BINDURA UNIVERSITY OF SCIENCE EDUCATION

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Department of Agriculture Economics and Extension

CURRENT AND FUTURE SUITABILITY OF *APIS MELLIFERA* IN EASTERN AND SOUTHERN AFRICA8

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DEDICATION

I pledge this project to my immediate family (Queen Memory, Unity, Mercy, Hope and Gen-Star) for all the moral and financial support given to me, with special mention to my friends for their unwavering inspiration and support in the successful completion of this research.

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The undersigned certify that they have read and recommended to the Bindura University of Science Education for acceptance, a research project entitled **"Current and Future Suitability of *Apis Mellifera* in Eastern and Southern Africa from 2019 to 2021,"** submitted by Nenhowe Samuel in partial fulfilment of the requirements for the degree of MSc Degree in Food Security and Sustainable Agriculture.

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ABSTRACT

Robust evidence underpinning the distribution of *Apis mellifera* races, their performance capacity and the adoption of Climate – Smart Apiculture (CSA) that fortifies Sustainable Developmental Goals linked (SDGs) to the four pillars of food and nutrition security and climate change being instrumental in poverty and hunger alleviation is currently lacking.

In this study, the climatic and environment suitability to *Apis mellifera* races native in Africa, Asia, and America either managed or feral habitat, was investigated using Ecological Niche Modelling approach and associate geographical information system under current and future suitability the year 2050 and 2070. Two types of maps were extracted from spatial analysis, one for current ecological conditions and the second one for future suitability conditions.

The study shows that most of Current and Future Suitability of *Apis Mellifera* in eastern and southern Africa is suitable for apiculture but more suitable areas are restricted to specific locations. In the future, environment suitability was found to be impacted by future climatic conditions mainly temperature and precipitation. Upper and eastern Sub-Saharan Africa will be impacted more than the middle or the far end of southern Africa. Apis mellifera relocation will be experienced especially at middle Sub-Saharan Africa map during 2070.

It could be expected that *Apis mellifera* races could be distributed widely throughout eastern and southern Africa currently and in the future as well and in reclaimed ecologies. The spatial analysis was done using the major climatic factors that could impact *Apis mellifera* races distribution and productivities capacity namely maximum and minimum temperatures, precipitation and suitable environment in eastern and southern Africa. The honeybee plays a significant role as a keystone species to balance the ecological ecosystem, food sovereignty and climate change, conserve biodiversity through pollination services and bio indication. As a livelihood strategy, beekeeping improves resilient living standards thus effects of climate change are worthy to note. 13 bioclimatic variables sourced from WorldClim at 2.5 arc minutes were used for mapping the *Apis mellifera* races distributions. MaxEnt was employed to project distribution of the races under RCP 2.6 and RCP 8.5 for the years 2050 and 2070. The results showed substantial changes in the probability of occurrences when projected to 2050 and 2070 under the two RCPs, slight decrease in *Apis mellifera* races distribution across the eastern and southern Africa as well, erratic areas with probability of less than 0.2 were observed with no species occurrences. Whilst, *Apis mellifera* year 2070 projections observed a high expansion in habitat and encroachment of habitats with probability of occurrence above 0.5 was recorded however no races inhabitants were observed. There is need to practice biodiversity conservation and avoid overexploitation of forests especially in areas predicted to no longer have suitable habitats for the *Apis mellifera* races.

Key Words: Beekeeping, *Apis mellifera*, Ecological Niche Modelling, Food Security, Climate Change.

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LIST OF ABBREVIATIONS

AGRITEX	Agricultural Technical and Extension Services
AUC	Area Under the Receiver Curve
Bp	Blood Pressure
CCD	Colony Collapse Disorder
CSA	Climate – Smart Agriculture
ENM	Ecological Niche Modeling
FAO	Food and Agriculture Organization
QGIS	Quantum Geographical Information System
GBIF	Global Biodiversity Information Facility
GDP	Gross Domestic Product
GHG	Greenhouse gas
HIV/AIDS	Human Immunodeficiency Virus/ Acquired Immunodeficiency Syndrome
IFPRI	Int. Food Policy Res. Inst.
IPCC	Intergovernmental Panel on Climate Change
RCP	Representative Concentration Pathways
ROC	Receiver Operator Curve
SANBI	South African National Biodiversity Institute
SDGs	Sustainable Developmental Goals
SDM	Species Distribution Model

CHAPTER ONE: INTRODUCTION

The purpose of this chapter is to give a background on beekeeping starting with the importance of *Apis mellifera* races and beekeeping, honey bee races in eastern and southern Africa and their contributions to the beekeeping industry and challenges that may impact on the productivities of these races. The background is concluded by analyzing the importance of projecting the impact of the environmental changes on the distribution and productivities of honey bee races, problem statement, objectives of the study, research questions, and justification of the research and the relevant references.

1.1 Background to the study

According to IPCC, (2006), (RUTTNER *et al*., 1975) robust evidence underpinning the distribution of *Apis mellifera* races, their performance capacity and the adoption of Climate – Smart Apiculture (CSA), (United Nations. SDGs, 2015, Centre for Studies in Food Security, 2012, Battisti, 2009, Latham, 1997) fortifying Sustainable Developmental Goals linked (SDGs) to the four pillars of food and nutrition security and climate change being instrumental in poverty and hunger alleviation is currently lacking. According to RUTTNER *et al*., (1975) *Apis mellifera* race is native to Asia, Africa but based on analysis by (FAO, 2003, Ruttner *et al*., 1988, http://www.fao.org/docrep/005/y4671e/y4671e0c.htm), honey bees has naturalized to other regions of the world through globalization in agriculture, their migratory behaviour and international trade (Anderson, 2010, FAO, 2003, Paul *et al*., 1999), for example *Apis mellifera* was imported from Africa to Brazil in 1956 to increase honey production. Ruttner *et al*., (1978), reviewed that 26 swarms accidentally escaped into the countryside and entered the United States of America through Texas. They are now established throughout the Central America, south-western states and southern California (Ruttner *et al*., 1978).

Honey bees are advanced four winged – stinging insect species that gathers nectar from flowers and process it to produce honey, wax, propolis, royal jelly with their venom considered medicinal (De la Morana, 2016, Latham, 1997). However, like any other insects they also provide complimentary essential service of transferring pollen from one flower to another (Hussein, 2001). According to Huang (2012), they facilitating pollination and the reproduction of flowering plants to farmers' pollinator-dependent crops. Rader et al., (2013) assessed that, of all the honey bee races, only Apis mellifera has been used extensively for commercial pollination of watermelons, nuts, fruits and vegetable crops.

According to Simpson, *et al*., (2005), *Apis mellifera* races has the capacity to support ecological ecosystem conservation and stability, regulate plants' genetic variation, (Andrewartha and Birch, 1984) and resilient survival of biodiversity, pest control, and decomposition as bio indicators for evaluating ecological ecosystem health. Amid the challenges of climate change and bioenergy the Food and Agriculture Organization (FAO, 2008, Latham, 1997) revealed that beekeeping is a resilient long standing and deep rooted sustainable livelihood activity for rural communities where in eastern and southern Africa, millions of honeybee colonies are kept in traditional and modern beehives in backyards and in forests using a holistic approach of indigenous and scientific management practices.

Beekeeping is a promising industry to correct climate change for sustainable food and nutrition sovereignty and a source of income (FAO, 2008). For example, beekeepers from Ethiopia make about ETB 360 – 480 (US$45 – 60) million from honey production yearly (FAO, 2008). Beekeeping has the capacity to enhance the socio-economic status of communities' social safety nets when dealing with epidemics and pandemics, HIV/AIDS, Asthma and blood pressure (Bp) at the household level (Springmann *et al*. 2016, Walsh, 2013).

Honey bees provide supplementary human dietary requirements through honey and royal jelly production, (De la Morana, 2016, Latham, 1997) yet again, protein-energy malnutrition, vitamin A deficiency, iodine deficiency disorders and nutritional anemia are the common nutritional challenges potentially addressed by honey and royal jelly consumption in the developing world (FAO, 2010a). Therefore, rendering to (United Nations. SDGs, 2015 and Centre for Studies in Food Security, 2012), apiculture industry fortifies the sustainable developmental goals linked (SDGs) to the four pillars of food and nutrition security and climate change.

According to Walsh, (2013), *Apis mellifera* races native to Africa include the *Apis mellifera* capensis which is found in South Africa, (Cordellier and Pfenninger, 2009, Raina and Kimbu, 2005), *Apis mellifera scutellata* which is found in South Africa, Lesotho, Eswatini, Zimbabwe, Malawi, inland Tanzania and eastern Zambia and *Apis mellifera* adansonii is native in Botswana, Namibia, Angola Uganda and Democratic Republic of Congo (DRC). On the other hand, *Apis mellifera yemenitica* occurs in countries like Mauritania, Mali, Chad, Sudan, Somalia and parts of Ethiopia (Rutterner, 1988). According to Walsh, (2013), the area where *Apis mellifera yemenitica* naturalize has hotter temperatures and the region is relatively drier for example Yemen desert, (Hepburn et al., 1998) and *Apis mellifera litorea* is found spread from Kenya down to Tanzania and the lower parts of Mozambique in the Eastern coastline.

Apis mellifera yemenitica is smaller in size compared to other categories of *Apis mellifera* races found in the eastern and southern Africa region (Ruttner, 1975). The race is native on the hot dry zone of northeastern Africa and the Arabic region (Rutterner, 1988), its native region stretches from the northeast African plateaus and savannas, following the region of the east Sahara Desert, across the Nile basin to the Arabian Peninsula. It is generally known as the Northeastern Africa and Arabian honeybee, but is also found in West African zones (Hepburn et al., 1998). According to (Mueller, 2012 and Fletcher, 1978), *Apis mellifera yemenetica* has naturalize in the region with high temperatures ranging from 27°C - 31°C with very low rainfall 30-300mm. Its natural habitat is the dry thorn bush, (Acacia) of Africa (Ruttner, 1975) and it has short hair cover (0.195mm), a short proboscis (5.48mm), wings (8.13mm) and legs (7. 12mm).

However, *Apis mellifera yemenetica* frequently migrate during the dry period of the year (Rashad and El-Sarrag, 1980), but there are no escaping problems reported from Oman and Yemen, yet in Sudan, absconding behaviour happens throughout the dry period.

Like any other living organisms in the global ecological ecosystems, (Dafar, 2018) *Apis mellifera* races of Eastern and Southern Africa are affected by thermal stress threats that inhibit their behavior, endanger their populations and result in limited contribution to their potential productivities to deliver ecological ecosystem services support. According to studies by Chensheng *et al*., (2014) climate change and ecology suitability to *Apis mellifera* races was investigated using ecological niche modelling approach under current and future conditions (2050 and 2070). Apart from the pests and diseases threats, (Dafar, 2018) special analysis was done using the major factors that could impact *Apis mellifera* races namely maximum and minimum temperatures, precipitation, slope, land type and distance from plants.

