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Ecological Niche Modelling For Indigofera Tinctoria L

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DECLARATION

The undersigned attest that they have read and approved this research project for submission for marking in accordance with the policies and procedures of the department.

Student: "..Signature: “Date

Supervisor: ……………………….............Signature: “Date

DEDICATION

This endeavour is a gift to loved ones and close associates

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I owe a lot of gratitude to my supervisor, Professor. L. Jimu, for his help and direction throughout the entire project.

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ABSTRACT

The prediction of the distribution of different species using climate change models has become an important tool for guiding biodiversity conservation. Climate change has become a global environmental issue altering the distribution and assemblage of species worldwide. This study aimed to determine impacts in changing of climate on *I tinctoria L,* assessing some places in Zimbabwe and also in the sub Saharan Africa. R Studio software was used to calibrate and project the distribution of *I tinctoria L,* in sub Saharan Africa. A total of 1418 occurrence records, 19 bio-climatic variables in modelling species' occurrences were used. Distributions were forecasted on years 2050 to 2070 being altered by two Representative Concentration Pathways (RCPs), that is RCP-8.5 and RCP-2.6. Present projections showed the probability of occurrence outside the area of current occurrence was >0.2. The future ecological niche models for *I tinctoria L,* of the 2 climatic scenarios, predicted significant changes in the current suitability.There was significant range extension in every scenario, demonstrating that climate change has a significant impact on the survival of *I tinctoria L* and ultimately increases biodiversity. Unlike many species whose distributions are likely to be seriously affected by climate change, predicted suitability areas in this study can aid in assessing the conservation status of plant species at a regional scale, hence a follow up in the field should be done to determine range size of *I tinctoria L.*

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LIST OF ACRONYMS AND ABBREVIATIONS

BIO	Bioclimatic variable
BIODIVERSITY	Biological Diversity
CARBORN DIOXIDE	Carbon dioxide
GBIF	Global Biodiversity Information Facility
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union of Conservation of Nature
MaxEnt	Maximum Entropy
QGIS	Quantum Geographic Information System
SDMs	Species Distribution Models
UNFCCC	United Nations Framework Convention on Change
WHO	World-Health-Organisation
WMO	World-Meteorological-Organization
%	Percent
°C	Degrees Celsius

CHAPTER 1

INTRODUCTION

1.1 Background Study

Climate variation or changes are an undeniable occurrence that is currently being felt globally at various stages (Mudereri, 2020). Due to the rapidly accelerating growth in greenhouse gases, the average global temperature increased by 0.65° to 0.85°C from 1888 to 2012 and is projected to reach 5.65° in the 21st century (Li et al., 2020). Carbon dioxide, methane, and nitrous oxide concentrations in the upper atmosphere have reached their greatest levels in 800,000 years. (2013, Kattsov) They've risen to levels of 180 to 300 ppm, 320 to 790 ppb, and 270 to 319 ppb, respectively (Kattsov, 2013).Because Africa's temperatures is expected to rise faster as compared to the rest of the world, it is considered a hotspot for climate change implications (Welborn, 2018). Temperature has increased by 1 °C above pre-industrial levels and 1.5 °C of warming is expected by 2050 and maybe will start to be experiencedas early as 2030 (Welborn, 2018).

Basing on the previous study of distribution of climatic variables (Mudereri, 2020), the arid savannahs have faced several hazards to their plant resources due to climate fluctuation. The quality of the environment and the abundance of the distribution of *I tinctoria L*, have been influenced greatly by precipitation and temperature. Mana Pools National Park's alluvial plains are thought to have become overpopulated with *I tinctoria L* species (Chapano, 2003).The causes of this growth and whether it is harming the biodiversity of the region ecologically are both still hotly contested. Natural environments for these plants include Mopane woodland, occasionally flooded woodland, various cultivated areas, and roadside locations (Schrire, 2012). Most of these species' habitats are occasionally flooded. There have been observable changes in the distribution of the *I tinctoria L* species as a result of climate change. For adaptive management and biodiversity protection, it is crucial to comprehend these climate implications on wildlife resources. The habitats of the majority of these species occasionally flood. As a result of climate change, the distribution of the *I. tinctria* species has significantly shifted.

It is crucial to understand how these climate conditions impact wildlife resources in order to practice adaptive management and maintain biodiversity. It has been discovered that there is a considerable impact of light intensity on the growth of the *l. tinctoria L.* despite the fact that this study used a randomised complete block design to get the shading time intervals (Budiastuti, 2017). In order to preserve the species and guide future management decisions, it is crucial to understand how climate change is affecting *I tinctoria L.*These changes will unquestionably alter ecological phenomena and process, such as plant species distribution, diversity, assemblage and morphology (Li et al, 2020).

