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IMPACT OF CLIMATE CHANGE ON THE MIOMBO ECO-REGION OF SUB-SAHARAN AFRICA.

MASAMBA TAFADZWA HELARY

B193313B

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DECLARATION

The undersigned attest that they have reviewed and approved this research project for marking in accordance with the department's standards and regulations.

Student: Masamba Tafadzwa Helary B193313B

Signature ……mth………
Date…31/05/2023…………….

Supervisor Prof L.Jimu

Signature………………………….. Date……………………………

DEDICATION

I did this for my future family.

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I am sincerely grateful and thankful to my supervisor Prof L. Jimu for being helpful with his unwavering support and supervision during my time of study.

I'd also want to thank my friends for their love unit and support during the research. Above all, I am grateful to God Almighty for providing me with wisdom, insight, and revelation during my studies.

ABSTRACT

Climate change has become a global environmental issue altering the distribution and assemblage of species worldwide. The prediction of the distribution of different species using climate change models has become an important tool for guiding biodiversity conservation.. The maximum Entropy (MaxEnt) algorithm in R software was used to model the distribution of the miombo eco-region in sub Saharan Africa. A total of about 4500 occurrence records and 19 bioclimatic variables were used in modelling the species' distribution. Distributions were forecasted to the years 2050 and 2070 under two Representative Concentration Pathways (RCPs), i.e. RCP_8.5 and RCP_2.6. Present projections showed a range decrease of the miombo eco-region and the probability of occurrence outside the area of current occurrence. The future ecological niche models for the miombo eco-region of the 2 climatic scenarios, predicted significant changes in the current suitability. All scenarios showed extensive range decrease, proving that climate change has a major impact on miombo eco-region.

Table of Contents

LIST OF ACRONYMS AND ABBREVIATIONS

AUC	Area Under the Curve
BIO	Bioclimatic variable
BIO-DIVERSITY	Biological Diversity
CO^2	Carbon dioxide
ENM	Ecological Niche Modelling
GBIF	Global Biodiversity Information Facility
IUCN	International Union for Conservation of Nature
KM^2	Square kilometre
MaxEnt	Maximum Entropy
QGIS	Quantum Geographic Information System
RCP	Representative Concentration Pathway
SDMs	Species Distribution Models
%	Percent
°C	Degrees Celsius

CHAPTER 1

INTRODUCTION

1.1 Background to the Study

Miombo eco-region is a large area of woodland and savanna in southern Africa. This covers around 2.7 million square kilometers (Hein 2016). It is distinguished by a varied range of tree species, including *Brachystegia*, *Julbernardia*, and *Isoberlinia* (Suzuki 1969). It is distinguished by a patchwork of open grasslands, wooded grasslands, and woodland savannas dominated by miombo trees (Brachystegia spp.). The miombo eco-region is one of Africa's most biologically diversified with a large number of endemic species (Campbell, Angelsen et al. 2007). Angola, Burundi, the Democratic Republic of the Congo, Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe are all part of the miombo eco-region. It has a tropical climate with two seasons dry from April to October and wet from November to March. The eco-region is located on a plateau at an elevation of 600 to 1,500 meters above sea level (Nikolaishvili and Dvalashvili 2015).

A multitude of concerns are threatening the miombo eco-region's biodiversity. Deforestation is occurring at a very big scale in the miombo eco-region as a result of charcoal manufacture, agricultural development (Beatty 2011). Climate change is affecting the miombo eco-region, it is vulnerable to the effects of climate change which include changes in rainfall patterns as well as a rise in the frequency and severity of droughts and floods (Kumar and Singh 2014). Unsustainable land use practices such as overgrazing, uncontrolled fires and improper agricultural techniques are causing soil erosion and degradation. This reduces the land's productivity and its ability to support biodiversity. Mining activities can have serious environmental consequences, such as deforestation, contamination of water resources, and habitat fragmentation (Eneh 2011).

