

Research Article

Modeling the impact of climate change on the distribution of *Hagenia abyssinica* in EthiopiaTsegaye Gobezie ^{1*}, Silesh Namomissa ² and Tamrat Bekele ³,¹ Department of Forestry, College of Agriculture , Wollo University, Ethiopia, email:

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Abstract: Research Highlights: *Hagenia abyssinica* is geographically localized, poor regenerated and endangered species in Ethiopia. Ethiopia has been experiencing variability of rainfall and rise in temperature due to the climate change. This study has hypothesized that the suitable areas for the species will be narrowed by the year 2070. **Background and Objective** The prediction of species distribution models help to implement appropriate conservation actions. The aim of this research was to identify the current and likely future distribution range and suitable areas for the species, and to determine the presence of *H. abyssinica* in risk in a short-term future. **Material and method:** To this end, occurrence data, bioclim variables, soil, elevation, and land cover map of Ethiopia were used. MaxEnt was used to predict distribution. Climate change impacts on the distribution of the species was performed using bioclimatic variables of the future climate data, 2070 (average for 2061-2080) was obtained from IPPC5 (CMIP5) at 30 seconds (1km) spatial resolution. The climate data was projected from GCMs, downscaled and calibrated using rcp4.5. **Results:** Both current and likely future distribution models were excellent and significantly better than random performance. This study has computed 59987 km² to be the low impact area for the species under current conditions and will remain habitat under future climates and 39025 km² area has been identified as the possible high impact areas or declining habitat. The model has also determined that 1238724 km² of the areas are unsuitable at present and for future climates. The current study found that 15751 km² of the area will be modified as a new suitable area for *H. abyssinica* due to climate change. **Conclusion:** Species distribution modeling is essential for the implementation of conservation actions that are compatible with the inevitable changing climatic conditions of the country.

Keywords: Climate Change; Ethiopia; *Hagenia abyssinica*; MaxEnt; Species Distribution Model

1. Introduction

Ethiopia has been experiencing variability of rainfall and rise in temperature due to the climate change [1]. Climate change has affected biodiversity [2]. Climate Change has aggravated insect pests' infestations [3], delay in fruits maturity, and poor survival of seeding [4] . Climate change are believed to be a persistent challenge jeopardizing further intervention activities to be carried out to improve the adaptation and survival of tree species in Ethiopia.

Species distribution modeling extrapolates species distribution data in space and time, usually based on a statistical model [5]. Varieties of statistical methods are available [6]. Recently, in a statistical explanation of MaxEnt for ecologists, the study has shown that MaxEnt is an appropriate option for ecological studies. This method has gained great interest by those working in

comparisons as it has shown higher predictive accuracy than many other methods when applied to “presence-only” data [5].

Many ecologists have conferred that global warming trends are modifying the species distribution [7,8]. Numerous studies globally have explained the response of the species to climate change (Cusick et al. 2007). So that, detailed knowledge of species' ecological and geographic distributions is fundamental for conservation planning [9].

The study species, *Hagenia abyssinica* is geographically localized, poor regenerated and endangered species in Ethiopia. The species has shifted its natural range during postglacial re colonization [10]. The species is one of the venerable tree groups under climate change [11]. So that, this study is conducted to predict the impact of climate change on *H. abyssinica* tree species in Ethiopia. This study has hypothesized that the suitable areas for the species will be narrowed by the year 2070. The research questions were: (i) what are the current and likely future distribution range and suitable areas for the species, and (ii) is *H. abyssinica* in risk in a short-term future due to climate change. This information helps to implement appropriate conservation actions.

2. Materials and Methods

2.1 Description of Study Area

Ethiopia is the most elevated part of Northeast Africa. The highlands (>1500 meter above sea level) constitute around 45% of the total area of the country. The altitude ranges from the highest peak at Ras Dashen (4620 meter above sea level), in Northern Ethiopia, down to the Danakil depression (120 meter below sea level), one of the lowest dry land points on the earth, in the Northeast part of the country.

2.1.1 The study tree

Hagenia abyssinica is a wind-pollinated and wind-dispersed dioecious (or polygamous) tree species that belongs to a monotypic genus in the Rosaceae family [12]. Flowering and seeding are observed all over the year with pick in the months with the coldest temperatures [13]. It is native to Ethiopia and found between 2450-3250 masl, in the vegetation region of Ethiopia. Rural communities relied on for generations to treat for various ailments, used as construction, furniture, and fuelwood [14]. Through its enormous importance, the species is one of the endangered tree species in Ethiopia because of over utilization [15]. The study species is geographically localized, poor regenerated and endangered species in Ethiopia. The species has shifted its natural range during postglacial re colonization [16].