Therefore, the application of ecological niche modelling methodologies should be based on a coherent conceptual framework for species' environmental and geographic distributions. Ecological Niche Modelling has been a significant tool to access plant distribution. (Barve, 2011) The degree employed during the niche modelling procedure has a significant impact on the model's outcome. It may be understated how crucial coarse-resolution elements like climate are for defining species ranges. The recent finding that climate has little effect on species distributions (Beale et al., 2008) is a pretty striking illustration of this constraint. As a result, ENM is crucial to access the spatial distribution of the species of *I tinctoria L*. When estimating species expansion or any prospective dispersion under altered conditions and circumstances, the term "ENM" should be used, but it is important to distinguish these values from their "actual" or "realized" manifestations. (Peterson,2012

Extreme heat waves, aridity, and altered rainfall variability are all anticipated to result from rising temperatures, especially in sub-Saharan Africa (Mudereri et al., 2020.). While the Eastern African region is predicted to grow more humid and have significant rainfall, the Southern and Northern African regions will experience substantial aridity, making those regions more susceptible to floods and waterborne diseases (Welborn, 2018). These modifications will undoubtedly affect ecological phenomena and processes, including species distribution, diversity, assemblage, and morphology, speeding up the extinction and origin of species (Li et al., 2020). As a result of the 0.85°C increase over the last century, plants have already started to project significant changes in quantity, quality, and life span(Mudereri et al., 2020). Many researchers have tried to recreate existing and expected future distributions of species in order to prepare for the unknowns that these bioclimatic changes bring to the environment(IPCC, 2007).

1:2 Problem Statement

It is unknown how climate change may affect *I. tinctoria's* spread in the future and how it would negatively affect the species' ability to reproduce. Indigofera tinctoria L is slightly considered to be of high economic, biological and aesthetic importance to other communities in the sub Saharan Africa. Currently there is little of no literature that is precise on how its environmental requirements, assemblage and distribution will be affected by climate change (Mapaure., 2019). Indigofera tinctoria L have low rate of population decrease around the world, hence making it difficult to make precise study. In other regions due to its large areal distribution, it has become "Least Concern" by the IUCN (International Union for Conservation of Nature) Red List. The conservation status of I tinctoria L has made it vulnerable to human activities such as tobacco curing and source of raw materials for rural home building.

1:3 Justification

Plants are important to humans for a different reason, including aesthetics, biology, and economics. People enjoy the beauty and appeal of the beautifully coloured plant species in wilderness areas, cultivations, and gardens around the world. Also Plant biodiversity is invaluable because it balances ecosystems, protects watersheds, mitigates erosion, moderate's climate, and provides shelter for animals. (Safriel, 2011) The drastic decrease in the population of *I. tinctoria L.* in Zimbabwe and other sub Saharan African countries has motivated the need to generate knowledge on the connection of the species' ecological niche and climate change. Understanding how climate change is affecting *Indigofera tinctoria L.* is crucial for the species' preservation and to inform upcoming management choices.Ecological niche modelling of *I. tinctoria l* is important as it helps in conservation efforts through predicting potential suitable habitats.(Bush 2002). Understanding the environmental parameters for *I. tinctoria l* species occurrences is key in decision making as it serves as baseline information for conservation planning.(Bush 2002) Thus, enhance *I. tinctoria l,* populations in relation to the current and future conditions.

1.5 Study Aim

To ascertain how *I tinctoria L.* is affected by climate change.

1.6 Study Objectives

1. 1. To foresee how climate change would affect the habitat

2. To assess *I tinctoria's* suitability for future growth under various environmental situations.

1.7 Research Questions

1. What is the current distribution of *I. tinctoria l*?
2. What is the likely suitable environment of *I. tinctoria L* for the years 2050 and 2070?

CHAPTER 2

LITERATURE REVIEW

2:1 Conservation Status of Endemic Species

The preservation of endemic species is a significant concern on a worldwide scale because in situ protection cannot guarantee their conservation (Coelho, 2020). Plant species that are endemic are typically more susceptible to manmade threats and natural changes, which increase their risk of extinction (Coelho, 2020). These species' preservation is a top priority on a global scale, but in situ protection cannot ensure their survival (Boreli 2010).

Plant species that are endemic are often at a higher risk of extinction because they are more vulnerable to environmental changes and man-made threats (Rabinowitz 1985). The Appendices to the Trade in Endangered Species of Wild Flora and Fauna Convention (CITES)contain a list of more than 30,000 species of animals and plants that have been harmed by international trade or could be harmed (Abensperg, 2009). To regulate trans-boundary trade in species and their derivatives, conventions normally use a system of permits and certifications. In addition, to ensure that such trade adheres to sustainability (Abensperg, 2009). On a worldwide basis, the preservation of these species is of the utmost importance,but in situ protection cannot guarantee their survival (Coelho,2020).

However, it is said that *I. tinctoria L,* conservation has increased in abundance in regions like Manna Pools National Park in Zimbabwe's alluvial plains. This was so due to some pleasant climatic variables which suit very well with the quality growth of the plant species *I tinctoria L*. The *I. tinctoria L*. is a weed species that is reasonably common but typically not numerous in crops, is not internationally threatened. It is a perennial plant in the family Fabaceae (Leguminosae) that is well known for its historical applications and other relevant uses. Due to climate change there have been noticeable variations in distribution of the species of *I. tinctoria L*.Botanical conservation can be employed to keep the endemic species in its natural habitat, claim Muller and Timberlake (1992). The majority of the time, it concentrates on species that are distinctive, spectacular, rare, or endemic (Mhlanga, L. and Mapaure 2019). The other focuses on the preservation of representative ecosystems and important vegetation types. The second criterion can be used to protect some of the vegetation kinds that the present study found.

