ADDIS ABABA UNIVERSITY

GRADUATE PROGRAMS

COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES

DEPARTMENT OF PLANT BIOLOGY AND BIODIVERSITY MANAGEMENT

The Ecology of *Helichrysum splendidum* and *Festuca macrophylla* in the Menz-Guassa Community Conservation Area and Their Future Distribution under Climate Change in the Central Highlands of Ethiopia

Shambel Alemu Chengere

Addis Ababa University

ADDIS ABABA, ETHIOPIA

JANUARY 2024

THE ECOLOGY OF *HELICHRYSUM SPLENDIDUM* AND *FESTUCA MACROPHYLLA* IN THE MENZ-GUASSA COMMUNITY CONSERVATION AREA AND THEIR FUTURE DISTRIBUTION UNDER CLIMATE CHANGE IN THE CENTRAL HIGHLANDS OF ETHIOPIA

Shambel Alemu Chengere

A thesis presented to the Department of Plant Biology and Biodiversity Management, Addis Ababa University, in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Plant Biology and Biodiversity Management

Addis Ababa University

Addis Ababa, Ethiopia

January 2024

ADDIS ABABA UNIVERSITY

GRADUATE PROGRAMMES

Declaration

This is to certify that the dissertation prepared by Shambel Alemu Chengere, entitled: "**The Ecology of *Helichrysum splendidum* and *Festuca macrophylla* in the Menz-Guassa Community Conservation Area and Their Future Distribution under Climate Change in the Central Highlands of Ethiopia**" and submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy in Plant Biology and Biodiversity Management complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

Name	Signature	Date

Advisor: Bikila Warkineh (PhD) Signature__________________ Date ____________

Advisor: Sileshi Nemomissa (Prof.) Signature________________ Date ____________

Examiner: ______________________ ( ) Signature___________ Date____________

Examiner: _____________________ ( ) Signature____________ Date____________

____ _______________

Chair of Department or Graduate Program Coordinator

DEDICATION

This dissertation is dedicated to the local people of Guassa who maintained and sustainably used their rich Conservation Area, the Guassa grass, despite the tremendous environmental and socio-political changes that took place over the years.

Figure 1. Partial view of *Festuca* grassland in the Guassa area (Photo: Shambel Alemu, 2020).

“ጓሳ ልብሴ፣ ጉርሴ፡ *Guassa Libse, Gurse*” another local community explained to me that Guassa grass means “EVERYTHING FOR THEIR LIFE” which provides several important ecosystem goods and services that classical economic markets fail to quantify.

ACKNOWLEDGEMENTS

First and foremost, it gives me a great pleasure to express my gratitude to my supervisors Dr. Bikila Warkineh and Prof. Sileshi Nemomissa for their unreserved guidance, undoubted support, and effective follow-up of the research work, comments and detailed reading and correcting of all the manuscripts to this end. My heartily acknowledgment goes to my research collaborators Dr. Cara Steger (Cornell University, Ithaca NY, USA) and Dr. Kflay Gebrehiwot (Samara University, Semera, Ethiopia). I would like to present my heartfelt thanks to all of you who continually followed me with your kind approaches, encouragement, patience, commitment, and confidence during this research work.

I would like to heartily acknowledge Addis Ababa University for sponsoring my PhD study. Especially, I would like to extend my deepest thanks to my department, Plant Biology and Biodiversity Management and the Graduate Programs of Addis Ababa University for covering the field work costs obtained from the thematic research project.

I would like to extend my deepest gratitude to all staff members of my Department (Plant Biology and Biodiversity Management) and the National Herbarium (ETH) colleagues; Dr. Ermias Lulekal, Dr. Wondwosen Tena, Prof. Zerihun Woldu, Dr. Debissa Lemessa, Prof Sebsebe Demissew, Dr. Awol Assefa, Prof. Zemede Asfaw, Mr. Habtamu Chekol, Mr. Mekbib Fikadu, Mr. Melaku Wondafrash, W/o Shewangziw Lemma, Mr. Wege Abebe, Tesfanesh Fiseha, Mr. Fiseha Getachew, Yirgalem H/silassie and Anteneh Mulat for their kindly approach, checking my progress, encouraging me to complete this work and for their cooperation in all aspects of the herbarium work.

I would like to express my special thanks to Prof. Monica Liliana Marian and Claudia Liliana Marian for their warm welcoming, hospitality and all rounded supports during my stay in Baia Mare, Romania, through Erasmus^{+} student exchange program and Royal Botanic Garden, Kew, London, UK, where I spent manuscript preparation and writeup activity of this dissertation.

I also want to send my friendship thanks to all my colleagues who have spent years in attending PhD program with me. Specially, Arayaselassie Abebe (Dr.), Zerihun Taddesse, Tibebu Inkosa (Dr.), Wondiye Kebede, Metshet Yinebeb (Dr.), and Eyob Tenkir would be duly acknowledged for their encouragement and provision of ideas during whole walks of my study.