2.2 Data Sources

2.2.1 Occurrence data

In this study, we covered all known *H. abyssinica* niches in Ethiopia. The information from ecological sampling, records from national herbarium of Ethiopia, and publishes materials [16] were used to identify the niches. From the study sites, 560 representative occurrence points at a distance of ranging from 2 to 5 km far apart were collected. This sampling approach helps us to avoid duplication of sample records [17].

2.2.2 Environmental variables

Current climatic data was obtained from WorldClim 1.4 database at 1 km spatial resolution. The 19 Bioclimatic variables, the interpolated of global climatic data such as average and seasonal temperature and precipitation records from the year 1960 to 2000 was used. Those variables are more directly related to the physiologic aspects of plant growth [18].

Future climate data was obtained from IPCC5 (CMIP5) at 30 seconds (1km) spatial resolution (WorldClim .org. /cmip5_30s). The climate data was projected from General Circulation Model, downscaled and calibrated (bias corrected) using WorldClim 1.4 as baseline 'current climate', rcp45 green gas scenarios. Then, the future climatic condition, 2070 (averaged for 2061-2080), was used for modelling the impact of climate change on species' distribution.

The soil data was obtained from the global soil database using the following port: <http://www.grid.unep.ch/data/data>. The soil texture from this database has been commonly used for species distribution modeling [19].

2.3 Selection of Species distribution modeling

Two types of analysis software were used, namely, MaxEnt and DIVA-GIS software [20]. MaxEnt helps to predict the potential distribution of a species under current and future climatic conditions, and DIVA-GIS to examine the impact of climate change on the species.

Today, many modeling tools are available [21]. In light of an increasing number of modeling methods, selection and utilization of a model is indispensable [22]. MaxEnt is an appropriate option for ecological studies. It has higher predictive accuracy than many other methods when applied to “presence-only” data [5].

2.4 Model Building and Evaluation

For this study, the MaxEnt V 3.2.0 [23] was used to run species distribution model. The model was built in accordance with the procedure used by [23]). For this study, 75% of the occurrence localities selected randomly was used as training data and the remaining 25% reserved for testing the validity of the models. The 560 number of occurrence records helps to reduce the sampling bias [24], therefore, the 10 percent threshold value selected. Duplicate presence points in one raster cell were removed from the analysis to reduce sampling bias [18].

Jackknife tests of variable importance were used to identify the performance of each variable in the models [25]. The predictive performance of specie distribution models was evaluated using AUC value. The values can range from 0.5 to 1.0. The AUC value closest to one is interpreted as the model performance is excellent [5].

2.5 Methods used to examine the impact of climate change on a species distribution

The assessment of the impact of climate change on the species distributions was performed by comparing the potential distribution areas in the current climate conditions with the future potential distribution areas based on a species' current climate preferences and future climatic conditions following [18].

Binary raster maps under the current climate and future projection were generated in MaxEnt, the outputs imported to DIVA-GIS to examine the impact of climate change on a species distribution, the pixel values re-classed and then the overlaying of future likely distribution on the current potential distribution map as outlined in [18].

DIVA-GIS was used to classify the study area into four kinds depending on the level of climate change impacts. The area was classified as (1) high impact areas, areas where a species potentially occur in the present climate but which will not be suitable anymore in the future, (2) areas outside of the realized niche, (3) low impact areas, areas where the species can potentially occur in both present and future climates, and (4) new suitable areas, areas where a species could potentially occur in the future climate.

3. Results

3.1 Distribution of *Hagenia Abyssinica*

Fig. 2 shows the representation of the MaxEnt model for *Hagenia abyssinica*. In this model, warmer colors show areas with better-predicted conditions. White dots show the present locations used for training, while violet dots show test locations.