There has been a study of biotechnology-based solutions for the preservation of indigenous plant species (Coelho, G.S and Romano 2020). Over the past few years, there has been a substantial increase in the application of biotechnological techniques for the conservation of plant species.These strategies provide fresh and complementary options of plans for the short, medium, and long terms (Rao, N.K. 2004).This study discusses the current state of the use of biotechnology-based solutions for the preservation of indigenous plant species (Romano 2020). Cryopreservation is given special consideration because it is the only long-term ex situ conservation technique that can support and supplement the other conservation measures for endemic species like the *I. tinctoria l.*

2:2 Endemism of Animals and Plants in Zimbabwe

Endemism is the condition in which a species is only found in a single, clearly defined geographic area, such as an island, state, country, or other defined zone; organisms that are native to a place are not considered to be endemic to it if they are also found elsewhere. (S. Anderson 1994).

Endemism is a result of ecological and historical circumstances. Geographically and physiologically isolated places, such as islands and remote island groups, are particularly prone to host endemic species (Vitousek, P, M. 1988).High endemism rates may also result from a region's climate and ecosystem being stable over time (Pete, 2015). Plants with a high rate of dispersal, which are able to reach such islands through wind or bird dispersal, are frequently those that become endemic on isolated islands (Carlquist, 1967)

2:3 Climate Change’s impact on Plant Species

The carbon fertilization effect, which is caused by an increase in photosynthesis due to a rise in atmospheric CARBORN DIOXIDE levels, is a direct result of climate change. (Adedeji, 2014). According to recent findings, global plant photosynthesis increased by 12 percent between 1982 and 2020, paralleling a 17 percent increase in atmospheric carborn dioxide levels. (Huber, Casar, et al. 1985)*I tinctoria L.* is one of the few examples of a species that, in contrast to many others whose distributions are projected to be significantly impacted by climate change, is predicted to survive and adapt effectively under climate change. As for *I tinctoria L*, it has the potential to flourish despite the difficult conditions brought on by climate change.

Some plants develop more as a result of greater photosynthesis since the vast majority of this increase in photosynthesis was driven by carbon dioxide fertilization brought on by high carbon dioxide concentrations. (Murthy, Dougherty, 1996)

Scientists discovered that as carbon dioxide levels rose above ground due to higher climate change, plant growth increased on average by 21% while growth below earth climbed by 28%.Some crops, including wheat and soybeans, benefit from higher carbon dioxide levels, increasing their yields by 12 to 14 percent. (Liancourt, Spence, 2013). The growth of some significant crops, including tropical and subtropical grasses, is unaffected by the rise in carbon dioxide. (Liancourt, Spence, 2013). On the down side, invasive species, especially plants like L. Cammara, have become more prevalent due to climate change. Reduced water tables have increased competition for water, which has caused other plants to perish. I. tinctoria, for instance, may survive in places with damp soil. (Kumar and Taylor, 2014)

The species of *I. tinctoria L*, they are said to have become abundant in the alluvial plains of the Mana Pools National Park (Chapano, 2003). Due to climate change there have been noticeable variations in distribution of the species of *I. tinctoria L*. Another study has revealed that there is a big effect of light intensity on the growth of the *I tinctoria L*. (Budiastuti, etal 2021). Climate changes will affect plant growth and how these changes will affect plant growth may depend in part on biotic context. (Pischl, 2016). Biotic changes such as increased temperature and more frequent or more severe droughts are predicted effects of climate change (IPCC 2014) that may cause stress for plants. These environmental changes may increase *Indigofera tinctoria* species reliance on symbiotic relationships to maintain growth and fitness (Kivlin et al. 2013).

Indigofera is the third-largest genus in the family of Fabaceae, with approximately 750 species and it is distributed across all tropical regions. Over *60 Indigofera* species are reported in traditional medicine. The uses depend on the country and the species, but similarities have been noticed. The *I. tinctoria L*., a weed species that is reasonably common but typically not numerous in crops, is not internationally threatened. It is a perennial plant in the family Fabaceae (Leguminous) that is well known for its historical applications and other relevant uses. According to the bioactive substances of this plant's therapeutic activity data, the use of this plant in conventional ways for the treatment of such disorders appears to be scientifically appropriate.

It is a great source of phyto compounds, which support human health and aid in the management of a variety of diseases and health problems. *I. tinctoria L,* also known as blue gold and true indigo, was one such well-known plant that was grown due to its great trading value in countries like India.

CHAPTER 3

MATERIALS AND METHODS

3:1Data Acquisition for Occurrences

The reference distribution data of *I tinctoria L*, was downloaded from the Global Biodiversity Information Facility (GBIF). The "presence-only" samples from GBIF were verified on QGIS version (OSGeo4W-2.6.1.-1) Brighton, for positional accuracy. Positional precision and spatial filtering were applied to a total of 1520 occurrences. Redundant and overlapping occurrences were filtered. After filtering, total records of 102 were removed leaving 1418 species occurrence after positional and spatial filtering was applied. **R version 3.3.0** was used for data analysis to explore and plot maps after the data acquired was filtered.

