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IMPACT OF CLIMATE CHANGE ON THE HABITAT OF AESCHYNOMENE GAZENSIS, AN ENDEMIC PLANT SPECIES IN ZIMBABWE.

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Abstract

In this study the impacts of climate change on the habitat of *Aeschynomene gazensis*, an endemic species of Zimbabwe were investigated. The maximum Entropy (Maxent) algorithm in R was used to model the distribution of *A.gazensis*. Occurrence records and bioclimatic variables were used in modelling. Distributions were forecasted under two Representative Concentration Pathways (RCPs), i.e. RCP 8.5 and RCP 6.0 for year 50 and year 70. Models for present projections showed range shrinkage for *A.gazensis*. All models reported acute range constriction, proving that climate change is a major threat to the area of occurrence for the species and might lead to extinction. There is a need to prioritize the species and other endemic species against climate change and protect them from human induced threats which destroy their habitat and exacerbate the extinction rate of the species.

Declaration

I, Mugove Valentine Rwezuva, hereby declare the work contained in this dissertation to be my own. All information that has been obtained from different articles, textbooks or other sources has been consequently referenced. I have not allowed and will not allow anyone to copy my work to pass it off as their own work or part thereof.

Mugove V. Rwezuva	**03/01/2023**
Name	Date

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List of Nomenclature

CBD	Convention on Biodiversity
CHA	Controlled Hunting Areas
CO_2	Carbon dioxide
EMA	Environmental Management Agency
FAO	Food and Agriculture Organization
GBIF	Global Biodiversity Information Facility
IUCN	International Union for Conservation Of Nature
IPCC	Intergovernmental Panel on Climate Change
WMA	Wildlife Management Areas
TFCA	Trans-Frontier Conservation Area
RCP	Representative Concentration Pathway
SDGs	Sustainable Development Goals
UN	United Nations

CHAPTER 1

INTRODUCTION

1.1. Background to the Study

Endemism refers to taxa that are restricted to small ranges, that is, a certain sized area or within several cells within a geographic grid (Bruchmann and Hobohm, 2010). Endemic species are species that exist in a single defined geographic location. It can be as a result of habitat rarity caused by historical factors such as severe destruction by man or the stability of an area during climate change and vegetation type coupled to rainfall. Endemism may occur on a variety of spatial scales either from continents, small islands or mountain tops. Endemic taxa can be classified by their age, origin, distribution and taxonomy, for example autochthonous endemics which are taxa that have evolved in the areas which they are currently being found and neo-endemics which are those that have recently evolved and have not had adequate time to disperse further hence their restriction in distribution (Morrone, 2008).

Climate change is amongst the major threats towards biodiversity and is expected to exacerbate biodiversity losses in the future ((Keith, et al., 2008); Heller and Zavaleta, 2009; Sintayehu, 2018). Endemic plant species are the ones which are more vulnerable to changes in climate due to their limited occurrence since they tend to go extinct in gross temperature rises. Climate change could surpass habitat loss as a result of the ongoing increase of atmospheric carbon posing great danger to biodiversity (Leadley, et al., 2010). Since the 1970s, temperatures have been rising by 0.20°C per every ten years, while the amount of precipitation has grown by 2% globally over the past century (IPCC, 2007). Mean annual temperatures have increased by 0.76° C between 1970-2001 in Lesotho (CCKP). Projected increases in mean annual temperature for the southern African region are 0.8°C, 0.9°C, and to 1.00°C by 2035(IPCC, 2014). Therefore, climate change possess danger towards biodiversity causing extinction of endemic species in the region and globally.