I am thankful to the local community members of Menz Gera Midir District, particularly Mehal Meda inhabitants who unreservedly helped and shared me their knowledge on the value of Guassa grass with their wonderful hospitality throughout my stay in the study area for field work. Specifically, I would really like to greatly appreciate the Guassa committee for allowing me to work on this study area. Permission to collect samples from the study area was granted by the Guassa Community Conservation Area committee, which consists of nine individual representatives from each kebele and the governing body of the area. I would like to thank Admasu Getaneh, Getabalew Aseffa and Abebe Gosim for their field assistantship and field guidance during data collection and through monitoring field experiment on the site.

I would like to acknowledge Rufford Small Grant Foundation for the financial support, and I would like also to thank IDEA Wild for their field equipment support which played an essential role in facilitating data collection and for the completion of this work.

Finally, I am very much grateful to my lovely wife Kidist Birhane, and my children Robsen Shambel and Nathan Shambel for their support, encouragement, and prayers throughout the study period. It is my truthful and sincere pleasure to present my gratitude towards my father Alemu Chengere, my mother Abebech Tadesse, my brothers and sisters Teshome Alemu, Belay Alemu, Birkineh Alemu, Geme Alemu, Belete Alemu, Biruk Alemu, Kefyalew Alemu, Bayu Alemu, Askale Alemu, Etenesh Alemu, Filagot Alemu and Getenesh Alemu for their kindest support at all phases of this study. My friends Tariku Bekele, Belay Bogale, Yilma Teshome, Mulualem Chekol, Abebe Regassa and Abebe Adunga are truly acknowledged for their support during my research period.

Above all, I would like to pass my special thanks to the Almighty God for His unspeakable support to this end.

THANK YOU ALL!!!!!

TABLE OF CONTENTS

Table of contents

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF ABBREVATIONS AND ACRONYMS

AA	Afroalpine
ANOVA	Analysis of Variance
AUC	Area Under Curve
AYCCA	Abune Yosef Community Conservation Area
CBNRM	Community Based Natural Resource Management
EFAP	Ethiopian Forestry Action Program
FAO	Food and Agricultural Organization
GLM	General Linear Model
GPS	Global Positioning System
GCCA	Guassa Community Conservation Area
IIED-CMNRA	International Institute for Environment and Development-Community Management Natural Resource in Africa
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LSD	Least Significant Difference
M.a.s.l	Meter Above Sea Level
MGCCA	Menz-Guassa Community Conservation Area
NPP	Net primary productivity
ROC	Receiver operator characteristic
SMNP	Simen Mountains National Park
SSB	Soil Seed Bank
WCMC	World Conservation Monitoring Center

List of the papers

I. Chengere SA, Steger C, Gebrehiwot K, Wube S, Dullo BW, Nemomissa S (2023). Quantifying shrub encroachment through soil seedbank analysis in the Ethiopian highlands. ***PLoS ONE*** 18(8): e0288804. ttps://doi.org/10.1371/journal.pone.0288804. (**Published**).

II. Chengere, S. A., Dullo, B. W., & Nemomissa, S. Influence of Aspect and Elevational Gradients on the Regeneration of *Festuca macrophylla* and *Helichrysum splendidum* plant species in GCCA, Central Highlands of Ethiopia. **(to be submitted)**

III. Chengere, S. A., Steger, C., Gebrehiwot, K., Nemomissa, S., & Dullo, B. W. (2022). Modeling Cultural Keystone Species for the Conservation of Biocultural Diversity in the Afroalpine. ***Environments***, *9*(12), 156. http://doi.org/10.3390/environments9120156. (**Published**).

IV. Chengere, S. A., Nemomissa, S., & Dullo, B. W. (2023). Predicting the current and future distribution of *Helichrysum splendidum* (Thunb.) Less., and *Euryops pinifolius* A. Rich., for the conservation of *Festuca macrophylla* Hochst. ex A. Rich. under the changing climate scenarios in Ethiopian highlands. **(to be submitted)**

Title:

The Ecology of *Helichrysum splendidum* and *Festuca macrophylla* in the Menz-Guassa Community Conservation Area and Their Future Distribution under Climate Change in the Central Highlands of Ethiopia

Shambel Alemu, PhD Dissertation
Addis Ababa University, 2024

Summary

In the Ethiopian highlands, the invasion of *Helichrysum splendidum* threatens ecosystem services in and around a community-based conservation area, particularly the provisioning of the *Festuca macrophylla* which is a highly valuable resource for the livelihoods of the local communities and for grazing by livestock and wildlife. The main objective of this research is to investigate factors responsible for a rapid encroachment of *Helichrysum splendidum* that might lead to and its abundance in the Menz-Guassa Community Conservation Area, Amhara Regional State, Ethiopia.

The study aimed to address four specific objectives. These are: 1) to assess the soil seed bank composition and density (Article I); 2) to investigate the effect of aspect and elevation on the natural regeneration status (Article II); 3) to describe a conservation assessment of the Afroalpine grass (*Festuca macrophylla*) by habitat suitability modeling (Article III); and 4) to assess habitat suitability of *Helichrysum splendidum* and *Euryops pinifolius* under changing climate scenarios for the conservation of *Festuca macrophylla* (Article IV).