3:2Procedure used to determine habitat suitability for *I tinctoria L*

Data on the species of *I.tinctoria L*, was acquired and also all the key environmental variables, current and future (2050 and 2070). Then following a process of accuracy positioning test done on the occurrences. And also correctional analysis was done so as to reduce biases using the Pearson's correlation. All these were done using the R software and other processes were attributed also to MaxEnt model. The output managed to state out key environmental variables and some potential for the species *I. tinctoria L.*

3:3 Environmental Variables

The important environmental determinants impacting the distribution of *I tinctoria L*, across its whole range were determined using bioclimatic variables. We used current climate data, (1950–2000) and future (Carbon dioxide concentrations predicted for 2050 and 2070 using the minimum and maximum emission representative concentration pathways). The data was downloaded from World Climate at 2.5 arc-minute resolutions (Table 3.1).

Climate change scenario assumes that greenhouse gas emissions will continue to increase through 2100 while RCP_2.6, considers that carbon dioxide emissions will decrease. If present patterns are simply extended out, RCP 8.5 is a fairly good description of where we will be in future; it tracks historical emissions within 1%. The 21st century will see an increase in emissions. RCP 8.5, which is commonly used to model worst-case climate change scenarios, was based on overestimation of projected coal outputs. RCP_2.6, according to the IPCC (2007), calls for carbon dioxide emissions to begin declining by 2020 and reach zero by 2100.

3.4 Model Parameters

A variety of raster and vector geographic data sets served as the foundation for prediction evaluations. According to (Makori, 2017) the variables employed in the ecological niche model (Table 3.1) were grouped to remotely sensed biotic variables acquired from space borne NDVI data.**Table** 3:1: climatic variables relevant to habitat suitability employed in this study:

Bioclimatic variable	Code Description
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp-min temp))
BIO3	Isothermally (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 Temperature 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

3:5 Species Modeling and Model Performance

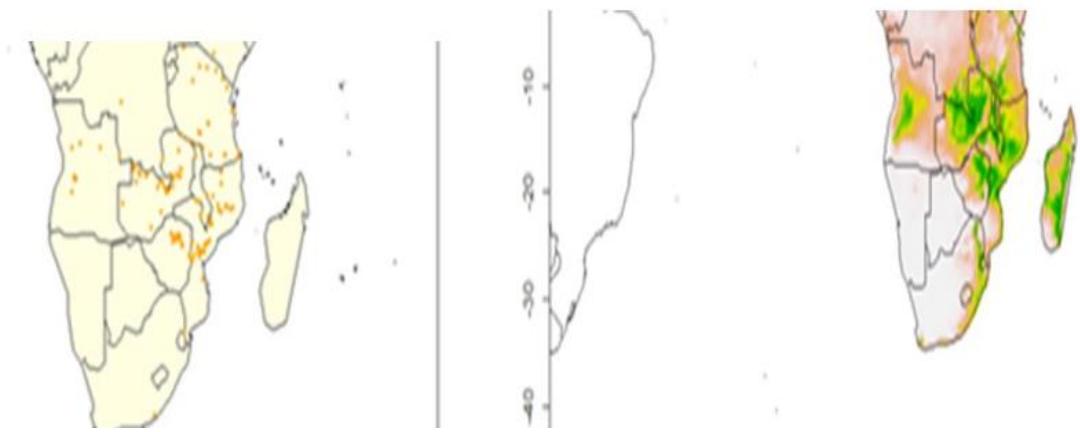
Species distribution modeling of *I tinctoria L*, was done using raster, rgdal, map-tools, mapdata, jsonlite, maps, rJava and dismo packages required in RStudio, so as to project the suitability of the species through map projections. R Studio is regarded highly in terms of performing better.Using presence-only data and the environmental predictors of the species, future probability of occurrence *I. tinctoria l*, was simulated using the specified scenarios (RCP 2.6 and RCP 8.5 for 2050 and 2070, respectively). Area Under Curve (AUC) was used to measure how closely the model performed to the value 10.

CHAPTER 4
RESULTS

4:1 Present Suitability of *I. tinctoria L.*

The present distribution of *I. tinctoria L*. indicates that environmental conditions for the species are favorable for its accretion (Fig 1). The model highlighted a strong correlation between present suitability results and its current distribution basing on species occurrence points available. All the species occurrence points were confined to areas within the range above 0.2 which describe conditions accommodating the species' environmental tolerance. All the species occurrence points were confined to areas within the range, above 0.2 which describe conditions accommodating the species' environmental tolerance. The model highlighted a strong correlation between present suitability results and its current distribution basing on species occurrence points available.