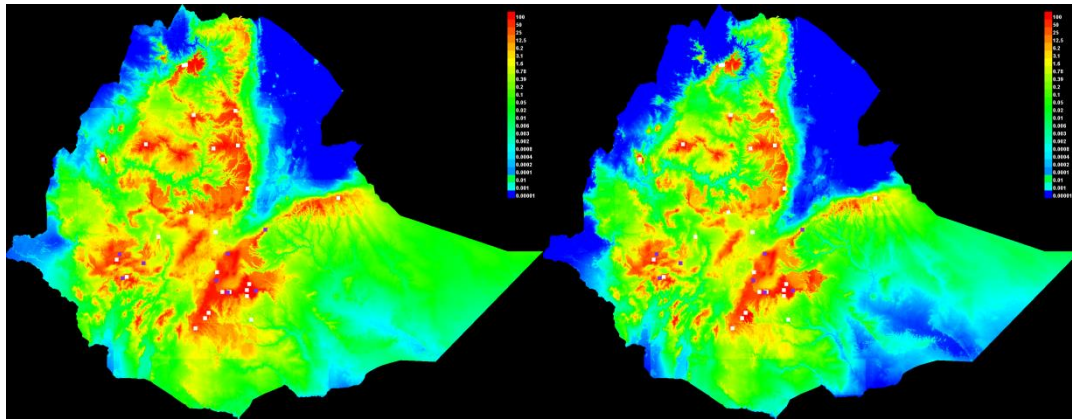


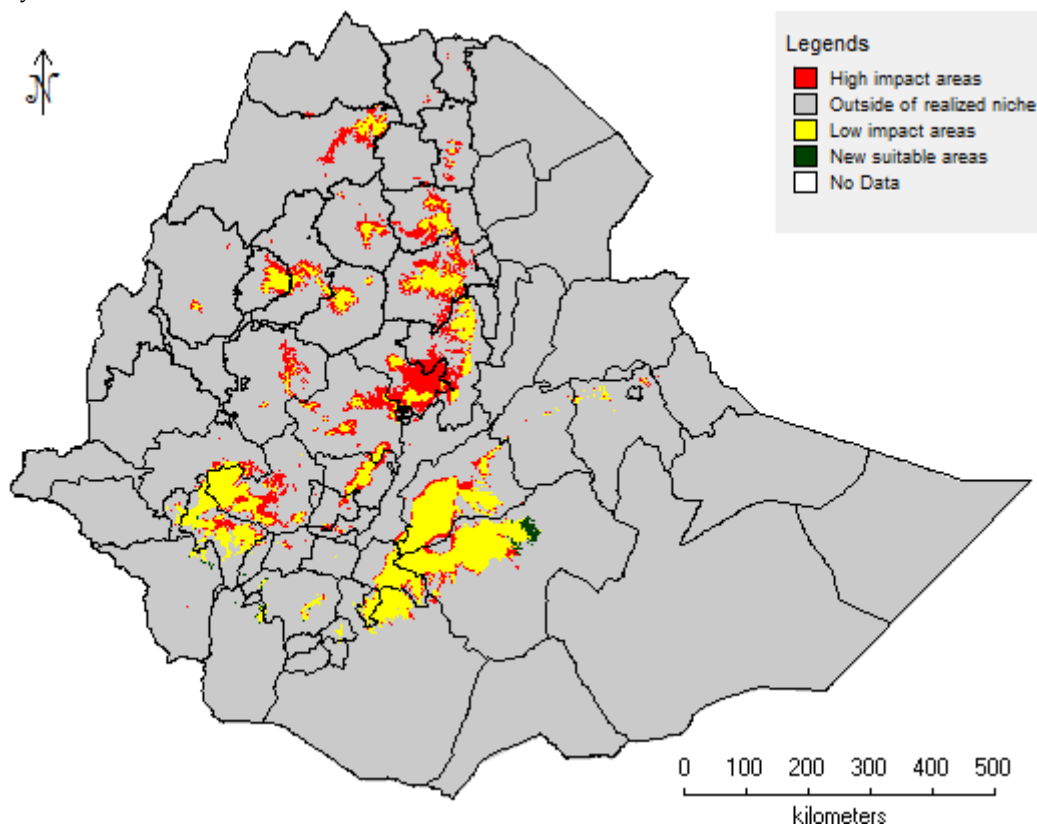
Figure 1 Distribution of *Hagenia Abyssinica* current (left side) and future (Right side) in Ethiopia

The highlands of Arsi, Sidama, Jima, South Wollo, North Wollo, Southern Tigray, North Gonder, Awi, East Gojam, West Shewa, Keffa, and East Harerghe. These areas were predicted to be potentially suitable for the species under the current climatic condition (1960-2000).

In contrast, the model has also represented those lowland areas of the country such as Afar, Gambela, South Omo, Somali, and North Gonder (Metma) that were poorly predicted for the survival and adaptation of *Hagenia abyssinica*. These are categorized as areas outside the realized niche of the species.

3.1 Modeling the Impact of Climate Change on *Hagenia abyssinica* Distribution

The red color indicated high impacted areas due to climate change (Fig. 6). The newly suitable areas such in Bale zone (Ginir, Goro and Gololcha Districts) and Benchi Maji zone (Meanit Goldiya District) are expected to be suitable for *H. abyssinica* occurrence due to the climate change expected by the year 2070.



The majority (93%) of the areas in Ethiopia were found outside of the realized niche for the species, whereas about 2.9% and 4.4% of areas were predicted as high and low impact areas, respectively (Table 1). On the other hand, 0.12% (1578 km²) area was identified as the new suitable for the adaptation of the species in the future due to the inevitable climate change predicted to occur in the area.

