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The impact of climate change on *Ziziphus mauritiana*, an exotic but naturalised fruit tree of food and income importance in sub-Saharan Africa

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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.

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Signature………………………….. Date……………………………

DEDICATION

I dedicate this project to my lovely family for their unwavering support throughout the journey of writing this project.

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Above all I would like to thank the Almighty.

ABSTRACT

This paper examines the potential impact of climate change on *Ziziphus mauritiana*, an exotic but naturalized fruit tree of food and income importance in Africa, under two different climate models (2. 6, and 8.5) for the years 2050 and 2070. The study finds that both models project a significant impact on the growth, yield, and quality of *Ziziphus mauritiana* due to rising temperatures, changes in rainfall patterns, and increased frequency of extreme weather events. The primary impacts are likely to be water stress and increased pest and disease pressure, with the 2.6 and 8.5 models projecting more severe impacts. However, the study also identifies adaptation measures that can help to mitigate these impacts, including the development of drought-tolerant varieties, and the use of pest and disease-resistant cultivars. The study concludes that raising awareness among farmers and policymakers about the potential impacts of climate change on *Ziziphus mauritiana*.

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CHAPTER 1

INTRODUCTION

1.1 Background to the study

Ziziphus mauritiana is originated in Central Asia and is originated from North Africa from Afghanistan to India's northern region (Chandra et al. 2010).It was first introduced to East Africa, particularly in Somalia, Ethiopia, and Kenya, before spreading to other parts of the continent. Over time, The tree has spread across the majority of African countries, including West Africa, Central Africa, and the southern parts of the continent (Khapoya, 2015) It has been naturalized in tropical Africa in countries like Iran, Syria among others (Pitrat, Chauvet et al. 1997). Researches shows that it has expanded to other countries including Zimbabwe and is commonly known as *masau* in arid and semi-arid areas (Maruza et al. 2017).

It is a valuable agroforestry tree species in Africa that helps farmers in rural areas establish resilience for their way of life. Its fruit is one of the most widely consumed fruits in Africa, and a sizable rural population uses the tree to produce a variety of goods, including wood fuel, fodder, organic manure, and herbs (Tougiani et al. 2009). Also, the extracts from the *masau* tree that are seeds, leaves, roots, and bark are used in traditional medicines to alleviate the symptoms of insomnia, skin disorders, and inflammatory ailments like fever, the tree is crucial to the integrated economy of dry regions.(Nyanga et al. 2008)

According to Nyanga et al. (2008), *Z. mauritiana* has the potential to provide a variety of advantages, including the socio-economic advancement of rural communities through the creation of jobs, increased family income, and the provision of a year-round supply of safe and high-quality beverages, environmental restoration, domestication of fruit trees, and the preservation of a significant food source. According to academic research, native fruits sustain a sizable share of Africa's rural people. Africa's urban and rural marketplaces both sell the fruits. According to reports, during the 1995–1996 drought, fruit was substituted for grains in some regions, such as Zambia, where fruit is an important part of the diet (FEW Bulletin, 1996). The fruit has enormous economic potential and a high nutritional value. Consequently, the fruit has assisted in reducing poverty.

Most of the wild fruit trees are facing several threats from increasing population, deforestation and climate change(Reza and Hasan 2019). Deforestation is a common act in rural communities and this has immeasurably contributed to the depletion of their population and habitat as well. Industrial agriculture is also contributing to their loss(Zafarnejad 2009). Studies have indicated that some wild fruit tree species may spread beyond of their existing geographic range, while others may yield fruit irregularly, with divisive effects of climate change, *Z. mauritiana* has a greater resilience capacity. Due to its promotion as a drought tolerant species, further introductions are likely. It is already found in many countries and has become an invasive species and invasions are likely to be improved varieties (Azam-ali et al. 2006)

1.2 Problem statement

Although *Z. mauritiana* is one of the most pervasive invaders of tropical ecosystems, most important research have focused on its economic significance, therefore there is insufficient knowledge about how the future distribution of *Z. mauritiana* in Africa will be impacted by climate change(Maundu et al. 2009).