Because the development of honey bee colonies requires good vegetation, (Huang 2012) most apicultural activities existed close to cultivated areas especially along the rivers. It is common knowledge that the main food for honey bees is nectar (RUTTNER, 1975) and pollen (Huang 2012) collected from flowering plants. Previous studies show that most eastern and southern

Africa region is suitable for apiculture, (Ruttner, 1975) but the more suitable areas are restricted to specific locations. In the future, *Apis mellifera* suitability in eastern and southern Africa was found to be impacted by future climate change conditions (Mueller, 2012). According to Ruttner, (1975), upper Southern Africa would be greatly impacted than central and southern part of Sub Saharan Africa. Apiculture is currently practiced widely throughout eastern and southern Africa and in reclaimed land (Dafar, 2018).

En route for comprehending this objective, Ecological Niche Modelling approach has also been considered as a proper way, (Amiri & Shariff, (2011) Ecological Niche Modelling approach was used previously to achieve somewhat similar objectives, (Amiri & Shariff, 2012) for example, rangeland suitability for beekeeping suitable wintering sites for honey bee colonies (Al-Qarni AS, 2006), and to identify the suitable locations for using modified beehives in Saudi Arabia (Al-Qarni AS 2006), and for other purposes related to honey bees' contribution on sustainable food security and climate change (Myung-Hee *et al*., 2001; Coulson *et al*., 2005). Ecological Niche Modelling approach has a good ability to analyse different climatic datasets, (Abou-Shaara 2013a) and to present the results on maps with geographical nature, even if these datasets are related to honey bee morphology.

Honey bee colonies are impacted by many factors including, temperature, precipitation, slope, land cover and distance from plants (Amiri *et al*., 2011, Amiri & Shariff 2012)
Aside from the question of access to public lands for extensive apiculture productivities, (Kremen *et al*., 2002, Yoruk & Sahinler, 2013) nowadays climate change is considered to be the main current and future challenge to apiculture. Climate change can impact honey bee colonies directly through altered maximum and minimum temperatures and precipitation dates (Mueller, 2012, Le Conte & Navajas 2008), or indirectly by shifting famous flowering plants calendar to mistime their food source availability (Rader *et al*., 2013). According to Rader *et al*., (2013) Honey bees that fail to adapt would stress and die from the impact of changing environment.

According to Ruttner *et al*., (1978), Ecological Niche Modelling helps in predicting the potential impacts of climate change on rangeland suitability to apiculture.
Ecological Niche Modelling is very important, (IPCC, 2014) to help ecologists and beekeepers as agents for improved pillars of food sovereignty and climate change, (Nelson *et al*., 2010) and their contribution on agricultural policy framework to take the right actions in the proper

times. Therefore, the objective of this study is to identify the potential areas at which apiculture projects can be successfully implemented in the future, and to compare it with the suitability map of current conditions.

According to IPCC, (2006) and Change, (2014), to achieve this objective, the available future temperatures and precipitation, beside slope, land cover and distance from plants were incorporated into the Ecological Niche Modelling spatial analysis to obtain the *Apis mellifera* future suitability maps. In light of this study proper recommendations for future suitability of *Apis mellifera* races for sustainable beekeeping industry are presented.

1.2 Problem statement

According to IPCC, (2006), Hegland *et al*., (2009), the number of honey bee colonies around the world has been declining at an alarming rate. National Geographic reports (2014), Battisti, 2009, and IPCC, (2006), reviewed that some regions have seen up to a seventy-five percent loss of their native honey bee populations in recent years. Although bee populations in Africa have stabilized somewhat, *Apis mellifera* races are experiencing declines that could impact food and nutrition pillars in the entire eastern and southern Africa (Walsh, 2013). For example, across Eastern and Southern Africa, according to (IPCC, 2014), *Apis mellifera* races were on the decline by as much as 45% in 2019.

Recent modelling indicates that pollinators - *Apis mellifera* population declines would increase child mortality and birth defects from increased vitamin A and foliate deficiency, respectively, (Springmann *et al*., 2016, Whitmee *et al*., 2015) and also increase the risk of heart disease, stroke, diabetes, and certain cancers in adults as a result of reduced dietary intake of fruits, vegetables, nuts, and seeds (Smith *et al*., 2015, Walsh, 2013). This revealed that, there is little information known on the consequences of predicted honey bee future distribution and performance capacity whether managed or feral, thus the imminent of this research.

1.3 Aim of the study

Use an Ecological Niche Modelling (ENM) approach to assess the current and future suitability of honey bee races in Eastern and Southern Africa.

1.4 Specific objectives

i. To determine the current suitability of the *Apis mellifera* races in eastern and southern Africa for sustainable beekeeping.
ii. To predict the impact of climate change to the distributions and productivities of important honeybee races in Eastern and Southern Africa.

1.5 Research question

The research questions that this study seeks to answer are:

- What is the current distribution status of *Apis mellifera* races in Eastern and Southern Africa?
- What could be the future distribution of *Apis mellifera* races in Eastern and Southern Africa under the changing climatic conditions?

1.6 Justification of the study

(Meinzen-Dick *et al*., 2012, Williams *et al*., 2011), one of the fundamental challenges of current ecologists is to anticipate the responses of complex ecological ecosystems to anthropogenic climate change. Therefore, the findings of this study will contribute to the prevailing knowledge and literature on the current and future suitability of beekeeping in eastern and southern Africa. Study results will model the likely distribution of the honeybees across eastern and southern Africa under a changing climate, thus, the knowledge base is widened on the effects of climate change to honey bee races suitability in Eastern and Southern Africa. This enhances sustainable beekeeping projects implementation for future national economic empowerment.

In line with Panayotou, (1995) and Perman, *et al*., (2003), the findings will help in future evidence-based policy formulation on honeybee races in light of the predicted climate change and environment suitability scenarios. This research will contribute towards profiling current and future suitability of beekeeping performance and identifying holistic techniques that can be explored to incorporate beekeeping industry into climate – smart agriculture approach (CSA), formal markets and enabling it to contribute to the gross domestic product (GDP) of the main economy.

Conclusively, (United Nations. SDGs, 2015, IFPRI, 2015, Battisti, 2009) findings from this research will give some responses to Sustainable Developmental Goals (SDGs) that fortifies correlation to climate change and sustainable food and nutrition sovereignty. For example, Sustainable Developmental Goal number one no to poverty, two zero hunger, three good health and wellbeing, eight decent work and economic growth and thirteen climate change (United Nation, SDGs – 2015, Latham, 1997). This will be achieved through projecting ecological climate change impact, increased dietary and nutrition security, poverty reduction, precision agricultural led development (Parliament of Zimbabwe, 2014 & IPCC, 2014) and ensuring the health, sustainability of Africa's ecological ecosystems and improved biodiversity distribution.

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CHAPTER 2: LITERATURE REVIEW

This chapter will review literature on Ecological Niche Modelling (ENM) and associated Geographical Information Systems (GIS) to predict the future suitability of *Apis mellifera* races for sustainable beekeeping in Eastern and Southern Africa. The review of literature will assess the taxonomy of the *Apis mellifera* races, distribution of *Apis mellifera* species in Eastern and Southern Africa and their contribution on improving Sustainable Developmental Goals linked (SDGs) to food security and climate change, will then look on climate change related threats to the *Apis mellifera* races. Conclusively will highlight on the importance of projecting the impact of the highlighted environmental changes on the distribution and productivities capacity of the honey bees.

2.1 Defining the concept of Ecological Niche Modelling

According to Warren *et al*., (2008) and Philip *et al*., (2006) Environmental Niche Models (ENMs) are a class of methods that use occurrence data in conjunction with environmental data to make a correlative model of the environmental conditions that meet a races' ecological requirements and predict the relative suitability of habitat. Philip *et al*., (2008), Warren *et al*., (2008), Ecological Niche Models are most often used in one of four ways: (1) to estimate the relative suitability of habitat known to be occupied by the races, (2) to estimate the relative suitability of habitat in geographic areas not known to be occupied by the races, (3) to estimate changes in the suitability of habitat over time given a specific scenario for environmental change, and (4) as estimates of the races niche.

The use of Ecological Niche Modelling approach (ENM) and associated Geographical Information Systems (GIS) to predict the future suitability of beekeeping in Eastern and Southern Africa become key, (Warren *et al*., 2008, Philip *et al*., 2008) because it is less expensive, it is precise, and observe no protocols hence serves time (IPCC, 2020, Warren *et al*., 2010) and observe the recommended social distance to prevent spreading of the lethal COVID – 19 (World Health Organization, 2020).

Ecological Niche Models represent in this context a powerful methodological tool to investigate both the drivers shaping the current distribution of endangered races and the potential new threats related to climate change and land use modifications (Warren *et al*., 2010, Whitfield *et al*., 2006). Alongside with their applications to the different research fields of conservation biology (DAFAR, 2018, Philip *et al*., 2006) and Ecological Niche Models have been intensively applied also to bio-geographical issues as well as to the hybrid discipline of conservation biogeography (Franklin J. 2013, Franklin, 2009).

Moreover, notwithstanding most of papers applying Ecological Niche Models to the above cited research fields focus on large scale (i.e., continental to global) patterns, (Amiri & Shariff, 2012, Amiri & Arekhi, 2011) other researches based on the implementation of Ecological Niche Models over national and regional extents showed that these modelling techniques allow the opportunity to gain deeper insights into the constraints imposed on races' distributions by the availability of suitable environmental conditions at local scales. In this contribution, will report the results of a research, carried out by means of Ecological Niche Modelling techniques, on the possible climatic variables affecting *Apis mellifera* races current and future distribution.

According to Nuru *et al*., (2002), starting from models based on the current climatic conditions, would inferred possible modifications in the future distribution of the *Apis mellifera* races across different global warming scenarios. Advancements in high-tech development such as Ecological Niche Modelling have revolutionized races predictive modelling (PEARSON, & DAWSON, 2003) by significantly improving the abilities to capture, manage, analyze and visualize now increasingly digitally-captured biodiversity resource data (Veloz, 2009).

Ecological Niche Modelling has offered natural resource managers and biological conservationists with improved techniques to analyze data of different origins (Veloz, 2009).
Natural Resource Managers and Biological Conservationists are accessed proficient to generate increasingly required spatial continuous data of environmental variables applications in apiculture production to improve dietary security and sustainable agriculture (PEARSON, & DAWSON, 2003).

Moreover, they also need high temporal resolution and thus have great potential to benefit from Ecological Niche Modelling approach and associate Geographical Information Systems applications, (Xu *et al*., 2017) which can integrate spatial climate and weather datasets, with positioning systems and remotely and in situ sensed information on soil status, nutrients, and fertility to predict honey and crop yields and other relevant parameters (Potts *et al*., 2010, Wilson, 1987). Likewise, ecological biodiversity races occurrence and habitat suitability can be modelled using Ecological Niche Modelling approach and associated Geographical Information Systems based spatial climate datasets for nature conservation (Xu *et al*., 2017).

