THE INFLUENCE OF CLIMATE CHANGE ON BEE SPECIES DISTRIBUTION ACROSS HABITAT TYPES IN KILOMBERO SAGCOT CLUSTER, TANZANIA

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EXTENDED ABSTRACT

Introduction

Bees are known to be the most important group of insects. They are economically and ecologically important to humans. Bees provide various products such as honey, bee wax and bee venom on which human society depends for livelihood. Bees further provide pollination services to agro-ecosystems and natural habitats without which productivity in these ecosystems would not be possible. The diversity and distribution of bee species is determined by type, quantity and quality of suitable habitats in an ecosystem. Several studies have confirmed the influence of climate change on bee distribution. Bee species are expected to respond differently to climate change, either by range shift or disappearance due to loss of their suitable habitats. This study was aimed at assessing the distribution of bee species across habitat types and the influence of climate change on bee populations in the Kilombero SAGCOT cluster of Tanzania.

Methods

Stratified sampling was employed, where the stratification was based on habitat type. The habitat types were; Closed Forests (CF), Grasslands (GL), Woodlands (WL) and Agro-ecosystems (AE). Transects were established within the strata and plots measuring 20 m x 40 m (0.08 Ha) were laid along the transects. The distance between transects was 300 m and between plots was 200 m. Sweep netting and pan trapping were used to capture bees within the plots. At each plot identification and enumeration of each bee species collected was done. The identification was done later in laboratory using taxonomical keys. Bee species composition was determined as the list of the identified bee species. Euclidean distance measure of similarity and Raup-Crick dissimilarity index were used to compare the similarity/dissimilarity in bee species composition between the habitat types. Bee richness was determined as the number of bee species encountered, relative abundance of

bee species was determined as the number of individual of each species relative to the total number for all species. Bee species diversity was determined by the Shannon-Wiener and Simpson Diversity Indices. Bee species evenness was computed by the Pielou's measure of species evenness, ($J = H'/\ln(S)$ where H' is Shannon Weiner diversity and S is the total number of species in a sample, across all samples in the dataset. Chi- square test was used to compare bee abundance and richness between habitat types.

The influence of climate change on the distribution of dominant bee species was determined using Maximum Entropy (MaxEnt) modelling. The four most dominant bee species selected for modelling were; *Apis mellifera, Meliponula ferruginea, Hypotrigona ruspolii* and *Liotrigona bottegoi*. Pearson correlation was used to determine multicollinearity between the environmental variables. The environmental variable obtained after running multicorrelation analysis were; Bio11, Bio13, Bio15, Bio18, Bio19, Bio3, Bio4, Bio7 and Land cover. The highest scenario for GHG emissions (RCP8.5) was used for future prediction of bee distribution for the years 2050 and 2070. Response curves were used to determine the relationships between the environmental variables and the probability of occurrence of bee specie. Jackknife test was used to determine the variable of importance and percentage contribution of variable in influencing bee specie distribution.

Findings

A total of 818 individual bees, belonging to 169 species from five families were collected during the study period. The dominant family was Apidae and the least dominant was Andrenidae. Euclidean distance measure of similarity shows high similarity of bee species composition between woodlands (WL) and closed forests (CF). The bee species found in Grasslands (GL) were more similar to WL compared to bee species found in the Agro-ecosystem (AE). The bee species in AE were less similar to CF, WL and GL. Pairwise comparison show the habitat types which were significantly different in bee species composition were; CF and AE ($p = 0.03$), WL and AE ($p<0.001$) and WL and GL ($p<0.001$). Bee species abundance differ significant in all habitat types (Chi sq = 5.34; d.f = 3; $p = 0.04$). Shannon-Wiener Index of Diversity (H') was highest in GL (H' = 3.358) and lowest in AE (H' = 2.012) while evenness was high in CF (E = 0.422) and lowest in AE (E = 0.141). This study revealed that bee species diversity, richness and abundance vary across the habitat types in Kilombero, thus potential implication on habitat conservation and bee species composition and diversity.

Precipitation of the wettest period (Bio13) contributed to about 70% in influencing bee distribution on current and future climate change of highest emission scenario (RCP8.5) for the years 2050 and 2070. The study predicted that *A. mellifera and M. ferruginea* will lose their suitable habitats under future climate scenario of 2050 while *H. ruspolii* and *L. bottegoi* will experience slight gain in suitable habitats. Under the future climate scenario of 2070, all bee species will lose their suitable habitats.

Conclusion

There is apparently high bee species composition, richness and diversity in the Kilombero SACGOT cluster and the distribution varied across habitat types. Climate change has a significant influence on the current and future distribution of bee species in Kilombero SAGCOT cluster with precipitation of the wettest period being the main climatic variable influencing the future distribution of bee species. Loss of suitable habitats for most bees is the major future climate impact on bee population thus conservation of suitable habitats for bees is of paramount importance.

Recommendation

Mainstreaming these observations in the Kilombero Cluster Development Framework implementation of different cluster value chains, it is important if we should have sustainable production systems that consider both environment and agriculture production. There is a need to develop climate adaptation and mitigation strategies for conservation of bee populations in Kilombero which consider conservation of the potential areas where predictions show a reduction in habitat suitability for bees. Bee conservation under the changing climate needs to consider habitat connectivity to allow bee migration not only between current suitable habitats, but also to the future suitable habitats as predicted by the model. Long term monitoring in changes in the dominant bee populations is essential for predicting future climate change response. Given the potential influence of habitat type on bee populations, future studies should go further on studying the influence of vegetation composition on bee abundance and diversity and their interactions.

Dissertation Structure

This dissertation is in publishable manuscripts format, which consist of four main chapters. Chapter one comprise of the General introduction, Problem statement, Justification of the study and Objectives. The chapter two (Manuscript one) is on the assessment of bee species composition and diversity across different habitat types in Kilombero SACGOT cluster, Tanzania. The chapter three (Manuscript two) is on the influence of climate change on the distribution of dominant bee species in Kilombero SAGCOT cluster, Tanzania. The chapter four is on the general conclusion and recommendation of the study.

DECLARATION

I, **DEBORA M. MAGESA** 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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Prof. P. K. T. Munishi **Date**

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DEDICATION

This work is dedicated to my beloved father Ezra Magesa, who has always believed me. Despite the fact that am the only girl in our family, still he believed that I can achieve the best in academics. He always wished for my master’s degree and never gave up on his wish. Your trust and courageous word to me were the motives of my achievement.

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LIST OF ABBREVIATIONS AND ACRONYMS

a. s. l	Above the sea level
AE	Agro-ecosystem
AUC	Area under Cover
CF	Closed Forest
DEM	Digital Elevation Model
E	Eastings
FR	Forest Reserve
GHG	Greenhouse gas
GL	Grassland
Ha	Hectare
m	Meter
MaxEnt	Maximum Entropy modelling
Min	Minute
Mm	Millimeter
N	Northings
NR	Nature reserve
ROC	Receiver operating characteristic
SAGCOT	Southern Agriculture Corridor of Tanzania
SOTER	Soil and Terrain digital database
UV	Ultra Violet
WL	Woodland

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background Information

Bees are known to be the most important group of insect (Devoto *et al.*, 2005) since, they provide various products such as honey, bee wax and also provide pollination services to the agro-ecosystems and natural habitats (Zattara and Aizen, 2021). According to Da Silva *et al*., (2012) approximately half of pollinators in tropical plants are bees, pollinating more than 72% of 1330 plant species. The pollination services provided by bees can contribute to the maintenance of plant diversity (Potts *et al.*, 2003) which is important for the productivity of the ecosystems. Bee species preference on floral resources and nesting site requirement varies (Ogilvie and Forrest, 2017), thus, there is necessity of studying bee composition and distribution in different habitat type. Despite of the importance of bee in the ecosystem, worldwide there have been several reports on bee decline (Drossart *et al*., 2019; Powney *et al*., 2019). This decline of bees is confirmed to be caused by several factors such as; Land use change, the use of pesticides, invasive species, pathogen and climate change (Goulson *et al.*, 2008).

The environmental factors such as climate change is among factors influencing the distribution of bee species (Kevan and Viana, 2003). Bee species are expected to respond differently to climate change, either by range shift or disappearance due to loss of their suitable habitats (MacLean and Beissinger, 2017). There are several studies which have confirmed climate change to influence bee distribution, abundance and morphology (Pyke *et al*., 2016). Therefore, this study was aimed at assessing the distribution of bee species across habitat types and the influence of climate change on bee populations in the Kilombero SAGCOT cluster of Tanzania.

1.2 Problem Statement

Given the great importance of bees in the ecosystems, several studies have pointed out bee decline to the level that cannot sustain the pollination services in both agroecosystem and natural habitat (Dar, 2019). There various reports on the dramatic decline of bee distribution, diversity and abundance, mostly from North America (Williams *et al*., 2001) and Europe (Cane and Tepedino, 2001; Goulson *et al*., 2008). Unfortunately, in most part of African continent very little is known about bee distribution. There are few studies conducted in East Africa on diversity, distribution and abundance of bees on natural and cultivated habitats in Kenya and Uganda (Gikungu, 2002; Martins, 2014; Morimoto *et al*., 2004; Munyuli, 2011; Njoroge *et al.*, 2004).

Currently, in Tanzania there are ongoing studies on bee funded by JRS projects, which are implemented by several institutions such as; Tanzania Wildlife Research Institute (TAWIRI) in mountane forests of the Eastern Arc Mountains, College of African Wildlife Management Mweka (CAWM) in Eastern Arc Mountains and Dar es Salaam Institute of Technology (DIT) are developing a national biodiversity data portal. These projects mainly focus on monitoring bee pollinators. Despite of these ongoing studies, the information about the bee species composition, diversity and distribution on different habitat types is still in adequate. This study was conducted in Kilombero SAGCOT cluster were agriculture activity is extensively practiced, and bees are key pollinator in their crops thus, studies on bees are crucial in the area for the maintenance of agriculture productivity. Therefore, this research aimed at determining the composition and diversity of bee species in different habitat type and also determine their influence to climate change.

1.3 Justification of the study

This study will provide baseline data on the composition and distribution of bee species in the southern part of Tanzania. This information will contribute to environmental conservation and restoration plans, which aim at maintaining the diversity and bee assemblage to enhance ecosystem services especially pollination for ecosystem productivity with a bearing on crop production. Beekeeping as an economic activity among the society contributing significantly to income will benefit substantially from this study. Moreover, the study will stir the need for conducting similar studies in other potential place. Future scholars may use this study as a reference material in conducting other related academic studies on the issues at stake.

1.4 Objective of the study

1.4.1 General objective

The main objective of this study was assessment of the influence of climate change on bee species distribution across habitat types in Kilombero SAGCOT cluster, Tanzania

1.4.2 Specific objectives

The specific objectives of the study were:

i. To determine the composition and diversity of bee species across different habitat types

ii. To assess the influence of climate change on the distribution of the dominant bee species

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CHAPTER TWO

2.0 BEE SPECIES COMPOSITION AND DIVERSITY IN DIFFERENT HABITAT TYPES IN KILOMBERO SACGOT CLUSTER, TANZANIA

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Abstract

Bees are important group of pollinator insects in the world as they play a key role of pollination in natural and agroecosystems**.** Habitat types have influence on the composition, species richness, diversity and abundance of bees. This study was aimed at investigating the composition and diversity of the bees within different habitat types in Kilombero SACGOT cluster. Stratified sampling was employed, where habitat types were stratified into: Closed forest (CF), Grassland (GL), Woodland (WL) and Agroecosystem (AE). Sweep netting and pan trapping were used to capture bees within 20 m x 40 m plots. Euclidean distance measure of similarity was used to compare bee composition among the habitat type. Pairwise comparison of bee composition in different habitat type was done using Raup-Crick dissimilarity index. Bee diversity, richness, abundance and evenness was determined. A total of 818 individual bees, belonging to 169 species from five families were collected during the study period. The dominant family was Apidae and the least dominant was Andrenidae. Euclidean distance measure of similarity shows high similarity of bee species composition between WL and CF. GL was observed to be more similar to WL and CL compared to AE. AE was less similar to CF, GL and WL. The pair comparison of bee species composition between the habitat types were significant different in CF and AE ($p = 0.03$), WL and AE ($p<0.001$) and WL and GL ($p<0.001$). The bee abundance was significant different between the habitat types (Chi sq= 5.34; d.f = 3; $p = 0.04$). Bee richness was highest in GL (75 species) and lowest in AE (53 species). GL had high bee diversity (*H’* =3.358) and lowest in AE (*H’* =2.012). CF had highest evenness (E= 0.422). Therefore, this study revealed that bee species diversity, richness and abundance varies among habitat types.