Table 1 Range of impact of climate change on *Hagenia abyssinica*

Range	Area (km square)	Percentage
High impact areas	39025	2.91%
Outside of realized niche	1238724	92.49%
Low impact areas	59987	4.48%
New suitable areas	1578	0.12%

4. Discussion

4.1 Distribution of *Hagenia Abyssinica* under Climate Change

The model has predicted four levels of climate change impacts: high impact areas, new suitable areas, area outside of the realized and low impact areas on *H. abyssinica* populations. Among the studied populations, *H. abyssinica* populations of North Shewa Zone (Wuchale district); North Wollo Zone (Meket and Guba Lafto districts); South Wollo Zone (Desie Zuria District); West Shewa Zone (Adda Berga District); North Gonder Zone (Janamora District); Southern Tigray Zone (Ambalage District and Ofla districts); Central Tigray zone (Degua Temben District) and Metekel Zone (Dangur District) were found to be highly affected by climate change. These results seem to be consistent with other research which found 25–41% of the currently suitable area for the African plant species would be became not suitable by the year 2085 (Lovett et al. 2005).

Collect germplasm before existing stands disappear under the prevailing climate changes and improving the connectivity between fragmented populations to ensure gene flow of adaptive genes was the general recommendation to safeguard the extinction of endangered species in an area (Hijmans et al. 2012). An alternative viable option to would be facilitating their migration or transfer to a newly suitable area such as in Bale zone (Ginir, Goro and Gololcha District), and Bench Maji zone (Meanit Goldiyya District) as these areas are predicted to be suitable for the climate change expected by the year 2070 for *Hagenia abyssinica*.

The model has also predicted that the majority of the land mass in Ethiopia would be outside of the realized niche zone; whereas, about 2.9% and 4.4% of the country's land mass is expected to be high and low impact areas, respectively. On the other hand, 0.12% (1578 km²) area will become the new suitable area due to the predicted climate change. Hence, the fate of this species remained highly restricted in some portion of the country. Therefore, maintenance of *Hagenia abyssinica* population in the existing area and introducing it to a newly suitable area is crucial for safeguarding these endangered species from extinction.

5. Conclusions

MaxEnt species distribution model was used to assess current and the likely future distribution range of *H. abyssinica* population in Ethiopia. The parameters used for evaluating the predictive ability of the models' generated by MaxEnt was the Area Under Curve (AUC) evaluated and the red (training) line showed a higher AUC than the blue (testing) line. Hence, the red line showed the “fit” of the model to the training data that indicated the real test of the models predictive power. Moreover, the blue line does not fall below the turquoise line then this indicates that the model performs better than a random model.

The current and likely future distributions of *H. abyssinica* were predicted and the required information was presented in the form of maps. However, the maps comprised only qualitative information whereas, quantitative information regarding current conditions and likely future distribution is very vital for stakeholders in setting conservation action.

The probability distribution of *H. abyssinica* modeled by the MaxEnt program appeared to be a reliable and stable model based on the diagnostic tests conducted within MaxEnt. This analysis predicted the potential distribution of *H. abyssinica*.

The model also identified where suitable environments for the species are likely to occur under climate change. The suitable areas for the species will be narrowed by the year 2070 with shifting to other suitable areas due to the influenced climatic variables mainly temperature and precipitation. This study has quantified about 59987 km² area as the low impact area for the species under current conditions and will remain habitat under future climates; 39025 km² area has been identified as the possible high impact areas or declining habitat due to climate change. The model has also determined 1238724 km² as areas that are unsuitable now and under future climates. The current study found that 15751 km² of the area will be modified as a new suitable area for *H. abyssinica* due to climate change.

Finally, the information regarding assessing trends towards identification and prediction of the potential, current, and future species distribution of the species is essential for the implementation of conservation actions under the changing climatic conditions of the country.

List of abbreviations:

AUC = Area under curve; MaxEnt = Program for maximum entropy modeling of species' geographic distributions; bio1 to bio 19 = indicates different bioclimatic variables; rcp= Representative concentration pathways.

Authors' contributions: design of the study, data collection, data analysis and interpretation, and drafting the article performed by the first author. The co-authors were research supervisor for first author

Funding: This study was funded by Wollo University and Addis Ababa University as a PhD research grant to the first author

Availability of data and material: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of interests: The authors declare that they have no conflict of interest.

Acknowledgements: The authors are grateful to the staff members of The National Herbarium, Ethiopia for their support during species identification.

Conflicts of interests: The authors declare that they have no conflict of interest. Authors' contributions: design of the study, data collection, data analysis and interpretation, and drafting the article performed by the first author. The co-authors were research supervisor for first author

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