Climate change is most likely to alter the distribution and composition of plants in the miombo eco-region (Reynard 2021). Some plant species may grow more dominant as temperatures rise and rainfall patterns shift, while others may struggle to survive. This may alter the structure and richness of the region's ecosystems. The Miombo eco-region is prone to wildfires due to increases in the frequency and intensity of temperature (Beedy, Nyamadzawo et al. 2014). This could have significant impacts on the region's vegetation and the wildlife that depend on it. Climate change is altering the distribution of species in the miombo eco-region. As temperatures rise certain species' will not be able to adopt to newly temperature's, they tend to relocate to higher elevations, where temperatures are lower. This is influencing the composition of the region's biodiversity. Disease outbreak is likely to be influenced as a result of climate change in the miombo eco-region. Higher temperatures and shifting rainfall patterns are fostering conditions conducive to the spread of diseases which will affect the species diverse (Vlek and Chitja).

1.2 Problem Statement

To determine the inadequate information on how the climate change will affect the future distribution of miombo tree species in the sub-Saharan Africa.

1.3 Justification of the Study

It is important to know information about climate change, so as to reduce its effects and impacts that it will be caused. The information is important because it will help to increase the population of this tree species thus increasing biodiversity. It will also provide baseline information for conservation planning and efforts. This will boost population of miombo species in existing and future conditions.

1.4 Aim of the Study

The aim of the study is to predict likely impact of climate change on the miombo eco-region of sub-Saharan Africa.

1.5 Objectives of the Study

1. To predict areas that are currently suitable for the miombo eco-region and to compare that with the known distribution.
2. Predict the likely impact of climate change on the natural range of the miombo eco-region.
3. Determine the climatic factors that determine the natural range of the eco-region.

1.6 Research Questions

1. What is the current suitability of the miombo eco-region of sub-Saharan Africa?
2. What are the likely impacts of climate change on the natural range of the miombo?
3. What are the climatic factors that determine the natural range of the eco-region?

CHAPTER 2

LITERATURE REVIEW

2.1 Species ecology

The Miombo eco-region is a huge savannah woodland habitat that stretches over southern Africa, including Angola, Zambia, Malawi, Mozambique, Tanzania, and Zimbabwe. This eco-region is distinguished by a diverse range of tree species that have adapted to various altitudes, temperatures, and soil types (Kambayi 2017). The major vegetation type it spans 3.6 million square kilometers across ten Southern African countries (Cadman, Petersen et al. 2010). Miombo woodland is the largest tropical seasonal woodland and dry forest formation in Africa. It spans an estimated 2.7 million km and is found in areas with nutrient-deficient soils and >700mm mean annual rainfall (Booi 2011). It is generally viewed as the model for the moist-dystrophic savannas of Africa (Frost 1996).

Over eleven nations in sub-Saharan Africa, the miombo eco-region has 3.6 million square kilometres of dominating vegetation (Thiel 2011). The woods connects to the Zambezi River and its tributaries and supports over 65 million people with essential life support systems (Du Plessis and Rowntree 2003). The miombo eco-region is predominantly in Central Africa and belongs to the World Wide Fund for Nature's classification of tropical subtropical grasslands, savannas, and shrub lands (ESARO 2020). It contains a variety of climates, from humid to semi-arid, tropical to subtropical, or even temperate, and includes an eco-region where *Brachystegia* and *Julbernardia* types of trees predominate

These trees typically produce a flush of new leaves just before the start of the wet season with rich gold and red colours masking the underlying chlorophyll, reminiscent of autumn colours in the temperate zone, this is done to reduce water loss during the short period of leaf loss during the dry season. Miombo forests can be categorized as either dry or wet depending on the quantity and distribution of rainfall each year (Jansen, Bagnoli et al. 2008). Dry forests can be found in regions with annual precipitation of less than 1000 mm, primarily in Zimbabwe, central Tanzania, and southern Mozambique, Malawi, and Zambia (Campbell, Angelsen et al. 2007). More than 1000 mm of rain fall each year falls in wet forests, which are primarily found in northern Zambia, eastern Angola, central Malawi, and south-western Tanzania (Frost 1996).