Keywords; Bee, Habitat type, Diversity, Abundance

2.1 Introduction

Bees are the most important group of pollinator insects in the world as they play a key role of pollination in natural and agroecosystems, pollinating wild plant and crops (Winfree *et al.,* 2009). Despite of how human dependents on bee fauna in the pollination role they play, their abundance, diversity and distribution is declining worldwide and this due to changes in land use, climate change, introduced species, and disease (Breeze *et al.,* 2021; Potts et *al.*, 2010; Winfree, 2010). To ensure a successful pollination and maximum production of crop, diverse populations of wild bees is required (Kremen *et al.,* 2004). There are about 20 000 to 30 000 known bee species in the world, of which 3000 bee species are found in the sub-Saharan Africa (Michener, 2007).

Bees are found in different types of habitat, where there is sufficient floral resources and suitable nesting sites (Michener, 2000). The nesting behavior of bees can influence how bee community responds to changes in habitat, thus, what is required by one species may not be necessarily for the other (Bartomeus *et al.*, 2013; Jacobson *et al.*, 2018). The change in availability of food and nesting resources for certain groups of bees, such as those that only nest in stems or are specialist feeders, can result in changing of the bee community composition of that particular landscape (Burkle *et al.*, 2013; Mallinger *et al.*, 2016; Potts *et al*., 2010; Sheffield *et al.*, 2013). There several research conducted in Central Europe and the America, which show that bee diversity and abundance are influenced by the structure and composition of their habitat types (Tscheulin *et al.*, 2011).

Ecologically, habitat heterogeneity and quality is considered as a basis for bee species diversity, this is because different habitat types provide different floral resources and nesting site (Kleijn *et al.*, 2004; Potts *et al.*, 2005; Steffan-Dewenter *et al.*, 2001). Comparative studies of species ecology in different habitat types can provide clues to the likely response of both species and communities in the study of the influence of habitat types on the diversity and abundance of pollinator insects. Bee community composition is expected to change within habitat type due to availability of different floral resource and nesting sites.

The difference in habitat type affect the composition, richness, diversity and abundance of flower-visiting insects mostly bees (Buchori *et al.*, 2019). However, there is a knowledge gap on the distribution of wild bees across different habitat type (Mandelik *et al.*, 2012a). Information on bee relative abundance and diversity gives an indication of pollinator activities (Kevan, 1999) and such information especially for the world bees on semi-natural and agricultural landscape are often missing. Information on bee fauna is useful in identifying and prioritize conservation measures for sustainable ecosystem productivity and crop production. Therefore, the objective of this study was to investigate the composition and diversity of the bee species within different habitat types in Kilombero SACGOT cluster.

2.2 Methodology

2.2.1 Study area description

The study was conducted in selected sites of SACGOT Kilombero cluster, in Morogoro region as described in Table 2.1.

Table 2.1: Description of study areas

District	Forest	Coordinates
Ulanga	Mselezi FR	37˚46´59˝E, 7˚2´0˝N
	Mahenge Scarpment FR	37˚30´0˝E, 9˚0´0˝N
Malinyi	Luvili General Land	36˚8´4˝E, 8˚56´39˝N
	Itongoa FR	36˚42´15˝E, 7˚46´41˝N
Kilombero	Kilombero NR	36˚20´59˝E E, 8˚13´17˝N
	Nyanganje FR	36˚42´15˝E, 7˚46´41˝N

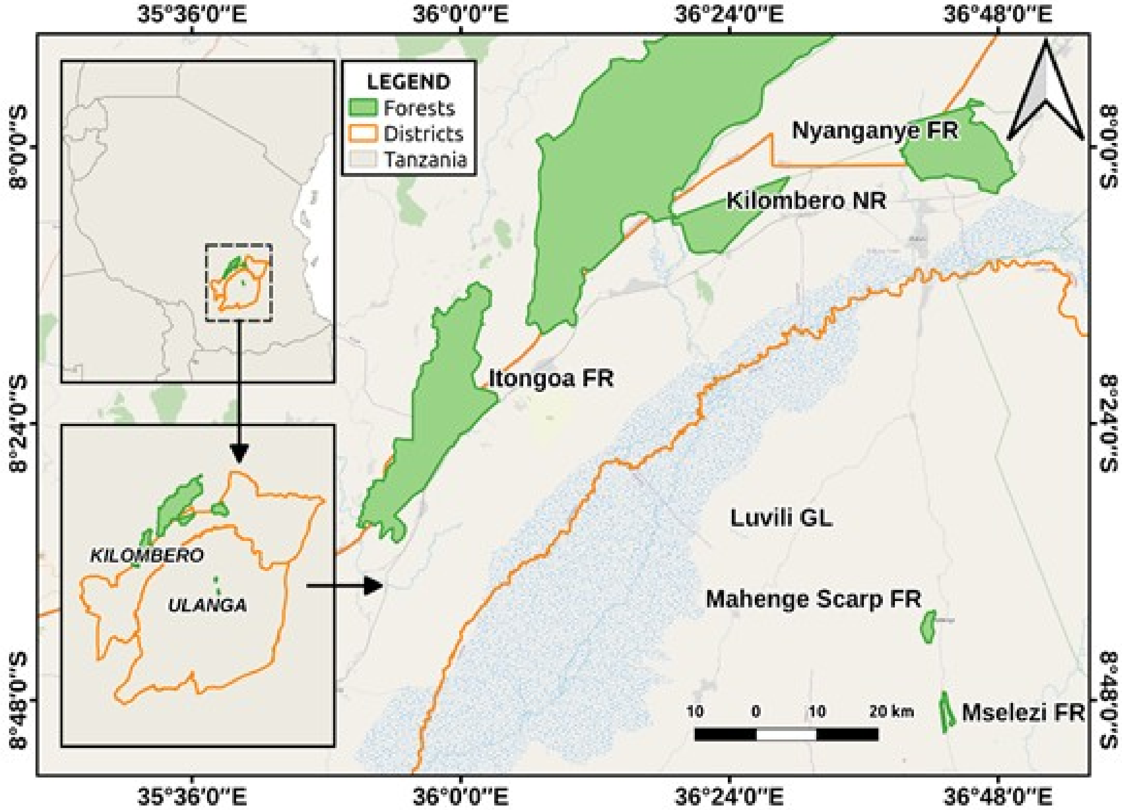

Figure 2.1: The map of the study area

Morogoro region is located in southeastern part of Tanzania (Figure 2.1). The region is situated between a latitude 5° 58′ and 10′south of the equator and between longitude 35° 25′ and 38° 30′ East Greenwich (Salehe and Hassan, 2012). There is a considerably variation of climatic condition from one district to another, this is mainly due to topographical variations in different parts of the region. The region has a sub-humid tropical climate, which has distinct dry and rainy season. The average annual rainfall is between 500 mm in low areas and 2200 mm in the mountainous areas (Kirimi *et al.*, 2018a) with the average temperature of 24° C, ranging from 18° C to 30° C in low and high area respectively (Wilson *et al*., 2015). The region has mostly sandy clay loams in the top soils and clays in subsoil. Currently, the predominant land use system is agriculture practice, charcoal production, beekeeping, fishing in the floodplain, hunting and utilization of forest products (Dinesen, 2016; Kirimi *et al.*, 2018b).

Agro ecosystem

The predominant human activities conducted in the habitat type is crop cultivation, the most cultivated crops were maize, banana, cassava, sweet potatoes, beans and sorghum. There were some herbaceous species which had floral resource found to emerge a side the farms such as; *Bidens pilosa* and *Commelina africana*. Most of the farms were monocrop. There some farmers who had beehives in their farm.

Woodland

Vegetation species which were mainly found in the woodland were; *Annona senegalensis*, *Aspilia mossambicensis*, *Brachystegia* species, *Bridelia cathartica*, *Combretum molle*, *Dalbergia melanoxylon*, *Dalbergia nitidula*, *Diplorhynchus condylocarpon*, *Lannea schimperi*, *Pericopsis angolensis*, *Pterocarpus angolensis*, *Stereospermum kunthianum*, *Piliostigma thonningii* and *Pseudolachnostylis maprouneifolia*.

Grassland

This type of vegetation was mainly found in lower-lying areas (Munishi and Jewitt, 2019; Alavaisha *et al.*, 2019; Legese and Balew, 2021) and in fallow lands. In the uplands, there were some few patches of upland grassland. The common species found in grassland were; *Cyperus species*, *Eragrostis pilosa*, *Hyparrhenia cymbaria*, *Hyparrhenia rufa*, *Panicum maximum, Pennisetum purpureum* and *Mimosa pudica*.

Closed Forest

A large part of the closed forest was found in upland areas and in forest along the river line. The vegetation comprises of moist and dry montane forest. The commonly species in this forest were; *Sorindeia madagascariensis*, *Terminalia kilimandscharica*. *Treculia africana*, *Grewia goetzeana*, *Bridelia micrantha*, *Milicia excels* and *Terminalia sambesiaca.*

2.2.2 Study design

The study area has different habitat type, thus, stratified sampling was employed, where the stratification was based on habitat type to capture the variation. The habitat types were; Grasslands (GL), Agroecosystems (AE), Woodlands (WL) and Closed forests (CF). Transects were established within the strata and plots of 20 m x 40m (0.08 Ha) were laid along the transect. The distance between transects was 300 m and between plots was 200 m (O'Connor *et al.*, 2019). The number of transect within the stratum was based on the size of the stratum (Figure 2.2).

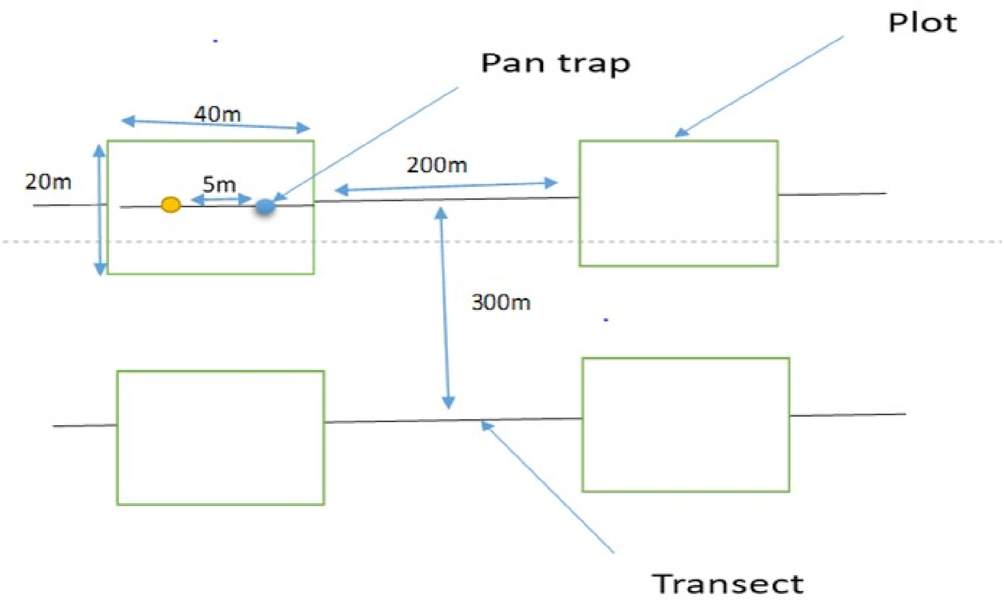

Figure 2.2: Layout of the plots in the stratum

2.2.3 Data collection

Bee sampling

Sweep netting and pan trapping were used to capture bees within the plots. Sweep netting was used as the supplement of pan trapping. Both methods were used to increase the sample, those bees which could not be captured using pan traps were captured by sweeping net. According to Wilson *et al.*, (2008), the application of these two methods concurrently to capture bees is the most effective way to sample wild bees. Sweep netting is an active method of sampling bees (Potts *et al.,* 2005), this method involved moving around the plot over 30 min interval mostly targeting the bees that were visiting flowers (Zink, 2013). The clock was stopped while bees were being transferred from the net to a kill jar, the same collector was associated with bee netting in all the plots to avoid biases (Westphal *et al.,* 2008). A transect cutting across the plot was established within the plot (Figure 2.2). Triplet pan traps were placed along the transect at an interval of 5 m. These pans were sprayed with UV fluorescent paint of blue, white and yellow (Leong and Thorp, 1999) and filled with 100 ml of water plus a drop of unscented detergent to break surface tension (Mandelik *et al.,* 2012a). The pan traps were set for 6 – 7 h between 0830 h and 1700 h (O'Connor *et al*., 2019). According to Nardone, (2013) this capture duration is the active hours for bees. In each plot the bees which were captured through sweep netting and pan trapping were combine and temporary preserved in one plastic containers containing 70% alcohol. The plastic container was marked with plot number, date of collection, location name and habitat type. The obtained bees were pinned, labeled, identified and quantified in African Seed Health Center Laboratory at Sokoine University of Agriculture. Identification was carried out using bee standard keys; the bees of the world (Michener, 2007), the bee genera and subgenera of Sub-Saharan Africa (Eardley *et al*., 2010), the wasp and bees in Southern Africa (Gess and Gess, 2014) and catalogue of Afrotropical bees (Eardley and Urban, 2010). Due to lack of local identification keys for bees, some species were only identified as morphotypes.