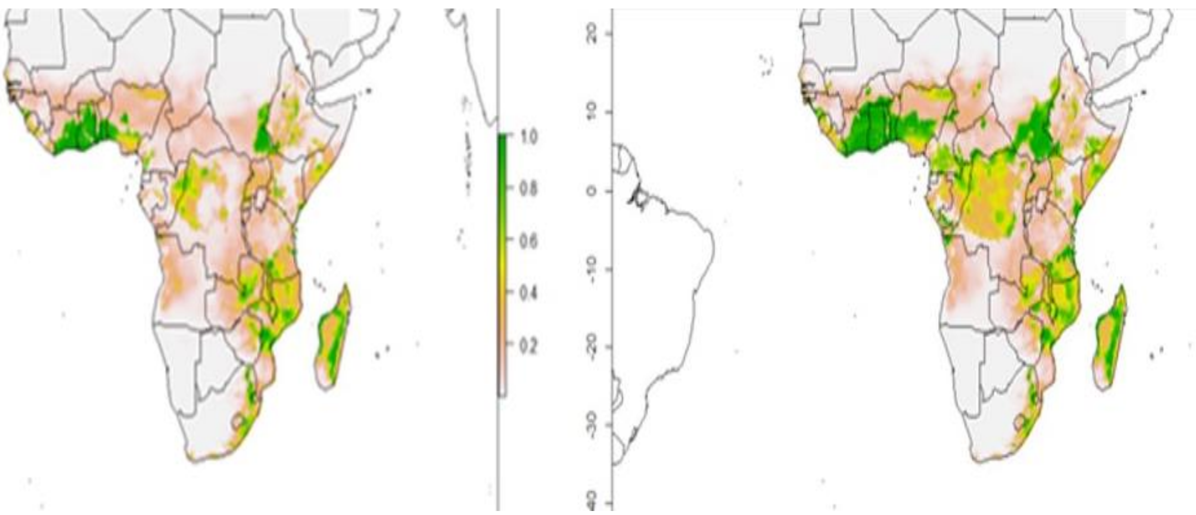
Figure 1



4:2 Future Suitability of ***I.tinctorial L.***

The future ecological niche models for *I.tinctoria L.* of the 2 climatic scenarios, predicted significant changes in the current suitability. The models (RCP 2.6 and RCP 8.5) all showed a significant expansion of the area suitable for *I. tinctoria L* when predicted to 2050 and 2070, respectively. (Figs 2)

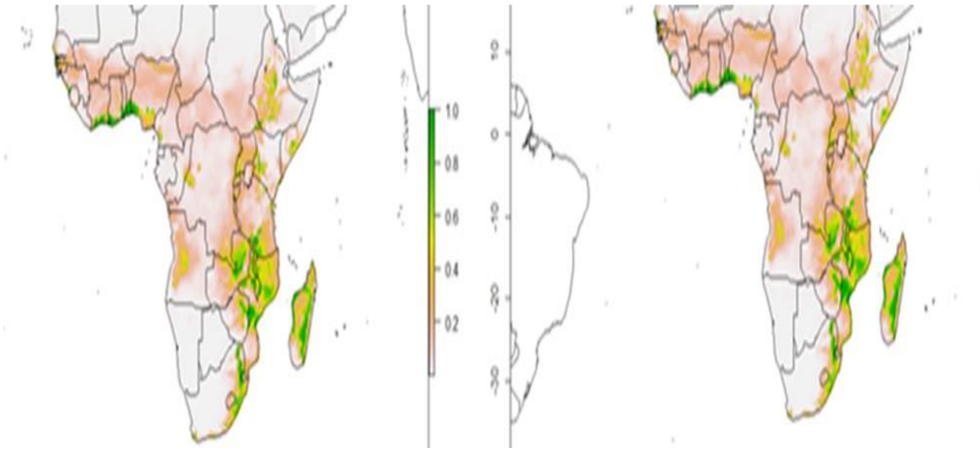
Figure 2



(i) (ii)

In a comparison to the current predicted distribution with projected future distribution (RCP_2.6) from the imagery (i) and (ii), there is decline in niche suitability in territories like Zambia, Zimbabwe, Angola and DRC for both 2050 and 2070 under RCP_2.6. A westward shift of *species'* ecological niche was observed for both RCP_2.6 2050 and RCP_2.6 2070. The suitability of *I. tinctoria L.* for both scenarios in the northern parts of the region has remained indistinguishable with current species suitability. Both scenarios under RCP_2.6 have showed same results in the changes of the ecological niche compared to the current suitability of *species*.

Figure 3



(i) (ii)

RCP_8.5 was observed to have an extensively higher expansion in the area suitable for *species* under the years 2050 and 2070, with the species covering an extensive range in 2070 than in 2050. The suitability zones expanded across central Africa, all the way to West Africa, covering fully some territories that had not been inhabited before.

The two models revealed that by 2050 the suitability of *I. tinctorial L.* for Angola will descent from 1.0 to 0.5 then further descent to below 0.3 by 2070. The models revealed that the species' suitable habitat will expand towards central and western parts of sub Saharan Africa by 2050, covering large portions of Benin, Togo and Ghana, then by 2070, the whole of Ghana will became the ultimate suitable habitat (suitability range of 1.0) for *I.tinctoria L.* . Findings indicated that by 2070, appropriateness of the species will expand rapidly towards the North.