A two-way ANOVA (Analysis of variance), General Linear Model (GLM), SAS statistical software version 9.0.1 (SAS Institute, 2001) for data analysis and the Shannon diversity index to

determine soil seedbank diversity and regeneration status (objectives 1 and 2). Then, vegetation was stratified and eight blocks (sampling sites) were selected across a range of elevation and aspect (northeast, northwest, southeast, southwest). Within each block, twenty, 5m x 5m plots were established (a total of 160 plots). Then, 480 soil samples were collected from five subplots (each measuring 1 m x 1 m) at three depths (0-3 cm, 3-6 cm, and 6-9 cm), which were then sieved and transferred the soil samples to pots in the Glasshouse for the soil seedbank to germinate. After twelve months we identified 74 plant species, representing 55 genera and 23 families that germinated from the soil seedbank. Out of the 74 plant species identified from soil seedbank germination, 11 species are endemic to Ethiopia. Species abundance was negatively correlated with elevation, with fewer species occurring at higher elevation. Meanwhile, species abundance was positively correlated with both northwest and northeast aspect. The highest seed densities were occurred in the upper three centimeters of soil and a gradually decreasing number of species and densities of seeds with increasing soil depth.

For the regeneration data collection, plots were stratified according to two elevational categories (<3350 m/lower and >3350 m/upper elevation) to test whether removal and subsequent regrowth will respond differently at low and high elevations from twenty 5m x 5m plots for a total of 160 plots. Results from the analysis of regeneration status showed that a total of 31 species, representing 27 genera and 16 families were recorded. The families with the highest number of species were Asteraceae (18 species, 22.5%), Fabaceae (3 species, 10%), and Poaceae (3 species, 10%). Of the total families, the dicots constituted 87.5% and monocots 12.5%. Species abundance was negatively correlated with elevation, with fewer species occurring at higher elevation. Meanwhile, species abundance was positively correlated with both northwest and northeast aspect. Germination of *H. splendidum* decreases over time showing less cover abundance as compared to the number of species before the removal was conducted.

For objective 3, MaxEnt (Maximum entropy model, Version 3.4.1) software was used to run habitat suitability model. Dataset of 119 occurrence points that were compiled, and gathered during fieldwork to run the model. For predicting suitable habitats of Guassa grass, 24 environmental variables were used. The 19 bioclimatic variables and average annual solar radiation data were downloaded from WorldClim (www.worldclim.org) at ~1 km^2 (30 arc second) resolution. The model performed highly according to the area under the curve (AUC =0.96), yet nearly 80% of highly suitable Guassa habitat falls outside the range of our training data. It was found that Guassa grass distribution is primarily limited by low mean temperature in the warmest quarter (BIO10, 36.7%), high precipitation in the wettest quarter (BIO16, 21%) and low precipitation in the driest quarter (BIO17, 15.6%).

For the fourth objective, the current and future distribution of *Festuca macrophylla*, *Helichrysum splendidum* and *Euryops pinifolius* were investigated under changing climate scenarios in Ethiopian highlands by using MaxEnt software. Two Representative Concentration Pathways, i.e., the intermediate (RCP 4.5) and extreme (RCP 8.5) were used for the years 2050 and 2070. Forty-eight, 51 and 53 occurrence data of *Festuca macrophylla*, *Helichrysum splendidum* and *Euryops pinifolius*, respectively, were collected during field visits to the GCCA in 2020. A total of 22 environmental variables including elevation, solar radiation index (SRI), and topographic position index (TPI) were used. Pearson's correlation was used to test for a collinearity of environmental variables that could produce a robust modeling of current and future suitable habitats of these species.

The results showed that the predicted suitable habitats for the three species, both current and future, were significantly influenced by elevation, topographic position index and Mean temperature of coldest quarter (Bio11). The predicted *Festuca macrophylla* habitat suitable distribution is limited to the central highlands of Ethiopia under different climate scenarios. While, the central highlands, northern, western, and north-western Ethiopia were the main habitat suitability distributions for *Helichrysum splendidum* and *Euryops pinifolius* in the current and future climate scenarios. These distributions were less suitable, moderately suitable, suitable, and highly suitable habitats. The comparative relative area between the various types of suitable habitat showed a decreasing trend from less suitable to highly suitable habitats, according to the future climatic scenarios.

In conclusion, the existing conservation approach, while admirable and promoting the growth of *H. splendidum* and the decline of *F. macrophylla*, calls for interventions to ensure its long-term persistency. The finging of this study urge managers to closely monitor the shifting populations of Guassa grass to determine whether the species is suffering from an extinction debt as a result of climate change's rapid warming at high elevations and altered rainfall patterns in the Ethiopian highlands.

Keywords:

Afroalpine, Conservation Area, Encroachment, Guassa grass, Regeneration potential, Species recovery

Chapter one

General Introduction

1.1. Background of the study

The encroachment of shrub into natural and semi-natural mountain grasslands is a severe and pervasive issue throughout the world (Brandt *et al.*, 2013). Most of these habitats, particularly the mountain grasslands below the potential tree line, were created through the removal of shrubs and forests, and their survival is largely dependent on traditional land use practices like livestock grazing and woody plant removal by fire (Wehn *et al.*, 2011). Without these activities, these man-made habitats experience biological succession toward shrub- or tree-dominated vegetation (Schirmel *et al.*, 2011), which reduces the amount of mountain grasslands. These changes were caused by recent changes in human demography and agricultural policies (Pôças *et al.*, 2011), and the problem has been made worse by global warming (Batllori and Gutiérrez, 2008). As a result, a variety of social, economic, and ecological activities that take place on both local and global sizes have changed the habitats of mountainous areas (Gerard *et al.*, 2010).