2.2.4 Data analysis

Bee species composition was determined as the list of the identified bee species in each habitat type. Euclidean distance measure was used to determine the degree of similarity of bee composition between the habitat types. Furthermore, pairwise comparison on bee composition between the habitat type was done using Raup-Crick dissimilarity index in R software.

Bee richness was determined as the number of bee species encountered, relative abundance of bee species was determined as the number individual of each species relative to the total number for all species. Be species diversity was determined by Shannon- Wiener and Simpson Diversity Indices. Bee species evenness was computed by the Pielou's measure of species evenness, (J = H'/ln(S) where H' is Shannon Weiner diversity and S is the total number of species in a sample, across all samples in the dataset. The data were tested for normality using Shapiro- Wilk test and found to be not normally distributed. Chi- square test was used to compare bee abundance and richness among the habitat type. Furthermore, Duncan test (Post hoc) was performed on bee abundance.

2.3 Results

2.3.1 Bee species composition among the habitat types

A total of 818 individual bees, belonging to 169 species from five families were collected during the study period. These bees belonged to families; Andrenidae, Apidae, Colletidae, Halictidae and Megachilidae. The most dominant family was Apidae and the least dominant was Andrenidae (Figure 2.3). *Apis mellifera, Meliponula ferruginea, Hypotrigona ruspolii*, *Liotrigona bottegoi*, *Hypotrigona gribodoi* and *Lipotricles* sp.2 were the species found in all the four habitat type (Appendix 2.1).

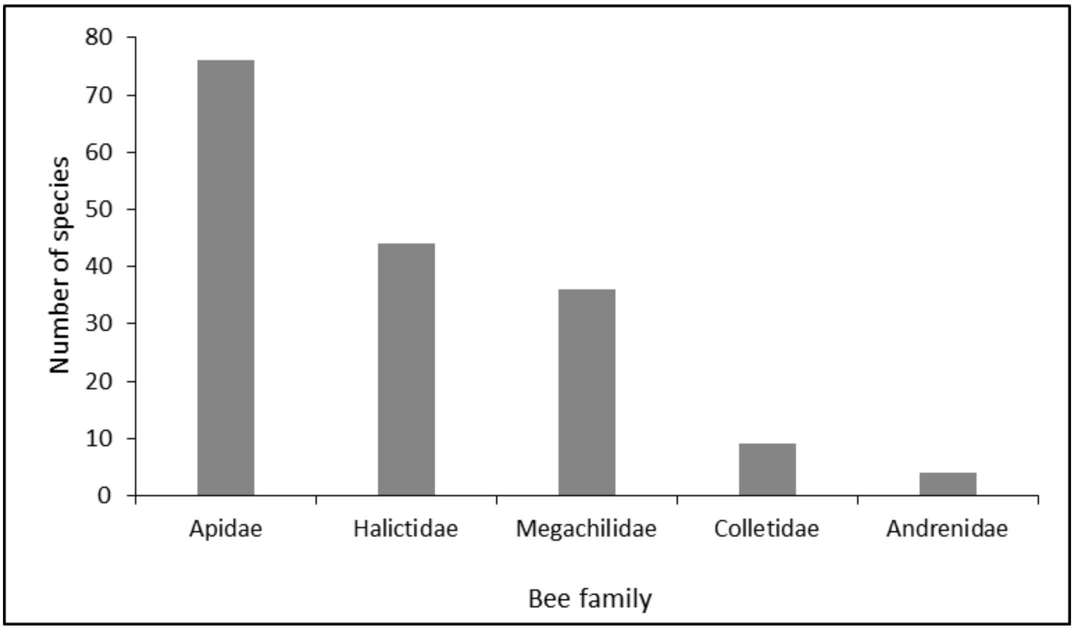

Figure 2.3: Bee species with their respective families.

The comparison of bee specie composition between the habitat types by Euclidean distance measure of similarity shows that, there was high similarity of bee species composition between WL and CL. However, bee specie composition in GL was observed to be more similar to WL and CF compared to AE, which was less similar to the rest of the habitat types (Figure 2.4).

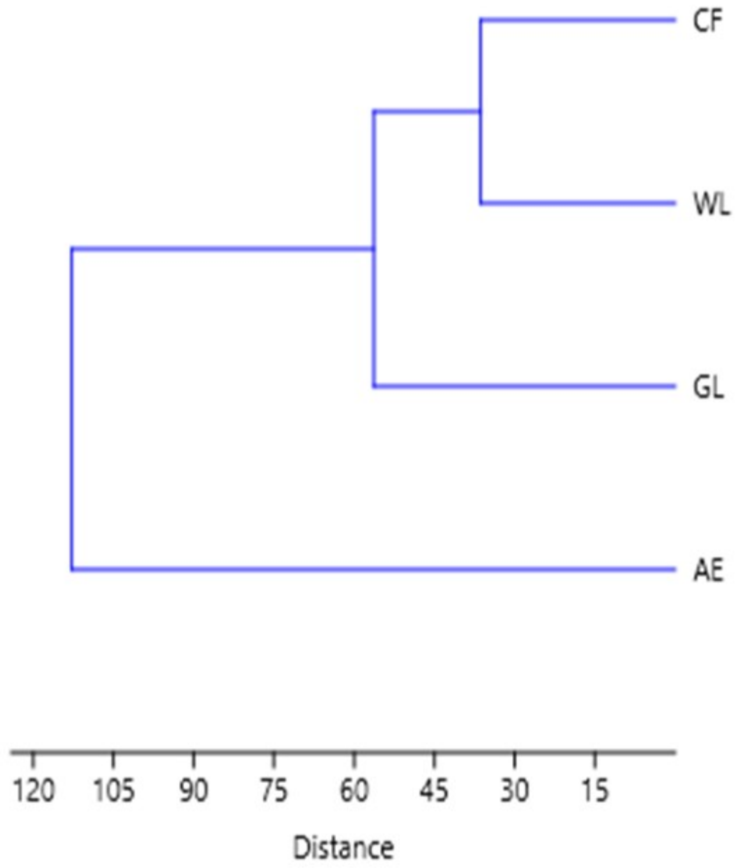

Figure 2.4: Cluster dendrogram of Euclidean distance similarity measure of bee composition between the habitat types were; AE= Agro ecosystems, CF= Closed forests, GL= Grasslands and WL= Woodlands

Moreover, the pairwise comparison performed using Raup-Crick dissimilarity index shows the pairs of habitat type which had significant dissimilarity of bee species composition were between; CF and AE ($p= 0.03$), WL and AE ($p<0.001$) and WL and GL ($p<0.001$) (Figure 2.5).

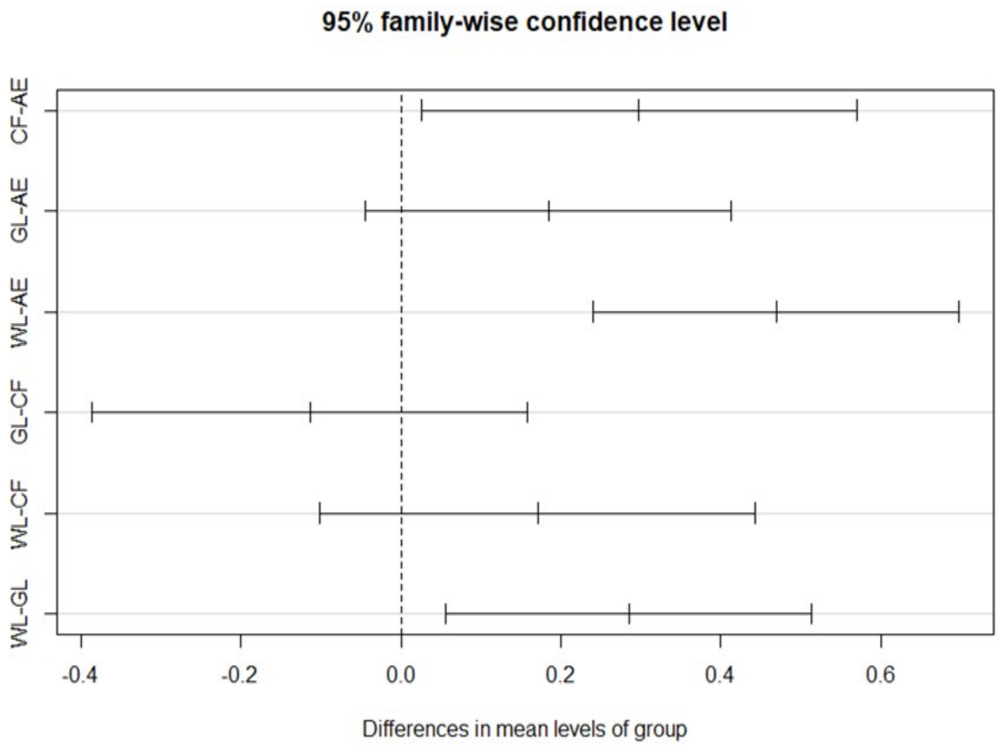

Figure 2.5: Raup-Crick dissimilarity index pairwise comparison of the habitat type were; AE= Agro ecosystems, CF= Closed forests, GL= Grasslands and WL= Woodlands

2.3.2 Comparison of bee species abundance, richness and diversity in different habitat types

The abundance of bee was highest in AE (234 individual) and lowest in CL (176 individual) (Table 2.2), the abundance was significant different between habitat types (Kruskal-Wallis test, H = 5.348; d.f = 3; p = 0.04), post hoc test done on the abundance show the significant difference was between GL and AE (p= 0.01) and between GL and WL (p= 0.02). Furthermore, bee richness was highest in GL (75 species) and lowest in AE (53 species) (Table 2.2), though not significant different between the habitat types (Kruskal-Wallis test, H = 3.515; d.f = 3; p = 0.31). Shannon-Wiener Index of Diversity (H’) was highest in GL (H’ =3.358) and lowest in AE (H’ =2.012). However, species evenness was highest in CF (E = 0.422) and lowest in AE habitat (E = 0.141) (Table 2.2).

Table 2.2: Bee species diversity indexes, richness, abundance and evenness in different habitat type.

	Agro ecosystem	Closed Forest	Grassland	Woodland
Richness	53	63	75	55
Abundance	234	176	199	209
Simpson (1-D)	0.590	0.917	0.887	0.875
Shannon (H)	2.012	3.281	3.358	2.869
Evenness (E)	0.141	0.422	0.383	0.320

2.4 Discussion

2.4.1 Bee species composition between habitat types

The results show that most of the species were from Apidae family. The family Apidae is the dominant family since most of bee species are found in this family (Eardley *et al*., 2009). This is found similar to a study by Potts *et al.*, (2003) in Mt. Carmel also indicated Apidae family dominating. Most bee species in Apidae family can travel long distance for foraging, makes them not being limited to the habitat type, thus increasing their availability in almost all the habitat type (Chiawo, 2017). Most of species in Apidae family are generalist foragers as they contain a wide range of resources that they could use, which increase their chances of existence (Bobadoye *et al*., 2017). However, from the results high abundance of *Apis mellifera, Meliponula ferruginea, Hypotrigona gribodoi, Hypotrigona ruspolii and Liotrigona bottegoi* contributed largely to the dominance of Apidae.

The results on comparison of the similarity of species composition between the habitat type shows that, the composition of bee species in AE are less similar to other habitat type. Bee species which were only found in AE were such as; *Ceratina viridis, Lasioglossum* sp. 2, *Lipotricles sp*. 3 and about 52% of rare species. The difference on bee composition in AE to other habitat type might have been influenced by the presence of disturbance in AE such as intensive management practice in farm such as tillage and the use of pesticide this could have led to destruction of the nesting sites for some species which led more species to shift to the natural habitat which are less disturbed (Desneux *et al*., 2007). This was also confirmed by Michener, (2000), who observed some of the species being very specific in their nesting and foraging requirement and prefer low disturbed habitat. These less disturbed habitats could be in WL, GL and CF compared to AE. Nevertheless, CF, WL and GL are forest which provides a wide range of the habitat site to various bee species due to presence of burrows, tree cavities, and young pithy plants (Gikungu, 2006) were these sites might not be in AE thus led to their difference in bee species composition.

Furthermore, CF and WL were observed to have more similar species composition compared to GL this might as well be due to the similarity of the vegetation composition which allow presence of similar floral resources and nesting requirements which favor similar bee species (Torné-Noguera *et al*., 2014). However, GL is composed of variety of herbaceous plant and it has open canopy compared to WL were the dominant plant are trees and shrubs and has low canopy. The difference in their habitat structure and availability of floral resources might have resulted to low similarity in their bee composition.

