BINDURA UNIVERSITY OF SCIENCE EDUCATION

DEPARTMENT OF NATURAL RESOURCES

Ecological niche modelling of *Colophospermum mopane* in sub Saharan Africa

MONTFORT MANJORO

B1852711

RESEARCH CONCEPT NOTE

FEBRUARY 2023

DECLARATION

The signatories attest that they have reviewed and authorized this research project for submission for marking in accordance with the policies and procedures of the department.

Student: Montfort Manjoro

Signature: M Manjoro Chiyadzwa   Date

Supervisor: Prof L. Jimu

Signature   Date

DEDICATION

This research project is dedicated to my family.

ACKNOWLEDGEMENTS

My supervisor, Prof. L. Jimu, provided invaluable advice and direction throughout the entire project, and I am very grateful for that. I also like to express my gratitude to Mr. Mahommad, T. Kachena, and E. Munondo for their contributions to this study.

I also want to express my gratitude to my family and friends for their unwavering love and assistance during the course of the study. I want to thank God Most High for making this job successful.

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The distribution and assemblage of species are shifting as a result of the worldwide environmental issue of climate change. Climate change model-based species distribution prediction is a crucial tool for guiding biodiversity protection. The goal of this study was to determine how climate change affects *C. mopane* in sub-Saharan Africa. The maximum Entropy (MaxEnt) approach in the R programming language was used to simulate the distribution of *C. mopane* in sub-Saharan Africa. The range of the species was simulated using 1420 occurrence reports and 19 bioclimatic variables. Distributions for the years 2050 and 2070 were anticipated using two Representative Concentration Pathways (RCPs), namely RCP_8.5 and RCP_2.6. The range of *C. mopane* was expected to grow, and there was a higher than 0.2 chance that it will be found outside of its current range. Future ecological niche models for *C. mopane* under the two climatic scenarios showed significant changes in the current suitability. All potential possibilities showed appreciable range expansion, indicating that climate change significantly affects the survival of *C. mopane* and ultimately results in more biodiversity. In contrast to many other species, the range of *C. mopane* is one of the few examples of a species that, based on our findings, is projected to persist under challenging climatic conditions, especially under the extreme scenario (RCP_8.5). In order to determine the size of *C. mopane's* range, further field research is required. The study's estimated suitability zones can be used to evaluate the regional conservation status of mopane species. One recommendation for the preservation of the species is in-situ conservation.

Contents

LIST OF ACCRONYMS

AUC	Area Under the Curve
BIO	Bioclimatic variable
BIODIVERSITY	Biological Diversity
CO^2	Carbon Dioxide
CH_4	Methane
CEPF	Critical Ecosystem Partinership Fund
SA	South Africa
ENFA	Ecological Niche-Factor Analysis
FAO	Food and Agriculture Organisation
GBIF	Global Biodiversity Information Facility
C	*Colophospermum*
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
KM^2	Square Kilometre
MaxEnt	Maximum Entropy
QGIS	Quantum Geographic Information System
RCP	Representative Concentration Pathways
SSA	Sub-Saharien Africa
SDMs	Species Distribution Models
UNFCCC	United Nations Framework Convention on Climate Change

WMO	World Meteorological Organisation
%	Percent
℃	Degrees Celsius

CHAPTER 1

INTRODUCTION

1.1 Background to the study

Colophospermum mopane is a tree species that dominates large parts of savannas in southern Africa, occupying over 4 million square kilometres (Scholes et al, 2002). It plays an important role in the region's ecology, economy, and culture. Ecological niche modelling is a useful tool used to understand the current and potential distribution of *C. mopane* across various spatial and temporal scales (Stevens, 2014).

Several studies have used ecological niche modelling to study the distribution of *C. mopane* in sub-Saharan Africa Graham (2004) used maximum entropy modelling (Max-Ent) to model the distribution of *C. mopane* in South Africa based on herbarium records and found that precipitation, temperature and soil variables were the most important predictors of its distribution. A more recent study by Ramoelo (2015) modelled the potential distribution of *C. mopane* across southern Africa under future climate change scenarios using Max-Ent. They found that the area suitable for *C. mopane* may expand by 32-46% by 2080, primarily expanding into areas in Mozambique, Zambia, and Malawi.

Mishra et al, (2016) took an interdisciplinary approach by combining ecological niche models with ethnobotanical models to map the distribution of *C. mopane.* They found that climatic variables as well as human factors like wood use, livestock presence, and protection status were important in shaping the realized niche of *C. mopane* (Cumming, 2014). Their results highlight the importance of anthropogenic factors in shaping plant distributions in addition to bioclimatic factors.

These studies show the utility of ecological niche modelling for understanding the distribution of the ecologically and economically important *C. mopane* tree in sub-Saharan Africa. Niche models can provide useful insights into how the distribution of this species may change in the future in response to climate change, land-use change, and other human impacts (Anderson, 2013:49).

1.2 Problem statement

Climate change is project to increase the frequency of droughts and temperatures throughout southern Africa which is habitat to *C. mopane*. This is likely to affect several plant species yet very little is known on how exactly forest ecosystems will be affected. Of particular note is missing information on how mopane forests in drier parts of southern Africa will be affected by the increasing temperatures and droughts.

1.3Significance of the study

1.3.1 *C. mopane* is an ecologically important species that dominates large parts of savannas in southern Africa. Understanding its distribution and the factors that drive its distribution can provide insights into the functioning of savanna ecosystems (Mishra et al., 2002). Niche models can identify areas that are climatically suitable for *C. mopane* but where it is currently absent, which could indicate locations where its propagation or reintroduction may be ecologically viable (Skidmore, 2011).

1.3.2 The distribution of *C. mopane* is likely to change in the coming decades in response to climate change, land-use change, and other anthropogenic impacts. Ecological niche models can predict how the distribution may change under future conditions (Ramoelo et al, 2015), which can help in long-term conservation planning. Some areas may become more suitable, while others may become less suitable. These models can identify locations where the species may expand into or retreat from.

1.3.3 *C. mopane* has a complex distribution shaped by both environmental factors as well as human activities like wood harvesting, livestock grazing, and fire management (Mishra et al., 2016). Niche models that incorporate both bioclimatic as well as anthropogenic variables can provide a more complete understanding of what drives the realized distribution of the species. This can yield insights into how human activities interact with and modify the effects of climatic factors.

