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Impacts of climate change on beekeeping in sub-Saharan Africa

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A RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE BACHELOR OF SCIENCE (HONOURS) DEGREE IN NATURAL RESOURCE MANAGEMENT.

DECLARATION

I certify that I wrote this research project on my own and that I have never submitted it in full or in part as part of another application for a degree.

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DEDICATION

I dedicate my research project work to God Almighty, my inspiration, and my source of knowledge, and insight. Throughout the course of my research endeavor, he has been my source of strength, and only on his wings have I been able to soar. Other part of dedication goes to my parents.

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ABSTRACT

The distribution and assemblage of beekeeping being impacted by climate change, which has become a global environmental problem. Models of climate change have emerged as a crucial resource for predicting the spread of habitats. The aim of the study was to ascertain how beekeeping in sub-Saharan Africa was affected by climate change. R software's maximum (MaxEnt) technique was used to estimate the current distribution of beekeeping in sub-Saharan Africa. Nineteen bioclimatic parameters and the distribution of beekeeping were modelled. Under the two (RCP) climatic models, specifically RCP_8.5and RCP_2.6, distribution was anticipated to be in 2050 and 2070, respectively. The species' distribution was compacted in relation to adaptability today and beekeeping's predicted distribution in the future. There is a steady deterioration, according to data for predicted future appropriateness. This amply proves that sub-Saharan Africa's beekeeping habitat is significantly impacted by climate change.

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LIST OF ACRONOMYS AND ABBREVIATIONS

AUC	Area Under the Curve
BIO	Bioclimatic Variables
FAO	Food and Agriculture Organization
GBIF	Global Biodiversity Information Facility
%	Percentage
RCP	Representative Concentration Pathway
SDMs	Species Distribution Models
NDVI	Normalized Difference Vegetation Index

CHAPTER 1

INTRODUCTION

1.1 Background to the Study

In Angola, traditional beekeeping was first documented by Europeans in 1954. David Livingstone observed the presence of wood and bark hives in the upper Zambezi region in 1854 (Illgner et al., 1998). Beekeeping involves the science of gathering, processing, and installing desired species of honeybee colonies in predetermined and standard boxes in appropriate locations. It also involves keeping the ideal number of colonies year-round and maximizing both the direct and indirect benefits of the activity (Sain & Nain, 2020). Beekeeping in sub-Saharan Africa is relatively low compared to the projected beekeepers capacity. This may be due to which implementation of modern agricultural methods (Lloyd, 2021). Beekeeping is an ancient historical practice in Ethiopia, Although it is challenging to pinpoint the exact beginning of beekeeping, it maybe have begun when Egypt mention Abyssinia as source of wax and honey (Daba et al., 2016). There are about 10 million colonies of bees and 1.9 million agricultural households that are involved in beekeeping in Ethiopia (Daba et al., 2016).

Activity of bees is influenced by climate change, which is characterized by high temperatures and could have a significant impact on bees behavior, distribution and biology (Ali Urooj et al., 2017). According to statistics provided by the FAO, 1.38 million metric tons (MT) of honey and 60.153 MT of beeswax were produced globally in 2004. In contrast to these totals, sub-Saharan Africa produced 135 373(MT) of bee wax, the majority of which came from a small number of nations (Ali Urooj et al., 2017). In terms of climate change African nations suffer both directly and indirectly effects on beekeeping for instance, the Southern African region, which includes Zambia, has felt the effects of climate change negatively, particularly in recent decades when extreme events like drought and floods have occurred more frequently than usual compared to previous similar lengths of time (Ali Urooj et al., 2017). According to Phiri, et.al (2013). Climate change results from internal natural processes, external forces, or enduring manmade changes in the atmosphere's structure or in land use (Ali Urooj et al., 2017). Some recent studies revealed that likely impacts of climate change on honey bee forage is a major threat. While migration and behavioral modifications may be able to enable these ecotypes species that are intimately linked to their environment thrive in new biotopes, climate changes are certain to have an effect on the survival of these ecotypes or honey bee species (Conte et al., 2008b).