2.4.2 Comparison of bee species diversity, richness and abundance between habitat types

The result shows low abundance of bees in the CF, could be because of the sampling technique used to sample bees. Pan trap method is mainly based on bee close to the ground, but not within the tree canopies (Wu *et al.,* 2018). Also this can be argued by the presence of dense tree coverage which could have led to less dense undergrowth, result to distinctly lower provision of flowers in the herb and shrub layers making the sites less attractive to bees (McKinney and Goodell, 2010; Wulf and Naaf, 2009). High abundance of bees in the AE was contributed by the presence of *Apis mellifera*, probably because they live in large colonies and tend to displace other bee on flower (Eardley *et al*., 2009). Additionally, high abundance in AE might be because of some farmers who had beehives in their farms.

Species richness and diversity was highest in WL, this might be due to availability of heterogeneity of floral resource, since floral resources are considered to be major driving force that directly regulates the diversity of wild bees' communities (Potts *et al.,* 2003; Roulston and Goodell, 2011). Also, high specie richness and diversity in WL could be as a result of the availability of variety of herbs, shrubs and grass which had flowers attracting bee to visit for foraging (Potts *et al*., 2003). This is also recognized by Morandin *et al*., (2007) and Svensson *et al*., (2000). Grassland is the habitat of major interest for bees since there able to offer rich floral and nesting resources. The presence of openness in GL allows increase of light intensity to facilitate the growth of shrubs and herbaceous plant which are a good source of pollen and nectar (Liow *et al*., 2001). Also the openness in GL allows the presence of ground nesting, since most of the solitary bees are ground nester, and they are specialist bee and they fly around their nesting site in search of floral resources so this might as well increase the richness of bees. This result is supported by

Gikungu (2002) who conducted a study in the Mount Kenya forest with the objectives of establishing the species diversity of bees in four habitat (open woodland, closed woodland, shrub land and pine plantation) found high bee diversity in the open woodland compared to other habitat.

Agro ecosystem had the lowest richness and diversity which contrast a few studies in East Africa (Gikungu *et al.*, 2011) have shown that agricultural ecosystems may support higher levels of bee diversity than forested areas. The contrast might be attributed to the fact that most of the farmers in the study area practiced monoculture (cultivation of one type of crop in the farm). Very few farms had more than two crops, which mainly cultivated maize and banana only. However, another reason might be because of most of the farms were in the early preparation stage for cultivation, weeding and land preparation was conducted, perhaps this might have led to low diversity compared to other habitat type. The study by Mandelik *et al.*, (2012b) also support that intensive management practice which are done during farm preparation such as; plowing for soil aeration, weeding and application of pesticides and herbicides, can likely contribute to the low wild bee diversity. Generally, high richness and diversity of bee species GL is mainly contributed by quality and quantity of the availability of the nesting and foraging site within the habitat type. The difference in the diversity, richness and abundance between the habitat type is due to variation of the available resources required by bee species.

2.5 Conclusion and recommendation

The study revealed that bee species diversity, richness and abundance vary among habitat types. Pollination service is provided by bees, it is obvious we cannot rely on bee for this service for free without taking into consideration their needs for survival. Therefore, this study was able to provide knowledge on how habitat type in natural ecosystems affect wild bee communities, and thus indicates a need of developing effective management practices, mainly in disturbed ecosystems. The areas in SAGCOT mainly dependent on agriculture economics, specific habitat and landscape management strategies are need to be seriously pursued particularly in degraded areas. These may include encouraging and training crop farmers to adopt pollinator friendly farming practices such as agroforestry, which allows habitat heterogeneity. A future study should measure the influence of environmental and anthropogenic factors and on bee abundance and diversity in the study area.

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APPENDICES

Appendix 2.1: Checklist of bee species and their abundance in four habitat type.

Species	**Family**	**AE**	**CF**	**GL**	**WL**	**Indv T**
Afranthidium sjoestdi	Megachilidae	0	1	0	0	1
Afroheriades sp.	Megachilidae	1	0	1	0	2
Afroheriades sp.1	Megachilidae	0	0	0	1	1
Afrosteris sp.	Megachilidae	1	0	0	0	1
Allodape armatipes	Apidae	0	0	1	0	1
Allodape interruptus	Apidae	0	1	0	0	1
Allodape macula	Apidae	0	4	0	0	4
Allodape punctata	Apidae	0	0	1	0	1
Allodapula monticola	Apidae	0	0	0	2	2
Allodapula sp. 1	Apidae	1	0	0	0	1
Allodapula sp. 2	Apidae	1	0	1	0	2
Amegilla (Aframegilla) sp. 1	Apidae	1	0	1	0	2
Amegilla caelestina	Apidae	1	0	1	0	2
Amegilla africana	Apidae	0	0	0	1	1
Amegilla atrocincta	Apidae	1	0	0	1	2
Amegilla capensis	Apidae	0	1	0	0	1
Amegilla sp. 2	Apidae	1	0	0	1	2
Andrena africana	Andrenidae	0	0	1	0	1
Anthophora (Heliophila aff. vestita)	Megachilidae	0	1	0	0	1
Apis mellifera	Apidae	149	27	63	43	282
Braunsapis facialis	Apidae	0	0	1	0	1
Braunsapis angolensis	Apidae	8	1	2	0	11
Braunsapis bouyssoui	Apidae	0	0	0	2	2
Braunsapis facialis	Apidae	0	1	0	0	1
Braunsapis foveata	Apidae	0	0	2	0	2
Braunsapis natalica	Apidae	0	0	0	3	3
Braunsapis rhodesi	Apidae	0	0	0	1	1
Braunsapis sp.	Apidae	1	0	0	2	3

Braunsapis sp. 1	Apidae	0	1	0	0	1
Braunsapis sp. 2	Apidae	0	1	0	0	1
Braunsapis sp. 3	Apidae	2	0	1	0	3
Braunsapis sp. 4	Apidae	0	0	1	0	1
Ceratina (Ctenoceratina) sp. 1	Apidae	0	1	0	0	1
Ceratina ericia	Apidae	0	1	0	0	1
Ceratina minuta	Apidae	0	0	3	0	3
Ceratina moerenhouti	Apidae	0	1	7	4	12
Ceratina nasalis	Apidae	0	1	0	0	1
Ceratina paulyi	Apidae	0	4	0	0	4
Ceratina penicillata	Apidae	1	0	0	1	2
Ceratina sp. 1	Apidae	0	0	1	0	1
Ceratina sp. 2	Apidae	2	2	2	0	6
Ceratina sp. 3	Apidae	1	1	0	0	2
Ceratina sp. 4	Apidae	1	2	0	0	3
Ceratina sp. 5	Apidae	1	2	0	0	3
Ceratina sp. 6	Apidae	1	1	1	0	3
Ceratina sp. 7	Apidae	0	1	1	0	2
Ceratina sp. 8	Apidae	0	1	1	0	2
Ceratina sp. 9	Apidae	0	1	1	0	2
Ceratina tanganyicensis	Apidae	0	0	0	2	2
Ceratina viridis	Apidae	4	0	0	0	4
Ceratina whiteheadi	Apidae	0	0	0	1	1
Cleptotrigona sp.	Apidae	0	8	2	1	11
Cleptotrigona sp. 1	Apidae	0	1	0	0	1
Coelioxys natalensis	Megachilidae	0	0	0	1	1
Coelioxys odin	Megachilidae	0	2	0	0	2
Coelioxys sp. 1	Megachilidae	1	0	1	0	2
Coelioxys sp. 2	Megachilidae	1	0	0	0	1
Colletes eardleyi	Colletidae	0	1	0	0	1
Creigtoniella ithanoptera	Megachilidae	0	0	1	0	1
Ctenoplectra antinorii	Apidae	0	0	0	2	2
Ctenoplectra sp. 1	Apidae	1	1	1	0	3

Ctenoplectra sp. 2	Apidae	1	0	0	0	1
Ctenoplectra terminalis	Apidae	0	1	0	0	1
Dactylurina schmidti	Apidae	1	0	0	1	2
Eupetersia (Calleupetersia) sp.	Halictidae	1	0	0	0	1
Halictus (Seladonia) sp. 1	Halictidae	2	0	0	0	2
Halictus (Seladonia) sp. 2	Halictidae	0	1	1	0	2
Halictus fascialis	Halictidae	0	1	0	0	1
Heriades (Pachyheriades) sp.	Megachilidae	0	0	0	1	1
Heriades (Pachyheriades) sp. 1	Megachilidae	1	0	1	0	2
Heriades bouyssoui	Megachilidae	0	0	0	1	1
Heriades scutellatus	Megachilidae	0	1	0	0	1
Heriades sp. 1	Megachilidae	0	0	0	1	1
Heriades sp. 2	Megachilidae	0	0	1	0	1
Heriades sulcatulus	Megachilidae	0	0	0	1	1
Hylaeus (Deranchylaeus) sp.	Colletidae	0	1	0	0	1
Hylaeus (Nothhylaeus) sp.	Colletidae	0	1	0	0	1
Hylaeus (Nothhylaeus) sp. 1	Colletidae	0	0	0	1	1
Hylaeus braunsi	Colletidae	0	4	0	0	4
Hylaeus heraldicus	Colletidae	0	0	0	1	1
Hylaeus sp. 1	Colletidae	0	1	0	0	1
Hypotrigona gribodoi	Apidae	5	17	0	8	30
Hypotrigona ruspolii	Apidae	3	3	1	23	30
Lasioglossum (Ctenonomia) sp. 1	Halictidae	0	2	3	1	6
Lasioglossum (Ctenonomia) sp. 2	Halictidae	0	0	3	0	3
Lasioglossum (Dialictus) sp. 1	Halictidae	0	2	2	0	4
Lasioglossum (Ipomalictus) sp. 1	Halictidae	0	0	2	0	2
Lasioglossum (Ipomalictus) sp. 2	Halictidae	0	0	1	0	1
Lasioglossum (Rubrihalictus) sp.	Halictidae	0	0	2	0	2
Lasioglossum (Sellalictus) sp. 1	Halictidae	0	0	1	0	1
Lasioglossum sp.	Halictidae	0	0	1	0	1
Lasioglossum sp. 1	Halictidae	0	0	0	1	1

Lasioglossum sp. 2	Halictidae	2	0	0	0	2
Lasioglossum(Pasadialictus) synavei	Halictidae	0	1	0	0	1
Lasioglossum(Rubrihalictus) sp.	Halictidae	0	0	0	1	1
Liotrigona bottegoi	Apidae	3	5	3	7	18
Liotrigona bottegoi	Apidae	0	1	0	0	1
Liotrigona sp.	Apidae	0	3	0	0	3
Lipotriches (Afronomia) sp.	Halictidae	0	0	1	0	1
Lipotriches (Lipotriches) hylaeoides	Halictidae	2	3	0	0	5
Lipotriches (Lipotriches) sp. 1	Halictidae	0	0	9	0	9
Lipotriches (Lipotriches) sp. 2	Halictidae	0	1	0	1	2
Lipotriches (Lipotriches) sp. 3	Halictidae	2	0	0	0	2
Lipotriches (Macronomia) sp.	Halictidae	0	0	0	1	1
Lipotriches (Trinomia) sp. 1	Halictidae	0	1	0	0	1
Lipotriches collaris	Halictidae	0	1	0	0	1
Lipotriches orientalis	Halictidae	2	0	2	1	5
Lipotriches rufipes	Halictidae	0	1	0	0	1
Lipotriches sp. 1	Halictidae	0	0	3	2	5
Lipotriches sp. 2	Halictidae	1	1	1	1	4
Lipotriches sp. 3	Halictidae	0	0	0	2	2
Lipotriches sp. 4	Halictidae	2	0	0	0	2
Lipotriches sp. 5	Halictidae	0	0	1	0	1
Lipotriches tridentata	Halictidae	5	0	1	0	6
Lipotriches vulpina	Halictidae	0	0	1	0	1
Macrogalea candida	Apidae	0	0	0	4	4
Megachile (Creightonella) sp. 1	Megachilidae	0	0	1	0	1
Megachile (Eutricharaea) sp. 1	Megachilidae	0	0	0	1	1
Megachile (Stenomegachile) sp. 1	Megachilidae	0	0	3	0	3
Megachile apiformis	Megachilidae	0	1	0	1	2
Megachile centrincularis	Megachilidae	0	0	5	0	5
Megachile ciacta combusta	Megachilidae	0	1	1	0	2