Our results portrayed a strong correlation between bioclimatic variables and future distribution of *I.tinctorial L* , the results displayed an Area Under the Curve (AUC) value of 0.941 (fig 3). It was observed that the dominant variable was annual precipitation (bio 12) which had 38% influence on our RCP 2.6 scenarios 2050 and 2070and RCP_8.5 2050 & 2070, then the warmest quarter's precipitation (bio 18) with has an 18% influence. The coldest quarter's average temperature (bio 11) and the seasonality of precipitation (bio15) respectively had a 12,5% and 10% influence. Mean diurnal range (bio 2) had an influence on the outcomes of the models with a contribution of 8%. Isothermality (bio 3) had a 5% contribution to the future suitability of *I. tinctoria L.*

CHAPTER 5

DISCUSION

Scholarly evidence suggests that suitable habitats will become scarce in the future as climate change impacts increase in severity and intensity, thereby threatening species population (Sanchez et al., 2011; Jinga & Ashley, 2019). *I. tinctoria L.* is one of the few examples whose range will expand as increasing temperature and precipitation open up new opportunities for its occurrence. The projected suitability of the species can be explained by its current ecosystem elasticity, demonstrating its ability to adapt to wide range of habitat conditions. in winter (John et al., 2007)

Ecological niche modelling has shown that the *I. Tinctoria L.*' niche will expand in the present and the future according to the two climate change scenarios (RCP 2.6 & RCP 8.5).It's important to highlight that the findings of this study imply the reverse, in contrast to the majority of species that are believed to be negatively impacted by climate change. (Chapano, 2003)

The model basing on occurrence points available highlighted a negative correlation between present suitability results and *Indigofera tinctoria L.*'s current suitability because the environmental conditions are not permitting (Global & Report, 2006). Madagascar had not been mapped with the occurrence points due to many factors possibly some being the species was not present in the area or there was lack of species occurrence data (Soyadi, 1976), but the area showed potential for the species occurrence(Kuhnert, 2019) . The actual occurrence and survival of the specie could be determined by the local environment, the surrounding anthropogenic conditions, together with climatic conditions such as temperature and precipitation (Mudereri et al., 2009).

The outcome from this study demonstrated a slight habitat increase of *I.tinctoria L.* in the region under RCP_2.6 as minimum temperatures and low precipitation currently considered to be limiting factors will remain the same. Temperature is projected to remain at 1.5°C-2°C towards the year 2050 (Pachauri, 2014). Evidence shows that by 2050, using RCP_2.6, threatened species will decrease or remain constant as emissions of carbon dioxide, CH_4 and nitrogen oxide, are mitigated(Uk, 2007) , but this is not the case with *I.tinctoria L*. The results show no change in habitat expansion or fragmentation under RCP_2.6 2070, rather the distribution remained the same as that under RCP_2.6 2050, meaning temperature and precipitation will remain unaltered (Frank, 2020). This explains that bioclimatic variables 11, 12, 15 and 18 had a greater impact on the distribution of this specie.(Fig.2)

The important environmental determinants impacting the distribution of *I tinctoria L,* across its whole range were determined using bioclimatic variables. We used current climate data, (1950–2000) and future (Carbon dioxide concentrations predicted for 2050 and 2070 using the minimum and maximum emission representative concentration pathways). The data was downloaded from World Climate at 2.5 arc-minute resolutions.

Area under the Curve (AUC) value was greater than 0.9, indicating that the model did a superb job at simulating *Indigofera tinctoria L's* possible future habitat. Therefore, it is safe to rely on the study's main conclusions and results. Our findings demonstrated that in determining the ideal habitat for *Indigofera tinctoria L.*, the temperature (Bio2, Bio3 & Bio11) and precipitation (Bio12, Bio15 & Bio18) factors played a key role. Temperature and precipitation have an impact on range availability and size for our species, which can survive high temperatures and precipitation(Global & Report, 2006) as highlighted by our study.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6:1Conclusion

This specie is one of the few examples of a species that, in contrast to many others whose distributions are projected to be significantly impacted by climate change, is predicted to survive and adapt effectively under climate change, particularly under the extreme scenario (RCP 8.5).). The present distribution of *I. tinctoria L*. indicates that environmental conditions for the species are favorable for its accretion (Fig 1).

The model highlighted a strong correlation between present suitability results and its current distribution basing on species occurrence points available. The species' predicted distribution demonstrated range expansion under present and future projections (in all climate change scenario models), indicating that this species has the potential to flourish despite the difficult conditions brought on by climate change.

The dominant variable was annual precipitation (bio 12) which had 38% influence on our RCP 2.6 scenarios 2050 and 2070and RCP_8.5 2050 & 2070, then the warmest quarter's precipitation (bio 18) with has an 18% influence. The coldest quarter's average temperature (bio 11) and the seasonality of precipitation (bio15) respectively had a 12, 5% and 10% influence. Mean diurnal range (bio 2) had an influence on the outcomes of the models with a contribution of 8%. Isothermality (bio 3) had a 5% contribution to the future suitability of *I.* The actual occurrence and survival of the species was also determined by the local environment, the surrounding anthropogenic conditions and together with climatic conditions such as temperature and precipitation (Mudereri et al., 2009).