2.2 Taxonomy of the *Apis mellifera* races

Apis mellifera scutellata is a slight creamy golden - yellow honeybee race located in the Southern Africa (Cordellier and Pfenninger, 2009). With respect to morphometric fonts related to body size and hair, it displays a mediocre position between *Apis mellifera litorea* and *Apis mellifera adansonii* (Davis *et al*., 1998). According to Ruttner, (1988), Raina and Kimbu, (2005), the exceptional feature of *A. mellifera scutellata* is that it has a long proboscis compared to its frame size and leg span but smaller than that of *Apis mellifera litorea*. Ruttner, (1988), the race is aggressive but hard working and very important on crops pollination services. The dimension of its proboscis is 5.5 mm, forewing 7.8 millimetres, hind leg 6.3 mm and cubital index of 2.3 (Ruttner, 1988) longitudinal of sternite 3 is 2.46mm and transversal of wax plate 2.mm (Hijmans et al. 2005 and Hepburn et al 1998). The *Apis mellifera scutellata* race is common in Namibia, Zimbabwe, South Africa, Malawi, Lesotho and eastern Zambia (Walsh, 2013). It is generally known as the African Killer Bee, but is also found in South and Central America zones (Walsh, 2013).

On the other hand, (Kaplan, 2004 and Oden, 2001), describes *Apis mellifera litorea* is a slight creamy yellow honey bee race closely identical to and very difficult for the layperson to positively distinguish it from *Apis mellifera scutellata* (Oden, 2001) and Walsh, 2013), but *Apis mellifera litorea* is slightly bigger in size compared to other categories of *Apis mellifera* races found in the sub-Saharan region. According to (Rashad and El-Sarrag 1980, Davis *et al*., 1998, Kaplan, 2004 and Oden, 2001), *Apis mellifera litorea* is native to the sideways of the east African coastline from Kenya to Mozambique where the environment is warm and there is some food throughout the year (Cordellier and Pfenninger, 2009, Ruttner, 1988). It has also naturalized to Ethiopia (Nuru *et al*., 2002) and in Somalia (Diniz *et al*., 2003). With respect to morphometric fonts related to body size and hair, (Diniz *et al*., 2003, Ruttner, 1988), *Apis mellifera litorea* exhibit a mediocre position between *Apis mellifera jemenitica* and *Apis mellifera adansonii*. The exceptional feature of *Apis mellifera litorea* is that it has a long proboscis compared to its frame size and leg span than either of the other identified races (Radloff and Hepburn, 2001). The dimension of its proboscis is 5.81 millimetres, forewing 8.4 millimetres, hind leg 7.26 millimetres and cubital index of 2.25 (Ruttner, 1988), longitudinal of sternite 3 is 2.46mm and transversal of wax plate 2.07mm (Hepburn *et al*., 1998).

According to (Whitfield *et al*., 2006), *Apis mellifera yemenitica* races are resilient to ecological threats, (Fletcher, 1978) and naturalize in the region with high temperatures ranging from 27°C

- 31°C with very low rainfall (30-300) mm. HEPBURN *et al*., (1998) reported that, *Apis mellifera yemenitica* races natural habitat is the dry thorn bush (Acacia) of Eastern Africa. However, behavioral physiognomies of these honeybees are not well recorded (Radloff and Hepburn, 2001).

According to Ruttner, (1988), *Apis mellifera yemenitica* races exhibit some dissimilarities in behavior, (Davis *et al*., 1998) they frequently migrate during the dry period of the year. However, (Rashad and El-Sarrag 1980, Davis *et al*., 1998) noted no colonies absconding problems from eastern highlands of eastern Africa regions for example Kenya, to Mozambique. In Zimbabwe and South Africa, (Radloff and Hepburn, 2001, HEPBURN *et al*., 1998.) reported that *Apis mellifera scutellata* colonies absconding happens frequently throughout the dry period in drier lowlands.

2.3 The distribution of *Apis mellifera* races in Africa

According to (Ruttner, 1988, and Whitfield *et al*., 2006), *Apis mellifera scutellata* is native to Eastern and Southern Africa, from Ethiopia to South Africa. In Ethiopia, *Apis mellifera scutellata* inhabits on the southwest humid midlands (Whitfield *et al*., 2006). Other morphoclusters in Ethiopia included *Apis mellifera jemenitica* in the northwest and eastern arid and semi-arid lowlands, (Radloff and Hepburn, 1999). *Apis mellifera bandasii* is native on the central moist highlands of Ethopia, (Amssalu *et al*., 2004) whilst *Apis mellifera monticola* has naturalized from the northern mountainous highlands, (Amssalu *et al*., 2004) and *Apis mellifera woyi-gambell* has adapted and occupied the south western semi-arid to sub-humid lowland parts of Ethiopia.

Honey bees of Uganda represented an important biogeographical gap, defining the population structure of *Apis mellifera scutellata*, (Ruttner, 1988, and (Amulen *et al*., 2017, Amssalu *et al*., 2004). However, morphometric analysis by (Amulen *et al*., 2017, Amssalu *et al*., 2004) of worker honey bees has resolved this issue. At lower altitudes <200 m), honey bees formed one distinct morphocluster typical of *Apis mellifera scutellata* throughout the African continent (Amulen *et al*., 2017, Amssalu *et al*., 2004). In comparison by, (Dutton *et al*., 1981 and Hao *et al*., 2007) *Apis mellifera scutellata* at higher altitudes (>2000 m) formed a separate distinct cluster of large, dark bees as mountain ecotypes.

According to Oden, (2001) the distribution of honey bee species, including *Apis mellifera scutellata*, in Taita Taveta District, Kenya, Zimbabwe, Malawi, South Africa, Lesotho, Swaziland and eastern Zambia also appears to be related to altitude, (Ruttner, 1988, and Amssalu *et al*., 2004, Amulen *et al*., 2017) with *Apis mellifera monticola* found to be most widespread in the humid highlands, (Kaplan, 2004) and *A. mellifera litorea* was most common in dry lowland of inland Tanzania.

Through advanced international trade and globalization in food security and climate change, *Apis mellifera scutellata* was introduced to Brazil in 1956 for increased honey production, (Ruttner, 1988) and facilitating pollination and the reproduction of flowering plants to farmers' pollinator-dependent crops (Huang 2012). Due to *Apis mellifera scutellata* migratory behaviour some colonies escaped, (Anderson, 2010 and Paul *et al*., 1999) and has spread too much of South America, to Central America and to the southern parts of North America. *Apis mellifera* race is an aggressive invader, (Anderson, 2010 and Paul *et al*., 1999) and its spread is facilitated by a high adaptability to variable ecological conditions (Piereira and Chaud-Netto, 2005) indicating that further spread is probable.

Discussions by (Kaplan, 2004 and Scheneider *et al*., 2004) revealed of traits and behaviour that are responsible for making this race a successful invader and existence certainly over massive and diverse spatial, (Whitfield *et al*., 2006) ranging from Scandinavia in the northern of African continent parts to the Cape of Good Hope in the south end of African continent, and from Dakar in the west to Oman in the east. Diverse inhabitants have adapted to different climatic rangelands conditions, (Whitfield *et al*., 2006, Dutton *et al*., 1981 and Hao *et al*., 2007) this dispersal over wide ranges with tremendously dissimilar temperatures and precipitations consequently resulted in variation of honey bee morphology and behaviour (Nuru *et al*., 2002).

2.4 Climate change impacts on races distribution

This section, reveals the main pathways by which climate change has affected apiculture production systems as well as the forces that may influence equitable *Apis mellifera* races distribution. According to Environment Africa Organization (2020) and (Walsh, 2013), *Apis mellifera* races and food systems value chains, however, face continued increases in environmental pressures. Chaplin-Kramer *et al*., (2014) Most prominently, natural and human-caused climate change influence the productivity capacity of honey bees, quality and quantity of dietary produce and honey bee ability to distribute equitably.

Some of the favourite bees' races known for honey making and plants pollination are in danger of getting extinct (Amulen *et al*., 2017, Abrol, 2012), thus an indirect future threat to food and nutrition security.

Multiple global environmental variables, such as climatic conditions, play a significant role in the requirements of biodiversity and wildlife conservation for their fundamental niche and affect their geographical distribution and productivities capacity (Chaplin-Kramer *et al*., 2014). Rendering to Yoruk & Sahinler, (2013), nowadays, climate change is considered to be the main future challenge to apiculture and sustainable food sovereignty, (Bell *et al*., 2007) and has an impact on the environment and its inhibitors. According to (B´en´e C, *et al*., 2016) climate change is likely to be the greatest cause of pollinator population decline with subsequent food insecurity.

Climate change affect food production of flowering species by reducing the abundance of pollinating insects, (Amulen *et al*., 2017, Abrol, 2012) and force shifting their regional distributions in search of suitable environment. According to Mueller, (2012) and Rader *et al*., (2013) global warming affects, the traditional time of plants flowering and will generally cause plant communities to shift their reproductive circles, (Parmesan, 2003) and these changes may result in mismatches between mutualistic plant pollinator pairs, thereby disrupting interactions and ecological ecosystem functionality.

Furthermore, reduced overlap between the timing of plant flowering and pollinator emergence may reduce the breadth of diet for pollinators, (Myers *et al*., 2015 and Mueller, 2012) resulting in decreased pollinator abundance and increased extinctions of both plants and pollinators.
Finally, increasing carbon dioxide (CO2) concentrations levels are also changing the atmospheric temperatures (Myers et al., 2014) and the nutritional value of important forage for pollinator species, with undetermined consequences for pollinators health (Myers et al., 2014). For example, temperature is very important for brood rearing and development (Petz *et al*. 2004 & Tautz *et al*. 2003) and bees foraging activity (Blazyte-Cereskiene *et al*. 2010, Potts *et al*., 2010) because vegetation is very important as source of food to honey bee colonies (Zaitoun & Vorwohl 2003). Climate change can impact honey bee colonies directly (Le Conte & Navajas 2008), or indirectly by impacting flowering plants (Rader *et al*., 2013).

This causes the population to fall sharply in various regions because of the interdependency ecosystems between plants and bees as a consequence perturbation in one population can distress the other (Rader *et al*., 2013, Potts *et al*., 2010). Another example of climate change impact cited the coral reefs as projected to decline by 70-90% at 1.5°C, (Cleland *et al*., 2006) and virtually all coral reefs will be lost. This is not only a tragedy for wildlife races but for also half a billion people that rely on biodiversity and wildlife as their source of food and nutrition -protein (Cleland *et al*., 2006).

Nelson *et al*., (2009), the effect of global warming on the environmental ecosystem is profound and widespread. According to Nelson *et al*., (2010), many races are migrating to areas with favourable conditions leaving very little to no populations in the native origins of the races. Nelson *et al*., (2009) Meteorological conditions variation can influence *Apis mellifera* races at different levels, (Hodson and White, (2010) and climate change can have an indirect effect on food sovereignty and sustainable livelihoods through its direct and indirect effect on honey bee behaviour and composition which has an impact on productivities.