Megachile combusta	Megachilidae	0	0	3	0	3
Megachile felina	Megachilidae	0	0	1	0	1
Megachile frontalis	Megachilidae	1	1	2	0	4
Megachile ianthoptera	Megachilidae	0	0	1	0	1
Megachile polychroma	Megachilidae	1	0	0	0	1
Megachile rufipes	Megachilidae	1	2	0	1	4
Megachile sp.	Megachilidae	0	0	0	1	1
Megachile sp. 1	Megachilidae	1	0	0	0	1
Megachile sp. 2	Megachilidae	1	0	0	0	1
Megachile sp. 3	Megachilidae	1	0	0	0	1
Meliponula sp.	Apidae	0	1	0	5	6
Meliponula bocandei	Apidae	0	2	1	4	7
Meliponula ferruginea	Apidae	2	36	8	53	99
Meliponula sp. 1	Apidae	0	0	1	0	1
Melitturga penrithorum	Andrenidae	0	0	0	1	1
Melitturga sp. 1	Andrenidae	0	0	0	1	1
Meliturgula braunsi	Andrenidae	0	0	1	0	1
Nomia (Leuconomia) sp. 1	Halictidae	0	0	1	0	1
Nomia chandleri	Halictidae	0	0	1	0	1
Nomia scitula	Halictidae	0	0	0	2	2
Nomia theryi	Halictidae	0	0	1	0	1
Noteriades sp.	Megachilidae	1	0	0	0	1
Patellapis (Zonalictus) sp.	Halictidae	1	0	1	0	2
Patellapis (Zonalictus) sp. 1	Halictidae	0	0	1	0	1
Patellapis sp. 1	Halictidae	0	0	0	1	1
Plebeina denoitti	Apidae	2	0	0	1	3
Plebeina hildebrandti	Apidae	0	2	1	3	6

Pseudapis sp. 1	Halictidae	0	1	1	0	2
Pseudapis sp. 2	Halictidae	1	0	0	0	1
Pseudoanthidium truncatum	Megachilidae	0	0	1	0	1
Scrapter avius	Colletidae	0	0	0	1	1
Scrapter calx	Colletidae	0	1	0	0	1
Serapista denticulata	Megachilidae	0	0	0	1	1
Sphecodes sp.	Halictidae	0	0	1	0	1
Tetraloniella aurantiflava	Apidae	0	0	0	1	1
Tetraloniella sp. 1	Apidae	0	1	0	0	1
Thyreus calceatus	Apidae	0	0	0	1	1
Thyreus delumbatus	Apidae	0	1	0	0	1
Thyreus pictus	Apidae	0	0	1	0	1
Trinchostoma sp.	Halictidae	0	0	0	1	1
Xylocopa caffra	Apidae	0	0	3	0	3
Xylocopa flavorufa	Apidae	2	0	1	0	3
Xylocopa hottentota	Apidae	1	0	2	0	3
Xylocopa inconstans	Apidae	1	1	2	0	4
Xylocopa lugubris	Apidae	1	0	1	0	2
Xylocopa nigrita	Apidae	0	1	2	0	3
Xylocopa scioensis	Apidae	1	0	10	0	11
Total		**234**	**176**	**199**	**209**	**818**

CHAPTER THREE

3.0 THE INFLUENCE OF CLIMATE CHANGE ON THE DISTRIBUTION OF DOMINANT BEE SPECIES IN KILOMBERO SAGCOT CLUSTER, TANZANIA.

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Abstract

Bees are the most important group of insect, as they facilitate to the wild and crop pollination. There is substantial evidence that, climate change is a key threat to the existence of bees. Climate change as impact on bee distribution. However, the effects of climate change on the distribution of bees remains unknown. This study was aimed at determining the influence of climate change on the distribution of dominant bee species in Kilombero SAGCOT cluster. Maximum Entropy was used for modelling species distribution. The species occurrence data was obtained for four dominant bee species (*A. mellifera, M. ferruginea, H. ruspolii* and *L. bottegoi*). Environmental variable used were 19 bioclim data, topographic data (elevation, slope and aspect), soil type data, land cover maps. Pearson correlation was done to test for multi collinearity between environmental variables. The predicted future climate change scenario used was the highest scenario for GHG emissions (RCP8.5) for the year 2050 and 2070. Jackknife test was performed to determine the variable of importance and contribution variable to the influence of bee distribution. The study predicted that *A. mellifera and M. ferruginea* will lose their habitat suitability under the future climatic scenario of 2050 while *H. ruspolii* and *L. bottegoi* will slightly gain its high suitable habitat. Meanwhile, under future climate change scenario of 2070, all bee species will lose their high habitat suitability. The model predicted precipitation of the wettest period (Bio13) as the main determinant of bee distribution in current and future climate change. Therefore, climate change is proven to have a significant influence on the current and future distribution of bee species in Kilombero SAGCOT cluster. Thus, there is a need to develop climate adaptation and mitigation strategies in our national development plan so as to encounter the change.

Keywords: Bees, Climate change, Environmental variables, Maximum Entropy

3.1 Introduction

Bees are the most important group of insect (Devoto *et al.,* 2005), as there are key pollinating agent in the ecosystems. Bees contributes to the maintenance of plant diversity (Potts *et al.,* 2003) that ensures the ecosystem productivity. More than 75% of the major world crops and 80% of all flowering plant species rely on insect pollinators (Potts *et al.,* 2016; Willmer, 2011). According to Pires and Maués (2020) it is estimated that one-thirds of the world's species of agricultural crops are pollinated by bees. The annual value of pollination service provided by bee is worldwide estimated to be US dollar 65-70 billion (Khalifa *et al.,* 2021).

Regardless of the important role bees play in the ecosystem, the analysis done from the historic records shows that, the diversity of bees declined in the United Kingdom, the Netherlands and Belgium is mainly during the 20th century (Biesmeijer, 2006). However, there several studies which declared that the decline of bees is as a result of several leading causes; changes in land use, competition with invasive species, pathogens, agrochemical usage, and climate change (Biesmeijer, 2006; Brown and Paxton, 2009; Potts *et al.*, 2010). Nevertheless, there is substantial evidence that, climate change is a key threat to the existence of bees in their ecosystems (Aguirre Gutiérrez *et al*., 2017a; Kerr *et al.*, 2015).

Climate change being a phenomenon occurring globally and excels the geographical boundaries, analysis done as confirmed climate change to impact bee pollinator distribution (Giannini *et al.,* 2017). Furthermore, studies by Devoto *et al.*, (2009) and Martins, (2014) have provided evidence of how climate influences the community of pollinators and their behavior. Moreover, several studies have proven climate change as a major threat for populations of both natural and managed species worldwide (Pacifici *et al.*, 2015; Potts *et al.*, 2016; Rafferty, 2017).

According to Giannini *et al.,* (2012) climate change as resulted to reductions and shift in the geographical distribution of bee and was determined by evaluating bee pollinators' loss of their suitable occurrence areas. The possible response of bee to the climate change, can either be adaptation to the new environment, migration to another suitable area or extinction (Reddy *et al.,* 2012). The adaption of bee to climate change is not most likely since climate change occurs too rapidly for populations to adapt by genetic change (Dew *et al.,* 2019). Climate change is expected to cause shifts in species composition (Esquivel Muelbert *et al.,* 2019), ecological mismatches (Wood *et al.,* 2018), and loss of suitable occurrence areas of species which compromise ecosystem functionality (Fei *et al.,* 2017). Therefore, it is important to understand species responses or their overall distribution trends to the ongoing climatic changes so as to maintain the ecosystem functioning. It is also important to examine the environmental variables affecting bee distribution. Therefore, this study was aimed at determining the distribution of dominant bee species under climate change scenarios.

3.2 Methodology

3.2.1 Study area description

The study was conducted in Kilombero cluster of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) located in Morogoro region (Figure 3.1), found in the southeastern part of Tanzania. The region is situated between a latitude 5° 58' and 10' south of the equator and between longitude 35° 25' and 38° 30' East Greenwich (Salehe and Hassan, 2012). The cluster covers a total area of 5500 square miles. It consists of some part Kilombero, Kilosa, Malinyi, Ulanga districts (Morogoro region) and part of Kilolo district found in Iringa region. The land use/ land cover of the cluster is mixed of forest, woodland, and agriculture land. The cluster consists of several protected areas which are found in some part or wholly, the areas includes; Village Forest reserves, National Forest reserve, Nature reserve, Game reserve (Selous), Kilombero game controlled area and National parks (Mikumi National Park and Udzungwa National Park). In lowland area the average rainfall is 500 mm while in highland areas the average rainfall is 2200 mm (Kirimi *et al*., 2018a). Elevation of the areas in Kilombero SAGCOT cluster range from 200m asl to 1600m asl with average temperature of 24. The temperature in lowlands is 18° C and in highlands is 30° C (Wilson *et al*., 2015). The type of soil is silt loamy in large part of area. Most of people practice agriculture and other economic activities practiced are charcoal production, beekeeping, fishing in the floodplain, hunting and forest product utilization (Dinesen, 2016; Kirimi *et al*., 2018b).

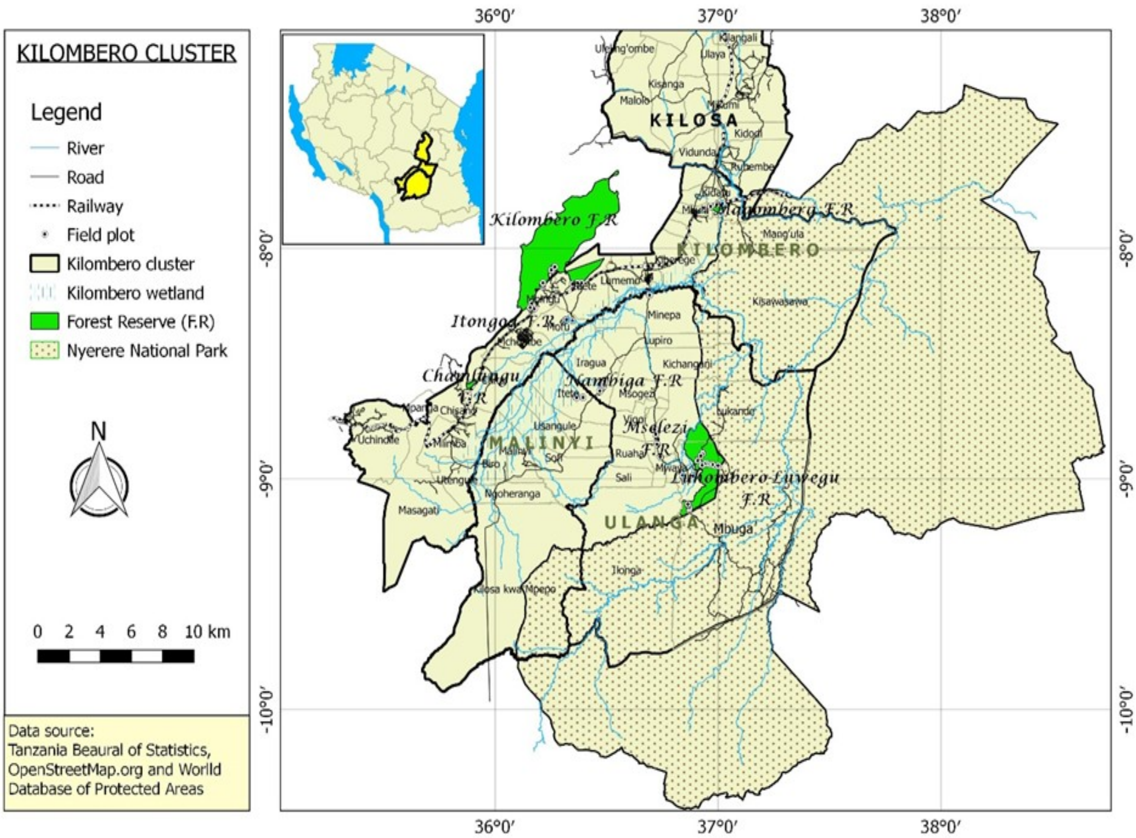


Figure 3.1: The map of the study area

3.2.2 Data collection

Species occurrence

The species occurrence data used was for the four dominant bee species; *Apis melifera*, *Meliponula ferruginea*, *Hypotrigona ruspolii* and *Liotrigona bottegoi*. The dominant bee species were obtained from the list of all bee species (Magesa *et al.*, unpublished). The process of determining the dominant species involved computing the mean abundance of all species in the four vegetation type. Bee species were ranked from the specie with the highest mean abundance to the lowest (Frieswyk *et al.*, 2007). Bee species occurrence data were the coordinates which were obtained using Global Positioning System (GPS) of the captured bee within the plot.

Secondary Data

The bioclimatic factors are the most significant factors in identifying environmental niches of species (Gebrewahid *et al*., 2020). A set 19 bioclimatic variables (Table 3.1) which were generated from a long-term recording of monthly rainfall and temperature value (1950–2000) which had a spatial resolution of approximately 1 km2 (30s) was downloaded from the WorldClim dataset (www. worldclim.org). Elevation, Aspect and slope were used as Topographic variables in modelling. The topographic variables were derived from DEM. Soil type was also an input variable, the information of soil type was derived from Soil and Terrain Digital Database (SOTER). Land cover was also included as one of the environmental variable, the land cover maps were generated in QGIS software. The highest scenario for GHG emissions (RCP8.5) was used to for the projections of future climate of the year 2050s and 2070s.