The largest of Africa's Regional Centre's of Endemism, the Zambezian phytochorion, is almost completely synonymous with the tropical African miombo woodland belt. In contrast to the Afromontane forests, the internal community structure of the miombo is relatively homogeneous, but the Zambezian vegetation is particularly rich in plant species, many of which are indigenous to the phytochorion.

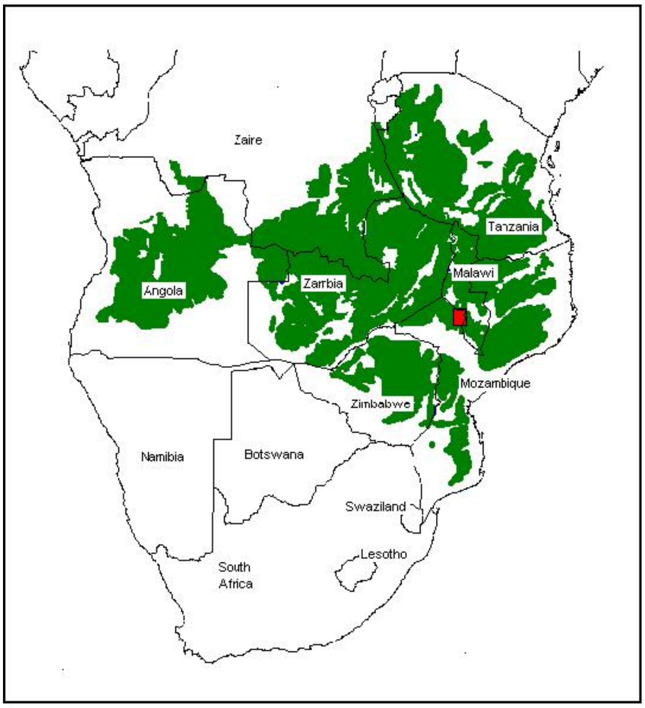


Fig 2.1: Distribution of miombo tree species

2.2 Importance of miombo

Numerous rural residents who depend on the resources offered by the forests depend on the miombo eco-region for their livelihoods. A wide variety of species produce non-timber goods like tourists, fruits, honey, animal feed, and fuel wood (Tewari 2012). Based on the quantity and distribution of rainfall each year, miombo forests are categorized as either dry or wet. Trees they have the ability to bind soil (Bartens, Day et al. 2008). Trapping carbons is also an importance of the miombo eco-region whereby they will reduce the rate of carbons through carbon sequestration. The tree species are also employed in the commercial production of pulp and fuel, as well as to make natural products like medicinal herbs from their leaf oil, lumber suitable for the construction of specific types of boards, and high-quality boards (Saba, Paridah et al. 2015).

2.2.2 Threats to the miombo

The growing population in high need of agricultural land unsustainable use and overharvesting of natural resources in parts of the miombo eco-region, combined with climate change impacts (e.g. drought, fires), leave insufficient time for many trees and associated species to regenerate naturally posing a serious threat to the products and services of the eco-region and to the livelihoods depending on them (Islam 2019).

Compounding the problem and hindering development of the miombo eco-region is, Deforestation and land use change, whereby there will be an increasing agricultural expansion which will allow an increase in land clearance hence this can lead to desertification (Ramankutty, Graumlich et al. 2006)(death of the miombo eco-region). Production of charcoal is another threat whereby, putting a large strain on the miombo eco-region, resulting in deforestation and land use change (Shumba, Carlson et al.). Climate change is another threat, changes in climatic patterns such as extended droughts or an increase in the frequency of extreme weather events can affect the distribution and abundance of tree species in the region (Netherer and Schopf 2010).

Unsustainable use of natural resources is one of the threat to miombo eco-region which might be because of no harsh environmental policies. Unsustainable harvesting practices can degrade the environment (Chidumayo and Gumbo 2010). Mining and extractive operations whereby heavy traffics will be used to clear the land for example open cast mining, causing habitat damage, loss of biodiversity and land degradation (Shamsa and Pervaiza).