1.3 Justification of the study

It is crucial to forecast how likely climate change will be to affect whether the habitat can support *Z. mauritiana*. It can assist us in comprehending how alterations in temperature, precipitation, and other environmental conditions may affect the species. We can identify regions where the *Z. mauritiana* species may be at risk and take action to safeguard those areas as well as the development of drought-resistant variants to secure the species' survival by estimating how the habitat of the species may change in the future. In many African nations, *Z. mauritiana* is a crucial species for ensuring food security and generating cash. Climate change-related loss or decline of it could have a severe negative economic and social impact on nearby populations. By speculating on the potential effects of climate on the suitability of the habitat to sustain *Z. mauritiana*, policymakers can make informed decisions about how to support communities that rely on the species for their livelihoods.

1.4 Aim of the research

The major aim of the research is to predict the likely impact of climate change on habitat suitability for sustaining *Z. mauritiana* in Africa.

1.5 Objectives of the study

To determine the extent of the habitat suitable for sustaining *Z. mauritiana* under current ecological conditions in Africa.

Determine the likely effects of climate on the suitable habitat that will be able to sustain *Z. mauritiana.*

Determine the ecological conditions suitable for the natural growth of *Z. mauritiana*

1.6 Research Questions

1. What are the current ecological conditions in Africa that are suitable for the growth and survival of *Z. mauritiana*?

2. How are the current ecological conditions and extent of suitable habitat for *Z. mauritiana* likely to change under different climate change scenarios?

3. What are the environmental factors that are most important for the natural growth of Z. *mauritiana?*

CHAPTER 2

2.1 *Ziziphus mauritiana* species ecology and distribution

Ziziphus mauritiana, commonly known as Indian jujube or ber, is a species of tree in the buckthorn family (Rhamnaceae) that is native to the Indian subcontinent and Southeast Asia(Gupta and Pradheep 2018). It is a small to medium-sized tree that can reach up to 12 meters in height and has a spreading, bushy canopy. *Ziziphus mauritiana* is a hardy and drought-tolerant tree that can grow in a variety of soil types, from sandy to loamy soils. It is well adapted to hot and dry climates and is often found in arid and semi-arid regions(Bekele-Tesemma et al. 1993). The tree is deciduous, shedding its leaves during the dry season and producing new ones when the rains return. The tree produces small, fragrant flowers that attract pollinators such as bees and butterflies. The fruits are small, round or oval-shaped, and turn from green to yellow or brown when ripe. The fruit is eaten fresh or used to make jams, jellies, and other sweet treats. The tree is also valued for its medicinal properties, and various parts of the tree are used in traditional medicine to treat a range of ailments(Sinha et al. 2017).

Ziziphus mauritiana is native to the Indian subcontinent and Southeast Asia, where it is widely cultivated and has been used for centuries as a source of food and medicine. It has been introduced to other parts of the world, including Africa, the Middle East, and parts of South America (Abdallah et al. 2016). In Africa, it has naturalized in many areas and is widely grown in home gardens, agroforestry systems, and in the wild .*Ziziphus mauritiana* is particularly common in the Sahel region of Africa, where it is an important source of food and income for rural communities. The tree is well-suited to the region's hot and dry climate and can provide a reliable source of food even during times of drought and food scarcity (Mougin et al. 2009).

2.2 Significance of the tree species

Ziziphus mauritiana, is an important tree species for many rural communities African communities (Gupta and Pradheep 2018. The tree provides a range of benefits, including food, income, medicine, and soil improvement, which can contribute significantly to the livelihoods of rural people (Kalinganire et al. 2008). Several studies have highlighted the significance of *Ziziphus mauritiana* to rural livelihoods. For example, a study conducted in Ethiopia found that *Ziziphus mauritiana* was an important species for supporting the livelihoods of rural communities and contribute a minimum of $100 for each household(Crawford et al. 2016). The tree was often grown in home gardens and agroforestry systems, and the fruit was sold in local markets or consumed by household members. The study also found that the leaves and branches of the tree were used as fodder for livestock, providing an additional source of income for many households.