Aeschynomene gazensis is an endemic leguminous plant that occurs in the eastern highlands of Zimbabwe and other southern parts of Africa. This plant has been used as medicine for both livestock and humans (Sahu et al., 2013). The leguminous plant is an endangered species according to the Red Data List as a result of being an edaphic sub climax which occurs on hydromorphic soils. Ecological niche modelling has been widely used in ecology, biogeography, and conservation biology such as conservation of endangered species, selection of natural reserves and influences of climate change on species distribution (Beale & Lennon, 2012; Meynecke, 2004). This study seeks to predict the impact of climate change on the range of *A. gazensis*.

1.2. Problem Statement

According to the IUCN Red Data list, *A.ganzensis* is an endangered endemic species in Zimbabwe and therefore it is considered to be facing extinction in the wild. Recent predictions illustrated that Africa is likely to experience major climate changes during the 21st century with the continent experiencing more dry and warm conditions in the most sub-tropical regions (Pienaar et.al, 2015).This is likely to pose a major threat to the occurrence of the *A.gazensis* species which has a relatively low migration rate, restricted habitat hence high probability of extinction.

1.3. Justification

Due to its restricted range, severely fragmented habitat and the likely impacts of climate change, *A. gazensis* is classified as an endangered and vulnerable species. Therefore, understanding the ecology and factors that limit the distribution of *A. gazensis* is important for conservation efforts. Nevertheless, threats on species do not operate in isolation rather in integration with other threats; hence an understanding of the combined effects of these threats is essential for recommending operative management actions (Klanderud and Birks, 2003).

1.4. Aim

- To predict the impact of climate change on the distribution of endemic species in Zimbabwe.

1.5. Objectives

- To determine the current suitability of *A.gazensis* in Zimbabwe,
- To predict the impact of climate change on the habitat and distribution of *A.gazensis.*

1.6. Research Questions

- What is the current suitability of *A.gazensis* in Zimbabwe?
- How will climate change impact the habitat and distribution of *A.gazensis*?
- What are the factors that determine the distribution of *A.gazensis?*

CHAPTER 2

LITERATURE REVIEW

2.1.Conservation status of endemic species

Currently, the world faces a global challenge of biodiversity loss. The wildlife extinction rates are now 1000 times greater than historical levels and future rates are projected to increase significantly (Kraus, Enns, Hebb, & Murphy, 2022). Globally, over 40,000 species are now assessed as threatened (International Union for Conservation of Nature) and up to one million species are at risk of extinction in the coming decades. Of the 938 extinct species and infraspecies, 93.8% are nationally endemic and 61% are confined to islands(Kraus, Enns, Hebb, & Murphy, 2022).Presently, different international organizations worldwide are dedicated to the identification, study and preservation of endemic species to prevent their disappearance and generate a global awareness regarding their importance for ecosystem balance (Morrison, 2021)

Global efforts have been made to enlist and recover endangered wildlife for over half a century starting with the first International Union for Conservation of Nature (IUCN) list of threatened species published in 1964 (Scott, 1965). The goal of many global conservation efforts is extinction prevention including the Convention on Biological Diversity (CBD) (Aichi Biodiversity Target 12) (UN, 1992), the United Nations Sustainable Development Goals (Target 15.5) (UN, 2018) and the draft post-2020 Global Biodiversity Framework (Target 4) (CBD, 2022).Countries like Canada have generated comprehensive inventories of nationally endemic species through reports from the IUCN Red List of threatened nationally endemic species and national endemism is queried through some taxon databases e.g.,(Beech, Rivers, Oldfield, & Smith, 2017). The inventory is dynamic and will continue to be refined (McMullin & Kraus, 2021) to support conservation efforts. It is prepared in an Excel spreadsheet and is used to develop metrics on the numbers of nationally endemic species by taxonomic group, province and territory, and conservation status. The inventory is used to clarify and focus on national conservation actions and reporting on global priorities including nationally endemic species, support decision-making and resource-allocation on threatened species by governments and conservation organizations.