Table 3.1: Bioclimatic variables used in species distribution modelling

Variable code	Variable type	Unit
Bio1	Annual mean temperature	m
Bio2	Mean diurnal range (max temp − min temp) (monthly average)	m
Bio3	Isothermality (Bio1/Bio7) × 100 °C	m
Bio4	Temperature seasonality (co-efficient of variation)	m
Bio5	Max temperature of warmest period	m
Bio6	Min temperature of coldest period	m
Bio7	Temperature annual range (Bio5 − Bio6)	m
Bio8	Mean temperature of wettest quarter	m
Bio9	Mean temperature of driest quarter	m
Bio10	Mean temperature of warmest quarter	m
Bio11	Mean temperature of coldest quarter	m
Bio12	Annual precipitation	m
Bio13	Precipitation of wettest period	m
Bio14	Precipitation of driest period	m
Bio15	Precipitation seasonality (co-efficient of variation)	m
Bio16	Precipitation of wettest quarter	m
Bio17	Precipitation of driest quarter	m
Bio18	Precipitation of warmest quarter	m
Bio19	Precipitation of the coldest quarter	m

Land use/ land cover data (LULC)

Land cover has been used to model the habitat suitability of various species over broad scale (Thuiller *et al.,* 2004). To obtain the land cover maps, landsat satellite imagery of the study area was selected by considering; the objective of the study which was capturing the land cover associated with bee habitat and the quality of the image. A quality image is a free cloud imagery and also considers the image acquisition time. Meanwhile, the appropriate image acquisition time is the images captured at more or less the same time of the year to avoid seasonal variability. Seasonal variability can influence the appearance of land use features which have impact on the quality of the analysis (Paul, 2014). There steps involved in formation of the land cover maps; First step, Landsat 8 images of the year 2021 were selected for analysis and downloaded from the data warehouse of USGS Earth Resources Observation and Science Center (EROS). Second step, Pre-processing of images was done to prepare image for classification analysis this was done using QGIS software v 3.4. Bands of the Landsat were downloaded as separate image files, and then stacked together. Mosaicing was done to join together all files then later clipped to get the full extent of the study area. Supervised classification was done using maximum likelihood (MAXLIKE) algorithm and the training classes were used. The image was classified into 8 classes; 1) Agriculture, 2) Forest, 3) Woodland, 4) Shrub, 5) Grassland, 6) Wetland, 7) Settlement and 8) Water. However, the selection was based on field observation (ground truth). Assessment of the accuracy of digital image classification output is essential (Künzer and Fosnight, 2001), was performed by a set of ground truth data and also comparing previous classified reference map with selected sampling points (Richards and Jia, 2006).

3.2.3 Data analysis

Species Distribution modelling

A total of 97 locations with bee species occurrence were recorded during field survey using the Global Positioning System (GPS) and then entered in Microsoft Excel and saved as "CSV." format. Pearson correlation was done in R software to determine multi collinearity between the bioclimatic (Bio1– Bio19), Topographic variable, soil data and land cover data (Elith *et al.*, 2006). The environmental variable with had r coefficient greater than 0.5 were omitted. Nine environmental variable were obtained; Bio11, Bio13, Bio15, Bio18, Bio19, Bio3, Bio4, Bio7 and Land cover. Species distribution modelling was done in MaxEnt Species Distribution Modelling software version 3.4.1 (Phillips and Dudík, 2008). MaxEnt was selected because is considered as the most accurate tool when there is presence data only and it uses maximum entropy algorithm which estimate the probability of species occurrence even in unidentified event regions (Phillips *et al.*, 2006). Species occurrence information for model calibration was divided into two; training set (75% of total occurrence records) and test set (25% of total occurrence records) for design assessment. All environmental factors were converted to the same pixel size (30 m) and projection (meter) ASCII raster grids format, as required by MaxEnt. The modelling process chosen had quadratic features. The performance of generated model was evaluated by calculating the AUC of the receiver operating characteristic (ROC) plot. Area under the curve measure range between 0 and 1, and perfect discrimination shows a value of 1(Phillips, 2006). Response curves were used to determine the relationships between the environmental variables and the probability of occurrence of bee specie. Analysis of variable contributions was done to determine relative contributions of the environmental variables to the MaxEnt model. The Environmental variable contribution on the species was measured by the percentage contribution table and jackknife test (Phillips and Dudík, 2008). The jackknife determined the importance of each variable by observing their influence in three situation; without variable, with only variable and with all variables (Yang *et al.,* 2013).

Future climate data

The climatic data obtained from WorldClim database was for the current (2021) and for the future climate change scenarios of the highest scenario for GHG emissions (RCP 8.5) of the year 2050 and 2070. The comparison of the habitat suitability of the selected bee species between the current and future distribution was done by subtracting the future and current suitability areas (Bakkenes *et al.*, 2002). The percentage habitat suitability of bee specie was obtained by calculating the total number of pixel and multiplying with the cell size of 4 × 4 km. ArcGIS was used to reclassify map according to probability range and generate final predictive maps showing areas of high, medium and low suitability for each specie in present and future for 2050 and 2070 of the scenario of RCP 8.5.

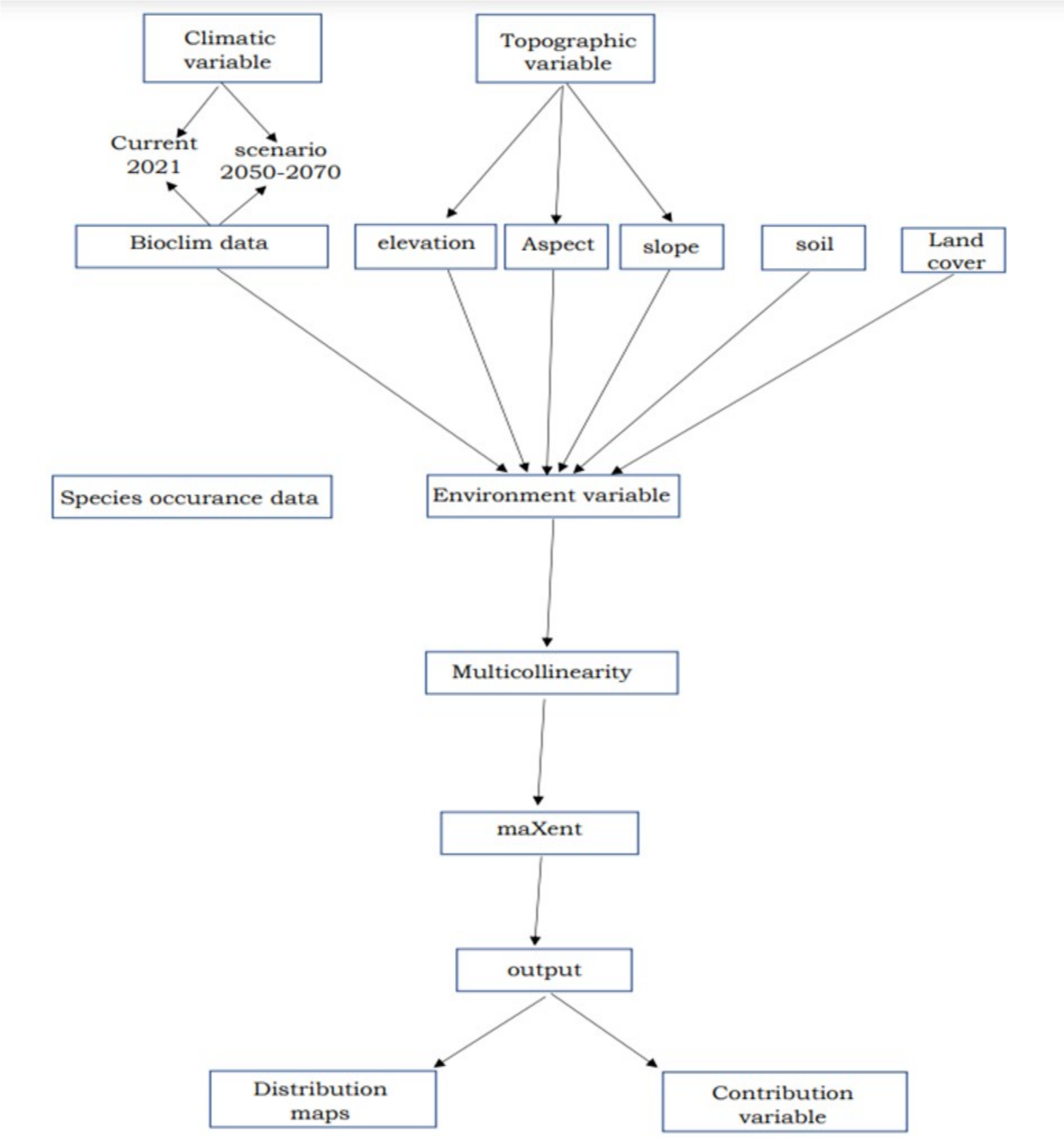


Figure 3. 2: The flow chart showing modelling in MaxEnt

Suitability threshold

The MaxEnt model provide probability of species occurrence ranging between zero and one which represents the habitat suitability of species(Graham and Hijmans, 2006). The suitability level of bee species, was categorized based on (Evangelista *et al*., 2013). The areas with $p < 0.3543$, $0.3543 \leq p < 0.5315$ and $p \geq 0.5315$ where categorized as low, medium and high suitability respectively.

Performance of the model

The performance of the model for the prediction of the distribution of bee specie was measured by determining the AUC value. The AUC ranges between zero and one, If the value is one it means it has the perfect discrimination (Fielding and Bell, 1997; Sutherst, 2014). The AUC was able to evaluate the ability of a model to discriminate presence from absence using the efficient autonomous threshold index. According to Thuiller *et al.*, (2008) the AUC performance scores could be divided into five categories; AUC≥0.90 (excellent), AUC = 0.8–0.9 (good), AUC = 0.7–0.80 (acceptable), AUC = 0.6–0.70 (bad), and AUC = 0.5–0.60 (invalid). The performance of the constructed model used for the prediction of all bee species in the current and future scenario had AUC of 0.963, 0.961 for *A. mellifera* and *M. ferruginea* respectively while *H. ruspolii* and *L. bottegoi* had AUC of 0.966. The prediction model was excellent, since AUC>0.90. This might be due to the efficient number of species occurrence data (Phillips *et al.*, 2006).

3.3 Results

3.3.1 Environmental variable contribution

The model predicted precipitation of the wettest period (Bio13) has the main determinant of species distribution of the dominant bee species in Kilombero SAGCOT cluster. Precipitation of the wettest period (Bio13) contributed greater than 70% to all the dominant bee species while other environmental variable; Precipitation seasonality (Bio15), Mean temperature of coldest quarter (Bio11) and Temperature annual range (Bio7) had a total contribution of less than 30% (Figure 3.4). The land cover contributed only to the distribution of *A. mellifera* by 0.9% (Figure 3.4). The percentage contribution of the environmental variable was different among the species, but similar for each specie for the future scenario of 2050 and 2070. The response curve revealed that, precipitation of the wettest period (Bio13) is directly proportional to the increase in the probability of occurrence of bee species (Figure 3.5). The illustration of the jackknife graph as dark blue, red and lighter blue bars shows different level of contribution of the environmental variables on the distribution of bee species (Figure 3.3).