1.3.4 *C. mopane* is distributed across several countries in southern Africa, so an understanding of its distribution at the regional level is important for cross-border conservation and management of this ecologically and economically vital species (Mishra et al, 2002). Niche models calibrated using regional datasets can map the distribution and future projections at this broad spatial scale.

1.3.5 *C. mopane* has economic and cultural significance as its wood is used for construction, fuelwood, and traditional medicine (Shackleston et al, 2002). Mapping its current and potential distribution can help in managing this resource sustainably and planning for the societal demands for its products (Ramoelo et al, 2015).

1.4 Aim

To ascertain the expected effects of droughts and rising temperatures on the distribution of *C. mopane* in southern Africa, the species' native range.

1.5Study objectives

The objectives of the study are to:

1.Define the southern African habitat range that is currently suited for *C. mopane.*

2.The distributional range of *C. mopane*, and the potential effects of climate change.

3. To determine the climatic elements that affect *C. mopane's* habitat appropriateness.

CHAPTER 2

LITERATURE REVIEW

2.1Climate Change and its impact on forest ecosystems

Climate change is the long-term alteration of temperature and weather patterns. It is a result of global warming which is largely as a result of the burning of fossil fuels like coal, oil, and gas (Wuebbles et al, 2001).Climate change is one of the most significant environmental challenges facing the world today (LITHUANIA). It has a profound impact on the global ecosystem, including forests. Forest ecosystems are particularly vulnerable to climate change, as they are dependent on specific temperature and precipitation regimes. One way to assess the impact of climate change on forest ecosystems is through ecological niche modelling (Estrada-Contreras, et al, 2015).

Colophospermum mopane is a tree species that is widely distributed throughout Sub-Saharan Africa (Howard 2014). It is an important component of savanna ecosystems and plays a significant role in the livelihoods of local communities. However, the distribution and abundance of *C. mopane* are likely to be affected by climate change (Ngarega,et al 2021). ENM can be used to predict how the distribution of *C. mopane* may change under future climate scenarios.

Several studies have explored the potential impact of climate change on *C. mopane* using ENM. For example, another study used ENM to predict the potential distribution of *C. mopane* under current and future climate scenarios (Masocha, et al 2021).

ENM was used to forecast how climate change may affect the distribution of *C. mopane* in sub Saharan Africa in a different study (Mwabvu et al, 2020). According to the study, *C. mopane's* distribution is probably going to move up into the mountains as a result of rising temperatures and less rain (Moreau 1963). Given that *C. mopane* is a crucial part of Zimbabwe's savanna ecosystems, this could have a big impact on them. The repercussions of climate change include severe droughts, water shortages, damaging fires, rising sea levels, flooding, melting polar ice, catastrophic storms and a reduction in biodiversity (Tsakiris and Loucks 2023).

In conclusion, using ENM to forecast how climate change will affect forest ecosystems, including those dominated by *C. mopane*, might offer important insights into the possible repercussions of climate change for biodiversity and ecosystem functioning. However, it's crucial to remember that ENM is a predictive tool and that, in order to guarantee the precision of the predictions, it should be used in conjunction with empirical data.(Ben-Akiva et al, 2001).

2.1.1Botany and Ecology of *C mopane*

Colophospermum mopane thrives in hot, arid, low-lying environments (200-1-150m above sea level) of southern Africa (Figure 1). It can be found growing in shallow, poorly drained alkaline soils with high lime content (Bağdatlı et al, 2021). Additionally, it flourishes in material that rivers have deposited known as alluvial soil. While the trees tend to range in height from 4 to 18 meters in South Africa and the surrounding regions of Botswana and Zimbabwe, they can also grow taller and form woodlands in the north, where these towering forests are known as cathedral mopanes.

Ecological niche modelling (ENM) is a tool used by ecologists to predict the distribution of species based on environmental factors such as temperature, rainfall and soil type (Parra et al, 2004). A study that utilized a maximum entropy model to forecast the distribution of the species also employed ENM to model the possible distribution of *C. mopane* in sub-Saharan Africa (Sanchez et al, 2010). Similar methods were applied in a different study by Coetsee and Witkowski (2007) to model the probable distribution of *C. mopane* in the South African Kruger National Park. The study discovered that the species could endure a wide variety of soil types and temperatures and was most prevalent in regions with significant rainfall and deep soils.