In addition to providing direct benefits to rural households, *Ziziphus mauritiana* can also contribute to broader development goals. For example, a study conducted in Burkina Faso found that the tree was an important component of agroforestry systems, which can support sustainable agriculture and improve food security in the region (Garrity et al. 2010). The study also found that the tree provided a source of income and employment for many households, particularly women who were involved in the processing and sale of fruit and other products derived from the tree.

2.3 Likely impacts of climate change on introduced but naturalised fruit trees

Climate change is likely to accelerate the occurrence of wild fires due to the rising in temperatures and prolonged fire seasons (Freire et al. 2019) which will affect its distribution in terms of its habitat. Studies indicate that due to climate change, certain wild tree fruit species may spread beyond their current geographic range, while others may have irregular fruiting patterns (Lamers, H. 2011). *Z. mauritiana* is more resilient to the polarizing effects of climate change. It has been known for being able to tolerate challenging circumstances like salt, drought, and waterlogging(Anil Kumar et al. 2022) Due to its promotion as a drought-tolerant species, further introductions are likely. It is already found in many countries and has become an invasive species and the invasions are likely to be of improved varieties (Azam-Ali et al. 2006). Also studies shows that they are different varieties *of Ziziphus mauritiana* that have been introduces that are dry tolerant.

Different studies have indicated that introduced but naturalized fruit trees are susceptible to the effects of climate change, including changes in temperature, precipitation, and the incidence of pests and diseases(Anderson et al. 2004). Species like Mango *(Mangifera induca*), which is a tropical fruit tree that is widely cultivated in many parts of the world is said to be vulnerable to temperature and precipitation changes, and may experience reduced growth and yield in warmer or drier conditions. Also, species like Citrus including oranges, lemons, and grapefruits, are vulnerable to heat stress and may experience reduced fruit quality and quantity in warmer temperatures. Avocado (*Persea americana*). Avocado trees are vulnerable to both drought and excessive rainfall, which can impact fruit production and quality. Mitigation strategies such as the development of drought-resistant varieties and the use of climate-smart agricultural practices can help maintain the resilience of these species to climate change.(Singh and Singh 2017)

CHAPTER 3

MATERIALS AND METHODS

3.1 Data Acquisition

Ziziphus mauritiana occurrence data was obtained from the Global Biodiversity Information Facility (GBIF, http://gbif.org).The ‘getData()’ function from the raster package was used to collect the current and future environmental data that is the bioclimatic and altitude data from The WorldClim project (http://worldclim.org, Hijmans 2005) uses latitude and longitude resolution of 2.5 arc. The climatic data for this study was restricted to 19 bioclimatic predictors demonstrated on the table below fig 3. A significant number of global climate models (GCMs) employed in the phase 5 Coupled Model Intercomparison Project were matched to produce future climate projections. (CMIP5) was also compiled from the worldclim. (RCP8.5) and (RCP2.6) was used to estimate change in terms of habitat suitability for *s*ustaining *Z. mauritiana* in Africa for the predictions of 2050 and 2070. The observed data was then validated before running the model to make sure data the species have geographic location by removing all species without coordinates. Validating observed data is an important step in ensuring the accuracy and reliability of species distribution models. The dataset was filtered to include only species with geographical coordinates (latitude and longitude) and that leaves a dataset of species with reliable location.

The Intergovernmental Panel on Climate Change (IPCC) developed these two climatic models (RCPs) to predict how future greenhouse gas emissions that will affect the climate system on Earth. According to RCP8.5, greenhouse gas emissions will keep increasing at the same rate, leading to high emissions levels and insufficient climate change mitigation, as well as a significant rise in sea level, an increase in the frequency of heat waves, and more violent extreme weather events. In contrast, RCP2.6 assumes that significant mitigation measures will be taken to keep global warming to less than 2°C over pre-industrial levels. According to this scenario, stringent environmental laws would be implemented and low-carbon technologies will be widely adopted. RCP2.6 predicts that by the end of the century, global temperatures will rise by 1.5°C to 2°C, which is in accordance with the Paris Agreement's requirement to keep global temperatures well below 2°C. For understanding expected future implications of climate change and directing policy decisions to reduce these effects, RCP8.5 and RCP2.6 are both essential resources. If we move quickly to combat climate change, RCP2.6 offers a more optimistic outlook, whereas RCP8.5 sends a dire warning about the consequences of inaction.