Ethiopia is one of the top 25 biodiversity-rich countries in the world, and two of the world's 34 biodiversity hotspots, namely: the Eastern Afromontane and the Horn of Africa hotspots (WCMC, 1994; Brooks *et al*., 2002; Hoffman *et al.*, 2016) which are regarded as the major center of diversity and endemism for several plant species. The diverse geography of Ethiopia gives rise to wide range of habitat in which we can find many endemic plants and animals. This has resulted in wide variations in rainfall, humidity, and temperature because of which the country embodies eight ecosystems (Friis *et al.*, 2010) that range from the highest elevations to the lowest elevations.

These eight broadly recognized ecosystems in Ethiopia includes, Afroalpine and Subafroalpine Ecosystem (3200 – 4620 m.a.s.l), Dry Evergreen Montane Forest and Grassland complex (1600 – 3300 m.a.s.l), Moist Evergreen Montane Forest ecosystems (1500 – 2600 m.a.s.l), *Acacia - Commiphora* Woodland Ecosystem (900 – 1900 m.a.s.l), *Combretum - Terminalia* woodland ecosystem (500 – 1900 m.a.s.l), Lowland, Semi-evergreen Forest ecosystem (450 – 650 m.a.s.l), Desert and Semi-desert Scrubland Ecosystem (<500 m.a.s.l), Aquatic Ecosystem (Friis *et al.*, 2010). However, according to the National ecosystem assessment of Ethiopia (EBI, 2022), the country embodies five broadly recognized ecosystems. These are: Mountain Ecosystem, Forest and Woodland Ecosystem, Aquatic and Wetland Ecosystem, Rangeland Ecosystem, Agro-ecosystem.

The Afroalpine and Subafroalpine ecosystem (3200 – 4620 m.a.s.l) region in tropical eastern Africa encompasses the elevated plateaus and mountains in East Africa (Gizaw *et al.*, 2013). The tropical Afroalpine flora offers well known examples of peculiar life forms, local endemism, and striking biogeographic connections (Hedberg 1957, 1964; Knox and Palmer 1995, 1998; Gehrke and Linder 2014).

The Afroalpine ecosystem mostly covers the higher African mountains and serves as the major water tower which is an essential source of water supply for agriculture (Abdikadir, 2013). The 2% Afroalpine habitat of Ethiopia considered as the largest Afroalpine in Africa and a home for several plants and animals of which some are endemic to Ethiopia (Wodaj *et al*., 2016). These Afroalpine ecosystems are characterized by the most eye-catching giant herb, lobelia (*Lobelia rhynchopetalum*), the evergreen tree heather (*Erica arborea*), shrubby and herbaceous perennial flowers (*Helichrysum* spp.) and there is a rich/lush grass (*Festuca macrophylla*) and herb flora including endemic succulents belonging to, e.g., the family *Crassulaceae.* The endemic mammals in this ecosystem include Walia ibex (*Capra ibex walia*), mountain nyala (*Tragelaphus buxtoni*), starck's hare (*Lupus starcki*), Ethiopian wolf (*Canis simiensis*), and gelada baboon (*Theropithecus gelada*) (Ashenafi & Leader-Williams, 2005; Gebrehiwot *et al.*, 2018). The giant mole rat (*Tachyoryctes macrocephalus*) is also a characteristic species of these ecosystems. Endemic birds found in these ecosystems include spot-breasted plover (*Vannellus melocephalus),* Ankober serin (*Serinus ankoberensis)* and other important birds include chough (*Pyrrhocorax graculus*), lammergeyer (*Gypaetus barbatus*) and golden eagle (*Aquila chrysaetos*) (Ashenafi *et al.*, 2005).

Guassa community conservation area (GCCA) is part of the Eastern Afromontane Biodiversity hotspot and among those high altitude Afroalpine ecosystems, in the central highlands. In this area we can find Afroalpine vegetation, endemic floral species like, *Festuca macrophylla, Kniphofia foliosa, Urtica simensis, Lobelia rhynchopetalum, Euryops pinifolius* and *Cynoglossum coeruleum* and, endemic and rare fauna (like Ethiopian wolf and Red fox) (Ashenafi *et al*., 2012: Wodaj *et al*., 2016). There are also 111 bird species recorded in the Guassa area, which is 12% of the 861 species of birds recorded for Ethiopia (Ashenafi, 2001). From these, 14 are endemic species of birds accounting for 48.3% of the endemic birds of Ethiopia. The area is also home to 18 species of mammals of which 7 are endemic to GCCA. Thus, Guassa harbors 22.6% of the endemic mammals and 48.3% of the endemic birds of Ethiopia respectively (Getachew, 2010; Biniyam and Tefera, 2011).