Climate change can modify the value and eminence of the floral ecosystem and upsurge or decrease colony collection volume and development (Potts *et al*., 2010, Le Conte and Navajas, 2008). Climate change affects resilient of new *Apis mellifera* races dispersal ranges, (Nelson *et al*., 2010) and gives rise to new competitive relationships between species and races, as well as among their parasites and pathogens.

Climate mitigation and the future of tropical landscapes motivate beekeepers to shift their apiculture systems (Gisbert Glaser *et al*., 2017), they will be obliged to favour moving their hives to new foraging areas and introducing foreign species to assess their worth in the new climate conditions.

2.5 Impact of projected environmental changes

According to Hodson and White, (2010), expecting the potential impacts of climate change on land suitability to Apis mellifera for sustainable apiculture is very important. The findings will help in future evidence-based policy formulation on bee races, biodiversity and wildlife conservation in light of the predicted climate change scenarios (Yanchao *et al*., 2021) thus future biodiversity and wildlife conservation and what the food and nutrition security status holds is absolutely scaled up.

According to Jingjie *et al*., (2021) projected evidence-based study results will model the likely distribution of the honey bees across the Eastern and Southern Africa under a changing climate.

Trinidad *et al*., (2021) revealed the power in devising projected indigenous and scientific knowledge on the effects of climate change to honey bees' rangelands suitability, (United Nations. SDGs, 2015, Porter *et al*., 2014, Latham, 1997) as it has huge contribution on sustainable developmental goals (SDGs) linked to food and nutrition security and climate change pillars. Hodson and White, (2010), projected studies have shown that in Eastern and Southern Africa, the presence of honey bees can increase crop yields of insect pollinated species by more than a third, (Ziska *et al*., 2016, Potts *et al*., 2010) this have impact on food security and sustainable livelihoods because bee hive products especially honey attract premium prices making it a valuable pollination services and honey commodity for income and nutritive food.

A recent study by (Ziska *et al*., 2016) revealed that, since 1842, there has been a one-third reduction in the protein content of goldenrod pollen, a late blooming plant that plays an important nutritional role for overwintering pollinators. Chamber experiments indicate further declines of *Apis mellifera* races with increased atmospheric carbon dioxide (CO2) concentrations (Ziska *et al*., 2016) and the impact of significantly reduced dietary protein for bees and other pollinators is currently unknown

According to Sean *et al*., (2021), the *Apis mellifera* race is not officially classified as threatened. However, recent studies by (Veronika *et al*., 2021, Potts *et al*., 2010) assumed honey bees are experiencing threats, including sharp temperature changes, season shifting, diminishing forage resources, limited biosecurity management like pests and diseases, as well as fire outbreak problems arising from the honey hunters, misuse of pesticides and insecticides in the environment. Although the net effect of climate change on pollinators remains uncertain, studies indicate that a reduction in animal pollination would decrease yields of numerous pollinator-dependent food crops that play important roles in providing food and micronutrients to humans (Chaplin-Kramer *et al*., 2014 and Eilers *et al*., 2011).

Much research and action is needed to mitigate these climate change threats, (Allsopp, 2004) and the South African National Biodiversity Institute (SANBI) has undertook an important scheme researching on the projected honey bees' forage resource requirement.

Johannsmeier *et al*., (2001), through projected ecological modelling for *Apis mellifera* races suitability in Eastern and Southern Africa has identified a future unique problem the Cape honeybee. Recent studies by (Springmann *et al*., 2016) has concurred with analysis by (Johannsmeier *et al*., 2001), that *Apis mellifera capensis* can become a social parasite if introduced in the other ecological niche native to subspecies of the *Apis mellifera scutellata* range.

To remedy this, (Regulation of Bio – prospecting, access and benefit – sharing, 2008) has advocated for establishment of a dividing line to separate the rangelands in which *Apis mellifera scutellata* and *Apis mellifera capensis* can be used for beekeeping activities and (Biodiversity Act No. 10 of (2004) strengthens the recent policy achievement by cohering that, no bees may be transported across the demarcation line.

Adopting and implementing the findings from the projected environmental change impact give some resilient biodiversity and wildlife conservation management (Springmann *et al*., 2016, Porter *et al*., 2014, Aliber, 2009) and enhance the sustainable developmental goals (SDGs) linked to climate change and sustainable food sovereignty (IFPRI, 2015, United Nations. SDGs, 2015, Aliber, 2009, Battisti, 2009). Recent modelling indicates that pollinators - *Apis mellifera* races declines would increase child mortality and birth defects from increased vitamin A and foliate deficiency, respectively, (Springmann *et al*., 2016, Whitmee *et al*., 2015, Latham, 1997) and also increase the risk of heart disease, stroke, diabetes, and certain cancers in adults as a result of reduced dietary intake of fruits, vegetables, nuts, and seeds (Smith *et al*., 2015, Springmann *et al*., 2016).

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CHAPTER 3: METHODOLOGY

3.1 Description of the Study Area

The study focused on three *Apis mellifera* subspecies of significant importance in the beekeeping industry in Eastern and Southern Africa (Figure 3.1). *Apis mellifera scutellata* is a race of importance to several countries, stretching from Ethiopia in the north-eastern part of the continent, through Kenya, Tanzania, Malawi, eastern Zambia, Zimbabwe and eastern Botswana, stretching down to South Africa (leaving the Cape tip where Apis mellifera capensis is restricted), Lesotho and Eswatini. *Apis mellifera yemenitica* occurs in countries in north eastern Africa such as Eritrea and Somalia stretching inland into Sudan and Chad. *Apis mellifera litorea* is restricted to the eastern coast line, from Tanzania down to Mozambique. The areas occupied by *Apis mellifera scutellata* are dominated with the miombo woodlands which are typically savanna, dominated by *Brachystegia* and *Julbernardia* species. *Apis mellifera yemenitica* typically occupies desert-like areas, typical of Yemen, from which the race derived its name. *Apis mellifera litorea* is suited to low altitude coastline areas in Tanzania and Mozambique.

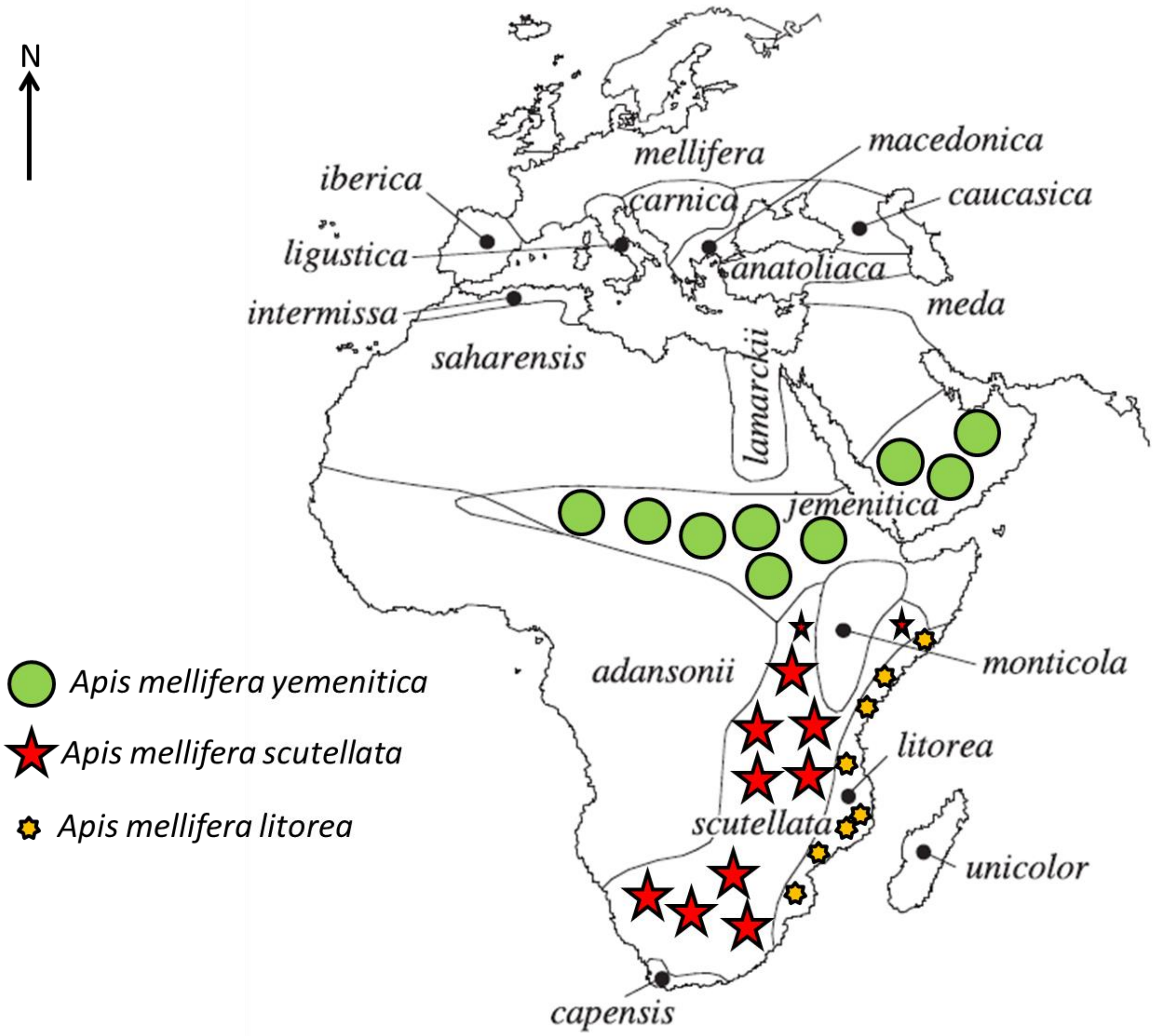

Figure 3.1. Sketch map of the distributions of the three study honeybee races (adapted from Moritz *et al*., 2002).

3.2 Acquisition of Occurrence Data

The raster data for the research was obtained from literature (Sheppard and Young, 2006, Whitfield et al., 2006) and it was digitized to produce a vector shape file with captured occurrence areas for *Apis mellifera scutellata*, *Apis mellifera yemenetica* and *Apis mellifera litorea* races using Quantum Geographical Information System (QGIS). Via the QGIS 'Georeferencer GDAL' plugin, the ground system geographic locations were assigned for the occurrences of the races. The data was used to generate pseudo-random points over the vector layer to give a dataset of 10088 georeferenced coordinates for the species in their respective occurrence areas.

The dataset was loaded to Wallace a modular, R-based platform for reproducible modeling of species niches and distributions to process the occurrence data for better data quality. A thinning distance of 50 km was used to remove the fewest records necessary to substantially reduce the effects of sampling bias, while simultaneously retaining the greatest amount of useful information for modeling. The thinning algorithm retained an optimal number of 10088 localities for *Apis mellifera scutellata, Apis mellifera yemenetica* and *Apis mellifera litorea* with well-defined latitudes and longitudes.