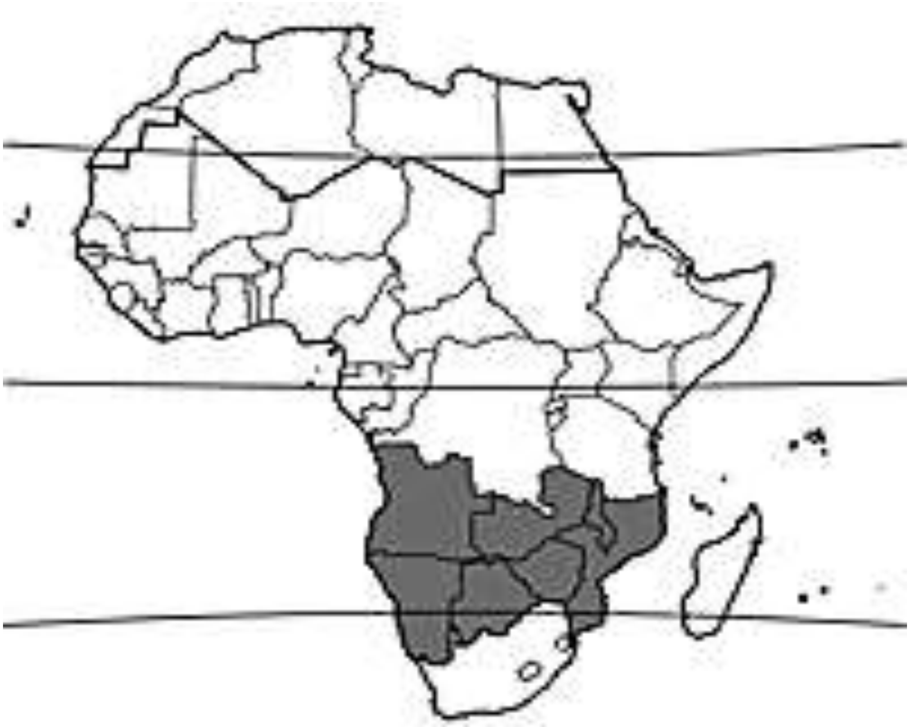


Figure 1:*C.mopane* distribution in sub Saharan Africa

2.1.2: *C. mopane's* range in sub-Saharan Africa

Southern Malawi, southern Mozambique, northern South Africa, northern Botswana, southern Zimbabwe and southern Zambia are all places where *C. mopane* can be found. In hot, low-lying areas of southern tropical Africa, it is prevalent over vast areas and is typically found at altitudes between 200 and 1200 m (Mitchell 2002). While suitable habitat regions dramatically shrink in the eastern half of southern Africa, the geographic range of *C. mopane* is anticipated to grow along the boarders of Zambia and Zimbabwe in the future, notably in the miombo plains (Timberlake et al, 2011). Six to nine trees at each site had their plant water potentials at dawn and noon analyzed.

The chemical changes brought on by the drought have an effect on the soil's qualities as well as the Mopani woods (Mataboge, et al 2016). According to a study conducted on the semi-arid Mopani Savanna veld to examine the effects of the drought that occurred from 1981 to 1993, Mopani trees were not damaged in comparison to other trees because they could endure protracted drought conditions. According to O' Conor's (1999), the majority of the litters from fading forests were from mopane trees, which persisted, while other types of shrubs were shown to be dying off. The difficulty brought on by climate change is the need to protect Mopani trees so that harvesting may continue and so that mopani worms can be made available to the most vulnerable disadvantaged people (Khwashaba 2018).

2.2Importance of predicting the impact of climate change on forest ecosystems

Particularly in sub-Saharan Africa, where the consequences of climate change are anticipated to be severe, the ecosystems of forests are significantly impacted by climate change (Mitchell 2013).The possible effects of climate change on the c*olophospermum* mopane spread in southern Africa.By trapping carbon dioxide from the atmosphere, forest ecosystems help to regulate the planet's climate and are essential to keeping the ecosystem on earth in balance. Therefore, for efficient forest management and conservation, it is essential to estimate the effects of climate change on forest ecosystems, including the ecological niche modelling of tree species like *C.mopane* (Kapuka et al, 2022).

For tree species that are vulnerable to changes in temperature and precipitation patterns, ecological niche modelling is a useful technique for anticipating the effects of climate change on forest ecosystems (Chalghaf et al, 2018). Mopane, also known as *Colophospermum* mopane, is a common tree species that predominates in many Southern African savannas. It is a crucial part of the ecosystem since it supports grazing and browsing animals as well as local communities' needs for food, medicine, and wood.The distribution of mopane is predicted to be greatly impacted by climate change, as it is extremely sensitive to changes in the temperature and moisture regimes (Magadza 1994).

Several studies have employed ecological niche modelling to predict the expansion of mopane in sub-Saharan Africa under various climate change scenarios (Jinga et al, 2020). An investigation by Moe et al,(2014) predicted the future distribution of mopane in Zimbabwe using a combination of climate and land-use change scenarios. According to the study, changes in temperature and rainfall patterns are projected to result in a considerable reduction in mopane's distribution by the year 2050. Ecological niche modelling was employed in a different study by Ramarolahy et al, (2021) to forecast how climate change may affect the distribution of mopane in Madagascar. The study discovered that due to changes in temperature and precipitation patterns, the distribution of mopane is likely to move to higher elevations (Byrne).

The spatial patterns of diversity and species distribution are gradually changing due to global climate change. Yet, little is known about how local climate affects a species' choice for one type of habitat over another in sub Saharan Africa (García Molinos et al, 2016). Therefore, it will be crucial to forecast species distribution patterns and identify environmental factors that promote species range expansion in order to establish management techniques for biodiversity protection (Franklin 2010).

CHAPTER 3

MATERIALS AND METHODS

3.1Description of the Study Area

The Kalahari Basin in Botswana is generally level or slightly raised.Under the Zimbabwean escarpment, the Mopane veld in Zimbabwe extends north-eastward into the Limpopo River Valley (Pienaar 2015).The slopes of the Zimbabwean escarpment farther downstream from Lake Kariba are covered in mopane trees (Du Plessis 2001).

The Zambezi Valley's terrain varies from level (especially near the valley bottom) to slightly elevated ground to an undulating landscape distinguished by the alternating dominance of Mopane veld and Miombo (Siebert 2012).The landscape of the Kalahari sands is largely level.These areas typically receive between 250 and 300 millimeters of rainfall each year.The approximate mean temperature ranges for the *C. mopane* habitat are listed in Table

Table 1:Climatic conditions and altitudinal ranges in the natural range of *C.mopane*

Country	Mean Temperature Range (˚C)	Mean Annual Rainfall (mm)	Altitudinal Range (m)
Zimbabwe	16-30	500-700	400-950
Zambia	14-30	700-1000	400-800
South Africa	15-31	250-400	400-700
Angola	16-25	100-400	100-400
Botswana	13-30	400-600	800-900
Mozambique	20-29	400-700	200-500
Namibia	12-31	100-550	150-1000
Malawi	19-28	700-800	450-500

3.2Acquisation of data

Direct downloads of *C. mopane's* occurrence information were made from the Global Biodiversity Information Facility (GBIF). Through the 'QGIS Georeferenced GDAL' plug-in, QGIS Version 2.6 was used to digitize the raster data obtained from the GBIF and create the vector shape file with captured occurrence areas for *C. mopane*.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 1754 random occurrence points. Maxent is a modular, rJava-based framework for reproducible modelling of species niches and distributions.

The main environmental factors affecting the distribution of *C. mopane* in sub-Saharan Africa were identified using bioclimatic data (Dawson et al, 2019).In our analysis, the 2050 and 2070 carbon dioxide concentrations predicted using the lowest and highest emission representative concentration scenarios (RCP_2.6 and RCP_8.5) were employed. We downloaded current and upcoming bioclimatic data from WorldClim with a 2.5 arc-minute resolution (Table 2). Using total radioactive forcing values of 2.6, 4.5, 6 and 8.5 watt/m2, the Intergovernmental Panel on Climate Change (IPCC) created four representative concentration trajectories (RCPs) (Worku, et al).