6.2 Recommendations

Predicted suitability areas in this study can aid in assessing the conservation status of other plant species at a regional scale. Findings of this study can be used to determine suitable areas for regeneration trials as part of conservation actions. Future research may additionally improve our modeling approach by analyzing each country separately and modelling real population sizes jointly or independently using real population data. Also in the prediction analysis we should consider the anthropogenic acticves

REFERENCE LIST

1. Adedeji, O. (2014). "Global climate change." Journal of Geoscience and Environment Protection 2(02): 114.
2. Brehm, J. M., et al. (2010). "New approaches for establishing conservation priorities for socio-economically important plant species." Biodiversity and Conservation 19(9): 2715-2740.
3. Budiastuti, M., et al. (2021). The role of organic fertilizer from natural dye waste and mycorrhizal inoculation on the growth of Indigofera tinctoria L. IOP Conference Series: Earth and Environmental Science, IOP Publishing.
4. Bush, M. B. (2002). "Distributional change and conservation on the Andean flank: a palaeoecological perspective." Global Ecology and Biogeography 11(6): 463-473.
5. Busia, K. (2005). "Monograph of Indigofera arrecta Hochst. ex A. Rich." Australian Journal of Medical Herbalism 17(4).
6. Caspar, T., et al. (1985). "Alterations in growth, photosynthesis, and respiration in a starchless mutant of Arabidopsis thaliana (L.) deficient in chloroplast phosphoglucomutase activity." Plant Physiology 79(1): 11-17.
7. Chalghaf, B., et al. (2016). "Ecological niche modeling for the prediction of the geographic distribution of cutaneous leishmaniasis in Tunisia." The American journal of tropical medicine and hygiene 94(4): 844.
8. Chitra, M., et al. (2003). "Bioefficiency of Indigogera tinctoria Linn. on isoniazid induced hepatotoxicity in albinorats." Ancient Science of Life 23(2): 79.
9. Deepalakshmi, A., et al. (2013). "Roadside plants as bio-indicators of urban air pollution." IOSR Journal of Environmental Science, Toxicology and Food Technology 3(3): 10-14.
10. Drezner, T. D. and B. L. Lazarus (2008). "The population dynamics of columnar and other cacti: a review." Geography Compass 2(1): 1-29.
11. Ecormier-Nocca, P., et al. (2021). "Authoring consistent landscapes with flora and fauna." ACM Transactions on Graphics (TOG) 40(4): 1-13.
12. Fontana, V., et al. (2014). "What plant traits tell us: Consequences of land-use change of a traditional agro-forest system on biodiversity and ecosystem service provision." Agriculture, Ecosystems & Environment 186: 44-53.
13. Gafurovna, A. K. and U. Gulmira (2021). "INTRODUCTION AND BIOECOLOGICAL PROPERTIES OF INDIGOFERA (INDIGOFERA TINCTORIA L) PLANT IN THE CONDITIONS OF SURKHANDARYA REGION." Galaxy International Interdisciplinary Research Journal 9(12): 1-3.
14. Gaston, K. J. (2022). "Birds and ecosystem services." Current Biology 32(20): R1163-R1166.

15. Hardy, K. (2016). "Plants as raw materials." Wild harvest: Plants in the hominin and pre-agrarian human worlds: 71-90.

16. Hegazy, A., et al. (2008). "Population dynamics of Moringa peregrina along altitudinal gradient in the northwestern sector of the Red Sea." Journal of Arid Environments 72(9): 1537-1551.

17. Hollósy, F. (2002). "Effects of ultraviolet radiation on plant cells." Micron 33(2): 179-197.

18. Jahan, S., et al. (2013). "Phenology, floral morphology and seed yield in Indigofera tinctoria L. and I. suffruticosa Mill." Bangladesh Journal of Botany 42(2): 231-237.

19. Jman Redzic, S. (2006). "Wild edible plants and their traditional use in the human nutrition in Bosnia-Herzegovina." Ecology of Food and Nutrition 45(3): 189-232.

20. Kremen, C. (2005). "Managing ecosystem services: what do we need to know about their ecology?" Ecology letters 8(5): 468-479.

21. Kupika, O. L., et al. (2017). "Impacts of climate change and climate variability on wildlife resources in southern Africa: Experience from selected protected areas in Zimbabwe." Selected studies in biodiversity.

22. Liancourt, P., et al. (2013). "Plant response to climate change varies with topography, interactions with neighbors, and ecotype." Ecology 94(2): 444-453.

23. Liang, Y., et al. (2006). "Importance of plant species and external silicon concentration to active silicon uptake and transport." New phytologist 172(1): 63-72.

24. Loyola, T. F. R. and R. Dias (2012). "Labeling ecological niche models." Natureza Conservação 10: 119-126.

25. Maksimov, V., et al. (2000). "Determination analysis in ecosystems: Contingencies for biotic and abiotic components." BIOLOGY BULLETIN-RUSSIAN ACADEMY OF SCIENCES C/C OF IZVESTIIA-ROSSIISKOI AKADEMII NAUK SERIIA BIOLOGICHESKAIA 27(4): 405-413.

26. Mano, R. and C. Nhemachena (2007). "Assessment of the economic impacts of climate change on agriculture in Zimbabwe: A Ricardian approach." World Bank Policy Research Working Paper(4292).