3.3 Acquisition of environmental data

The distribution and abundance of *Apis mellifera* races, the diversity and structure of their communities, and the functioning of the whole ecosystems is strongly influenced by climatic patterns of temperature, precipitation, and their seasonal changes (Xu *et al.*, 2017, Harrison et al., 1993). Thus, for simulation, 19 bioclimatic variables (Bio1–Bio18) were sourced from WorldClim http://worldclim.org, (Hijmans et al., 2005) database at 2.5 seconds of latitude and longitude generated by interpolation from climate data spanning fifty and seventy years (Table 3.1). Specifically, “bioclimatic” variables that are likely to influence the distributions of *Apis mellifera scutellata*, *Apis mellifera yemenetica* and *Apis mellifera litorea* honeybee races were examined.

Table 3.1 Bioclimatic variables determining species distribution

Name	Variable	Units
Bio 1	Annual Mean Temperature	ºC
Bio 2	Mean diurnal range	ºC
Bio 3	Isothermality (BIO2/BIO7) * (100)	ºC
Bio 4	Temperature seasonality (standard deviation *100)	ºC
Bio 5	Max Temperature of Warmest Month	ºC
Bio 6	Min Temperature of Coldest Month	ºC
Bio 7	Temperature Annual Range (BIO5-BIO6)	ºC
Bio 8	Mean Temperature of Wettest Quarter	ºC
Bio 9	Mean Temperature of Driest Quarter	ºC
Bio 10	Mean Temperature of Warmest Quarte	ºC
Bio 11	Mean Temperature of Coldest Quarter	ºC
Bio 12	Annual Precipitation	mm
Bio 13	Precipitation of Wettest Month	mm
Bio 14	Precipitation of Driest Month	mm
Bio 15	Precipitation Seasonality (Coefficient of Variation)	mm
Bio 16	Precipitation of Wettest Quarter	mm
Bio 17	Precipitation of Driest Quarter	mm
Bio 18	Precipitation of Warmest Quarter	mm
Bio 19	Precipitation of Coldest Quarter	mm

3.4 Data analyses

R and the associated R Studio were used to determine both current suitability and future suitability, considering climate change. To facilitate this, a number of library packages useful for ecological niche modelling were loaded into R. These were raster, rgdal, maps, mapdata, dismo, rJava, maptools and jsonlite. The bioclimatic variables (Table 3.1) were downloaded directly into R using the ‘getData ()’ function. Using all the data together, species distribution models were constructed using the Maxent algorithm, which tries to point out the combination of environmental responses that best predicts the occurrence of the races.

3.4.1 Present Suitability

To assess the prediction potential of the models for each honeybee race, cross validation was used by setting aside 20% location points and the remaining 80% was used as training data. This was done by making data frames of latitudes and longitudes for each model, then adding indices that created five random groups of the observations. A function to hold one fifth of the training data (20%) and another for the four fifths (80%) as training data was coded and applied in R. After this, the Species Distribution Model using the Maximum Entropy (Maxent) algorithm was fit into R to see the combination of climatic variables which best predicted the occurrence of the races. The outcome was then used to compare the importance of the different variables in the final model. The ‘response ()’ function were used to check the environmental variables that contributed most to the distributions of the honeybee races. The ‘predict ()’function was used to map the predicted probabilities of the honeybee race occurrences.

3.4.2 Predicted Future Suitability

The ‘evaluate ()’ function was used to come up with the AUC, using the previously generated 20% test data. Climate estimates for Representative Concentration Pathway scenarios RCP8.5 and RCP 2.6 for the years were loaded into R using the ‘predict ()’ function.

3.5 References

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CHAPTER 4: RESULTS

4.1 Current and future suitability of *Apis mellifera scutellata*

4.1.1 Current Suitability of *Apis mellifera scutellata*

Apis mellifera scutellata distribution model (SDM) highlighted abundant species occurrences across the north-eastern parts of South Africa, parts of Namibia, Zimbabwe and southern Malawi, where the habitat is favourable with the probability of occurrence above 0.5. Very few occurrences were predicted to be found in western Zambia with a probability below 0.5. Some parts of Angola and Tanzania have favourable conditions above 0.6 but with no abundant *Apis mellifera scutellata* species occurrences.

4.1.2 Future Suitability of *Apis mellifera scutellata*

When projected to 2050 and 2070 under the RCP 2.6 and RCP 8.5, there are a few things noticeable from this model output. First, comfortingly, habitat is predicted to be good in areas where there are lots of honeybee occurrences, subtle but substantial changes were noted in the probability of occurrences of the *Apis mellifera scutellata* race. Findings from the modellings showed a slight decrease in *Apis mellifera scutellata* race distribution across Sub Saharan Africa was noted as the area exhibited a contraction of favourable habitat. Sporadic areas with the probability of less than 0.5 were observed with no races occurrences.

Finally, it is interesting to note that there seem to be distinct regions of favorable habitat for *Apis mellifera scutellata* species. Patterns like this in model output can be used to generate hypotheses about the genetic structure across the *Apis mellifera scutellata* species range, about local phenotypic adaptation, and even to suggest areas where additional surveys might be beneficial for finding populations distribution of endangered *Apis mellifera* races (Fig 4.1).

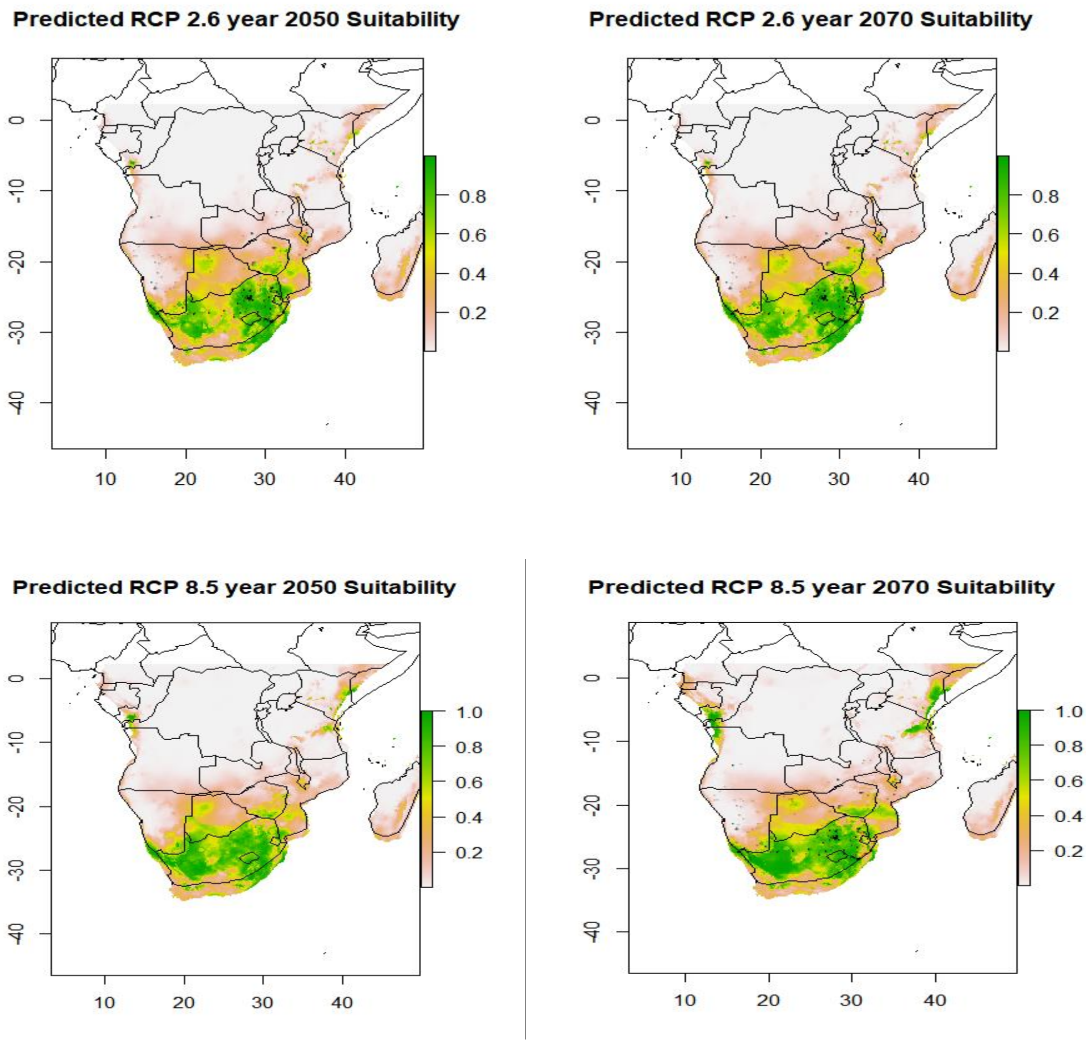

Figure 4.1 future suitability of Apis mellifera scutellata.

4.1.3 Model performance and variable contribution

Prediction of *Apis mellifera scutellata* under the two models showed high areas under the receiver operator curve (ROC). The representative concentration pathway (RCP) 2.6 for the year 2050 had the value of 0.942 and 0.942 for the year 2070 respectively whilst RCP 8.5 had the value of 0.837 under the year 2050 and 0.818 for 2070. Isothermally (BIO2/BIO7) (×100) (BIO3), mean temperature of coldest quarter (BIO11) and precipitation of driest month (BIO14) were identified as the most important bioclimatic predictor variables for the distribution of *Apis mellifera scutellata* 2050 and 2070 predictions under RCP 2.6 (Fig 4.2c) and RCP 8.5 (Fig 4.2b) respectively. Isothermality (BIO2/BIO7) (×100) (BIO3), precipitation of wettest month (BIO13), mean temperature of wettest Quarter (BIO8) were the most important predictors influencing the distribution of suitable habitat for the years 2050 and 2070 under RCP2.6 and RCP8.5 (Fig 4.2a and Fig 4.2d).