The number of emissions will rise in the twenty-first century. An overestimation of predicted coal production served as the foundation for the worst-case climate change scenario model RCP_8.5. We used the most severe climate change scenario (RCP_8.5), which predicts that greenhouse gas emissions will increase until the year 2100, along with RCP_2.6, which is a "very stringent" approach and suggests that CO2 emissions will decline. If current trends are simply maintained, RCP 8.5 is a credible forecast of where we will be in the future; it closely matches historical emissions to within 1%. RCP_2.6 calls for CO2 emissions to begin declining by 2020 and to reach near zero by 2100 (IPCC, 2007).

Table 2:Bioclimatic variables and code description

Bioclimatic Variable	Code Description
BIO1	Annual Mean Temperarture
BIO2	Mean Diurnal Range (Mean of monthly max temp-min temp)

BIO3	Isothermality (BIO2/BIO7) (×100)
BIO4	Temperature Seasonality
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperarture of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality(Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

3.4 Ecological niche modelling

The raster, rgdal, maps, mapdata, dismo, rJava, maptools, and jsonlite library packages were installed into the R studio. Using the getData () function, the bioclimatic variables (bio1, bio2, bio3, bio4, bio5,bi06, bio7, bio8, bio9, bio10, bio11, bio 12, bio13, bio14, bio15, bio16, 21,bio18,bio19) with high changes of influencing the occurrence of *C.mopane* species were downloaded into R. The Maxent alogarithm, which seeks to determine the biggest combination of environmental reactions that best predicts the existence of the species, was used to build ecological niche models (Slater and Michael 2012).

CHAPTER 4

RESULTS

4.1 Current suitability of *C. mopane*

Colophospermum mopane is currently adapted to large areas of Southern and Eastern Africa. Ecological niche modelling research has identified the ideal environmental conditions for *C. mopane* suitability, which include the average annual temperature between 18 and 24 °C,seasonal rainfall ranging from 400 to 800 millimeters, primarily in the scorching summer and also for alkaline soils, pH values between 7 and 9.

These characteristics suggest that *C. mopane* now lives in the following regions for long stretches, thrives in the warm, alkaline soils of the Kalahari region in northern Botswana where it has considerable control over the vegetation.It also has a sizable, suitable habitat in the northern miombo woods of Zimbabwe and Zambia, which are characterized by their acidic soils and hot, dry summers.Mopane forests are prevalent in parts of the provinces of Limpopo and Mpumalanga in South Africa, as well as in northern Mozambique.Although less widespread, there are isolated areas of suitable habitat in southeast Angola.

The aforementioned locations have substantial contiguous mopane populations because of the typically favourable environmental conditions.Climate change puts the appropriateness of the future in jeopardy. Studies suggest that the mopane habitat may change southward when temperatures increase past what is thought to be the species' threshold. This could lead to population declines and range constriction in the more northern regions of the current distribution.

C.mopane thrives in the current environmental circumstances in some parts of Southern and Eastern Africa, where it can grow to form vast woods. In the future, however, climate change effects could make the range less suitable, especially in its northern most portion.

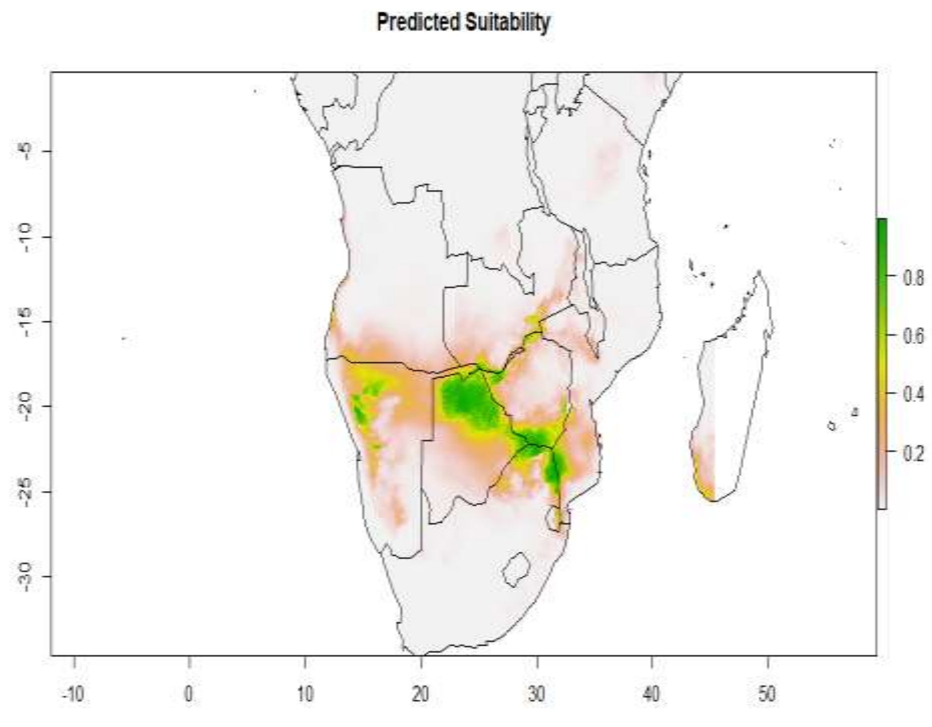


Figure 2: Predicted suitability of *C. mopane*

4.2 Future distribution of *C. mopane* in relation to climate change

Colophospermum mopane is projected to be highly impacted by climate change due to its unique biological niche needs. Studies anticipate that altering rainfall patterns and rising temperatures will lead to:

4.2.1 Range contractions

According to modelling studies, the mopane's range will move south if temperatures increase above the species' threshold of 18–24°C. The areas of the mopane's current range that are furthest north are predicted to be most impacted by this.

4.2.2 Population declines

If suitable habitat contracts as a result of range contraction, mopane populations are projected to decline dramatically. This may have the greatest impact on mopane woodlands in northern Botswana, Zimbabwe, Zambia, and Mozambique.