In the African continent, there have been strides to preserve endemic species. The Eastern Arc mountain region in Tanzania has been identified as one of the top 25 biodiversity "hotspots" worldwide, and contains a large proportion of endemic species. Losses in biodiversity in Eastern Arc have been largely attributed to the use of fire and the clearing of forests for agriculture, which have increased dramatically in the past century (Burgess, et al.). The need for action in this region has been recognized by many international organizations, such as Conservation International and the World Wildlife Fund. The current efforts in the Eastern Arc regarding conservation are minimal and in need of more oversight and ideas about how to best preserve the remaining biodiversity.

Also, in Botswana a country in southern Africa, there have been measures put in place to conserve biodiversity in the country. The country has set aside 45% of its land area as protected areas which include national parks, game reserves, private wildlife and nature reserves, Wildlife Management Areas (WMAs), Controlled Hunting Areas (CHAs), forest reserves and national monuments. The national parks, game reserves, WMAs and CHAs are governed by the provisions in the Wildlife Conservation and National Parks Act, 1992. The Ministry of Youth, Sport and Culture through the National Museum, Monuments and Art Gallery are responsible for a number of botanical monuments. Botswana has one designated Ramsar site, covering the Okavango Delta, and one World Heritage Site, the Tsodilo Hills, which are protected through the management standards attached to Ramsar and World Heritage Site listings respectively.

In Zimbabwe, there is well- crafted legislation aimed towards protecting biodiversity through the Environmental Management Act under the Environmental Management Agency. Zimbabwe is also a signatory to several international conventions such as the Convention of Biodiversity (CBD) which vouches for the conservation of biodiversity. The Parks and Wildlife Management Act under Zimparks and Wildlife, distinguish plant and animal species that are considered to be threatened and prohibit their destruction by creating conservation areas to ensure efficient conservation e.g. the Trans-Frontier Conservation Area (TFCA) in the Eastern highlands. The mines and minerals act recognises the severe impacts associated with mining on the environment and has clear procedures that need to be followed in order to undertake prospecting and mining in the country. The water act regulates the use of water and controls the discharge of effluent into water bodies to reduce pollution rates.

2.2.Impact of climate change on plant species

The world is undergoing an extinction crisis, the most rapid loss of biodiversity in the planet history with climate change being the major drivers of extinction. Variation in temperatures and precipitation regimes will result in altered breeding times of species and shifts in distributions.

Changes in rainfall patterns and average global temperatures will surpass the resilience of many ecosystems due an unprecedented combination of change in climate and increased greenhouse gas emissions (IPCC, 2007).By 2100, ecosystems will be exposed to atmospheric CO_2 levels substantially higher than in the past century and global temperatures will be highest altering the structure, reducing biodiversity and perturb functioning of most ecosystems, and compromising the services they currently provide (Parry, Canziani, Palutikof, van der Linden, & Hanson, 2007). Climate change mostly affects endemic species which occur in confined habitats. Changes in the allocation and abundance of plant communities and habitat types have been widely observed with a growing global body of evidence that species and ecosystems are already altering due to climate change (Kaesli, Redmond, & Nigel, 2012). In the tropics, some changes are more noticeable in montane regions, where vegetation zones may be shifting upwards as temperatures rise. In Costa Rica, for example, changes in precipitation attributed to climate change have been linked, along with an epidemic fungal disease, to catastrophic declines in the populations of amphibian and anoline lizards (Kaesli, Redmond, & Nigel, 2012).

In addition, climate change also affects the species distribution, composition and interactions. The distribution of species is determined by temperature, rainfall, geographical barriers and other ecological factors. With each season's isotherms moving north in the northern hemisphere and south in the southern hemisphere, animal and plant species as well follow their optimum conditions, assuming there is space to move to and the species is capability to migrate. Motile animal species can migrate as their optimum ecological conditions move. Although sessile animals and plants are unable to migrate, the distribution of those with relatively short life-cycles will also advance along a front as natural selection favours those along the leading edge of changing conditions and reduces the survival rates of those living at the sub-optimal edge of their moving habitat.

