.

Appendix 4: Tree species preferred by stingless bees in the study area

S/N	Tree species	Local name (Nyamwezi)	Bee species observed	
			<i>M. ferruginea</i>	<i>H. ruspolii</i>
1	<i>Pericopsis angolensis</i>	Mbanga	√	√
2	<i>Erythrophleum africanum</i>	Mgando	√	√
3	<i>Julbernardia globiflora</i>	Muba	√	√
4	<i>Diospyros mespiliformis</i>	Mnumbulu	√	x
5	<i>Combretum molle</i>	Mlama	x	√
6	<i>Brachystegia boehmii</i>	Muyombo	x	√
7	<i>Combretum zeyheri</i>	Msana	x	√
8	<i>Commiphora sp</i>	Msaki	x	x
9	<i>Pseudolachnostylis maprouneifolia</i>	Mtungulu	x	x
10	<i>Combretum fragrans</i>	Mlozyaminze	x	x
11	<i>Pterocarpus angolensis</i>	Mninga	x	x
12	<i>Burkea africana</i>	Mgando mkalati	x	x
13	<i>Hymenocardia ulmoides</i>	Mtonto	x	x
14	<i>Terminalia sericea</i>	Mzima	x	x
15	<i>Mimusops densiflora</i>	Mkonze	x	x
16	<i>Acacia royumae</i>	Mgongwa	x	x

Note: The sign (√) indicates trees found nested by stingless bees during the and (x) trees reported by hunters as potential nesting trees used as nesting substrates by stingless bees in the study area.

Appendix 5: Stingless bees nest sites preferences in tree cavities

Tree species	Tree attributes (Frequency)				Stingless bee species		Frequency	
	LB	DB	LT	DT	<i>H. ruspolii</i>	<i>M. ferruginea</i>	Number (N)	Percent (%)
<i>Pterocarpus angolensis</i>	1	10	7	10	17	11	28	(46.7)
<i>Erythrophleum africanum</i>	2	2	6	4	4	10	14	(23.3)
<i>Julbernardia globiflora</i>	0	3	4	4	3	8	11	(18.3)
<i>Diospyros mespiliformis</i>	0	0	2	1	2	1	3	(5.0)
<i>Combretum molle</i>	0	0	0	1	0	1	1	(1.7)
<i>Brachystegia boehmii</i>	0	0	1	0	1	0	1	(1.7)
<i>Combretum zeyheri</i>	0	0	2	0	2	0	2	(3.3)
	3	15	22	20	29	31	60	(100.0)
Percent (%)	5	25	37	33				

Key: LB= Live branch, DT= Dead tree trunk, DB= Dead branch, LT= Live tree trunk