4.2.3 Changes in seasonal rainfall patterns

Changes in seasonal rainfall patterns may have an impact on the establishment, regeneration rates, and survival of mopane seedlings. This may eventually cause a fall in mopane populations, particularly in drier regions.

4.2.4 Shifts to higher elevations

In regions where mopane survives, the species' distribution may change to higher elevations where it is cooler. Other plant species experiencing a warming climate have shown signs of this.

4.2.5 Changes in the composition of the woodland

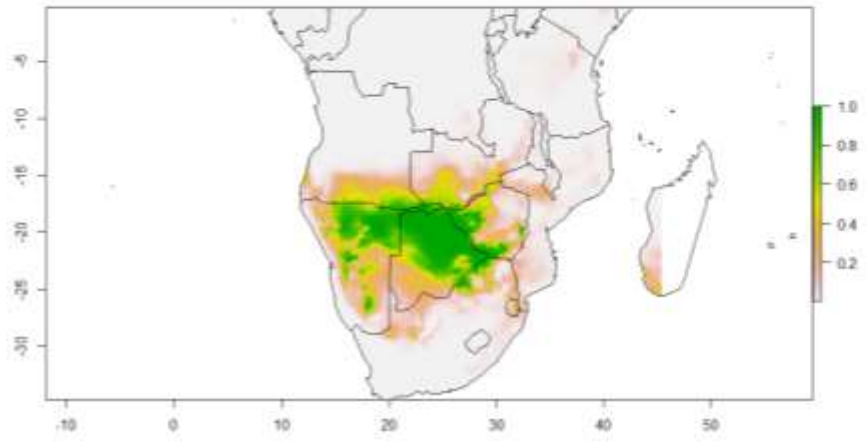
As populations of mopane decline in some regions of their range, they may be replaced by other plant species that are better suited to warmer weather.mopane-rich woodlands may undergo changes as a result.

4.2.6 Species' limited climatic tolerance

Colophospermum mopane is seriously threatened by climate change. Mopane woodlands, which support a diverse range of life forms and offer ecological services, may require conservation measures to prevent negative effects and assure their long-term survival.

RCP_2.6 discovers a decrease in the suitability of niches in countries like Zambia, Zimbabwe, Angola, and South Africa for the years 2050 and 2070 when comparing the current expected distribution with the projected future distribution.The ecological niche of *C. mopane* shifted westward in both RCP_2.6 2050 and RCP_2.6 2070. Based on current species appropriateness, *C mopane* continues to be equally suitable for both scenarios in the northern parts of the region.

According to RCP_2.6 (2050) and 2070, while it was previously unsuitable, the suitability region will move toward Namibia (Angola currently has a habitat suitability range below 0.2; in both 2050 and 2070, it will have a habitat suitability range above 0.2).



(a)

(b)

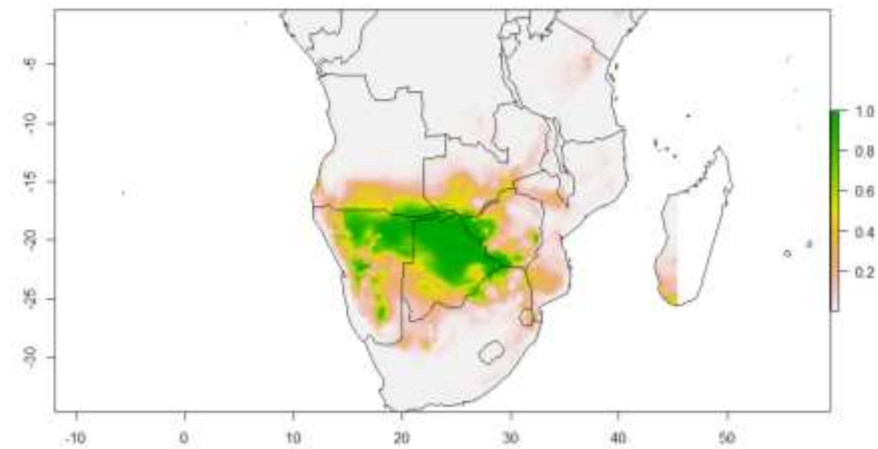
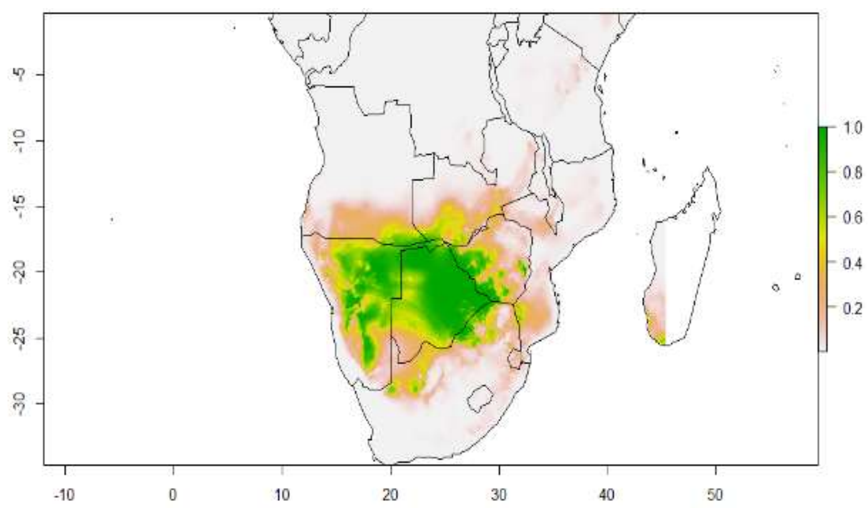


Figure 3: Predicted distribution of *C.mopane* for RCP 2,6 for 2050(a)&2070(b)

(a)