Guassa is named after the Guassa grass (*Festuca macrophylla*) that is valued by local communities for its uses (Steger *et al.*, 2020). This grass is very important for the livelihoods of the local communities. The Guassa area, for instance, provides services such as livestock grazing, as a firewood, and cutting Guassa grass (*Festuca macrophylla*) which is highly valued by the local people because of its multipurpose uses, such as thatching, making household equipment, baskets, painting brushes, mattresses and shepherds' raincoats and farm implements like rope making, whips (Giraf) and providing income from sell of the grass (Ashenafi, 2001; Phillipson, 2010; Amessie, 2014; Steger *et al.*, 2020, 2021, 2022).

Climate change is another phenomenon to be considered when studying the distribution of plants in conservation areas, because many environments have experienced major changes. Nevertheless, some plants are at risk of going extinct due to climate change. The functions of ecosystems will change because of changes brought about by climate change in temperature, rainfall patterns, flooding, and sea level rise (Adger *et al.*, 2009). This will cause ecosystems to expand or contract. High extinction rates will result from species failing to adapt as their habitats move due to changes in temperature and rainfall patterns (Berg *et al.*, 2010). The impact of climate change on species varies according to regions and it has a greater and faster impact in the extreme north and south as well as high mountainous areas (Adger *et al.*, 2009). Because species found in these areas have no alternative habitat to which they may migrate and are more prone to become locked in these extreme regions (Adger *et al.*, 2009).

Each species has a range of climate change tolerance, and when it reaches its ecological limit, it may either adapt to the change or shift its ranges to avoid extinction (Berg *et al.*, 2010). Through upslope migration (range expansion towards higher altitude or retraction from lower altitude), mountain species can sometimes track newly suitable climate conditions; however, topography and range loss can occasionally trap species in isolated and ultimately unsuitable habitats

(Dullinger *et al.,* 2012). Endemic species usually exhibit attributes such as narrow (and single) geographical range, only one or a few populations, small population size and little genetic variability, over-exploitation by people, and the need for specialized ecological niches that increase their risk of extinction (Essl *et al.,* 2009)

For developing an effective management plan considering climate change vulnerabilities, it is important to project species' existing range and project its future range shift using climate-related factors in order to assess and foresee any changes in their natural or man-made origins (Fourcade *et al.*, 2014). One method of estimating an organism's potential distribution for a future period is modeling an organism's ecological niche while considering environmental factors including altitude topographic position, aspect, temperature, humidity, and precipitation (Phillips *et al.*, 2006). The Maximum Entropy algorithm (MaxEnt), whose predictions start with the principle of maximum probability of occurrence of the species from the presence data and the bioclimatic variables associated with each sampling site, is one of the most widely used tools to model the distribution of species in geographic space and their environmental tolerances (Phillips *et al.*, 2006). Due to rising shrub encroachment, climate change and human pressure, GCCA which is home to many endemic species, e.g., *Festuca macrophylla* is deteriorating.

Festuca macrophylla Hochst. ex A. Rich. (Poaceae) is perennial herb which grows within altitudinal range of 3000-4100 m.a.s.l. It is characterized by its dense tussocks with erect culms to 1m tall (Phillips, 1995). It is known only from the two floristic regions of Ethiopia that is northern highlands of Gonder and Shewa floristic regions. It is Endemic to Ethiopia (Phillips, 1995).

Helichrysum splendidum is well known in Guassa Community Conservation area and it is a fast-growing shrub with woody base, grow up to 1m high (Tadesse, 2004; Mashigo *et al*., 2015). It is Characterized by its gray color leaf, presence of woolly trichomes on stem (important for reducing water loss), aromatic smell, persistent bright yellow flower, extensive root systems (extended below the root zone of other plants, Pooley, 2003). This easy to grow shrub requires very little care if it is given a large enough area to spread. Furthermore, both morphological and physiological factors such as high reproductive efficiency, small leaf areas to limit transpiration, allelopathic effect help *Helichrysum splendidum* to become successful and able to grow at a wide range of altitudes from 2500-4300 m.a.s.l (Hae, 2018). In the study area, according to the local community and other stakeholders (such as FZS, local authorities), the spread of this species is rapid and threatens local biodiversity and people's livelihoods. Claudio and David (1997) also pointed out the high rate of spread of *Helichrysum splendidum* and its invasion of other habitats such as *Festuca* grasslands.

For the past 400 years, the Menz Guassa people have been conserving the natural resources they depend on, perhaps one of the earliest known examples of indigenous Natural Resource Conservation Area in Sub-Saharan Africa (Ashenafi, 2001). The Menz-Guassa community developed their own system of management known as 'Qero Siriat' or the 'Qero system', with elected leaders named 'Aba Qero' (Ashenafi, 2005). The Qero system was charged with protecting and regulating the use of the Guassa area. This area is now recognized by the Amhara National Regional State as the "Menz-Guassa Community Conservation Area/MCCCA" under proclamation number 97/2012 (Ashenafi, 2001; Ashenafi, 2005). According to Qero Siriat, this natural resource is conserved for three to five years in a row before cutting the grass. When Aba Qeros felt that the Guassa grass has grown well, the area generally becomes open from mid of

April to mid of July for the local community to harvest and use the Guassa grass (Ashenafi, 2001; Ashenafi, 2005).