2.3 Likely impacts of climate change

There is a change in the climate between 1901 and 2016 the average global temperature climbed by around 1.8°F.1 (Hens 2016). The average global temperature can change by one or two degrees, which might result in potentially hazardous changes to biodiversity. For instance changes in rainfall can cause an increase in floods, droughts, or extreme rainstorms as well as more frequent and severe heat waves.

Shift in temperature and rainfall patterns due to climate change pose some serious impacts on the miombo tree species such as potential loss of tree species , forest species displacement and migration, increase in drought incidence and extreme summer temperatures are linked to an increase in dieback processes such as growth reduction, defoliation, loss of vegetative vigor, and mortality, possible introduction of damaging agents, such as pests and pathogens that can be aided by altered environmental circumstances and a longer vegetative period (Chidumayo 2011).

Decreased relative humidity, and convective winds. An increase in temperature causes evapotranspiration to occur at a rapid rate, which in turn causes water shortages and raises the water deficit. However, it is clear that climate change results in a drop in species richness and a change in species composition, it also results in an increase in species richness (Lesk, Anderson et al. 2022).

2.4 Ecological niche modelling

Ecological niche model also referred to as SDMs is one of the approaches used by ecologists to make climate change predictions. The Ecological niche model rely on estimations on how ecological systems will shift in responses to climate by model how the favourable habitats available to a particular species will shift under different climatic change scenarios. The approach relies on the assumption that the species distribution, abundance, diversity, structures of the communities and functioning of the whole ecosystem is highly motivated by climatic patterns of precipitation, temperature and changes in their seasons. This method is focused on mapping changing climate in terms of a species' fundamental physiological tolerances in order to identify the species' climatic or environmental niche: the whole range of climatic circumstances in which it is likely to occur. Once a species' "climatic space" has been defined, it may be mapped into geographic space using either present climatological data or projections based on future climate change models.

It is important because assess the significance of different climatic factors in determining the species' geographic range. The Maxent Entropy technique was employed to make predictions based on 19 environmental variables. Predictions were made under (RCP 8.5 and RCP 2.6) for year 2050 and 2070. Ecological niche modelling is increasingly used in environmental management to examine environmental change consequences, habitat suitability assessments, and endangered species protection. Environmental niche models are often employed in one of four ways: evaluating the relative appropriateness of a species' habitat, predicting the suitability of a habitat in a geographic region where the species is not known to exist, estimating conservation status over time given a specified environmental change scenario, and lastly predicting a species niche

CHAPTER 3

MATERIALS AND METHODS

3.1 Data acquisition

Occurrence data on the predicted distribution of the miombo species were obtained from the Global Biodiversity Information Facility (GBIF, http://gbif.org). The resolution of 2.5 arc seconds 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 data from the WorldClim project (http://worldclim.org, Hijmans et al. 2005).

3.2 Climate change Models and Environmental data

Table 3.1: 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	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

3.3 Niche modelling

The installation of library packages was done into the R through R studio, namely the raster, rgdal, maps, mapdata, dismo, rJava, maptools and jsonlite packages. The bioclimatic variables that is (bio1 to bio19) (Table 3.1) with high changes of influencing the occurrence of miombo species were downloaded directly into R using the getData () function (McIntosh et al.2022). Ecological niche models were constructed using Maxent alogarithm, which attempts to identify the greatest mix of environmental reactions that best predicts the existence of the species. Bioclimatic predictors made up the entirety of the climate data used in the investigation. The worldclim was also used to produce matched future climate projections for a sizable number of global climate models (GCMs) used in the phase 5 Coupled Model Intercomparison Project (CMIP5). (RCP8.5) and (RCP2.6) were used to estimate change for the projections of 2050 and 2070, before running the model the observed data was then verified to make sure that the species geographic locations were accurate by deleting any species without coordinates. The ground system geographic locations were assigned to generate random points over the vector layer in occurrence regions in order to create a dataset of georeferenced coordinates for each species in the occurrence areas. In order to process occurrence data and enhance data quality the data was then exported to Microsoft Excel and fed into the Maximum Entropy (Maxent) module, producing a total of about 4500 random occurrence points. Maxent is a modular, rJava-based framework for reproducible modeling of species niches and distributions.