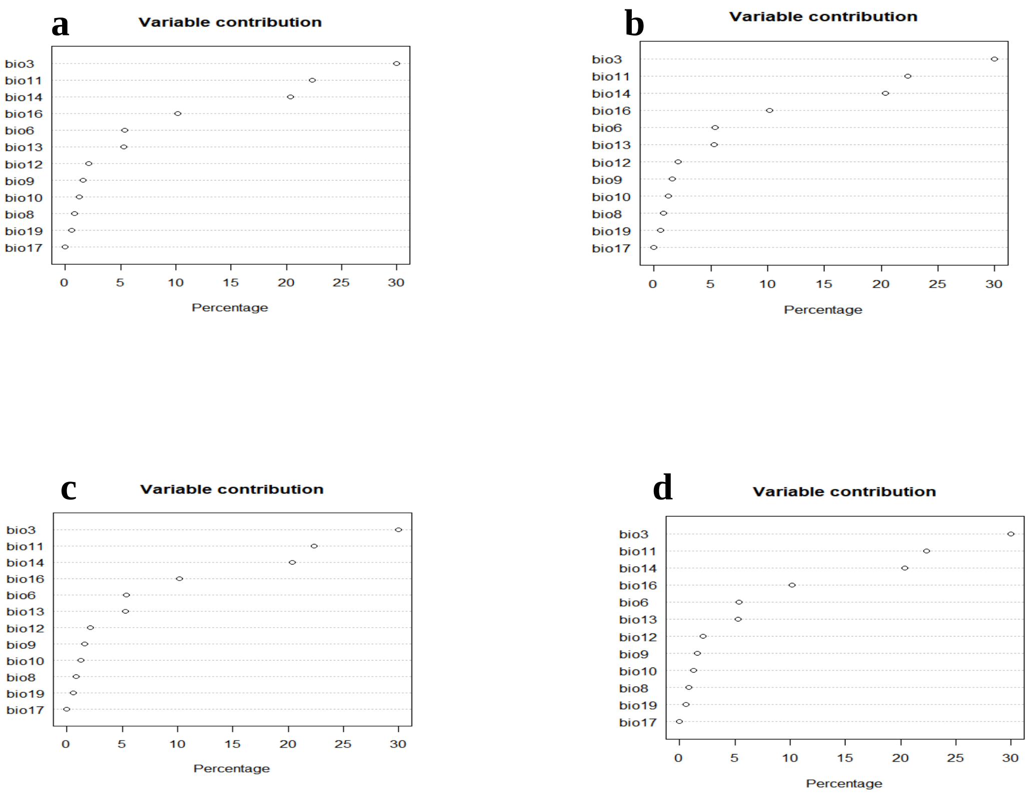

Figure 4.2 shows the variable contribution of climatic variable (a) variable contribution for the RCP 8.5 the year 2050, (b). Variable contribution for the RCP 8.5 the year 2070 for Apis mellifera scutellata. (c) variable contribution for the RCP 2.6 the year 2050, (d). Variable contribution for the RCP 2.6 the year 2070 for Apis mellifera scutellata.

4.2 Current and future suitability of *Apis mellifera litorea and yemenitica.*

4.2.1 Current Suitability *Apis mellifera litorea and yemenitica*.

On the other hand, Species Distribution Model (SDM) also indicate that *Apis mellifera* (*litorea and yemenitica*) are native to central and eastern Africa. There are no *Apis mellifera* races found in places where the probability of occurrence was below 0.2. Suitable ecological conditions are presented further at locations along with the coastal areas of Madagascar. However, the *Apis mellifera* race is not currently recorded to inhabit this area.

4.2.2 Current Suitability of *Apis mellifera litorea*

Apis mellifera litorea race is located sideways of the east African coastline where there are favourable habitat conditions stretching from Kenya, coastline Tanzania to south of Mozambique, where the environment is warm and there is some food throughout the year. *Apis mellifera litorea* follows the coastal areas of the Indian ocean, and this gave the study an orientation to the eastern coasts of Eastern Africa covering countries like Mozambique, parts of Kenya, Tanzania and Somalia. This region has a temperature range of 21°C to 29°C from the south to the north of the Indian Ocean shores in Eastern Africa, and this region is relatively hot and humid. The region stretches for a distance of approximately 5000 kilometers.

4.2.3 Future Suitability of *Apis mellifera litorea*

When projected to 2050 and 2070 under the RCP 2.6 and RCP 8.5, subtle but substantial changes were noted in the probability of occurrences of the *Apis mellifera litorea.* A slight decrease in *Apis mellifera litorea* species distribution across eastern Africa was noted as the area exhibited a contraction of favourable ecological habitat. Random ecological areas with the probability of less than 0.2 were observed with no *Apis mellifera litorea* races occurrences (Fig 4.3).

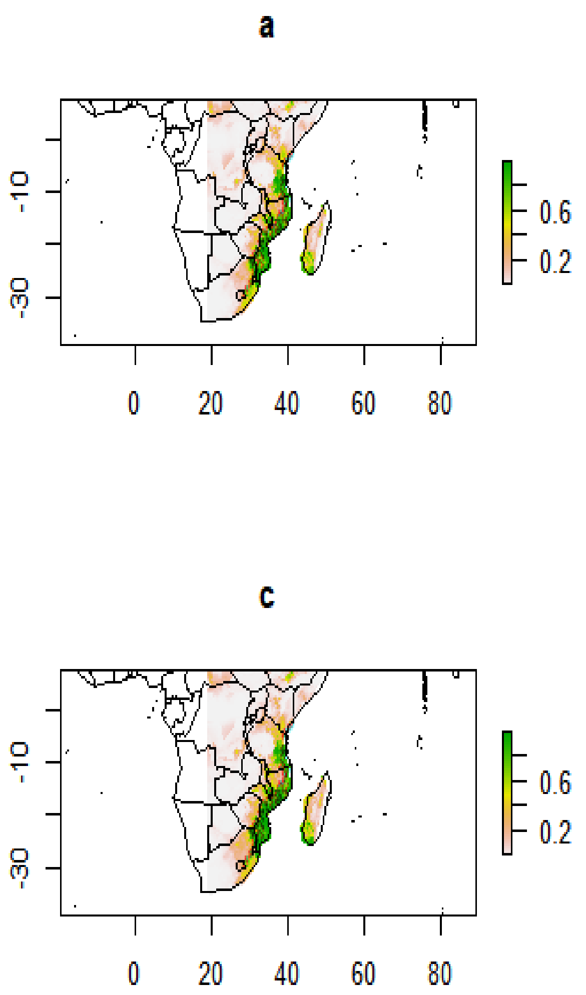

Figure 4.3 future suitability of Apis mellifera litorea, (a) and (b). future suitability for the RCP 2.6 the year 2050 and 2070 respectively. (c) and (d). future suitability for the RCP 8.5 the year 2050 and 2070 respectively.

4.2.4 Model performance and variable contribution

The *Apis mellifera litorea*' models had a high area under the ROC curve. RCP 2.6 for the year 2050 had the value of 0.873 and 0.863 for the year 2070 whilst RCP 8.5 had the value of 0.837 for 2050 and 0.818 for 2070. Precipitation of warmest quarter (BIO18), precipitation of driest quarter (BIO17) and mean temperature of wettest quarter (BIO8) were identified as the most important bioclimatic predictor variables for the distribution of *Apis mellifera litorea* for 2050 and 2070 predictions under RCP 2.6 (Fig 4.4a & Fig 4.4b) and RCP 8.5 (Fig 4.4c & 4.4d).

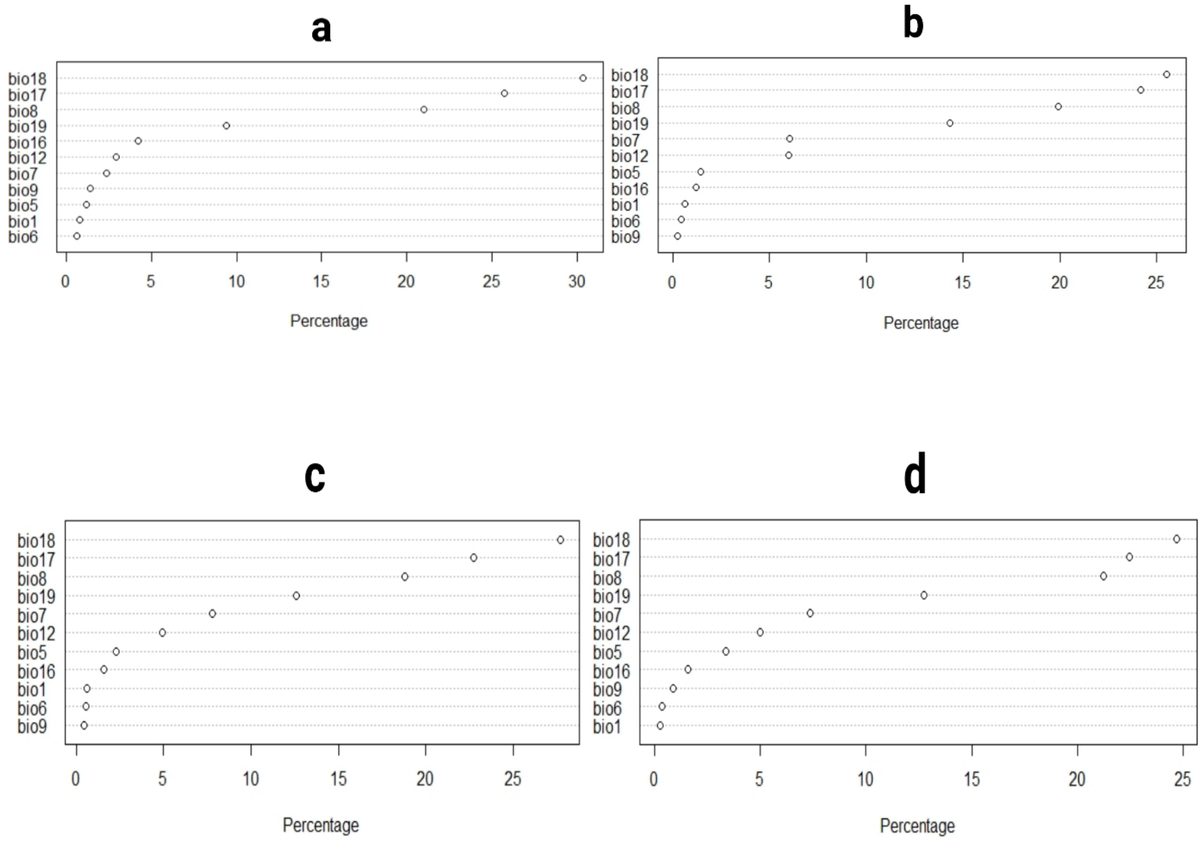

Figure 4.4 shows the contribution of climatic variable (a). Variable contribution for the RCP2.6 the year of 2050 (b). Variable contribution for the 2.6 the year of 2070 (c). Variable contribution for the RCP8.5 the year 2050 (d). Variable contribution for the RCP 8.5 the year 2070 for Apis mellifera litorea

4.3 Current and future suitability of *Apis mellifera yemenitica*

4.3.1 Current Suitability of *Apis mellifera yemenitica*

Apis mellifera yemenitica occurs in countries like Kenya, Mauritania, Mali, Chad, and Sudan. It has also been identified from Ethiopia and Somalia. Most of the areas lie in the tropics, but some of them have climate ranges from arid in the North to wet-and-dry in the south, for example, Sudan is dry in the north and wet in the south. The variations in the length of the dry season mostly depend on the most prevailing airflow, between the dry northeasterly from the Arabian Peninsula and moisty southwesterly winds from the Congo River Basin and other sources of moist air.