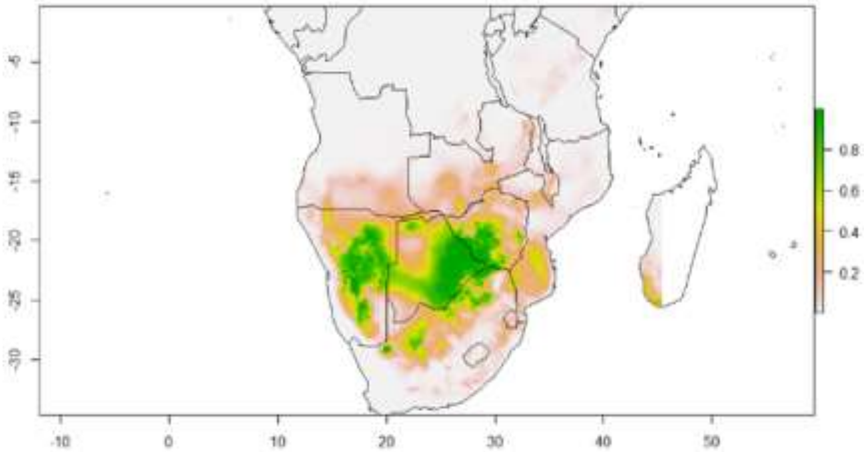
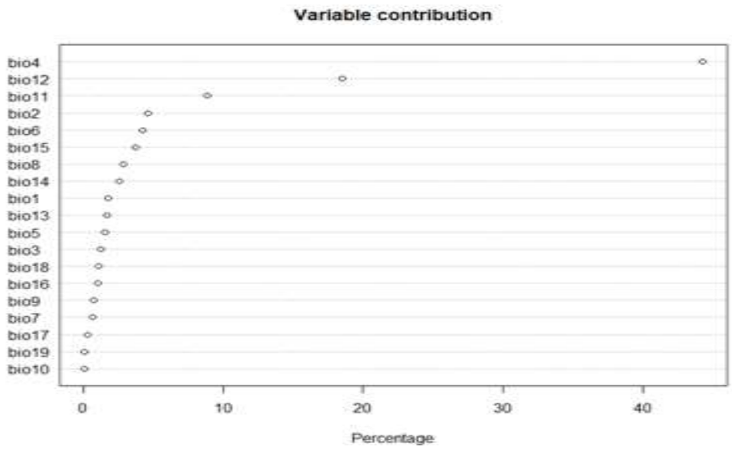
(b) 

Figure 4:Potential distribution of *C.mopane* for RCP 8.5(2050) (a)&(2070)(b)

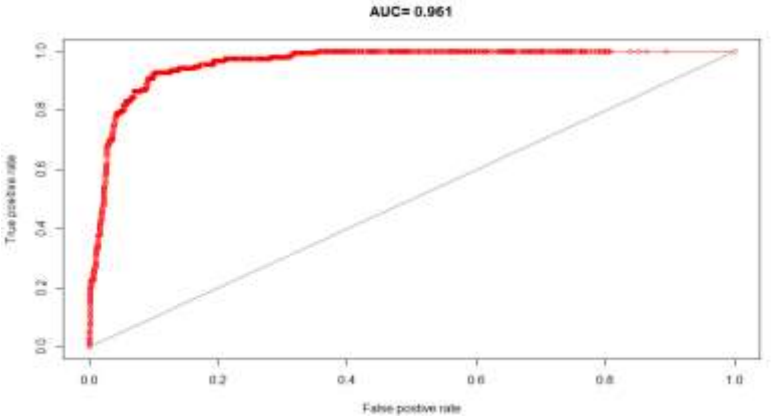
RCP_8.5 was found to have a significantly higher expansion in the *C mopane*-suitable region between the years 2050 and 2070, with the species occupying a larger range in the latter year than the former. The suitability zones extended from southern Africa all the way to West Africa, completely enclosing some formerly uninhabited areas. The two models showed that by 2050, mopane's appropriateness for Angola would have decreased from 1.0 to 0.5, and by 2070, it would have decreased even more, to less than 0.3. The models showed that by 2050, the species' suitable habitat would cover a significant portion of South Africa, Zimbabwe, and Namibia, and by 2070, the entire country of Namibia would become the species' most suitable habitat (suitability range of 1.0). The results show that by 2070, the species' adaptability will rapidly shift northward.

Our findings demonstrated a statistically significant correlation between bioclimatic parameters and the anticipated distribution of *C. mopane*, with an Area Under the Curve (AUC) value of 0.941 (fig. 5a & b).

Our four scenarios (RCP_2.6 2050 & 2070 and RCP_8.5 2050 & 2070) were shown to be most affected by annual precipitation (bio 12), which had a 38% influence, and quarterly precipitation (bio 18), which had an 18% influence. 12% and 10%, respectively, were the indicators for the coldest quarter's average temperature (Bio 11) and the seasonality of precipitation (Bio 15).The results of the models were affected by mean diurnal range (bio 2), which contributed 8% to the results. In terms of *C.mopane's* potential usefulness, isothermality (bio 3) contributed 5%.



(a)



(b)

Figure 5**:**Demonstrating percentage contribution and level of confidence in the bioclimatic factors (a&b)

CHAPTER 5

DISCUSSION

C. mopane ecological niche modelling has shown that the species' niche will expand and contract in the present and the future for the two climate change scenarios (RCP_2.6 & RCP_8.5). The study's conclusions indicate that not all species are anticipated to be adversely affected by climate change if the current trends in pollution and climate change (RCP 8.5) persist. However, the actual prevalence and survival of *C. mopane* could be impacted by the local environment, adjacent anthropogenic situations, the availability of trees, and climatic elements including temperature and precipitation (Mudereri, 2009).

The analysis's findings demonstrated that the minimal temperatures and low precipitation that are currently considered to be limiting factors will not alter under RCP_2.6, resulting in a minor habitat expansion for *C. mopane* in the area.The model based on available occurrence points demonstrated a positive correlation between the findings of current suitability and the future suitability of *C. mopane,* and as a result, the temperature is expected to stay between 1.5°C and 2°C.

It is projected that the habitat for *C. mopane* will grow under the extreme carbon emission scenario (RCP_8.5). Some research claim that as the severity and intensity of climate change impacts increase,lack of suitable habitats will get worse, affecting the population of species (Sanchez et al, 2019). Some species, like *C. mopane*, will expand while others will contract. The species' current habitat flexibility, which demonstrates its capacity to adjust to a variety of environmental conditions, can be used to illustrate why the species is expected to be suited for the habitat.