CHAPTER 4

RESULTS

4.1 Predicted Current suitability of the miombo eco-region

Miombo species are currently available on the southern part of Africa (Fig. 4.1). In Madagascar species distribution is found everywhere.

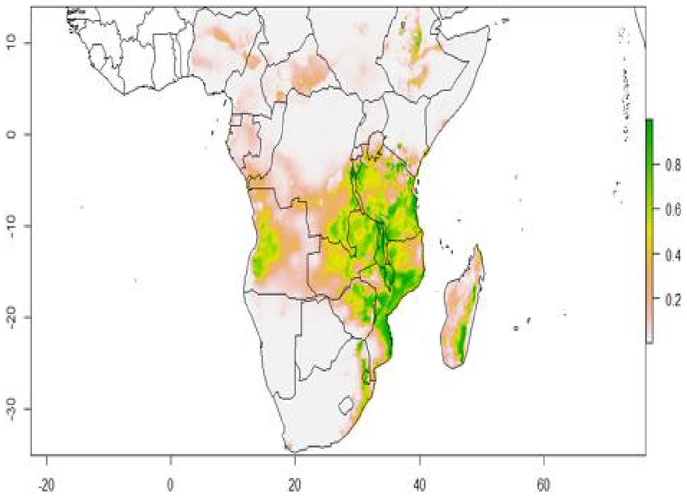


Figure 4.1: Current suitability of the miombo.

4.2 Impact of climate change on the miombo

a

b

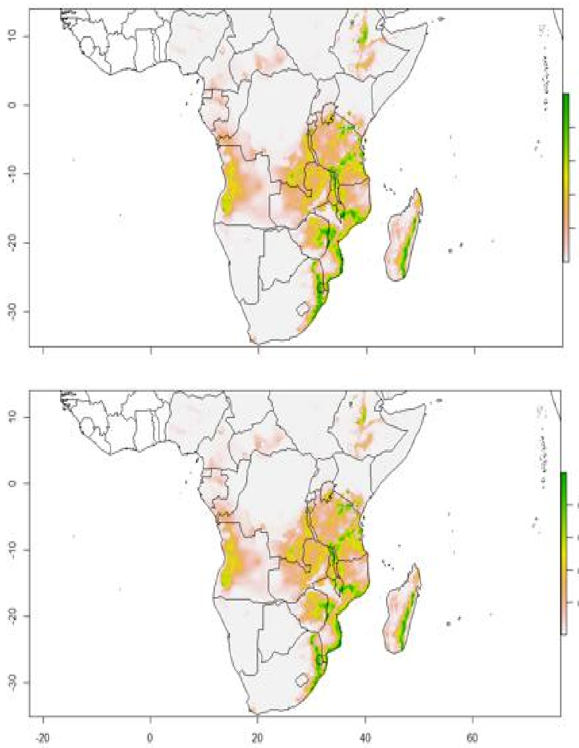


Fig 4.2: Potential distribution of the miombo under the RCP _2.6 climate change model for 2050(a) & 2070(b)

The predicted distribution with projected future distribution, (RCP_2.6 2050) there is a slight decrease in niche suitability in the sub-Saharan Africa. There is a decrease, niche suitability in Angola, Mozambique, Tanzania and Zimbabwe. In Madagascar there is also a decrease in the distribution of species which ranges from 0.6 to 0.8. There is also a slightly decrease on the species distribution in South Africa (Lesotho and Swaziland). Slight decrease of biodiversity is also seen on the middle west of sub-Saharan Africa especially in Angola.