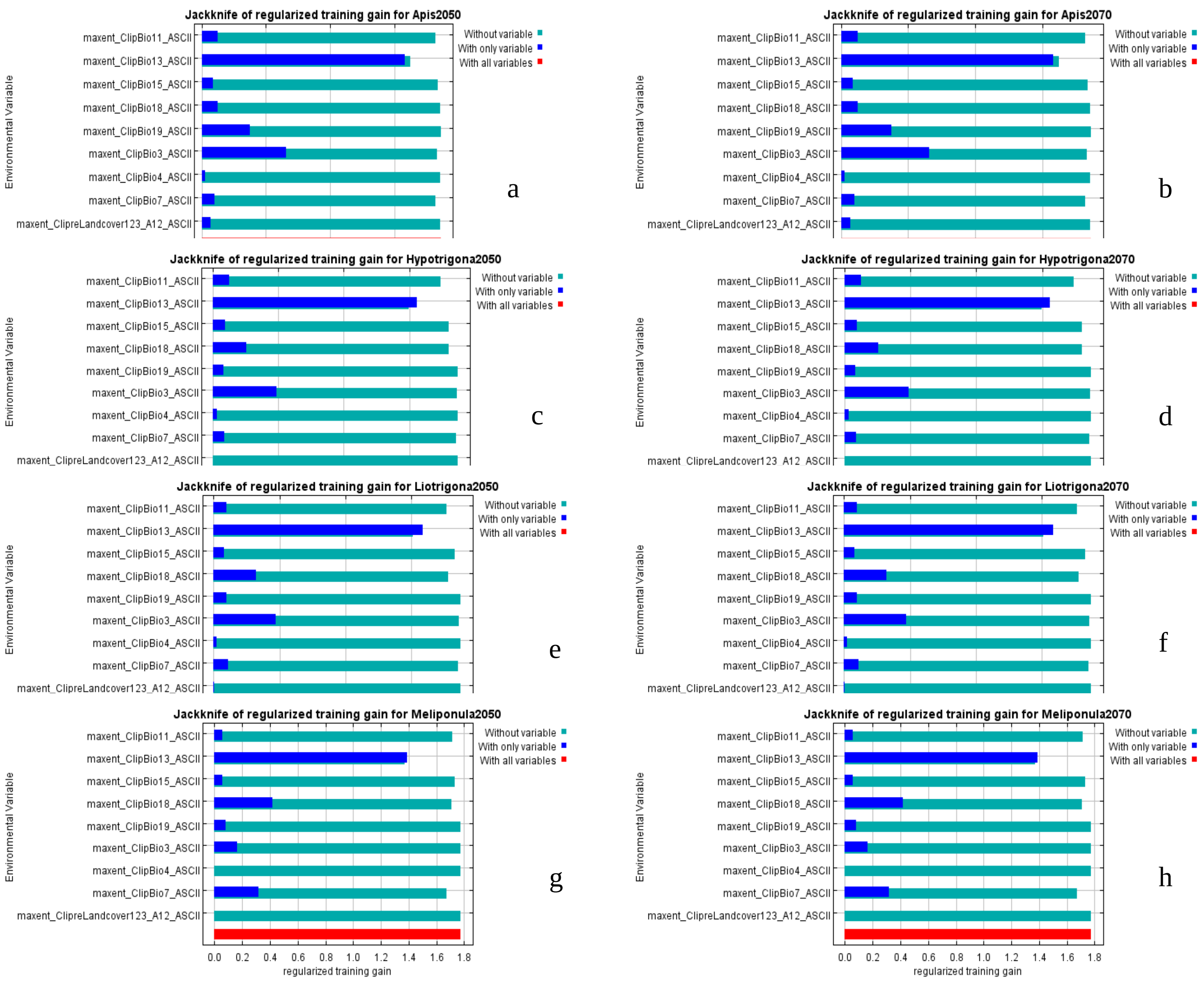


Figure 3.3: Relative predictive power of different environmental variables based on the jackknife of regularized training gain in MaxEnt models for *A. mellifera*: a 2050s, b 2070s; *H. ruspolii*: c 2050s, d 2070s; *L. bottegoi*: e 2050s, f 2070s; *M. ferruginea*: g 2050s, h 2070s.

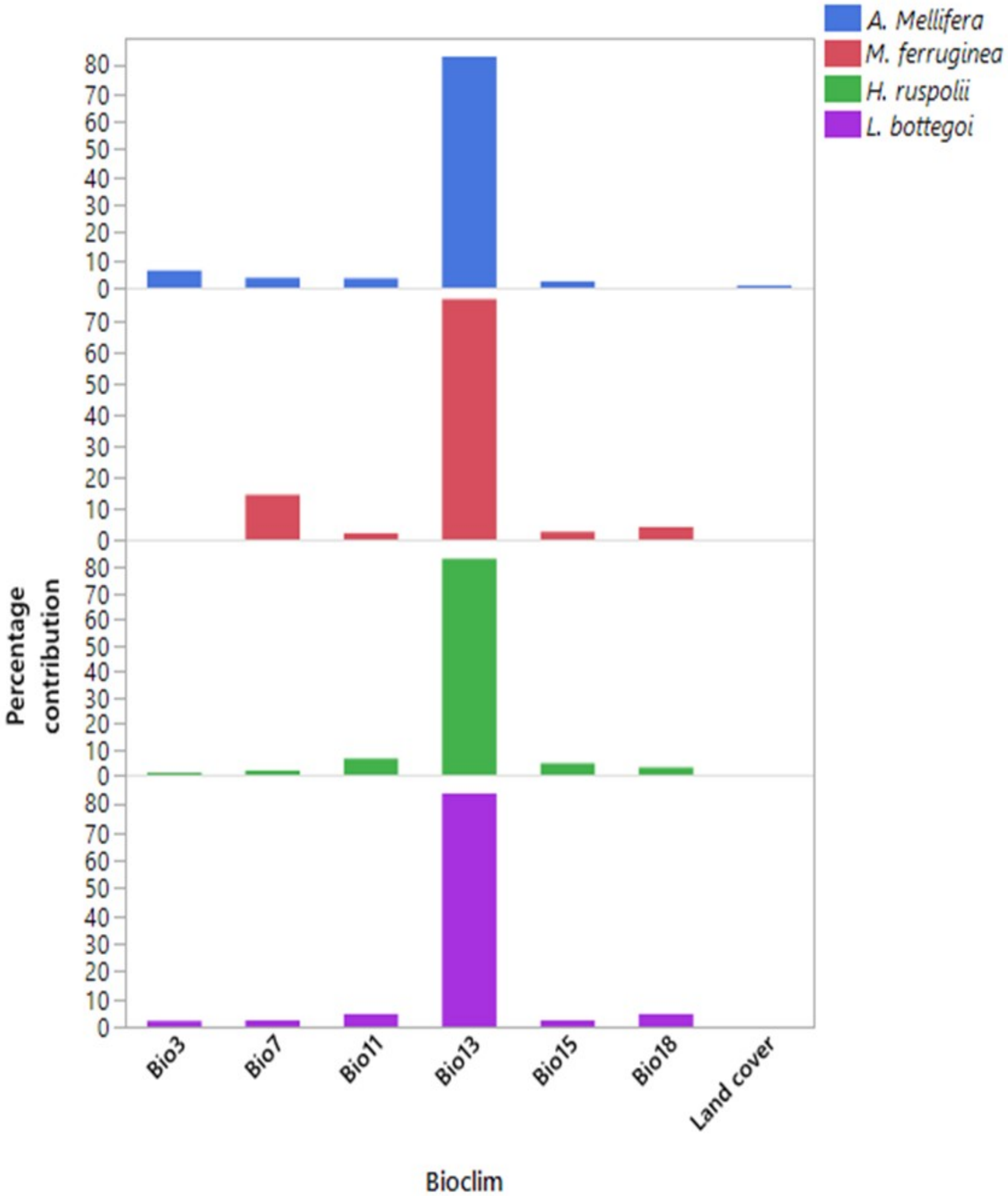


Figure 3. 4: Relative contribution of the environmental variables to the MaxEnt model under future climate scenario in Kilombero SAGCOT cluster.

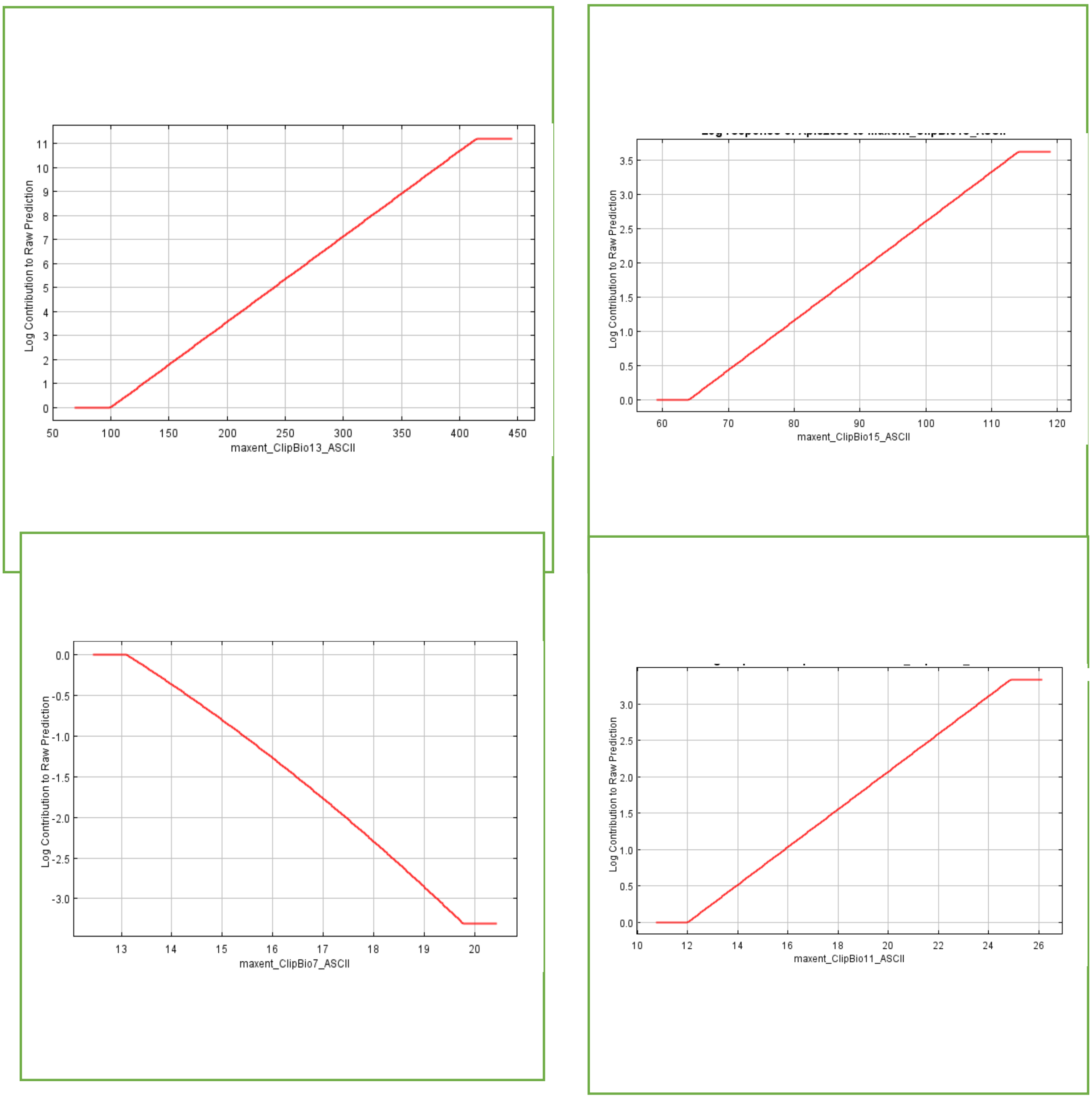


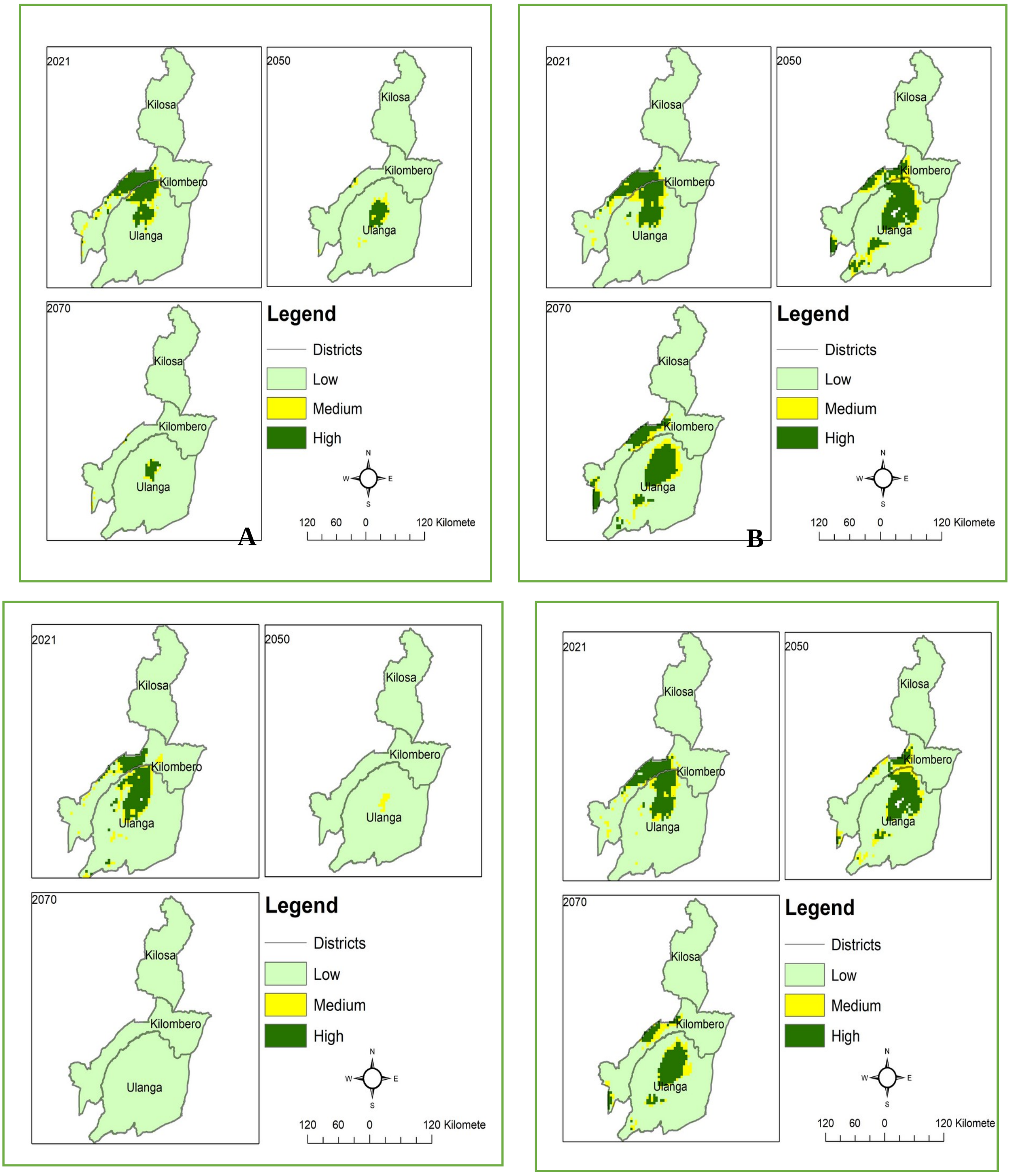
Figure 3. 5: Response curve showing the variation of Bioclim variable with the probability of species occurrence.