Plant species which have very slow maturation time and a constricted optimum temperature range might not survive if the speed of climate and associated ecological changes exceeds their life-cycle. Seedlings at the leading edge might grow but not reach reproductive age before rising temperatures bring suboptimal conditions to bear. Vegetation zones around mountains are likely to move upwards in response to rising temperatures, assuming rainfall is not greatly affected and this leads to the extinction of endemic species that are adapted to conditions on isolated mountaintops. Given that temperature influences the timing and success of breeding, migration and species distribution, it is very likely that climate change is the driving factor behind these shifts.(Brommer, 2004).

Climate change is also responsible for the augmented incidence and severity of wildfires. Temperature, in particular, as well as atmospheric moisture, wind, drought and lightning, all have a strong influence on the occurrence of wildfires (BC Ministry of Forests & Range Wildfire Management Branch. , 2009). These will occur especially in areas where they are already a major threat: southern Africa, the Americas, Australia and parts of Europe (France, Italy, Portugal and Spain) (Bosomworth, 2007). Fires are not only becoming more intensive and more frequent but are also likely to spread into ecosystems that have not traditionally caught fire. Ecosystems that have not adapted to fire will suffer greater and longer-lasting damage. Annually, fires consume millions of hectares of the world's forests, causing the loss of biodiversity and human and animal lives(FAO, 2006).However, some forest and grassland ecosystems have evolved positively in response to frequent fires due to natural and human causes, maintaining their dynamic equilibrium and high biodiversity; others are negatively affected, resulting in the destruction of the forests or long-term site degradation(Goldhammer, 1999).

CHAPTER 3

MATERIALS AND METHODS

3.1. Acquisition of occurrence data

Occurrence data used for this study were obtained from the Global Biodiversity Information Facility (GBIF). The species under study was searched on the GBIF platform for occurrence. Duplicate records were removed using R while ensuring that outliers were removed as well. A total of 245 locations with *A.gazensis* occurrence were presented on GBIF after the search. Data cleaning was done and occurrence records with geo-referencing errors were removed using positional precision and spatial filters. The occurrence points with valid and useful information were reduced to 30 for *A.gazensis.*

3.1.1. Software Used

Ecological niche modelling experiments were performed using R (Version 1.4.1717) software and R studio (Version 1.4.1717). The first stage of data analyses was downloading several library packages into R, namely the raster, rgdal, maps, map data, dismo, rJava, maptools and the jsonlite packages. The downloaded library packages were installed in R and were called to create plots for the called packages.

3.1.2. Environmental Variables and Climate Change models

Bioclimatic and altitude data at a resolution of 2.5 arc seconds of latitude and longitude were obtained from the (WorldClim) database. Specific bioclimatic variables likely to influence species distribution were downloaded directly into R using the 'get Data ()' function from the 'raster, package. The most influential variables in determining the future distribution of this species include bio 5 (maximum temperature of the warmest temperature), bio8 (mean temperature of the wettest quarter), bio 17 (Precipitation of the driest quarter) and bio 18 (precipitation of the warmest quarter).The study assessed changes in suitable habitat ranges in the years 2050 and 2070 climate conditions under RCP6.0 and RCP8.5. The areas of suitability changes for the current and future were analysed under two categories to identify the areas of suitable and none suitable. It is shown that in the RCP6.0, the habitat grows fragmented and will continue to fragment due to increased temperature rises which leads to extinction of the *A.gazensis* species in Zimbabwe.