The predicted distribution with projected future distribution, (RCP_2.6 2070) there is a slight increase in decrease in niche suitability in sub-Saharan Africa. Angola, Mozambique, Tanzania and Zimbabwe they also show an increase decrease in niche suitability. Species distribution is decreasing at an increasing rate in the miombo and this is mostly seen in Zambia whereby distribution inclined in decrease. In Madagascar there is also a decrease on the distribution of biodiversity (range, 0.8). Species have increased on decreasing on the distribution in Chad. The miombo eco-region in Ethiopia has showed slight change in the distribution of species.

a

b

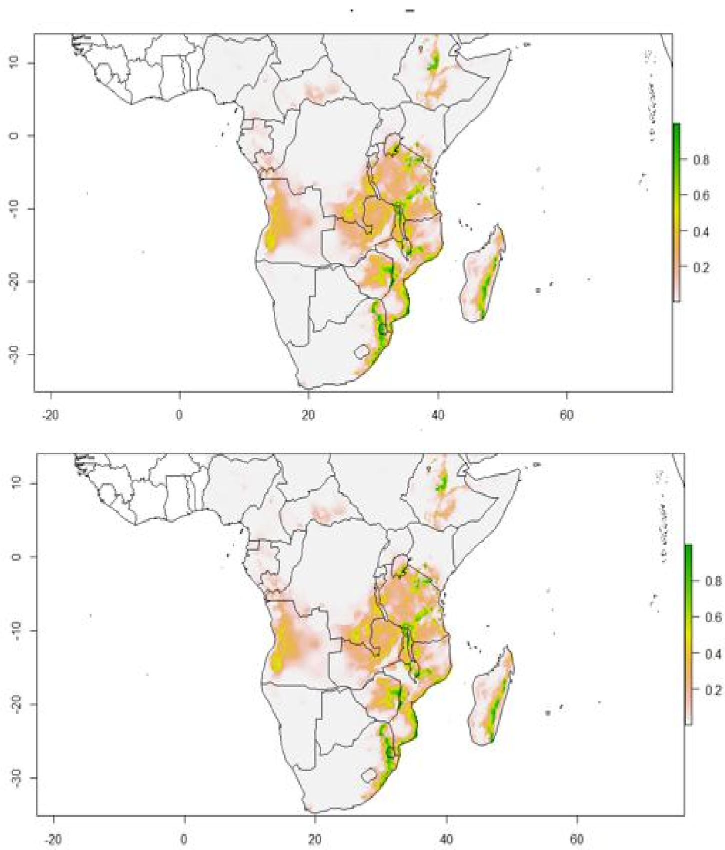


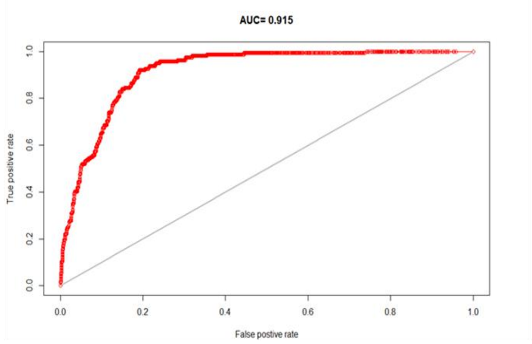
Fig 4.3: Impact of climate change on the miombo under the RCP_8.5 climate change model for 2050(a) & 2070(b)

The predicted distribution with projected future distribution, (RCP_8.5 2050) there is a wide shrink in niche suitability in the sub-Saharan Africa. The species decrease was commonly on the southern part of Africa. Niche suitability in Angola decreased at an increasing rate (0.4 - 0.1). Madagascar is constantly decreasing in species, (range 0). In Zimbabwe range of niche suitability is prone to extinct, and also in Ethiopia miombo species are about to extinct.

The predicted distribution with projected future distribution, (RCP_8.5 2050) there is an inclined-decrease/wider shrink of niche suitability in the sub-Saharan Africa. There is a decrease in the distribution in some nations for example Ethiopia which is prone to extinct. Madagascar have got a slight decrease and there is a significant decline in the number of species (0.8).