27. McGlathery, K. J., et al. (2004). The importance of primary producers for benthic nitrogen and phosphorus cycling. Estuarine nutrient cycling: the influence of primary producers, Springer: 231-261.

28. Mhlanga, L. and I. MAPAURE (1999). "Vegetation Studies of Selected Islands and Adjacent Mainland on Lake Kariba, Zimbabwe."

29. Mhlanga, L. and I. Mapaure (2000). "A floristic classification of shoreline vegetation around Lake Kariba, Zimbabwe." Kirkia: 153-169.

30. Murthy, R., et al. (1996). "Effects of carbon dioxide, fertilization, and irrigation on photosynthetic capacity of loblolly pine trees." Tree Physiology 16(6): 537-546.

31. Norval, R., et al. (1982). "The ecology of Rhipicephalus zambeziensis and Rhipicephalus appendiculatus (Acarina, Ixodidae) with particular reference to Zimbabwe."

32. Nyairo, R. and T. Machimura (2020). "Potential effects of climate and human influence changes on range and diversity of nine fabaceae species and implications for nature's contribution to people in Kenya." Climate 8(10): 109.

33. Opedal, Ø. H., et al. (2015). "Linking small-scale topography with microclimate, plant species diversity and intra-specific trait variation in an alpine landscape." Plant Ecology & Diversity 8(3): 305-315.

34. Osei-Owusu, A. K., et al. (2019). "The global cropland footprint of Denmark's food supply 2000–2013." Global Environmental Change 58: 101978.

35. Salgueiro, L., et al. (2010). "Raw materials: the importance of quality and safety. A review." Flavour and Fragrance Journal 25(5): 253-271.

36. Seneviratne, S. I., et al. (2010). "Investigating soil moisture–climate interactions in a changing climate: A review." Earth-Science Reviews 99(3-4): 125-161.

37. Shaheen, H., et al. (2017). "Ecosystem services and structure of western Himalayan temperate forests stands in Neelum valley, Pakistan." Pakistan Journal of Botany 49(2): 707-714.

38. Sylla, M. B., et al. (2016). "Climate change over West Africa: Recent trends and future projections." Adaptation to climate change and variability in rural West Africa: 25-40.

39. Taylor, S. and L. Kumar (2014). "Impacts of climate change on invasive I. tinctoria L. L. distribution in South Africa." African Journal of Environmental Science and Technology 8(6): 391-400.

40. Valdivia-Carrillo, T., et al. (2017). "Phylogeography and ecological niche modeling of the desert iguana (Dipsosaurus dorsalis, Baird & Girard 1852) in the Baja California Peninsula." Journal of Heredity 108(6): 640-649.

41. Dulloo, M.E., Hunter, D. and Borelli, T., 2010. Ex situ and in situ conservation of agricultural biodiversity: major advances and research needs. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *38*(2), pp.123-135.

42. Kruckeberg, A.R. and Rabinowitz, D., 1985. Biological aspects of endemism in higher plants. *Annual review of ecology and systematics*, pp.447-479.

43. Abensperg-Traun, M., 2009. CITES, sustainable use of wild species and incentive-driven conservation in developing countries, with an emphasis on southern Africa. *Biological Conservation*, *142*(5), pp.948-963.

44. Coelho, N., Gonçalves, S. and Romano, A., 2020. Endemic plant species conservation: Biotechnological approaches. *Plants*, *9*(3), p.345.

45. Surrell, K. 1987. The shore types of Lake Kariba, Zimbabwe. A case study using Landsat MSS. Report from a minor field study. Working paper 47. Swedish University Of Agriculture. Uppsala.

46. Timberlake, J.R. 1995. Colophospermum mopane: Annotated bibliography and Review. The Zimbabwe 'Bulletin of Forestry Research No. 11. Forestry Commission, Harare, Zimbabwe.

47. Timberlake, J. 1997. Sites of interest for Botanical Conservation in the Communal Lands of the Zambezi Valley in Zimbabwe. Unpublished report. Zambezi Society, Harare, Zimbabwe.

48. Timberlake, J. and Mapaure, I. 1992. Vegetation and its conservation in the Eastern mid-Zambezi Valley, Zimbabwe. Transactions of the Zimbabwe Scientific Association. 66, 1-14.

49. Timberlake, J., Nobanda, N. and Mapaure, I. 1993. Vegetation survey of the Communal Lands: North and West of Zimbabwe. Kirkia, 14 (2), 171-272

50. Rao, N.K., 2004. Plant genetic resources: Advancing conservation and use through biotechnology. *African Journal of biotechnology*, *3*(2), pp.136-145.

51. Coelho, N., Gonçalves, S. and Romano, A., 2020. Endemic plant species conservation: Biotechnological approaches. *Plants*, *9*(3), p.345.

52. Vitousek, P.M., 1988. Diversity and biological invasions of oceanic islands. *Biodiversity*, *20*, pp.181-189.

53. Noss, R.F., Platt, W.J., Sorrie, B.A., Weakley, A.S., Means, D.B., Costanza, J. and Peet, R.K., 2015. How global biodiversity hotspots may go unrecognized: lessons from the North American Coastal Plain. *Diversity and Distributions*, *21*(2), pp.236-244.