In addition to defining new distribution regions, climate change also create new competitive connections between species, races, and their diseases and parasites (Conte et al., 2008b). The case selected villages in Manyoni District, Tanzania revealed the direct effect of climate change in relation to beekeeping, 63.5% and 13.1%, respectively, of beekeepers believed that the low rainfall and temperature had an impact on the low honey yield (Godfrey, 2018). Rainfall is necessary for flowering plants to flourish, from which bees extract nectar and pollen, and it also supplies drinking water for honey bees, which are a key component of the creation of honey. (Godfrey, 2018). Changes in the distribution of the flower species on which honey bees depend for sustenance are one of climate change's biggest effects on honey bees (Conte et al., 2008b). Roubik (2012) concluded that numerous factors of change led to a loss in the pollination services supplied by honeybees in both natural and managed habitats, as pollination directly affects ecosystem function and, ultimately, local and regional economy (Ali Urooj et al., 2017). It also affects the growth and foraging activity of flowers, as well as the generation of nectar and pollen, which are closely related to colonies (Ali Urooj et al., 2017).

Predicting areas that will be suitable for beekeeping is of greater importance in a number of ways. In order to successfully manage an apiary and lower the possibility of circumstances that could result in bee population losses, precision beekeeping combines technology and statistics (Robustillo et al., 2022). Model can be integrated into system for making decisions that will notify beekeepers of unusual events in the hives and help beekeepers to manage them effectively (Robustillo et al., 2022). Additionally, it is crucial to identify regions that are conducive to beekeeping because difficulties in beekeeping pose a threat to the future of our food supply. As a result and study on the possible causes of honey bee shrink in distribution is crucial (Switanek et al., 2017). It is also important to predict suitable areas for beekeeping because it gives starting point for land use planning, implement adaptive management strategies and initiatives in view of current and future situations.

1.2 Problem Statement

Although considerable researched done before in Africa on the subject of beekeeping, it is unclear how the future distribution in Southern Africa will be impacted by climate change. It is this last aspect that which much of the existing literature on beekeeping in Africa has tended to be distorted largely as a result of ill-considered speculation by Eurocentric bee scientists. Therefore the focus of this study will cover a gap between distorted speculations by Eurocentric bee scientist and current knowledge that is not yet proven.

1.3 Justification of the Study

Major justification of the study mainly focuses on why it is important to predict areas that will be suitable for beekeeping in relation to climate change in sub-Saharan Africa. Predicting environmental conditions for beekeeping occurrences is important for decision-making since it provides baseline information for planning and efforts. Future estimation of beekeeping benefits can be projected for example honey, wax and other honey products. The research may also shed light on how beekeeping species distribution and abundance in sub-Saharan Africa may be affected by climate change. In addition, scientist can compare current and future data models to make predication on species distribution based on climatic models or other ecological projects (Ledford, n.d.). Since EN can be used to forecast future suitable sites in sub-Saharan Africa, the distribution of the species, and areas where it may possibly face challenges due to changing climate change is crucial. Furthermore, it improves beekeeping management that has been found through elements like loss reduction, intensive management, and appropriate planning in Africa as a whole. In order to prevent obstacles faced by honey bees from endangering the future of our food supply, it is even more crucial to predict regions appropriate for beekeeping.

1.4 Aim of the Study

The aim of the study is to forecast how beekeeping in sub-Saharan Africa will respond to climate change.

1.5 Objectives of the Study

1. To determine the current suitability of beekeeping in sub-Saharan Africa.
2. To determine future suitability areas for beekeeping for the years 2050 and 2070 under different climatic scenarios.
3. To determine climatic variables affecting beekeeping distribution under different climatic change scenarios for the year 2050 and 2070.

1.6 Research Questions

1. What is the current distribution of beekeeping in sub-Saharan Africa?
2. What is the climate change’s effect on future suitability of beekeeping for the years 2050 and 2070?

3. What climatic variables will have the greatest impact on beekeeping distribution in Africa in the years 2050 and 2070?

CHAPTER 2

LITERATURE REVIEW

2.1 Beekeeping Species and Ecology

Beekeeping in Africa is divided into eleven subspecies or races (Illgner et al., 1998). These species have been tamed in Africa for the purpose of making honey. Subspecies are mostly categorized using different morphological traits (Irk et al., 2016). There are 11 honeybee subspecies in Africa and Madagascar (Irk et al., 2016). There are differences in the ecology of honeybees within and between races, which are thought to be the result of adaptive responses to a variety of ecological factors, including climate, patterns of resource supply, and predation pressure (Philosophy, 2002). The bee population in Africa is relatively high, though in some areas its, adaptive preferred forest and bush-savannah habitat is becoming increasingly threatened by deforestation. Given its extensive geographical distribution and its importance to the local and world economy through its products. It can be viewed as extremely successful, adaptive species around. Additionally, there is space for expansion in African apiculture as only a small part of honeybee colonies are managed economically, with many nations still relying on traditional methods for beekeeping (Irk et al., 2016).