3.2 Model of Parameters

Numerous geographic raster and vector data sources were used to generate the forecasts based on research from Makori (2017). The variables in the species distribution model (Table 3.2.1) were aggregated to create a remotely sensed biotic dependent variable from space-borne normalized differential vegetation index (NDVI) measurements.

Fig 3.3: Climate variables included in this study that are important for habitat suitability.

Name	Variable	Units
Bio1	Mean dual range	ºC
Bio 2	Annual mean temperature	ºC
Bio3	Min temprature of the coldest month	ºC
Bio 4	Temprature seasonality	ºC
Bio 5	Max temp of the warmest month	ºC
Bio 6	Max temprature of the coldest month	ºC
Bio 7	Mean temp of the coldest quarter	ºC
Bio 8	Mean temp of the wettest quarter	ºC
Bio 9	Max temp of the warmest quarter	ºC
Bio 10	Mean temp of the wettest quarter	ºC
Bio 11	Max temp of the warmest quarter	ºC
Bio 12	Annual precipitation	Mm
Bio 13	Coefficient variation	Mm
Bio 14	Precipitation of the coldest quarter	Mm
Bio 15	Precipitation of the driest months	Mm
Bio 17	Precipitation of coldest quarter	Mm
Bio 18	Precipitation of the coldest months	Mm
Bio 19	Precipitation of coldest quarter	Mm

3.4 Data Analysis

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 that are (Table 3.2.1) with high changes of influencing the occurrence of *Z. mauritiana* species were directly downloaded into R (McIntosh et al., 2022). The Maxent alogarithm, which seeks to determine the biggest combination of environmental responses that most accurately forecasts on the occurrence of the species, was used to build ecological niche models.

3.5 Model of evaluation

A model for the analysis of receiver operating characteristic (ROC) curves with threshold independence(Peterson et al. 2008) (was used to assess the performance of the model. The probability that a classifier appropriately relates presence (sensitivity) to absence (specificity) or background points is represented by the area under a ROC curve Peterson, Papeş et al. 2008). One (1) represents a perfect occurrence area, while an AUC value of zero (0) suggests an impossible occurrence zone (Peterson et al. 2008)

CHAPTER 4
RESULTS

4.1 Present suitability of *Z. mauritiana*

The current adaptability of *Ziziphus mauritiana*, an invasive but naturalized fruit tree species, relies on a number of variables, including climate, soil characteristics, and management approaches. *Z. mauritiana*, however, thrives in tropical and subtropical areas with moderate to high rainfall and well-drained soils in general. In various regions of Africa, *Z. mauritiana* is extensively farmed. The species can tolerate periods of drought and high temperatures, making it especially well-suited to regions with hot, dry summers and cool winters. *Z. mauritiana* is currently grown in several nations throughout African in terms of specific geographic regions. The plant is commonly grown in these nations in regions with good soil. The species is commonly grown in these nations in regions with favourable conditions and weather, such as well-drained soils, moderate to high rainfall, and temperatures between 20°C and 30°C. Overall, a number of variables, such as the regional climate, soil characteristics, and management practices, influence how suitable *Z. mauritiana* is right now. However, the species, which is cultivated in many nations throughout Africa, is often well-suited to tropical and subtropical environments with hot, dry summers and cool winters.