When the wet season approaches, the local community ends the use of the resource and evacuates the area to allow the re-growth of the *F. macrophylla*. The date of closing was culturally predetermined. The community of Menz-Guassa reports that the territory has been closed for protection since July 12th of the opening year when the apostolic fast ends for many Orthodox Christians (Ashenafi and Leader-Williams 2005). Following the closing date, community-elected guards patrol and protect the area to allow re-growth and sustaining this natura resource for future use (Ashenafi, 2005; Getachew, 2010; Biniyam *et al.*, 2011). The area is currently managed through a system based on indigenous knowledge including livestock grazing, firewood collection and harvesting Guassa grass (Ashenafi *et al.*, 2012).

1.2. Statement of the research problem

One of the primary issues of ecological studies is to understand the factors that affect shrub encroachment, vegetation diversity, abundance, and distribution in the mountain grasslands. The ability of a plant to colonize a particular area is determined by both biotic (e.g., herbivory, and interspecific competition) and abiotic (e.g., elevation, aspect, and soil properties) factors. The significance of properly identifying those factors arises from a fundamental concern for the sustainable use of the global biodiversity and conservation areas, which support many aspects of human livelihoods and well-being by providing products like sources of food, medicine, clothing, firewood, sources of various household utensils, and tools with widely acknowledged values (Robi *et al.*, 2017).

Most of the research on plant invasions in mountains has been on the distribution of non-native species and the dynamics of spread along elevation gradients. However, these gradient studies frequently miss the highest mountains. Therefore, considerably less is known about the status of invasive species in alpine areas (Alexander *et al.,* 2016). Moreover, studies on shrub/bush encroachment in Ethiopia are limited to lowland areas (e.g., Dalle *et al.*, 2006).

Conservation areas in the Afroalpine ecosystems are considered free of non-native species or only host a small number of them (Alexander *et al.,* 2016). This is because of several factors including the limited number of propagules, the rarity of introducing species adapted to grow in alpine habitats to high elevations, and the potent barrier of undisturbed native alpine vegetation against invasion (Alexander *et al.,* 2016). Currently, according to our observation and the local communities' perception (during workshop and training), *Helichrysum splendidum* is invading the area in abundance while *Festuca macrophylla* is losing the ground in the study area (Wube *et al.,* 2021). In the recent past, *H. splendidum* has increased in abundance and area coverage by suppressing the growth of *F. macrophylla* in the GCCA. *F. macrophylla* is very useful resources for the local communities and the spread of *H. splendidum* directly affects their livelihoods. The biological factors driving the invasion of *H. splendidum* in the GCCA are unknown. Furthermore, the impact of climate change on the current and future potential suitable habitats of these species is less understood.

Therefore, it is an interesting and scientifically useful to understand the biological and environmental factors driving the invasion of *Helichrysum splendidum* in the GCCA. Such a study provides ecological data on the expansion of *Helichrysum splendidum* and its impact on *Festuca macrophylla* in GCCA. Further, the findings of this work will enable to foster science-based management options.

1.3 Research Questions, Hypothesis and Objectives

1.3.1 Research questions

- How do elevational variability and aspects affect the distribution and abundance of plant species?
- Is there a significant difference between *Helichrysum splendidum* and *Festuca macrophylla* in terms of seedbank density and germination? Which species has a high potential for regeneration based on their soil seedbank density and germination?
- How do the soil seedbank density of *Helichrysum splendidum* and *Festuca macrophylla* vary along elevational gradient and across different aspects?
- How does species composition changes along depth and environmental gradients in Menz-Guassa Community Conservation Area (MGCCA)?
- How do *Helichrysum splendidum* and *Festuca macrophylla* distributions respond to climate change?

1.3.2 Research Hypothesis

Regeneration potential and soil seed bank status of *H. splendidum* and *F. macrophylla* vary along elevation and altitudinal gradient; ecological factors (such as: elevation and aspect) affect the structure of *H. splendidum* and *F. macrophylla* plant species. Species distribution model can indicate the impact of climate change on species survival and suitable habitats of *Festuca* *macrophylla*, *Helichrysum splendidum* and *Euryops pinifolius* under pressure of anthropogenic factors and future climate scenarios in GCCA.

1.3. 3 Objectives

1.3.3.1 General objective

The main objective of this research is to investigate the ecological factors responsible for fast encroachment of *Helichrysum splendidum* and the related causes for its dominance over *Festuca macrophylla*, and the impact of climate change in the Guassa Community Conservation Area, Amhara Regional State, Ethiopia.

1.3.3.2 Specific objectives

This research has the following specific objectives.