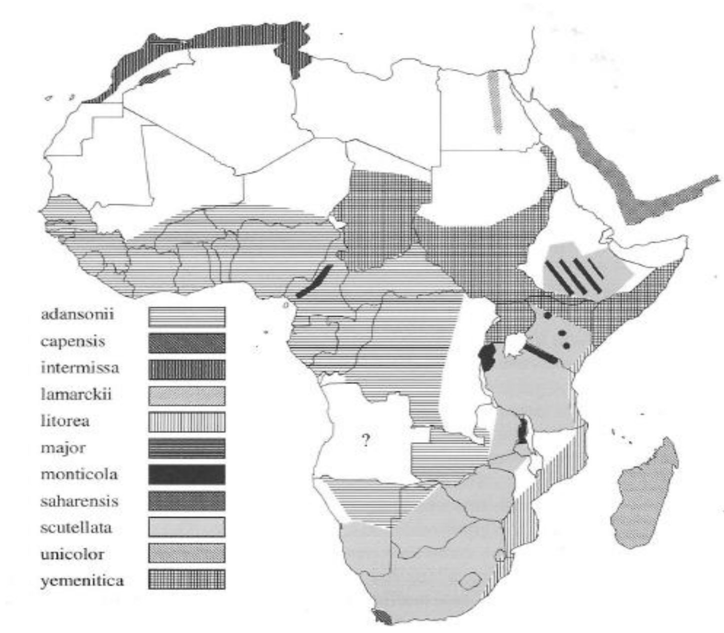


Figure 1: Beekeeping distribution in Africa (Illgner *et al., 1998*)

2.2 Importance of Beekeeping in Sub-Saharan Africa

Beekeeping is growing more and more significant around the world as it offers the chance to pollinate flowering plants, both wild and farmed, increases food yields, produces honey, and ensures the preservation of habitat and biodiversity (Klein et al, 2007; Ricketts et al, 2008; FAO, 2009). Along with formal employment in recognized businesses, the beekeeping industry also generates self-employment for unregistered dealers of bee products (Messages et al., 2004). If extracted and processed properly, honey can be a non-perishable good, allowing for sales of the product far outside of the primary harvest seasons.

One of the primary advantage of bees is pollination, which is necessary for 75% of the world's most valuable crops (Production et al., 2021). More than one-third of the plants on Earth are pollinated by honey bees, thus beekeeping is crucial for plant productivity (Karadas & Birinci, 2018). In terms of pollinating agricultural crops, bees are thought to have a global economic value of between US$235 and US$577 billion annually. Beekeeping provides a means of income. By giving rural residents a steady income, it is also a sustainable and low-cost investment option to reduce poverty (Production et al., 2021). The indigenous African. Hives or colonies, as well as beehive products, are sold by farmers to gain money (Shek Mohammed & Hassen, 2021). Beekeeping, a non-farm activity for rural households, increases household earnings and benefits the national economy both directly and indirectly (Daba et al., 2016). The value of outputs generated, such as honey, bee wax, queen bees, and bee colonies, as well as additional goods, such as pollen, royal jelly, bee venom, and propolis for cosmetics and medicine, are all included in the direct contribution of beekeeping (Daba et al., 2016).

In Ethiopia, the beekeeping industry generates over 2 million jobs (Abro et al., 2022). For example, the Mastercard Foundation has committed millions of dollars in the industry over the past eight years to help about 70 000 young people who are unemployed find work. (Abro et al., 2022). Additionally, beekeeping permits some risk avoidance by producing a dependable, high-quality product that helps rural farmers thrive during economic downturns (Illgner et al., 1998). Moreover, in 2006 South Africa was only 0.11 percent of world production and the 64th-largest producer of honey (1,500 tons) (Report, 2008). Beekeeping enterprise have been known to increase crop yield and environmental conservation in the world (Mwandifura et al., 2021)

Extremely dry weather would have a negative impact on the habitat of bees since it would diminish pollen production and degrade its nutritional quality. Although it is generally accepted that each race of honey bee develops at a different rate, climate change has the potential to affect the development cycle of honey bees. The development of honey bees may be impacted by climate change at a different rate. New competition between species and races, as well as between their parasites and diseases, might result from climate change, which can also define new honey bee distribution regions. Beekeepers will also be required to alter their apiculture practices that not all respondents found effective. It is well known that climatic factors like temperature and precipitation severely restrict the range of Africanized honey bees (Vinícius et al., 2012).