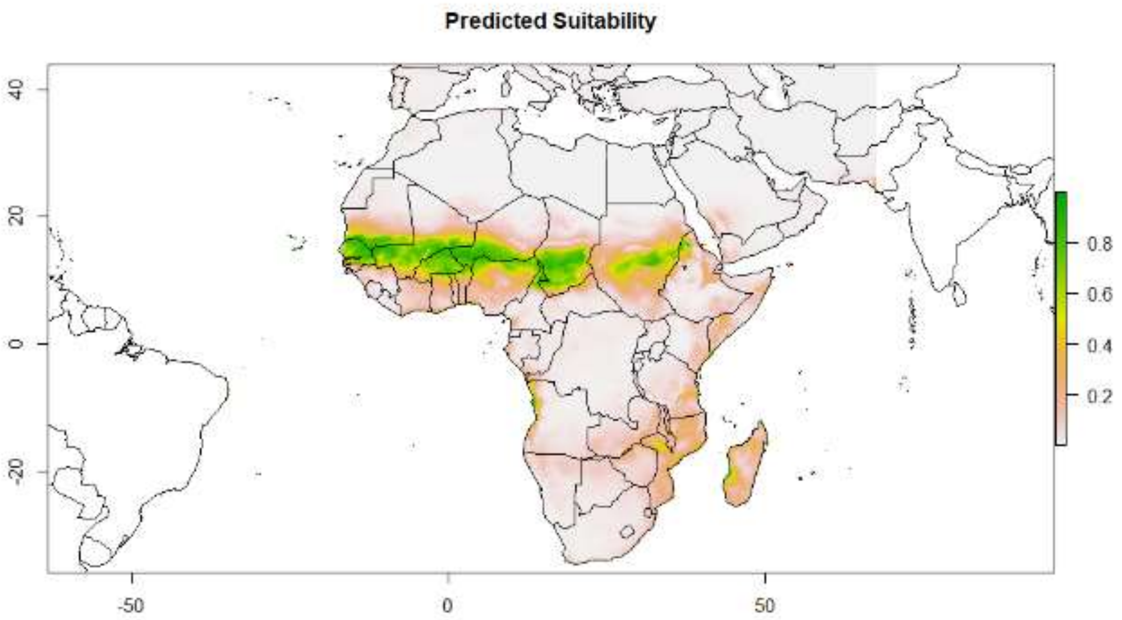
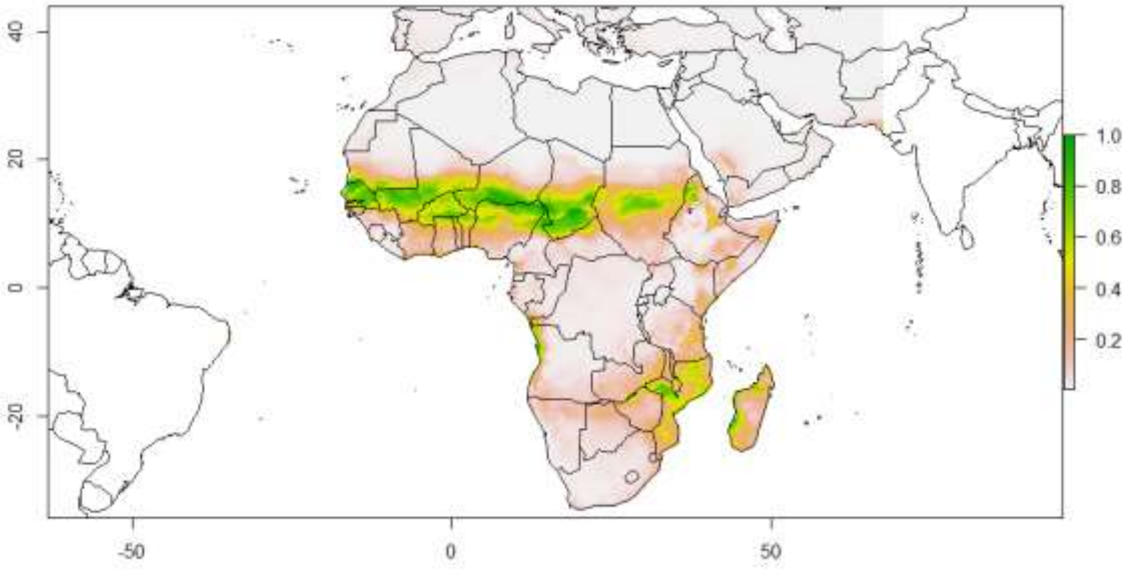