Table 1: Bioclimatic variables **(**Dupin, 2011**)**

Bio01	Annual Mean Temperature	T
Bio02	Mean Diurnal Range (Mean of monthly (max temp – min temp))	T
Bio03	Isothermality$\left[\left(\frac{Bio02}{Bio07}\right) \times 100\right]$	T
Bio04	Temperature Seasonality (Standard deviation $\times$ 100	T
Bio05	Max temperature of warmest month	T
Bio06	Min temperature of coldest month	T
Bio07	Temperature annual range (Bio05 – Bio06)	T
Bio08	Mean temperature of wettest quarter	T + R
Bio09	Mean temperature of driest quarter	T + R
Bio10	Mean temperature of warmest quarter	T
Bio11	Mean temperature of coldest quarter	T
Bio12	Annual precipitation	R
Bio13	Precipitation of wettest month	R
Bio14	Precipitation of driest quarter	R
Bio15	Precipitation of seasonality (Coefficient of variation)	R
Bio16	Precipitation of wettest quarter	R
Bio17	Precipitation of driest quarter	R
Bio18	Precipitation of warmest quarter	T + R
Bio19	Precipitation of coldest quarter	T + R

3.2.Species Model

The 11 bioclimatic i.e. (bio1, bio 5, bio 6, bio 7, bio 8, bio 9, bio 12, bio16, bio 17, bio 18 and bio 19) variables considered to influence the occurrence of the endemic plant species were downloaded directly into R using the 'getData ()' function. The data was then run in R to acquire the plots from the called packages. After this, the Species Distribution Model using the Maximum Entropy (Maxent) algorithm was fit into R to see the combination of climatic variables which best predict the occurrence of the species. The outcome was then used to compare the importance of the different variables in the final model. To see how the species would respond to variations in each climatic variable, response curves were constructed using the model through the ‘response ()’ function. Finally, in order to map the predicted probability of species occurrence, predicted values using the response curves were generated for every cell in the buffered region using the ‘predict ()’function and superimposed to the original occurrence locations.

CHAPTER 4

RESULTS

4.1.Occurrence and current suitability of *A.gazensis*

Aeschynomene gazensis is dominant in the Eastern Highlands of Zimbabwe along the Mozambican border (Figure 1a, b).

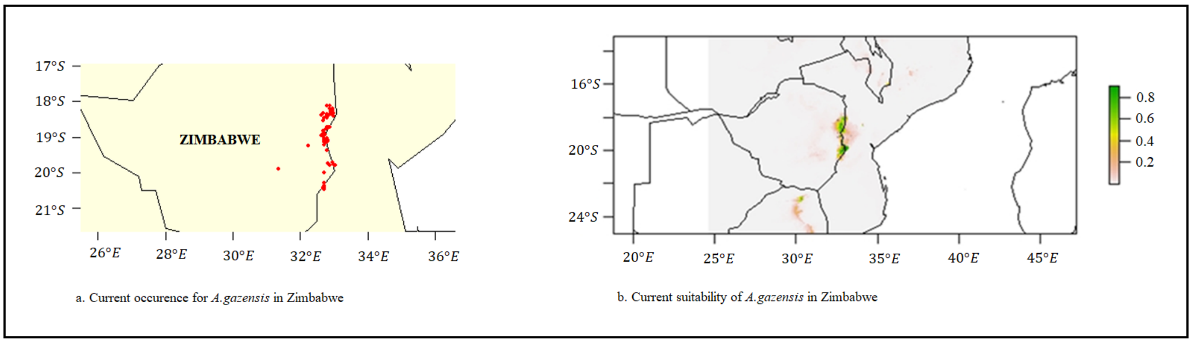

Figure 1: (a) Occurrence and (b) current suitability of *A.gazensis*

4.2. Predicted future distribution models under RCP2.6

The suitability of the habitat to the species becomes substantially reduced from year 50 to year 70 (Figure 2).