Given the significant contribution, beekeeping makes to ecosystem services and the worrisome fall in honeybee populations (Irk et al., 2016). Bees are crucial pollinators of many native plant species that make up the various habitats, including forest spring ephemerals, montane meadow wildflowers, and others (Mathematics, 2016). In most areas with flowering plants, bees are significant pollinators. Around the world, insects pollinate 80% of flowering plants, with bees contributing to 85% of that pollination. Up to 90% of fruit tree blossoms also depend on bee pollination (Mathematics, 2016).

CHAPTER 3

MATERIALS AND METHODS

3.1 Data Acquisition

International (i.e., Global Biodiversity Information Facility; http://www.gbif.org/) provide new data for SDM tools, and instructions for georeferencing in this procedure (Graham et al., 2009). Occurrence data for beekeeping were directly downloaded from the (GBIF, http://gbif.org)In order to process occurrence data and enhanced data quality, the data were cleaned in Microsoft Excel, yielding a total of 16279 random occurrence points. At a resolution of 2.5 arc sounds of latitude and longitude, the 'getData ()' function from the raster package was used to gather the present and future environmental information, specifically the bioclimatic and altitude from data from the World Climate project (http://worldclim.org. Only bioclimatic predictions adding up to 19 were used as climate data in the investigation. For the estimates of 2050 and 2070, (RCP8.5) and (RCP2.6) were utilized to estimates change.

3.2 Climate Change Models and Environmental Data

The predictions were based on a variety of raster and vector geographic data sets. The variables employed in the species distribution model (Table 3.1) were grouped to remotely sense biotic dependent variable obtained from space borne NDVI statistics.

Table 1: Climatic variables relevant to habitat suitability employed in this study.

Name	Variable	Units
Bio 1	Annual Mean Temperature	^oC
Bio 2	Mean Diurnal Range (Mean of monthly (max temp - min temp))	^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 Quarter	^oC

Bio 11	Mean Temperature of Coldest Quarter	^{o}C
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

3.3 Ecological Niche Modelling

Library packages were installed into R version 4.2.2 and using R Studio version 4.2.2, namely the raster, rgdal, maps, mapdata, dismo, rJava, maptools and jsonlite packages. The bioclimatic variables were downloaded directly into R using the getData () function (Mirzaei et al., 2017). Ecological niche models were constructed using Maxent alogarithm which attempts to identify the greatest mix of environmental reactions that best predicts the existence of species. EN modeling is a method for quantitatively connecting the distribution of one species to the regional variance in bioclimatic variables (Makori et al., 2017). The environmental variables such as bioclimatic conditions, geography, and vegetation that affect the habitats in which various creatures (such as honeybees) flourish are correlated by the EN model (Makori et al., 2017). The model is focused on modeling how the advantageous habitats accessible to a specific species would vary under various climatic change (Baede et al., 2001).

CHAPTER 4
RESULTS

4.1 Present Suitability of Beekeeping in Sub-Saharan Africa

The model for predicting current suitability for beekeeping demonstrated that habits are consistent with the species existing geographic distribution. According to the model there is a significant link between the outcomes of the current suitability distribution and its current distribution is taken into account for the current suitability. According to the current suitability zones for beekeeping in Africa, the highest ranges, which are above 0.6, are primarily found in sub-Saharan Africa in nations like South Africa (Lesotho and Swaziland), and the scale steadily lowers as the map moves further north. On a scale of 0.4, a large number of nations are dispersed; among them are Botswana, Mozambique, Zambia, Ghana, the Ivory Coast, Ethiopia, Kenya, and Uganda. Additionally, it demonstrates that the sub-Saharan region of Africa is one of the continent's best regions for beekeeping. Moreover, it also reveals that African countries concentrated in latitudinal range of -10 stretching northwards up to latitudinal range of 30 ranges below 0.2. Some of the countries in 0.2 range includes Mauritia, Mali, Niger, Chad, Sudan and Algeria to list but a few. In general the current predicted suitability for beekeeping shows that the most suitable areas are under the prevailing climatic patterns is sub-Saharan Africa stretching from longitude range of about 20 to 50 and latitudinal range of about -35 to 0.