- ✓ To assess the status of the soil seed bank of GCCA interms of species diversity, composition and seedbank density,
- ✓ To assess the regeneration status of *Festuca macrophylla* and *Helichrysum splendidum,*
- ✓ To identify the ecological factors that give competitive advantage for *Helichrysum splendidum* over *Festuca macrophylla* based on field experimentation,
- ✓ To study the current and predict the potential suitable habitats of *Festuca macrophylla, Helichrysum splendidum* and *Euryops pinifolius* plant species under climate change scenarios in Ethiopia

Article I-Published

PLOS ONE

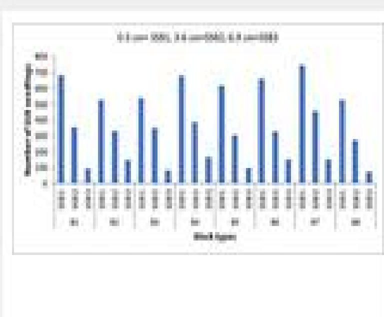
OPEN ACCESS PEER-REVIEWED

RESEARCH ARTICLE

Quantifying shrub encroachment through soil seed bank analysis in the Ethiopian highlands

Shambel Alemu Chengere[1*], Cara Steger[2©], Kflay Gebrehiwot[3,4©], Sisay Wube[5‡], Bikila Warkineh Dullo[1‡], Sileshi Nemomissa[1‡]

1 Department of Plant Biology and Biodiversity Management, College of Natural and Computational Sciences, Addis Ababa University, Addis Ababa, Ethiopia, **2** Department of Natural Resources and Environment, Cornell University, Ithaca, NY, United States of America, **3** Department of Biology, Samara University, Semera, Ethiopia, **4** Applied Behavioural Ecology and Ecosystem Research Unit, School of Ecological and Human Sustainability, University of South Africa, Florida, South Africa, **5** Forest and Rangeland, Ethiopian Institute of Biodiversity, Addis Ababa, Ethiopia



Chengere SA, Steger C, Gebrehiwot K, Wube S, Dullo BW, Nemomissa S (2023) Quantifying shrub encroachment through soil seed bank analysis in the Ethiopian highlands. PLoS ONE 18(8): e0288804. https://doi.org/10.1371/journal.pone.0288804

Chapter Two

Quantifying shrub encroachment through soil seedbank analysis in the Ethiopian highlands

Shambel Alemu Chengere[1], Cara Steger[2], Kflay Gebrehiwot[34], Sisay Wube[5], Bikila Warkineh Dullo[1], Sileshi Nemomissa[1]

[1]Department of Plant Biology and Biodiversity Management, College of Natural and computational Sciences, Addis Ababa University, Addis Ababa P.O. BOX 3434, Ethiopia; shambel.alemu@aau.edu.et; bikila.warkineh@aau.edu.et; sileshi.nemomissa@aau.edu.et, [2]Department of Natural Resources and Environment, Cornell University, Ithaca NY 14850, USA; cara.steger@gmail.com, [3]Department of Biology, Samara University, Semera P.O. BOX 132, Ethiopia; kflay77@gmail.com, [4]Applied Behavioral Ecology and Ecosystem Research Unit, School of Ecological and Human Sustainability, University of South Africa, Private Bag X5, Florida 1710, South Africa, [5]Forest and Rangeland, Ethiopian Institute of Biodiversity, Addis Ababa P.O. BOX 30726 Ethiopia; sisaywube20@gmail.com

Abstract

This study aimed to understand the impact of shrub encroachment on native species in the Guassa Community Conservation Area in Ethiopia. The soil seedbank composition and density across different elevations and aspects, and management systems within the area were assessed. The vegetation was stratified and eight blocks were selected across a range of elevation (<3350 m and >3350 m) and aspect (northeast, northwest, southeast, southwest). Within each block we established twenty 5m x 5m plots for a total of 160. We then collected soil samples from five subplots (1 m x 1 m) at three depths (0-3 cm, 3-6 cm and 6-9 cm) for a total of 480 samples, which were established in pots in greenhouse. We calculated species abundance by totaling the number of seedlings that emerged from each sample. To determine the variability in the abundance of *Festuca macrophylla* and *Helichrysum splendidum* in the soil seedbank along altitudinal gradient, we used two-way ANOVA using SAS statistical software version 9.0.1. Shannon diversity index was used to determine species diversity in the soil seedbank. After counting all the seeds, we identified 74 plant species represented in the soil seedbank which belong to 55 genera and 23 families. Eleven species are endemic to Ethiopia. At the lower elevation range, the effects of aspect ($P < 0.0088$) and soil depth ($P < 0.005$) are not significant to determine the abundance of seeds of *H. splendidum* and *F. macrophylla*. But when the factors are segregated, both aspect and soil depth play a significant role ($p < 0.0001$) regarding the abundance of the seeds of the competing species at lower elevation. At higher elevation, the effect of soil depth is significant ($P < 0.0001$) for determining the abundance of *H. splendidum*. Soil depth and aspect have no significant effects on soil seedbank abundance at this elevation.

Keywords: Afroalpine, Encroachment, Guassa Community Conservation Area, Restoration.