To better comprehend the distribution and potential range shifts of mopane under climate change, ecological niche modelling is a beneficial technique. The findings can assist direct management and conservation planning to guarantee the long-term survival of mopane woodlands in Sub-Saharan Africa. A more comprehensive understanding of mopane's ecological niche might be possible with additional study that takes into account more significant biotic and environmental aspects (2014, Chirara et al). *Colophospermum* mopane's possible geographic distribution in Zimbabwe under the country's present and future climates is being modelled.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1Conclusions

A few species, including *Colophospermum mopane*, are predicted to prosper under climate change based on our findings, particularly under the worst case scenario (RCP_8.5). The distributions of many species, however, are predicted to undergo significant alterations as a result of climate change. The projected distribution of the species revealed both range expansion and contraction in line with estimations for the present and the future (from all climate change scenario models), indicating that these species may be able to endure in mild climatic conditions. The species' well-known habitat flexibility is most likely to blame for this.

The main variables of mopane's distribution are related to the climate, particularly the temperature and precipitation. Mopane grows best in warm climates with little to moderate rainfall.

In conclusion, improved climate projections, adaptation planning, monitoring, and research on mopane's value, along with a more thorough understanding of the ecological niche of the mopane trees, and also taking into account factors other than climate, could help ensure the continued provision of ecosystem services by mopane woodlands in the future.

6.2Recommendations

To determine the mopane tree's range extent in sub Saharan Africa, a field investigation should be followed up on.The estimated suitability zones from this study can be used to assess the *Colophospermum* mopane's regional conservation status.As part of conservation efforts, the findings of this study can be used to choose suitable sites for restoration experimentation.Future research could improve our modelling approach by looking at each nation separately and collaborating with or simulating actual population sizes that are mostly dependent on mopane trees for survival. This was not possible in this investigation since it was financially challenging to travel to every part of sub Saharan Africa where *C. mopane* are found and we were unable to collect current accurate population statistics.

Conduct more thorough niche modelling analyses that take additional environmental and biotic factors into account, (research X, Y, and Z on *Colophospermum* mopane, ecological niche modelling, and miombo forests). The type of soil, fire patterns, herbivore activity, and interactions with other plant species could shed light on the variables affecting the dispersal of mopane.

Create adaptation plans to reduce any potential harm from mopane's range expansion. This could involve managed displacement, assisted migration, land use modifications, and management of herbivore populations. This can be enhanced through implementing conservation strategies in the core mopane ecosystem that will survive climate change the best. By doing this, mopane woods' long-term existence will be supported.

Encourage cooperation between scientists, decision-makers, and land managers to incorporate niche modelling insights into choices and actions in the field. Utilize climate models with increased resolution to improve climate projections. As a result, more precise forecasts of probable range alterations due to climate change will be available.

References

Chapungu, L., Takuba, N. and Zinhiva, H. 2014. A Multi-method Analysis of Forest Fragmentation and Loss: The Case of Ward 11, Chiredzi District of Zimbabwe. *African Journal of Environmental Science and Technology* 8(2):121-128.

Coates-Palgrave, M. 2002. Trees of Southern Africa, 3rd Edition, Struik, Cape Town.

Doswald, N., Willis, S. G., Collingham, Y. C., Pain, D. J., Green, R. E. and Huntley, B. 2009. Potential impacts of climatic change on the breeding and non-breeding ranges and migration distance of European *Sylvia* warblers. *Journal of Biogeography* 36:1194–1208.

FAO, 2014; Food and Agriculture Organization (FAO). 2014. State of the World's Forests 2014.Rome (available at Accessed 21 February 2023).

Keenan, R. J. 2015. Climate change impacts and adaptation in forest management: a review. *Annals of Forest Science* 72:145-167.

Makori, D. M., Fombong, A. T., Abdel-Rahman, E. M., Nkoba, K., Ongus, J., Irungu, J., Mosomtai, G., Makau, S., Mutanga, O., Odindi, J., Raina, S. and Landmann, T. 2017. Predicting spatial distribution of key honeybee pests in Kenya using remotely sensed and bioclimatic variables: Key honeybee pests distribution models. *ISPRS International Journal of Geo-Information* 6(3):66

Potgieter, M. 2015. Edible insects in Africa, an introduction to finding, using and eating insects. Wageningen: Agromisa Foundation and CTA. p. 34. ISBN978-90-8573-146-7

Warren, D. L. and Seifert, S. N. 2011 'Ecological niche modeling in Maxent: The importance of model complexity and the performance of model selection criteria', *Ecological Applications*, 21(2):335–342. doi: 10.1890/10-1171.1.

World Wildlife Fund (WWF). 2023. Deforestation and forest degradation. An Overview. Available at (www.worldwildlife.org/threats/deforestation-and-forest-degradation) Accessed 21 February 2023.

Yackulic, C. B., Chandler, R., Zipkin, E. F., Royle, J. A., Nichols, J. D., Campbell-Grant, E. H. and Veran, S. 2013. Presence-only modelling using MAXENT: When can we trust the inferences? *Methods in Ecological Evolution* 4:236–243.

Zhou, Y., G. Varquez, A. C., and Kanda, M. 2019. High-resolution global urban growth projection based on multiple applications of the SLEUTH urban growth model - Scientific Data. Nature; www.nature.com. https://doi.org/High-resolution global urban growth projection based on multiple applications of the SLEUTH urban growth model - Scientific Data

Bağdatlı, M. C. and Y. Ballı (2021). "GIS Mapping of Land Slopes, Soil Depths, Erosian Classes, Large Soil Groups and Some Soil Properties: A Case Study of Kayseri Province in Turkey." Universal Journal of Agricultural Research **9**(5): 166-175.

Ben-Akiva, M., et al. (2001). "Network state estimation and prediction for real-time traffic management." Networks and spatial economics **1**: 293-318.

Bryant, C. and B. Lomba (2004). African Trees: A Photographic Exploration, Juta and Company Ltd.

Byrne, C. "Part A. Education."

Chalghaf, B., et al. (2018). "Ecological niche modeling predicting the potential distribution of Leishmania vectors in the Mediterranean basin: impact of climate change." Parasites & vectors **11**: 1-9.