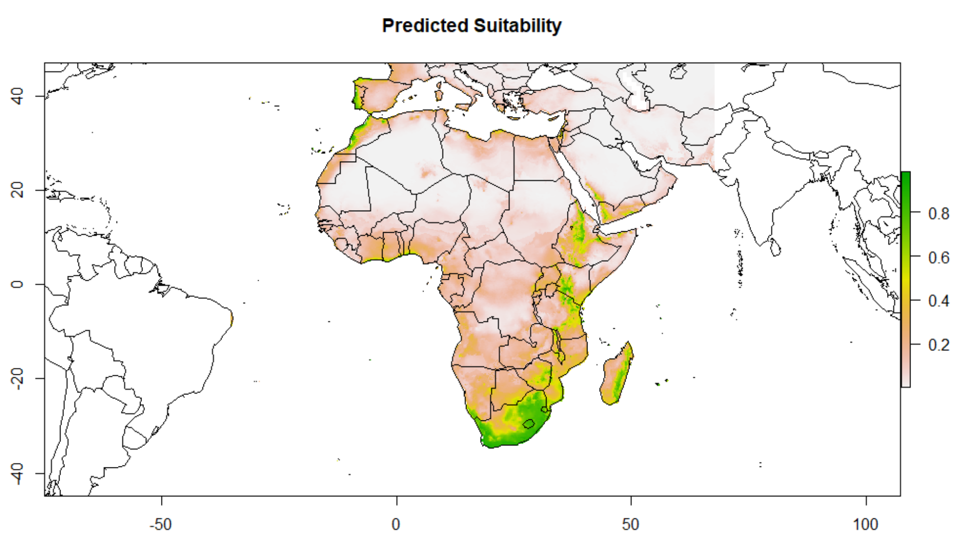


Figure 2: Current predicted suitability of beekeeping in Africa.

4.2 Future Suitability of Beekeeping

There is a significant visible shift in habitat suitability for beekeeping under various climatic conditions and the two RCP models. Under RCP 2.6 for the year 2050 there is a visible shrink of the habitats suitable for beekeeping. For example countries in the sub-Saharan part like Zimbabwe, Ivory, Ghana and Benin downgraded from scale of 0.4 to 0.2. In the northern part some countries continued to reduce comparing from current suitability and predicted suitability for the year 2050 und RCP 2.6 model. This shows there are slim chances of successful beekeeping activities in northern part of Africa.

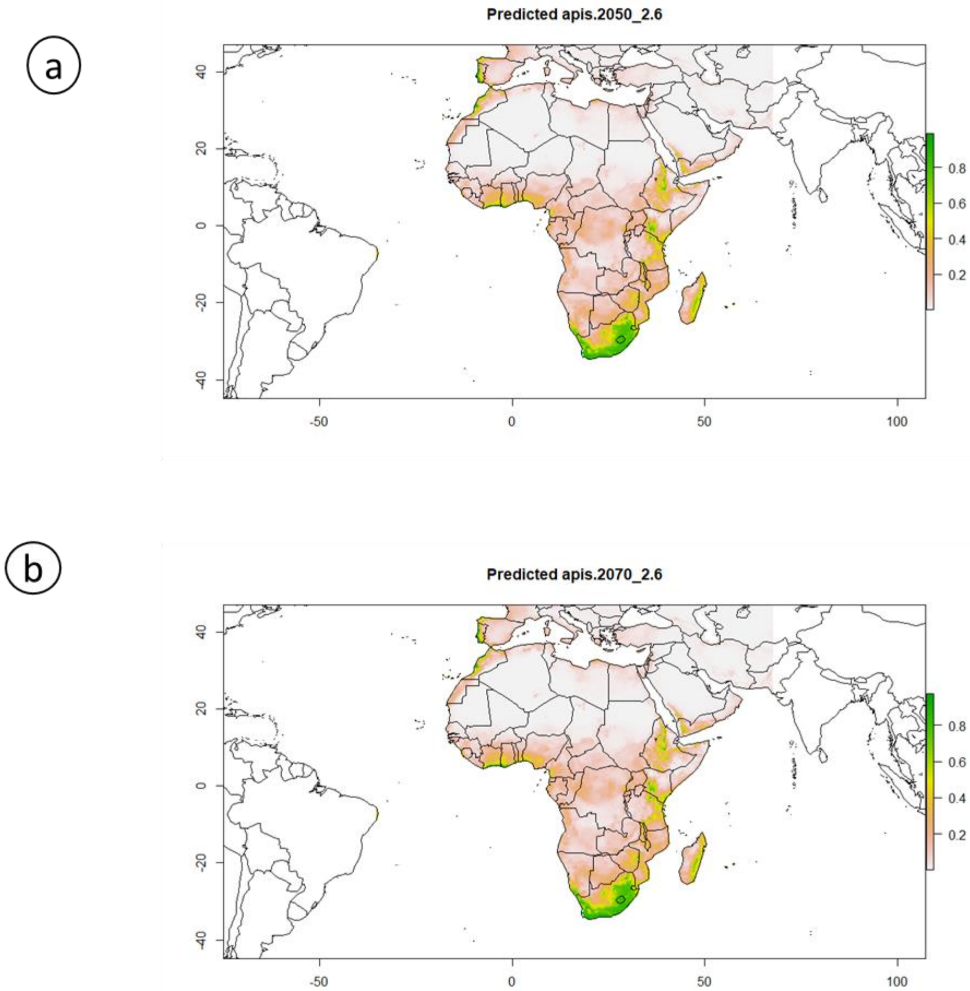


Figure 3: Predicted distribution of beekeeping for RCP2.6 2050(a) and 2070(b)