4.3.2 Future Suitability of *Apis mellifera yemenitica*

Apis mellifera yemenitica projections to 2050 and 2070 under the RCP 2.6 and RCP 8.5 observed a high expansion in the races' suitable habitat. The *Apis mellifera yemenitica* races were largely concentrated in regions with favorable habitats conditions including Central Africa, Cameroon, Uganda, Rwanda, Burundi, parties of Kenya, Ethiopia, Tanzania, Somalia, South Sudan and Chad.

Encroachment of suitable habitats towards parts of Niger and Nigeria, Saudi Arabia and Oman with probability of occurrence above 0.5 was recorded. The projection for 2050 under the RCP 2.6 and RCP 8.5 displayed that the Democratic Republic of Congo had probability of occurrence of below 0.1 indicating that the area has unfavorable ecological conditions (Fig 4.5a and Fig 4.5c), however, the projection for 2070 indicated an increase to above 0.3 indicating that the area increased habitability for the yemenitica races (Fig 4.5b and Fig 4.5d).

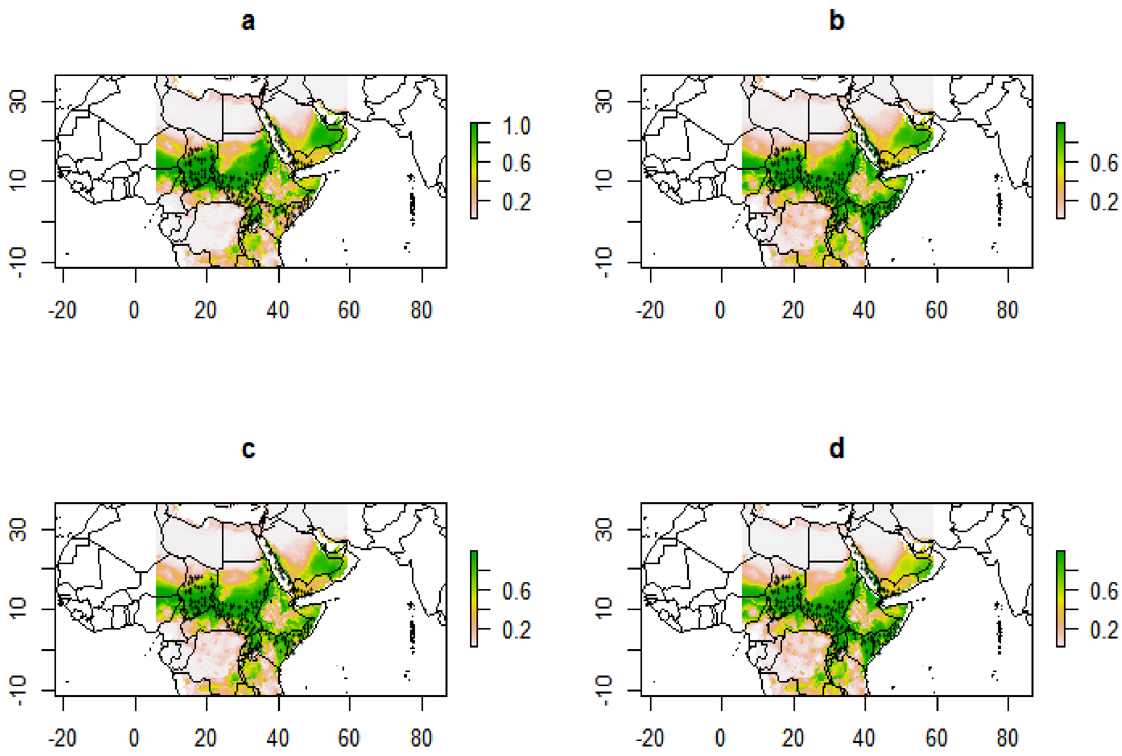

Figure 4.5 future suitability for Apis mellifera yemenitica, (a) and (b). Future suitability for the RCP 2.6 the year 2050 and 2070 respectively. (c) and (d). Future suitability for the RCP 8.5 the year 2050 and 2070 respectively.

4.3.3 Model performance and variable contribution

The *Apis mellifera yemenitica* modelling indicated that precipitation of warmest quarter (BIO18), annual mean temperature (BIO1), temperature annual range (BIO7) were the most important predictors influencing the distribution of suitable habitat for the years 2050 and 2070 under RCP2.6 (Fig 4.6a and Fig 4.6b) and RCP8.5 and RCP 8.5 (Fig 4.6c and Fig 4.6d). Notably, the models were most sensitive to precipitation of warmest quarter (BIO18) which is the most important predictor variable for *Apis mellifera yemenitica* races under all the RCPs for the projections of 2050 and 2070.

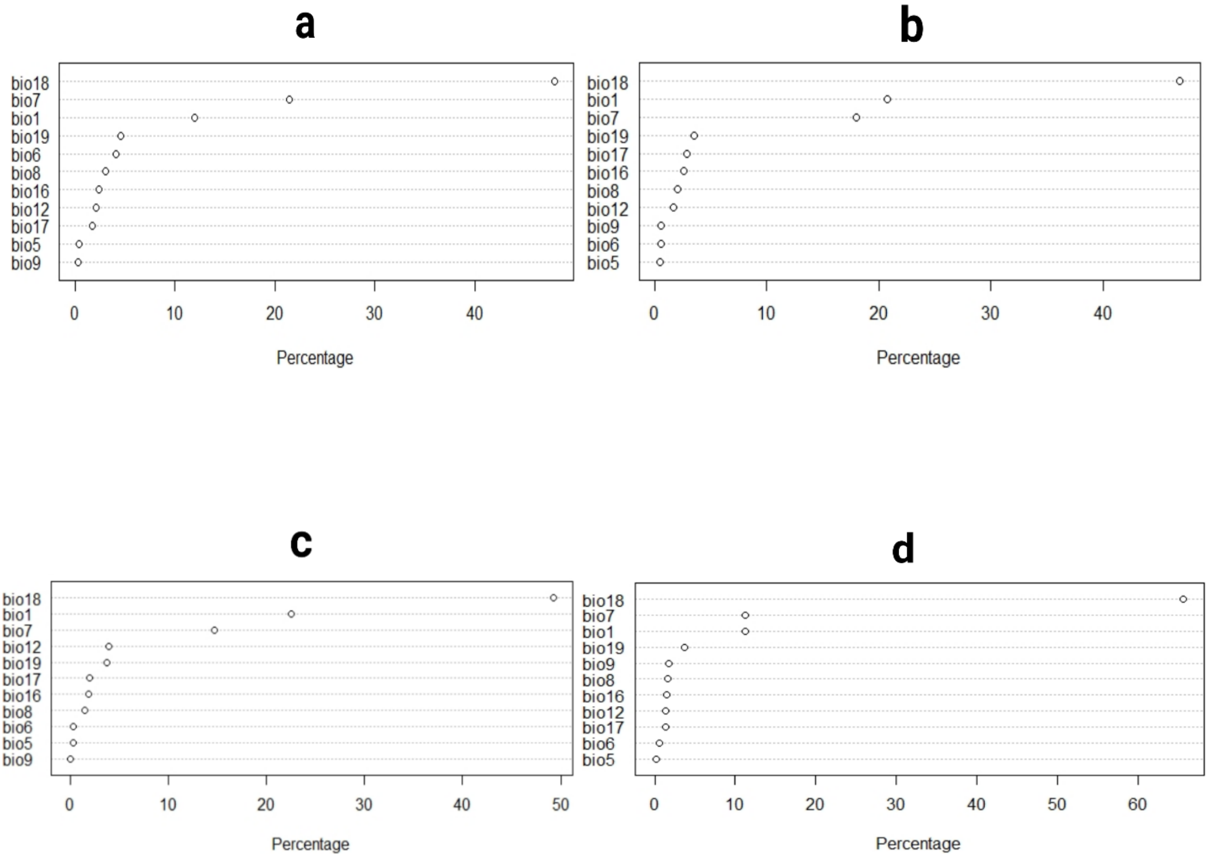

Figure 4.6 shows the contribution of climatic variable (a). Variable contribution for the RCP2.6 the year of 2050 (b). Variable contribution for the 2.6 the year of 2070 (c). Variable contribution for the RCP8.5 the year 2050 (d). Variable contribution for the RCP 8.5 the year 2070 for Apis mellifera yemenitica.

CHAPTER 5: DISCUSSION

This study modelled the current and future suitability of *Apis mellifera* races in Africa to determine the potential impact of climate change on their future distributions and hence future beekeeping potentials of areas occupied by these races. According to United Nations. SDGs (2015), *Apis mellifera* races has been observed for its greatest role on fortifying sustainable developmental goals linked (SDGs) to climate change pillars and food and nutrition security pillars. For example, many plants pollination is one of the best ways of improving sustainable dietary production (Walsh, 2013, Admasu and Nuru (2002), significant economic contribution in sustainable crops production (DAFAR, 2018, Admasu and Nuru (2002) and human nutrition security (IFPRI, 2015, Latham, 1997), bee venom-*Apitoxin* production used in medicine as a treatment for rheumatism (Walsh, 2013, Acevedo, and Real, 2012) and other joint diseases due to its anti-inflammatory action, sustainable honey and royal jelly production systems (B´en´e C *et al*., 2016), Thus, investment in the modelling of the current and future suitability of apiculture sector means improves on Agroecology Ecosystem Research for future climate challenges resilient building and preparedness (Zhu *et al*., 2013), this insight on the adoption of climate-smart agriculture, diversifying existing sources of income, enhancing agricultural yield of smallholder farmers, and creating employment opportunities. Some random locations were selected within the more suitable regions for apiculture as presented in Fig (4.1, 4.2, 4.4, 4.6 and 4.9), (GUISAN & THUILLER 2005) the locations were selected randomly mainly from the suitable, semi-arid and desert nature at different governorates in Eastern and Southern Africa regions. However, these estimates of *Apis mellifera* races distribution and potential performance have several flaws. It focuses only on modelling the factors of climate such as temperature and precipitation, it lacks information about biosecurity, it inadequately account for wild enemies of bees and impact of globalization of agriculture industry.

5.1 Current and future suitabilities of *Apis mellifera scutellata*

The current and future habitat suitabilities and distribution of *Apis mellifera scutellata* are exhibited on (Fig 3.1, 4.1 and 4.2, Moritz *et al*., 2002). According to Fig 4.1 in line with research revealed by (Moritz *et al*., 2002, Radloff and Hepburn, 2001), *Apis mellifera scutellata* is found to be native and is a race of importance to several countries, stretching from Ethiopia in the north-eastern part of the continent, through Kenya, Tanzania, Malawi, eastern Zambia, Zimbabwe and eastern Botswana, stretching down to South Africa, (Fig 3.1 and

Moritz *et al*., 2002, Radloff and Hepburn, 2001) however, the distribution isolate Lesotho and Eswatini thus leaving the Cape tip where *Apis mellifera capensis* is restricted.