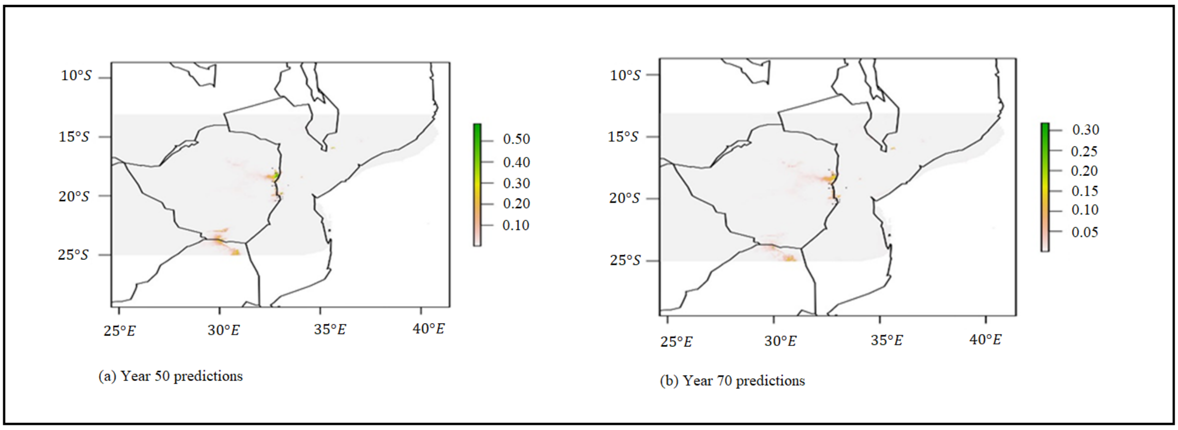

Figure 2: Predicted habitat suitability for *A.gazensis* under the RCP 2.6 model.

4.3. Predicted future distribution models under RCP 8.5

The occurrence of *A.gazensis* is projected to decline from year 50 to year 70 as a result of the continued gross environmental changes in the habitat (Figure 3). In the event that the environmental variables continue to change the species will eventually die off and go extinct.

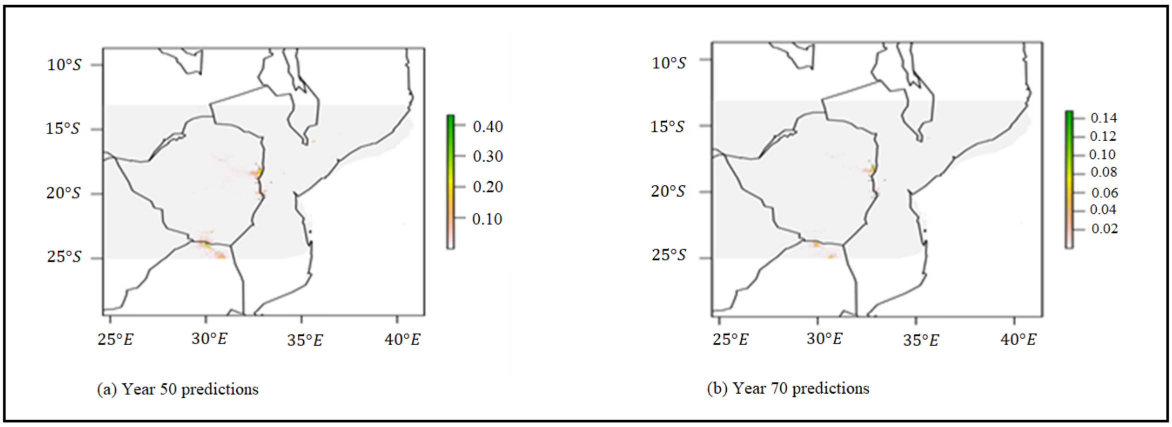

Figure 3: Predicted habitat suitability for *A. gazensis* under the RCP 8.5 model.

4.4. Factors determining contribution

5. The most influential variables in determining the future distribution of *A. gazensis* are bio 5 (maximum temperature of the warmest temperature), bio8 (mean temperature of the wettest quarter), bio 17 (Precipitation of the driest quarter) and bio 18 (precipitation of the warmest quarter (Figure 4).