The findings of this study, in comparison between current predicted distribution and future predicted distribution under RCP model 2.6 for the year 2070 shows that there a continued noticeable decline in species geographical range suitability in the continent as a whole for example in territories like Algeria, Lybia, Sudan, Congo, Cameroon, and Central African Republic. On the other hand, the RCP model also shows that species distribution, abundance, diversity and its geographical range suitability is not significantly influenced by shift in climate change scenarios for both year 2070 in countries like South Africa, Lesotho, Ivory Coast, Namibia, Malawi, Tanzania, Uganda, Ghana, Benin, Nigeria, Morocco, Kenya, Ethiopia, and Mozambique with range ≤0.4. The suitability of beekeeping for both scenarios in countries like Zimbabwe, Botswana Angola, Zambia, Malawi, DRC, Congo, CHAD, Cameroon and Central Africa Republic has remained indistinguishable in comparison with current predicted suitability of beekeeping.

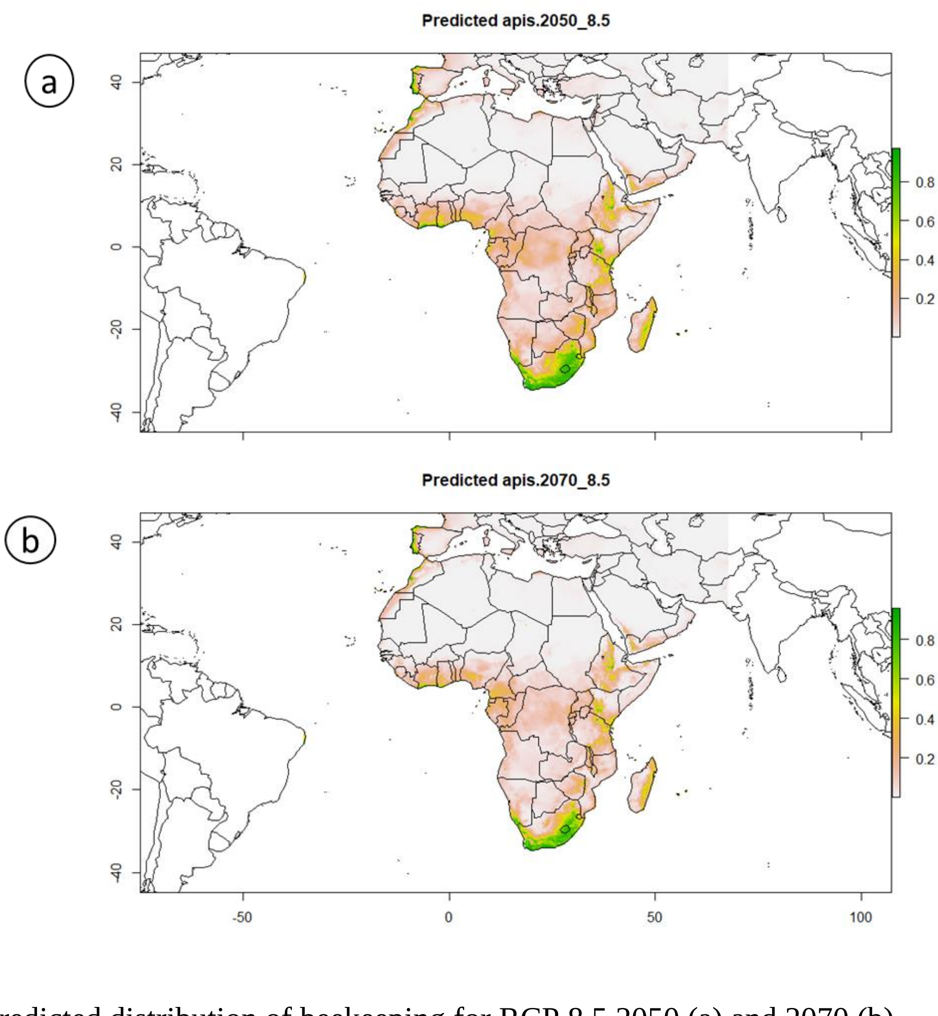
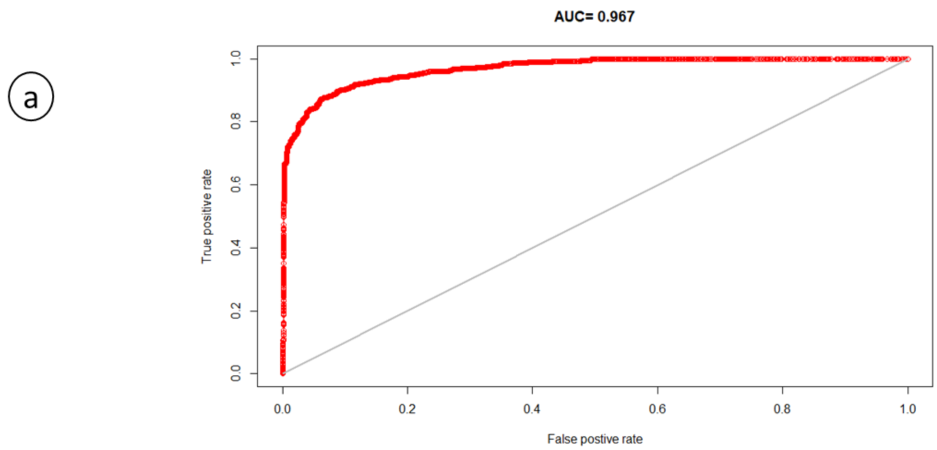