Cristoffer, C. and C. A. Peres (2003). "Elephants versus butterflies: the ecological role of large herbivores in the evolutionary history of two tropical worlds." Journal of Biogeography **30**(9): 1357-1380.

Dingaan, M. and P. J. du Preez (2018). "Vachellia (Acacia) karroo communities in South Africa: an overview." Pure and Applied Biogeography: 109-141.

Du Plessis, F. (2001). A phytosociological synthesis of Mopaneveld, University of Pretoria.

Encroachment, B. "BUSH ENCROACHMENT IN NAMIBIA."

Estrada-Contreras, I., et al. (2015). "Climate change and effects on vegetation in Veracruz, Mexico: an approach using ecological niche modelling." Acta botánica mexicana(112): 73-93.

Franklin, J. (2010). Mapping species distributions: spatial inference and prediction, Cambridge University Press.

García Molinos, J., et al. (2016). "Climate velocity and the future global redistribution of marine biodiversity." Nature Climate Change **6**(1): 83-88.

Howard, C. C. (2014). "In the shade of the mopane: Ledebouria in Namibia." Cactus and Succulent Journal **86**(3): 92-98.

Jinga, P., et al. (2020). "Climate change reduces the natural range of African wild loquat (Uapaca kirkiana Müll. Arg., Phyllanthaceae) in south-central Africa." Regional Environmental Change **20**: 1-13.

Kapuka, A., et al. (2022). "Climate change threatens the distribution of major woody species and ecosystem services provision in southern Africa." Science of The Total Environment **850**: 158006.

Khwashaba, M. (2018). Vulnerability and resilience in the Mopani district municipality in a changing climate, North-West University.

LITHUANIA, A. I. "Climate change is one of the most significant challenges humanity faces today, and it requires urgent action of various stakeholders to develop a sustainable way of living, adapt to the impacts of climate change and build resilient communities. Lithuanian Innovation Laboratory on Climate Actions." М 34 Математичні методи, моделі та інформаційні технології в економіці. Матеріали VIII Міжнародної науково-методичної конференції. Чернівці: Чернівец. нац. ун-т ім. Ю. Федьковича, 2023. 176 с. ISBN 978-966-423-781-6: 5.

Magadza, C. (1994). "Climate change: some likely multiple impacts in Southern Africa." Food Policy **19**(2): 165-191.

Makhado, R. A., et al. (2014). "Factors influencing the adaptation and distribution of Colophospermum mopane in southern Africa's mopane savannas-A review." Bothalia-African Biodiversity & Conservation **44**(1): 1-9.

Mataboge, M. S., et al. (2016). "Effects of climate variability on the harvesting and preservation of Mopani worms." Indilinga African Journal of Indigenous Knowledge Systems **15**(2): 34-38.

Midgley, G. F. and W. J. Bond (2015). "Future of African terrestrial biodiversity and ecosystems under anthropogenic climate change." Nature Climate Change **5**(9): 823-829.

Mitchell, P. (2002). The archaeology of southern Africa, Cambridge University Press.

Mitchell, S. A. (2013). "The status of wetlands, threats and the predicted effect of global climate change: the situation in Sub-Saharan Africa." Aquatic sciences **75**(1): 95-112.

Moreau, R. (1963). Vicissitudes of the African biomes in the late Pleistocene. Proceedings of the Zoological Society of London, Wiley Online Library.

Mutota, L. H. and H. Čížková (2021). "A REVIEW OF THE ROLE OF WOODY VEGETATION IN THE SUSTAINABLE WATER MANAGEMENT IN AREAS WITH DRY CLIMATES, WITH A SPECIAL ATTENTION ON AGROFORESTRY."

Ngarega, B. K., et al. (2021). "Forecasting the effects of bioclimatic characteristics and climate change on the potential distribution of Colophospermum mopane in southern Africa using Maximum Entropy (Maxent)." Ecological Informatics **65**: 101419.

Nzei, J. M., et al. (2022). "Assessment of climate change and land use effects on Water Lily (Nymphaea L.) habitat suitability in South America." Diversity **14**(10): 830.

O'Connor, T. (1992). "Woody vegetation–environment relations in a semi-arid savanna in the northern Transvaal." South African Journal of Botany **58**(4): 268-274.

Parra, J. L., et al. (2004). "Evaluating alternative data sets for ecological niche models of birds in the Andes." Ecography **27**(3): 350-360.

Périé, C. and S. de Blois (2016). "Dominant forest tree species are potentially vulnerable to climate change over large portions of their range even at high latitudes." PeerJ **4**: e2218.

Pienaar, B. (2015). "THEBIOGEOGRAPHYOF BRACHYSTEGIA WOODLANDRELICTSINSOUT HERNAFRICA."

Rosenstock, T. S., et al. (2019). "A planetary health perspective on agroforestry in Sub-Saharan Africa." One Earth **1**(3): 330-344.

Sanchez, A. C., et al. (2010). "Identifying the global potential for baobab tree cultivation using ecological niche modelling." Agroforestry systems **80**: 191-201.

Scholes, R., et al. (2002). "Trends in savanna structure and composition along an aridity gradient in the Kalahari." Journal of Vegetation Science **13**(3): 419-428.

Siebert, F. (2012). A phytosociological synthesis of Mopanieveld vegetation at different spatial scales using various classification methods, Citeseer.

Slater, H. and E. Michael (2012). "Predicting the current and future potential distributions of lymphatic filariasis in Africa using maximum entropy ecological niche modelling." PloS one **7**(2): e32202.

Timberlake, J. and E. Chidumayo (2011). "Miombo ecoregion vision report." Occasional Publications in Biodiversity **20**.

Tsakiris, G. and D. Loucks (2023). "Adaptive Water Resources Management Under Climate Change: An Introduction." Water Resources Management: 1-13.

Worku, T. A., et al. "Assessment of Reservoir Performance Under Climate Change: A Case Study in Shumbrite Reservoir, Upper Blue Nile Basin, Ethiopia." Mekash S., Assessment of Reservoir Performance Under Climate Change: A Case Study in Shumbrite Reservoir, Upper Blue Nile Basin, Ethiopia.

Wuebbles, D. J. and A. K. Jain (2001). "Concerns about climate change and the role of fossil fuel use." Fuel processing technology **71**(1-3): 99-119.