Figure 4.1: Predicted current suitability areas of *Z. mauritiana* in sub-Saharan Africa

4.2 Future suitability of *Z. mauritiana* under RCP 2.6 and 8,5 for the years 2050 and 2070.

b



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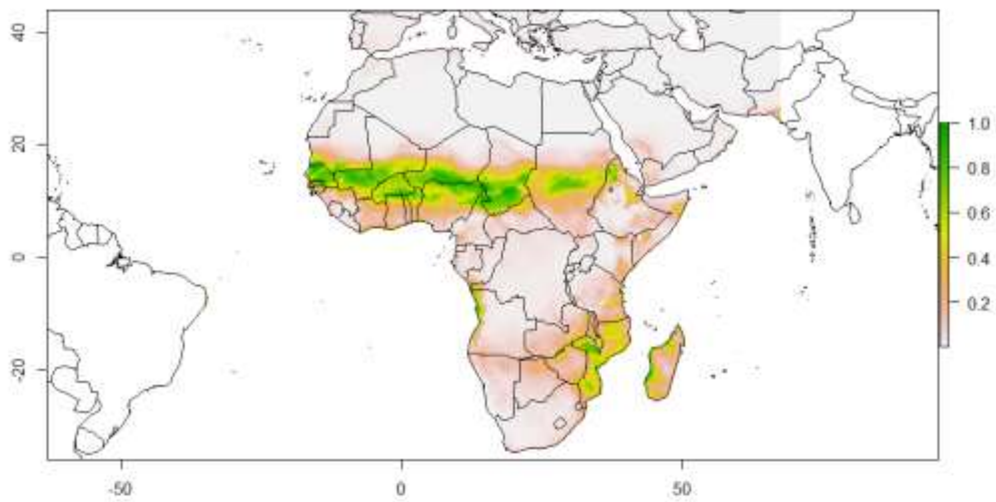
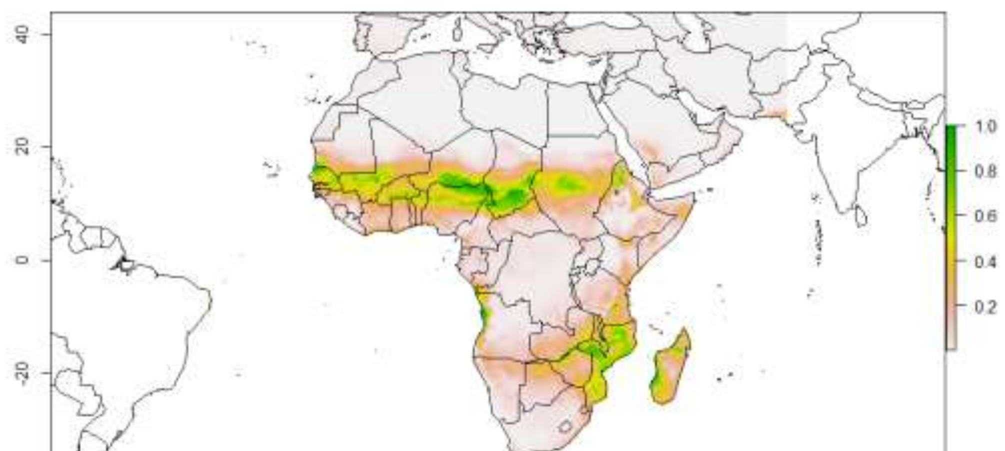


Figure 4.2: Predicted distribution of *Z. mauritiana* for RCP 2.6_ 2050 (a) & 2070 (b)