Moreover, (Fig 4.2, WorldClim http://worldclim.org, Xu *et al.*, 2017, Harrison et al., 1993) *Apis mellifera scutellata* has naturalized where the habitat is favourable with the probability of occurrence above 0.5. It is fundamental to note and comprehend here what the colour scale on Fig 4.2 code symbolize, yellow representing no ecological suitability change, greener colors representing ecological suitability improvement, and browner colors representing ecological suitability degradation. According to Fig 4.2, very few occurrences were predicted to be found in western Zambia with a probability below 0.5. Some parts of Angola and Tanzania have favourable conditions above 0.6 but with no abundant *Apis mellifera scutellata* species occurrences.

Apis mellifera scutellata occupies many different habitats in Sub Saharan Africa (Fig 4.1, Radloff & Hepburn, 2001), and has even spread to South America, to Central America and to the southern parts of North America. *Apis mellifera* race is an aggressive invader, (Anderson *et al*., 2010 and Paul *et al*., 1999) and its spread is facilitated by its high migratory behaviour and resilient adaptability to variable ecological conditions (Piereira and Chaud-Netto, 2005) indicating that further spread is probable.

However, *Apis mellifera scutellata* occurrence notably on (Fig 4.3) the models were most sensitive to Isothermally (BIO2/BIO7) (×100) (BIO3), mean temperature of coldest quarter (BIO11) and precipitation of driest month (BIO14) were identified as the most important bioclimatic predictor variables for the distribution of *Apis mellifera scutellata* 2050 and 2070 predictions under RCP 2.6 (Fig 4.3c) and RCP 8.5 (Fig 4.3b) respectively. Isothermality (BIO2/BIO7) (×100) (BIO3), precipitation of wettest month (BIO13), mean temperature of wettest Quarter (BIO8) were the most important predictors influencing the distribution of suitable habitat for the years 2050 and 2070 under RCP2.6 and RCP8.5 (Fig 4.3a and Fig 4.3d).

Ecological niche modelling has proven to be useful in gathering predictive multiple global environmental variables, such as climatic conditions of honeybee habitats because this research has noticed that it plays a significant role in the requirements of biodiversity and wildlife - *Apis mellifera* conservation for their fundamental niche and affect their geographical distribution and productivities capacity (Chaplin-Kramer *et al*., 2014). Rendering to Yoruk & Sahinler, (2013), nowadays, climate change is considered to be the main future challenge to *Apis* *mellifera scutellata* distribution and sustainable productivities potential, (Bell *et al*., 2007) and has an impact on the environment and its inhibitors. According to Fig 4.2 and in line with findings by B´en´e C, *et al*., (2016) climate change is likely to be the greatest cause of pollinator population distribution and decline with subsequent food insecurity.

5.2 Current and future suitabilities of *Apis mellifera litorea*

The *Apis mellifera litorea* race ecological niche model allowed creating detailed distribution maps (Fig 4.4, Fig 4.5 and Fig 4.6). Thus, the niche model helps to create maps that indicate current and future geographic regions that suggest areas for the conservation of *Apis mellifera litorea* race. According to Fig 4.4 and Fig 4.5 *Apis mellifera litorea* race is located sideways of the east African coastline where there are favourable habitat conditions stretching from Kenya, coastline Tanzania to south of Mozambique. This region has a temperature range of 21°C to 29°C (WorldClim http://worldclim.org, Xu *et al.,* 2017) from the south to the north of the Indian ocean shores in Eastern Africa, and this region is relatively hot and humid.

According to FRANKLIN, (2009), regardless of the set of data used to exhibit Fig 4.5 and Fig 4.6, modelling suggested that the geographical distribution of *Apis mellifera litorea* remains abundant in areas with the occurrence probability of above 0.3 (GUISAN & THUILLER, 2005), which provide suitable habitat. The honeybees are threatened by variable climatic conditions but they survive by ability to adjust their behaviour to weather conditions particularly they shun the outdoors when it rains and in extremely hot weather in order to survive thereby, they thrive in the predicted suitable regions.

However, the *Apis mellifera litorea* distribution models has been identified to be most sensitive to bioclimatic predictor variables for the year 2050 and 2070 predictions under RCP 2.6 (Fig 4.7a & Fig 4.7b) and RCP 8.5 (Fig 4.7c & 4.7d) where precipitation of warmest quarter (BIO18), precipitation of driest quarter (BIO17) and mean temperature of wettest quarter (BIO8) were noted as the most important. According to Fig 4.6 and in line with findings by B´en´e C, *et al*., (2016) climate change is likely to be the greatest cause of *Apis mellifera litorea* population limited distribution and decline with subsequent climate change and food insecurity impact. According to Pearson and Dawson, (2003), Guisan and Thuiller, (2005), has acknowledged that *Apis mellifera litorea* races population is dwindling and undergo constricted suitable habitats for their sustainable distribution (Guisan and Thuiller, (2005), there is greater need to adopt and implement some climate – smart justice approaches on identified habitats landscape to serve these extinguishing vulnerable races (Therrell *et al*., 2007) and facing habitats loss as anthropogenic GHG emissions increase. The effects of climate change in the Sub-Sahara subsequently continue to increase thereby diminishing the habitats for the race. Potentially suitable habitats for *Apis mellifera litorea* was noted in Madagascar however, (Therrell *et al*., 2007) revealed that the Indian Ocean is remaining as the major geographical dispersal barrier that limit the distribution of *Apis mellifera litorea* into the region despite the suitabilities of the environmental conditions for the species.

5.3 Current and future suitabilities of *Apis mellifera yemenitica*

According to Fig (4.4 and 4.8) and Dodd *et al*., (1994) has revealed that *Apis mellifera yemenitica* occurs in desert like countries for example Yemen, Kenya, Mauritania, Mali, Chad, and Sudan. *Apis mellifera yemenitica* has also been identified from Ethiopia in line with other previous modellings and in Somalia but *Apis mellifera yemenitica* is suitably distributed across the central and eastern parts of Africa covering parts of Niger, Nigeria, Chad, Sudan and Ethiopia with temperature ranges of about 25°C to 30°C. According to Dodd *et al*., (1994) and Fig 4.9 show encroachment of suitable habitats towards parts of Yemen, Saudi Arabia and Oman with probability of occurrence above 0.5 was recorded. In order to realize this development, it is important to note and comprehend here what the colour scale code symbolize, for example yellow representing no ecological suitability change, greener colors representing ecological suitability improvement, and browner colors representing ecological suitability degradation.

However, it is important to note that the current suitability of climate exhibited on Fig 4.8 where the *Apis mellifera yemenitica* currently occurs is likely to decline whilst favorable conditions will develop in areas shown on Fig 4.9 where the *Apis mellifera yemenitica* race is currently unavailable. Especially as shown on (Fig 4.10) the models were most sensitive to precipitation of warmest quarter (BIO18) which is the most important predictor variable for *Apis mellifera yemenitica* races under all the RCPs for the projections of 2050 and 2070. The persistence of *Apis mellifera yemenitica* populations reflects the consequence of some adaptive dynamics by which species manage to overcome the climatic constraints posed by a changing climate (Montesino *et al*., 2010). It is also possible that, as suggested by (Midgley *et al*., 2003), the combined impact of future rangelands transformation due to climate change will reduce suitable habitats even more than predicted for the *Apis mellifera* races. Results of climate change can alter the quality of the floral environment and increase or reduce colony distribution, performance capacity and development thereby hindering *Apis mellifera* races occurrences in some susceptible ecological parts. There could be changes in the geographical distribution and occurrences of pest and diseases whose expression depends on climatic factors.

According to Costa *et al*., (2003), Parts of Saudi Arabia, Oman and Yemen in Asia were predicted to be favorable with occurrence probabilities ranging from 0.3 to above 0.5 for *Apis mellifera yemenitica* races. Concurrently, Fig 4.9 exhibit the projection for 2050 and 2070 under RCP8.5 reflecting more suitabilities in adjacent areas in the Democratic Republic of Congo, Cameroon and Tanzania. Similarly, the *Apis mellifera yemenitica* races distribution has extended to Argentina and the USA (Costa *et al*., 2003 and Dodd *et al*., 1994), but due to cold climatic condition *Apis mellifera yemenitica* races has come to a halt. Therefore, (Pinto *et al*., 2005 and Mueller, 2012.) suggested that hot environments are conducive to the *Apis mellifera yemenitica* races expansion outside its current distribution range. However, findings from this research concurred with (Franck *et al*., 2001) among other cited research works that suitabilities of ecological habitats status is influenced by climate change it is a pivotal factor in determining distribution statistics and performance capacity.

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CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

Based on the findings, adoption of a holistic approach for *Apis mellifera* races and beekeeping industry adaptation to climate change is key, thus modelling current and future habitat suitabilities technology and indigenous beekeeping experience and knowledge are an input to identify distribution pattern of different local honeybees, productivities capacity, and biological behaviours at different localities in East and Southern Africa. *Apis mellifera* races population and honey production scales are well below its potential and output can be increased by a gradual adoption of ecological ecosystem research using ecological niche modelling approach and quantum geographical information systems for future climate change impact resilient building, shift from traditional apiculture production systems to intermediate technology climate-smart apiculture production systems. The use of ecological ecosystem research and development can lead to current and future suitabilities preparedness of apiculture industry amid climate change challenges. This can lead to implementation of precise biodiversity and wildlife conservation approaches. For example, *Apis mellifera* races can result to fortified sustainable developmental goals linked (SDGs) to climate change pillars and food and nutrition security pillars through increased plants pollination, 3-fold increases in yields of honey and can be very profitable because of low input costs.

Apiculture industry is in line with the sustainable policies of many African governments in environmental conservation and towards sustainable use of natural resources for sustainable climate justice. Apiculture increases household incomes and collectively contribute to the main economy thus increased Gross Domestic Product (GDP), adds to food security and creates opportunities for the empowerment of women, youth and the less advantaged in the communities. There are substantial market opportunities for *Apis mellifera* races, honey, beeswax and other hive products and financial returns can be increased through various methods of adding value and through marketing of minor products. Eastern and Southern Africa has an extremely diverse vegetation resource that flowers over different seasons and provides an almost ideal environment for beekeeping and a great opportunity to venture into niche markets and specialized flavours with organic honeys from reserves and sacred forests.

6.2 Recommendations

For the reason that this research finding Fig 4.1 and Fig 4.4 showed that current and future suitabilities of rangeland habitats for *Apis mellifera scutellata*, *Apis mellifera litorea* and *Apis mellifera yemenitica* are affected by predicted climate change across the Eastern and Southern Africa much agroecological research and action is needed to mitigate these future climate change threats. It is also important to adopt climate - smart justice approaches for resilient building of biodiversity and wildlife conservation. Cross breeding of *Apis mellifera* races from different ecological habitats has potential to produce resilient hybrid species that are adaptive to future climatic conditions. Morphometric analysis should be used for further research and improvement. The behaviour and productivity capacity of selected local honeybees from different ecologies should be tested in controlled research stations and on-station evaluation, selection, and multiplication of selected native honeybees are the most critical issue that needs to be addressed to increase honey production and bee population.