Figure 4: Predicted distribution of beekeeping for RCP 8.5 2050 (a) and 2070 (b)

Current suitability when compared to RCP_8.5 for the year 2050 shows that climate change significantly affect future suitability of beekeeping in sub-Saharan Africa. There is noticeable decline in species distribution density. The results of this study showed a noticeable reduction in the suitability of beekeeping in countries like Niger, Algeria, Mali, Burkina Faso, Mauritius, Democratic Republic of Congo, Somalia and Libya by 2050 with a range of 0.2. On the other hand the model indicates that there is no appreciable change in niche appropriateness for the years 2050 in nations like Zimbabwe, Ivory Coast, Ghana, Nigeria, Guinea, Angola and Mozambique, with range of 0.2 the model predicted that beekeeping will be critically endangered under RCP model 8.5 for the years 2050 in nations like Botswana and Zambia, with arrange that is 0.2.

Current suitability model compared to RCP_8.5 for the year 2070 also shows that the decline in future suitability of beekeeping in Africa is mainly from the countries range of 0.6 to 0.4 on the scale. For example many countries dropped from 0.6 to 0.4 namely Zimbabwe, Mozambique, Tanzania, Kenya, Malawi and Ethiopia, Democratic Republic of Congo, Mauritius and Morocco. The model also indicates that due to the anticipated effects of climate change, there is a significant probability of extinction for the beekeeping activities in Africa.

The predictions of the models demonstrate that results were reliable with an AUC of about 0.967. The findings of this investigation contemplated a strong correlation exists between bioclimatic factors and the predicted distribution of beekeeping in the future. With good modeling results, AUC, one of the efficient assessment factors for maximum entropy modeling, tends to be high.(Hosni et al., 2022). To determine the prediction efficacy of distributional models created from presence-absence species data, the area under the receiver operating characteristic (RO) curve, also known as the AUC, is frequently utilized (Lobo et al., 2008). AUC is frequently employed in distribution modeling literature, even when the primary goal is not discrimination capability. (Lobo et al., 2008).



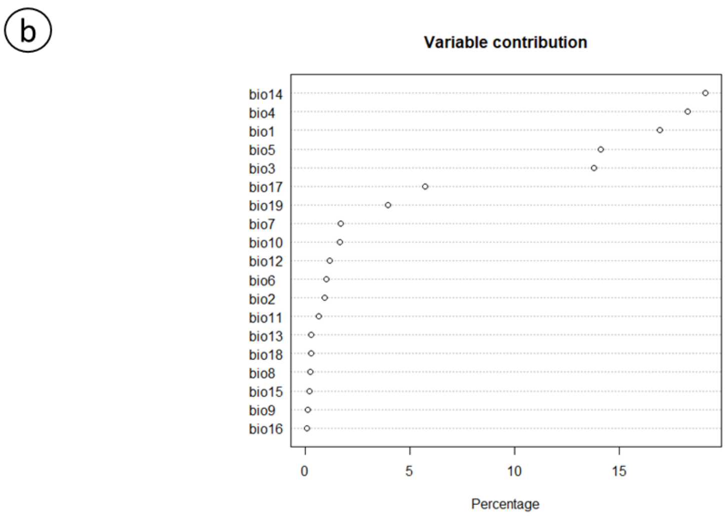


Figure 5: Showing the contribution of AUC (a) and Variable contribution (b).