3.3.2 Current distribution of the species

The current distribution of the four dominant bee species was mainly influenced by Bio13 where; *A. mellifera* (83.4%), *M. ferruginea* (77.1%), *L. bottegoi* (84.1%) and *H. ruspolii* (83.5%). The result of prediction of bee current distribution show that, the specie with most suitable habitat (high) was *H. ruspolii* which cover 376 000 ha followed by *L. bottegoi* (366 400 ha), *M. ferruginea* (355 200 ha) and *A. mellifera* (344 000 ha) (Figure 3.6, Table 3.2).On the other end, at the probability of (medium) *M. ferruginea* was found to be the specie with the most habitat suitability covering a total area of 161 600 ha, followed by *H. ruspolii* (137 600 ha), *A. mellifera* (131 200 ha), and then *L. bottegoi* (128 000 ha) (Figure 3.6, Table 3.2).

Table 3. 2 : Change of habitat suitability for the four dominant bee species under climate change scenario of 2050 and 2070

		2021	2050		2070	
Species	**Probability range**	**Area (Ha)**	**Area (Ha)**	**Relative change (%)**	**Area (Ha)**	**Relative change (%)**
A. mellifera	low	3 216 000	3 547 200	2.24	3 609 600	0.42
	Medium	131 200	59 200	-0.49	27 200	-0.22
	high	344 000	102 400	-1.64	52 800	-0.34
H. ruspolii	low	3 177 600	2 944 000	-1.58	3 049 600	0.72
	Medium	137 600	217 600	0.54	184 000	-0.23
	high	376 000	520 000	0.98	457 600	-0.42
L. bottegoi	low	3 196 800	3 088 000	-0.74	3 200 000	0.76
	Medium	128 000	195 200	0.46	163 200	-0.22
	high	366 400	398 400	0.22	328 000	-0.48
M. ferruginea	low	3 172 800	3 664 000	3.33	3 691 200	0.18
	Medium	161 600	27 200	-0.91	0	-0.18
	high	355 200	0	-2.41	0	0



C

D

Figure 3.6: Maps showing predicted distribution for current and future climate change scenario of 2050 and 2070 for the dominant bee species were; A= *A. mellifera*, B= *H. ruspolii*, C= *M. ferruginea* and D= *L. bottegoi*

3.3.3 The change in species distribution under future scenarios

The prediction of bee species under future scenario of 2050 show a slightly gain of habitat of high suitability for *H. ruspolii* (0.98%) and *L. bottegoi* (0.22%), while *A. mellifera* and *M. ferruginea* will lose habitat of high suitability by -1.64% and -2.41% respectively (Figure 3.6, Table 3.2). Meanwhile, under the future scenario of 2070 three dominate species will lose habitat of high suitability by 0.48% for *L. bottegoi*, 0.42% for *H. ruspolii* and 0.34% for *A. mellifera* while *M. ferruginea* will lose all its high suitability habitat (Figure 3.6, Table 3.2).

3.4 Discussion

According to this study, climatic factors were the main drivers of bee distribution which contrast to several literatures (Kennedy *et al*., 2013; Ricketts *et al*., 2008) were land use is found to affect the wild bees distribution. The model predicted that the precipitation of the wettest period (Bio13) was the main determinant on the distribution of the four bee species then followed by temperature (Bio7 and Bio11).

Generally, the results are consistent with a study by Rahimi *et al*., (2021), were the model predicted in both seasons (spring or summer/fall) temperature and precipitation were more important predictors of wild-bee communities compared to other environmental variables such has landscape composition, landscape quality, or topography. Furthermore, study by Papanikolaou *et al*., (2017) also show that the bee abundance fluctuates in response to varying temperature and precipitation. However, the variation of precipitation and temperature demonstrated by the response curves, show that the increase in precipitation and temperature will result to increase in the probability of high suitability of bee occurrence.

The current distribution of *A. mellifera* and *M. ferruginea* is mostly on the Kilombero and Ulanga district. The model predicted that on 2050, almost all of the part of Kilombero district, *A. mellifera* will lose its high suitable habitat and remain with some part in Ulanga, whereby in 2070 it will lose the remaining part of Kilombero and further decrease in Ulanga. Meanwhile *M. ferruginea* will lose all of it high suitable habitat by 2050. Meanwhile, the response to climate change and current occurrence for *H. ruspolii* and *L. bottegoi* is observed to be almost similar. These species are currently predicted to be in western part of Kilombero and largely on northern part of Ulanga district. The future distribution of these species by 2050 shows a slightly increase in Ulanga and shift in range to the lower part in Kilombero and Ulanga district. In 2070, *H. ruspolii* and *L. bottegoi* will decrease in their suitable habitat and loss the habitat connectivity between the two district and creating patches on both districts.

The results supports the notion that, under the influence of climate change, there bee species which will gain suitable habitats (Giannini *et al.*, 2020) or will lose habitat (Giannini *et al.*, 2012, 2017). The species that will gain habitat such as *H. ruspolii* and *L. bottegoi* might possibly adapt with the climate change. Meanwhile, *A. mellifera* and *M. ferruginea* will experience loss of suitable habitat and this might possibly fail to tolerate to the climate change. However, under future climate change scenario 2070 all the species will show decreasing in suitable habitat, this is because they might not be able to tolerate further to the change, leading them to shift in areas where they will find a suitable habitat.

Precipitation and temperature is an important bioclimatic factors for bee activity such as flight and feeding activity (Devoto *et al*., 2009). This study was able to reveal precipitation and temperature as the determinant of bee distribution. This is also supported by other findings (Feehan *et al.*, 2009; Prieto-Torres *et al.*, 2020), were there is a possibility of the suitable area for some species to be reduced while for others might shift to compensate for the increase in temperature or precipitation. The extreme precipitation as effect, that could possibly result to bee species to either decrease, shift range or go extinct (Reddy *et al.,* 2015). The possible effect induced by this climatic variable are; disruptions of the mutualistic interactions in plant-pollinator networks which is due to mismatches in shifting ranges and asynchrony in phenology e.g. (Brosi and Briggs, 2013; Burkle and Alarcón, 2011; Kudo and Ida, 2013) or could lead to direct physical effects on both flowers and their pollinators and also the interference of the timing of pollinator visitations. According Huang *et al.,* (2009) intensive rainfall is accompanied by increase in storm exposure, the storms may leave many plants to vulnerable physical damage. Additionally, high amount of rainfall cause dilution of the nectar, which force bee to visit many flowers in order to meet their energetic requirements (Cnaani *et al.,* 2006). Also, bees will have to travel a long distance even outside their usual range in search of nectar (Fisogni *et al.,* 2011).

Furthermore, study by Memmott *et al.,* (2007) examined that, when precipitation condition becomes extreme the rate of flower visitations diminishes. Additionally, extreme precipitation lead to a considerable risk of survival to the insect flying closer to the ground, by causing immersion in pools of water (Dickerson *et al.,* 2014). Also, the pools created during extreme rain will spoil the habitat especially for bee species nesting in the soil. According to Orr et al., (2021) suggested that humidity may act as a key role in limiting the distribution of bees (such as spoilage of pollen resources especially for solitary bees). Therefore, precipitation and temperature have greater influence on the distribution of bees. The study observed difference in response among the bee specie. Whereas, *A. mellifera* will lose some part of their suitable area while *M. ferruginea* will lose all of its suitable area. Meanwhile, *H. ruspolii* will slightly gain by shifting and creating patches of suitable habitat while *L. bottegoi* will slightly gain in 2050 but develop patches of suitability of different size from *H. ruspolii*. The difference in response among the bee species might be as a result of variation of response in traits (e.g., body size) nest site, sociality and physiological differences (Aguirre-Gutiérrez *et al.,* 2017b; Forsman and Wennersten, 2016). This information cannot be specifically shaded light on each bee species regarding its difference in response because little is known on traits and behavior response of bee species to climate change in the study area. Habitually, most of insect species induces significant response to climate change, and it might be the shifting of the timing of life-cycle events, shifting range boundaries or the density of individuals, changing morphology, reproduction, or they can go extinct (Rosenzweig and Tubiello, 2007).

Interestingly, numerous studies have detected the signs of such climatic responses (Ayres and Lombardero, 2000; Bale *et al.,* 2002; Battisti, 2008; Harrington, 2001; Hughes, 2000; Menéndez *et al.,* 2007; Netherer and Schopf, 2010; Parmesan, 2006). Generally, the distribution of species is determined to a large extent by climatic variables, so, where never there will be changes in climate, the distribution and abundance will be modified (Chitiki, 2020; Parmesan, 2006). Climate change is expected to be dominant regulator of determining the distribution of species in different geographical region (Barbet-Massin *et al.,* 2013; Shabani *et al.,* 2016). The observed ongoing climate change is likely to induce significant responses to insect species (Robinet and Roques, 2010) and the degree of the imposed response will vary between bee species depending on the preference of habitat and food resource requirement of the individual specie (Boggs, 2016; Denis *et al.,* 2011).

3.5 Conclusion and recommendation

Climate change is proven to have a significant influence on the current and future distribution of bee species in Kilombero SAGCOT cluster. The precipitation of wettest period was a main variable that influence the distribution of dominant bee species. This study represents the first step in forecasting the effects of climate change on the future distribution of bee species in Kilombero SACGOT cluster. The study highlights the need to develop climate adaptation and mitigation strategies for conservation of bee populations in Kilombero which consider conservation of the potential areas where predictions show a reduction in habitat suitability for bees. Bee conservation under the changing climate needs to consider habitat connectivity to allow bee dispersal not only between current suitable habitats, but also future suitable habitats as predicted by the model. Long term monitoring in changes in the dominant bee populations is essential for predicting long term climate change response especially bee pollinators which influence crop production. Given the potential influence of anthropogenic activities on both bee population and climate, future studies would also focus on the influence of environmental and anthropogenic factors on bee abundance and diversity and their interactions.

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CHAPTER FOUR

4.0 CONCLUSION AND RECOMMENDATION

4.1 Conclusion

Based on the findings from this study the following conclusions are made;

i. There is apparently high bee species composition, richness and diversity in Kilombero SACGOT cluster, whereas, the distribution varied across habitat types.

ii. Climate change has a significant influence on the current and future distribution of bee species in Kilombero SAGCOT cluster.

iii. Precipitation of the wettest period was the main climatic variable influencing the current and future distribution of bee species.

iv. There will be loss of suitable habitats for most bee species, which is the major future climate impact on bee population thus conservation of suitable habitats for bees is of paramount importance.

4.2 Recommendation

Based on the results from this study it is recommended that;

i. Mainstreaming these observations in the Kilombero Cluster Development Framework implementation of different cluster value chains it is important if we should have sustainable production systems that consider both environment and agriculture production.

ii. There is a need to develop climate adaptation and mitigation strategies for conservation of bee populations in Kilombero which consider conservation of the potential areas where predictions show a reduction in habitat suitability for bees.

iii. Given the potential influence of habitat type on bee populations, future studies should go further on studying the influence of vegetation composition on bee abundance and diversity and their interactions.

iv. Bee conservation under the changing climate needs to consider habitat connectivity to allow bee migration not only between current suitable habitats, but also to the future suitable habitats as predicted by the model.

v. Long term monitoring in changes of the dominant bee populations is essential for predicting future climate change response.

vi. Further studies should be conducted on the behavior and morphology of different bee species, so as to broaden the understanding of their response to climate change.