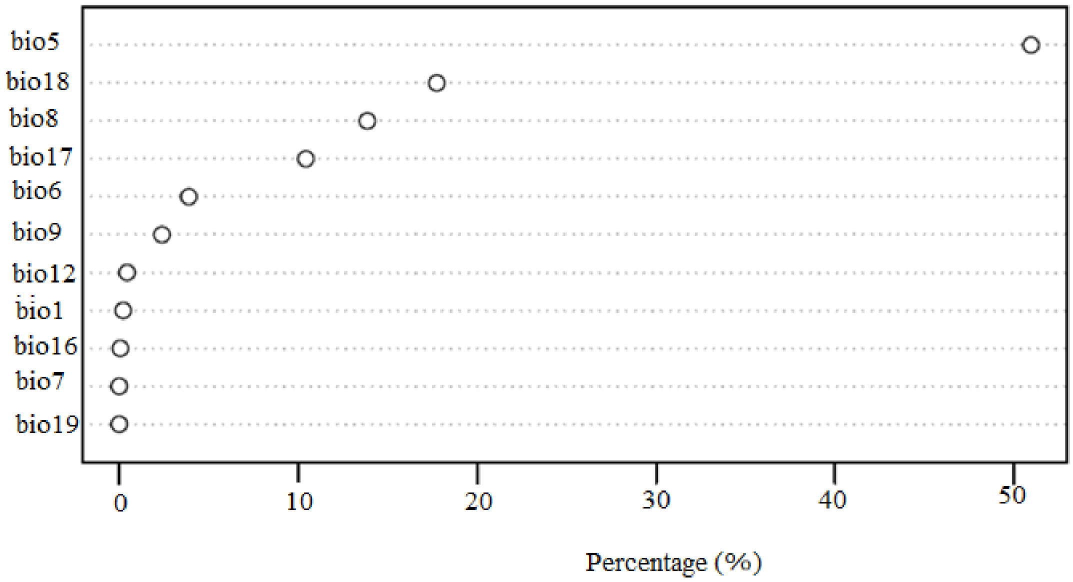

Figure 4: Bioclimatic variables affecting the distribution of *A.gazensis*.

CHAPTER 5

DISCUSSION

The current suitability of *A.gazensis* modelled in this study indicated that the species thrives in the eastern highlands of Zimbabwe. The wet climatic conditions characteristic of this region makes it suitable for this species. As a result, the habitat for *A.gazensis* restricted to this area characterised by high rainfall, heavy mists and dew from the moisture laden air moving inland from the Indian Ocean.

Ecological niche modelling of *A.gazensis* showed that the species will seriously be seriously be affected by climate change with a strong possibility of the species being threatened by extinction. The threat posed by climate change to *A.gazensis* is high under both RCP 2.6 and 8.5, thus it doesn't matter whether the current levels of greenhouse gas emissions continue to rise or decrease, and the species will still be seriously affected in the next few decades.

Specifically, the habitat for *A.gazensis* is projected to decrease under either intense carbon emission situation (RCP8.5) or reduced emissions (RCP2.6). Studies have shown that suitable habitats become scarce in the near future as weather change impacts rise in severity and intensity, thereby threatening species population (Keith, et al., 2008).

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1. Conclusions

This study showed a restricted habitat for *A.gazensis*, which is consistent with endemic and threatened species. Ecological niche modelling further showed that the habitat of *A.gazensis* will continue to shrink going into the future as climatic conditions become dryer and warmer, putting the species under heavy stress, increasing the probability of the species becoming extinct.

6.2. Recommendations

Given the current and future threats of climate change on *A.gazensis*, it is recommended that a conservation strategy for this species and other endemic and endangered species be put in place to avoid the species going extinct. It is also recommended that similar studies be conducted on other endemic species in order to have a full understanding on how such species will be affected by climate change. This will help conservationists to come up with a holistic conservation strategy for all endemic species in Zimbabwe.

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