The results of this study indicate that Precipitation of Driest Month (bio 14) was the most significant variable influencing the predicted future suitability of beekeeping, with an influence of about 19% on the two RCP models used for the years 2050 and 2070. This was followed by Temperature Seasonality (standard deviation *100) (bio 4) with an influence of about 18% and Temperature Annual Range (bio 1) with an influence of about 17%. Precipitation of the coldest quarter (bio 9) with about 4%, Precipitation of the driest quarter (bio 17) with about 6%, and Max Temperature of Warmest Month (bio 5) with about 14% significantly demonstrate change on influence on the models used for this study.

The outcome of this study shows that Precipitation of Driest Month (bio 14) was the most significant variable influencing the predicted future suitability of beekeeping with about 19%

influence on the two RCP models used for both year 2050 and 2070, this was followed by Temperature seasonality (standard deviation *100) (bio 4) with about 18% influence and temperature Annual Range (bio 1) with about 17% influence. Max Temperature of Warmest month (bio 5) had about 14% and Isothermality (bio 3) with about 3%, Precipitation of driest quarter (bio 17) with about 6% influence and Precipitation of coldest quarter (bio 9) with about 4% significantly shows change on influence on the models used for this study.

CHAPTER 5

DISCUSSION

Species distribution models of beekeeping highlighted a rampant deterioration of the species niche, under two distinct climatic models (RCP_2.6 and RCP_8.5) threatening the future suitability of the beekeeping industry in Africa. The primary food supply of bees, flowers, being altered by climate change has an indirect impact on the honeybee life cycle. Therefore, any type of climatic change or honey bee migration from one geographic region to another is going to have observable effects (Conte et al., 2008a). There is a link between the widespread reduction of honeybees and other pollinating insects and climate change (Mathematics, 2016). Climate change is a crucial factor directly causing the loss of honeybee colonies (Mathematics, 2016). Point furhey supported by another school of thought argues that Pollinators will need to be safeguarded to ensure that they continue to perform their pollination role, which is so crucial for the economy and for the ecological balance as a result of climate change (Conte et al., 2008a). Elevated temperatures, which are a result of climate change and affect bee activity, could have a significant impact on their biology, behavior, and distribution (Ali Urooj et al., 2017)

The study also revealed that climate change indirectly affect future suitability of beekeeping in sub-Saharan Africa. Taking into consideration the fact that there the unaccounted effect of climate change on forage. Day duration, the highest daily temperature, and the number of days that are consistently over a particular temperature threshold are all potential influences on bee life cycles. Bees' foraging, or food gathering, is also influenced by the ambient temperature (Lloyd, 2021). Dryer climates will result in less flower nectar production for honeybees to gather. Examples of this include lavender blossoms, which yield no nectar when the weather is too dry, making honeybee harvesting more challenging (Ahmad et al., 2017). From the above school of thoughts it is true that projected future suitability of beekeeping distribution in Africa is highly affected by bio factors mainly under variability of precipitation specifically bio 14, bio 19, and bio 3 and temperature specifically bio 4, bio 1 and bio 5. The study's results also indicates that the variables for temperature, specifically bio 4, bio 1 and bio 5 and the factors for precipitation specifically bio 14, bio 19 and bio 3. Critical bee behavior, food availability, and colony death are correlated with threshold temperature and precipitation indices (van der Schriek et al., 2021)The actual result of the AUC test was 0.967. This suggests that model was excellent at modeling the prospective environment for beekeeping in the future.

CHAPTER 6
CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

Climate change is projected to be a major threat on the suitability of the sub-Saharan Africa habitat for beekeeping. Beekeeping is forecasted to deteriorate under both (RCP_2.6 and 8.5). Some other key findings includes that the continuous deterioration of beekeeping habitat in sub-Saharan Africa is also influenced by bioclimatic variables.

6.2 Recommendations

Predicted suitability areas in this research can assist in assessing conservation means of insect species at national and regional level, hence a continuous assessment and monitoring in this field should be practiced to determine the range size of the insect species for natural resources evaluation especially coming up with inventory list of threatened species. The outcome of this study can be used to figure out suitability areas for regeneration trials. The approach used in this study can also be used to figure out suitability habitats and coming up with conservation mechanism and conservation plans for the insect species with significance importance in the region. Moreover, the output of the study can be referenced in developing insects' inventory lists which can be used for early prediction signs of climate change at a local and global scale

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