The results portrayed a strong correlation between bioclimatic variables and future distribution of miombo species, the results displayed an Area Under the Curve (AUC) value of 0.915 (fig 4.4). The outcome of this study shows that Precipitation of Coldest Quarter (bio 19) was the most variable which influence the predicted future suitability of the miombo distribution with about 18% influence on all RCP model used for this study for both year 2050 and 2070, followed by Annual Precipitation (bio 12) with about 17% influence and Mean Diurnal Range (Mean of monthly (max temp - min temp) (bio 2) with about 16% influence on the models used for this study. Max Temperature of Warmest Month (bio 15) had about 3% and Mean Temperature of Coldest Quarter contribute to about 2%.

a



b

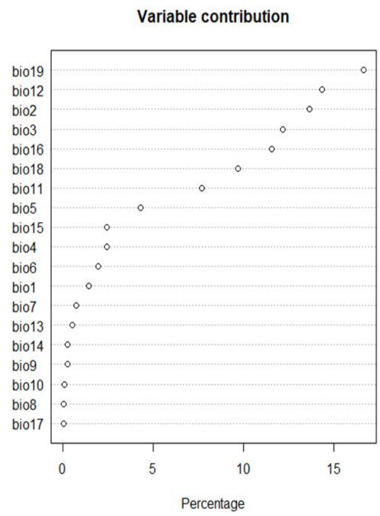


Fig 4.4: AUC(a) and Variable contribution(b).

CHAPTER 5

DISCUSSION

Under two different climatic models (RCP _2.6 and RCP _8.5) for both the present and the future forecast of the species suitability, species distribution of the miombo indicated a rampant deterioration of the species' niche. Continuous rise of pollution trends over the anticipated targets under RCP_8.5 will probably result in the extinction of the species throughout the region (Gandia, Bosch et al. 2023).

The results of this study indicated that under RCP 2.6, the habitat of miombo species in southern Africa will gradually deteriorate as the mean diurnal range and temperature seasonality continue to be the main influencing factors (Durrell 2018). The study findings according to (Kar 2022) they support the RCP 2.6 forecast that threatened species will either increase in number or decrease as carbon dioxide, CH_4, and nitrous oxide emissions are reduced.

Drawing judgment from the comparison of the observed coordinates and predicted suitability, there is a negative correlation between the present suitability result and the future niche suitability. This might be due to the unfavorable environmental conditions for ecological systems. Cameroon and Central Africa Republic show the highest level of species susceptibility to extinction owing to climate change in the comparison between current suitability and expected future suitability for the years 2050 and 2070 under the RCP model.

Swaziland demonstrates that it is not severely impacted by the change in climate scenarios on the basis of a comparison between current expected suitability and future suitability this may be because effective mitigation and adaptation measures have been put in place. The outcome of the study shows change in habitat fragmentation of miombo species under RCP_2.6 for both year 2050 and 2070 this might be due to different changes in temperature and precipitation changes.

Area Under the Curve (AUC) value for test dataset was 1, indicating that the model was brilliant for simulating miombo species future potential habitat (Fig 4.4 b) hence, shows that the findings from this study can relied on. The findings of this study show that the variables to Precipitation of Coldest Quarter (Bio 19) was essential in describing the suitability for miombo species (Fig 4.4a). Temperature and precipitation have influence on range availability and growth for miombo species which cannot survive high temperature and precipitation as indicated by our study.

CHAPTER 6

CONCLUSION

In conclusion, sub-Saharan African miombo eco-region is predicted to be significantly impacted negatively by climate change. These effects can change the structure and distribution of the miombo ecosystems which may have an effect on biodiversity and the ecosystem services offered by miombo eco-region. As a result it is imperative to take action to reduce and adapt to climate change's effects on miombo ecosystems and safeguard these significant ecosystems from future deterioration.

RECOMANDATION

Predicted suitability areas in this study can aid in assessing the conservation means of tree species at the national and regional levels. The approach utilized in this study can also be used to determine suitable habitats and develop conservation mechanisms and plans for the tree species in the region. The results of this study can be utilized to choose appropriate locations for regeneration experimentation as part of conservation efforts. Future study could also enhance our modeling strategy by conducting a country-by-country analysis and jointly modeling or modeling independently real population sizes using real population numbers. This was not possible in this investigation because, from what we could tell, we were unable to gather precise demographic data that was currently spatially constrained.

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