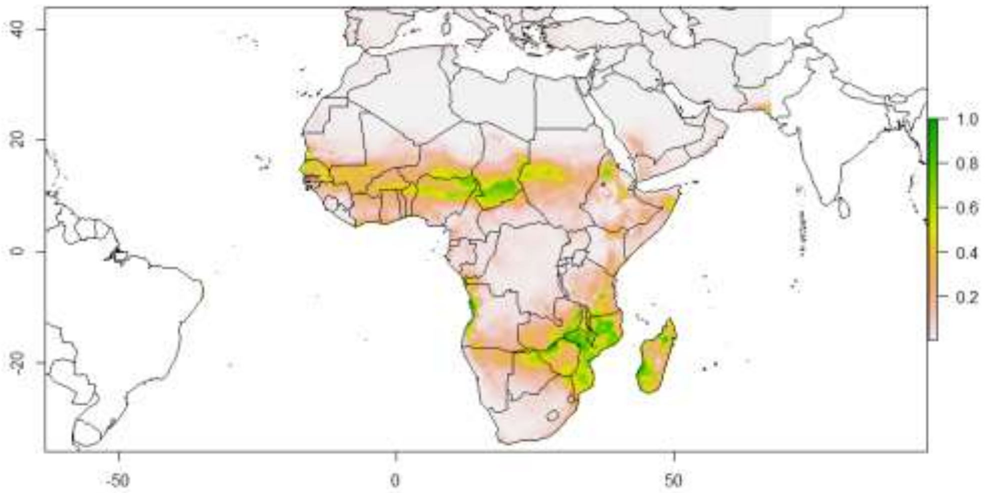
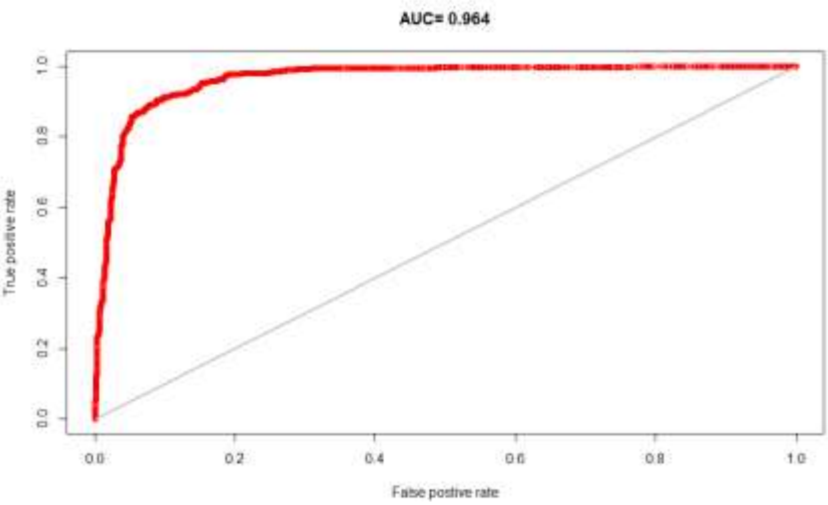


Figure 4.3: Predicted distribution of *Z. mauritiana* for RCP 8.5_ 2050 (a) & 2070 (b)

RCP _8.5 was observed to have significant impacts on species geographical range suitability for both year 2050 and 2070 as compared to RCP _2.6**.** Fo**r** 8.5**,** both year 2050 and 2070 the suitability of *Z. mauritiana* was projected to decrease in many parts of Africa by the year 2050 and 2070. However, under a low emissions scenario (RCP 2.6), the suitability of *Z. mauritiana* was projected to remain stable or even increase in some parts of Africa by the year 2050 and 2070.The outcome of the study shows a strong correlation between bioclimatic variables with the predicted future distribution of *Z. mauritiana*, with AUC of about 0.964 (

b



a

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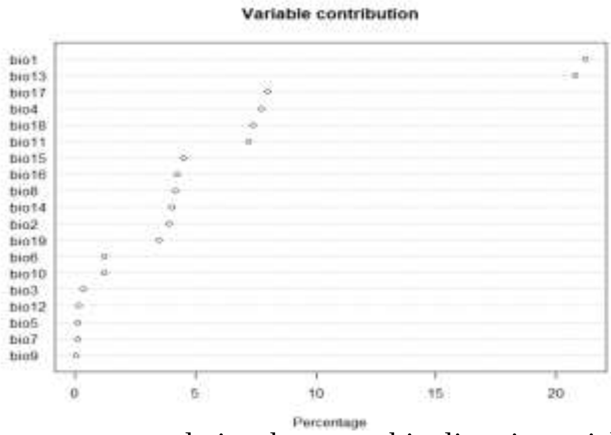

Fig 4.4a and b shows a strong correlation between bioclimatic variables and the predicted future distribution of *Z. mauritiana*.

The outcome of this study shows that Mean diurnal (bio 1) was the most variable which influence the predicted future suitability of *Ziziphus mauritiana* with about 23% influence on all RCP model used for this study for both year 2050 and 2070, followed by Temperature seasonality (bio 13) with about 21% influence and Mean Temperature of Wettest Quarter (bio 2) with about 5% influence on the models used for this study. Mean Temperature of the Coldest Quarter and the Maximum Temperature of the Warmest Month (bio 5) both contributed significantly to about 1 %. (Fig 4.4 b)

CHAPTER 5

DISCUSSION

The findings of this study shows a positive incremental changes of *Z. mauritiana* habitat in the Africa region under RCP 2.6 as the mean diurnal range and temperature seasonality continue to be the most prevailing factors to the tree species in Africa.

Under the worst-case scenario of the 8.5 paradigm for climate change effects on *Ziziphus mauritiana*, an exotic yet naturalized fruit tree important for food and income in some countries, is projected to be catastrophic. As predicted by this model, *Z. mauritiana's* growth, yield, and quality will all be significantly impacted by an increase in temperature, a rise in the frequency and severity of extreme weather events, together with a decrease in rainfall. Water stress is probably one of the crucial effects of climate change on *Ziziphus mauritiana* in the 8.5 model. The study shows a significant decrease in the species distribution(Mishra et al. 2021). The tree may not receive enough water due to decreased rainfall and higher temperatures, which may result in slower development, a lower yield, and lower quality fruit.

However, the habitat for *Z. mauritiana* on other parts of Africa is projected to further increase under the extreme carbon (C) emission scenario (RCP_8.5). Due to its promotion as a drought-tolerant species, different climatic scenarios create new opportunities for its occurrences (Mishra et al. 2021). The species' present habitat elasticity explains its anticipated appropriateness, exhibiting its capacity to adapt to a broad range of habitat circumstances. *Z. mauritiana* is known to be dominant in both arid and semi-arid environments.

Area Under the Curve (AUC) value for test dataset was 1, indicating that the model was brilliant for simulating *Z. mauritiana* future potential habitat hence, shows that the findings from this study can be relied on. Temperature and precipitation have influence on range availability and growth for *Z. mauritiana*, which can survive high temperature and precipitation (Bugmann *et al.*, 2014).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

The impact of climate change on *Ziziphus mauritiana*, an exotic but naturalized fruit tree among African nations of food and income importance in Africa, is expected to be significant under the two models on the years 2050 and 2070. The 2.6 model predicts a relatively minor impact, while the 8.5 models predict more severe impacts. . Since rising temperatures and altered rainfall patterns have an impact on the development, yield, and quality of the tree, water stress and increased pest and disease pressure are likely to be the main effects. Depending on the local climate that best matches the species' habitat, the distribution and appropriateness may differ from one nation to the next. *Ziziphus mauritiana's* vulnerability to climate change is a major problem for Africa's ability to secure food and revenue. However, with appropriate adaptation measures, it is possible to minimize these impacts and ensure the long-term sustainability of this important crop.

6.2 Recommendations

With the expected increase in water stress under both models, it is crucial to develop new cultivars that are more tolerant to drought conditions. Due to increase in temperature an increase in pests and diseases pressure is likely to happen, so it is essential to use pest and disease-resistant cultivars to minimize the impact on the yield and quality of *Ziziphus mauritiana*. Also, it is important to raise awareness among farmers and policymakers for the likely effects of climate change on *Ziziphus mauritiana* and need for adaptation measures. This may involve capacity-building programs, knowledge-sharing platforms, and policy incentives to promote the adoption of climate-smart agriculture practices. In addition, encouraging research and development of new technologies and practices that can support the resilience of *Ziziphus mauritiana* to climate change. This may include the development of new cultivars, better pest and disease management techniques.

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