2.1. Introduction

Ethiopia is a country located in the Horn of Africa, characterized by a wide variety of landscapes such as rugged mountains, river valleys, flat-topped plateau, deep gorges, and rolling plains. The country is also known for its vast wealth of natural resources and biological diversity, which spreads across higher altitude areas, from mountain peaks to one of the lowest and hottest places on earth. The country is also the second most populous in Africa experiencing a major land cover change (Kindu *et al.*, 2013; Gashaw and Dinkayoh, 2015). The land cover changes in the country are mainly taking place from lands with natural vegetation to agricultural lands and residential area. Several studies (Tegene, 2002; Bewket, 2002; Tefera, 2011; Kindu *et al.,* 2013; Molla, 2014; Alemu *et al.,* 2015), show that Ethiopia's ecosystems including forest, woodlands, grasslands and shrub lands are rapidly declining while farmland and bare land are expanding over time. The leading factor for these is population growth which resulted in competition for natural resources, pervasive poverty, food insecurity, high unemployment rate, drought and other socio-political factors (Bewket, 2002; Bekele, 2003; Molla, 2014). These has led to rapid expansion of agricultural land and expanding bare land at the expense of the loss of native vegetation. Comparing land cover in the high and lowlands of Ethiopia, the changes in ecosystem are more severe in the highlands of Ethiopia (Eshetu and Hogberg, 2000). This is because of high population pressure, shrub expansion and long-term cultivation on the highland areas (Kindu *et al.,* 2013).

From the above factors, shrub expansion into grasslands is reported worldwide (Archer *et al.,* 1995; Fang *et al.,* 2001), affecting both low and highland grasslands (Van Auken 2009; Maestre *et al.,* 2009). Especially shrub expansions in the highlands are being reported by different scholars leading to ecosystem service changes. This vegetation change has been attributed to climate change, atmospheric CO_2 concentrations, nitrogen deposition, and changes in local management practices such as agricultural expansion, cutting, grazing pressure or increased fire frequency (Archer *et al.,* 1995; Briggs *et al.,* 2005; Montané *et al.,* 2009). The transition from grassland to an ecosystem dominated by woody species could lead to dramatic changes in community structure and function, such as reduced species richness and diversity (Lett and Knapp 2005) and risk increased fire (Montane *et al.,* 2010).

The shift from a grass-dominated to a shrub-dominated ecosystem is likely to have a significant impact both on plant productivity and location due changes in the distribution of net primary productivity (NPPs) between aboveground and belowground components (Lett *et al.,* 2004). Consequently, grasses have a high distribution of NPPs below ground, while shrubs may release more NPPs above ground (Jackson *et al.,* 2002). The increase in aboveground NPP due to shrub encroachment is due to the potential of shrubs to support a much larger leaf area than grasses under similar climatic and resource constraints (Knapp *et al.*, 2008).

Shrub encroachment is common in most arid and semi-arid biomes of the world. For instance, the transformation of large areas of former black grama pastures (*Bouteloua* spp.) in dense thickets of bush lands (Van Auken, 2000), of the United State was caused by the dramatic increase in density of mesquite (*Prosopis glandulosa*) and creosote bush (*Larrea triangotensi*). Increased abundance of shrubs has been a major problem for African pastures used for livestock (Augustine and Mcnaughton, 2004). In South Africa, for example, 13 million hectares are under bush encroachment and it is estimated that, together with the loss of savannah systems, more than two billion people worldwide will be affected (Eldridge *et al.*, 2011). In East Africa, a 10% increase in bush area reduces grazing by 7%, and grazing is eliminated at 90% bush cover (Oba *et al.,* 2000). In Ethiopia, the Borana rangelands, the encroachment of shrubs and unpalatable forbs threatened about 83% of the rangelands (Angassa and Oba, 2007). Furthermore, in the Nechisar National Park shrub encroachment deteriorated herbaceous species cover-abundance (Yusuf *et al.*, 2011).

Guassa Community Conservation Area, one of the Afroalpine grassland, is characterized by rich biodiversity and ecosystem services in Ethiopian highlands. It is a home to a large amount of fauna and flora (Ashenafi, 2001). The local community living around Guassa area traditionally managed and uses the resource for various purposes. For example, the area provides services such as livestock grazing, as a firewood, and cutting Guassa grass (*Festuca macrophylla*) which uses for various purposes such as thatching, making household equipment, baskets, painting brushes, mattresses and shepherds’ raincoats and farm implements like ropes and whips. At present, nine farmers' associations collectively manage an area recognized by the Amhara National Regional State as the Guassa Community Conservation Area (GCCA). This area plays crucial role for the livelihood and coping strategies of the community living around the area, especially during periods of drought, by providing food for animals. On the other hand, the local community uses different shrubs mainly *Helichrysum splendidum* as wood for cooking and for keeping their households warm during cold time (Ashenafi and Leader-Williams, 2005).

However, this Afroalpine region which has global and local importance is under increasing threat from high rate of expansion of *H. splendidum* shrub and its encroachment over other habitats like *Festuca* grassland. *H. splendidum* is a fast-growing shrub; it can grow to 1.5 m x 1 m within 2 years, forming a dense grey mound. This easy to grow shrub requires very little maintenance if it is given a large enough area to spread. On the study area, according to the local community and other stakeholders (like FZS, local government bodies), the spread of this species is fast and it threatens the local biodiversity and their livelihood. The high rate of expansion of *H. splendidum* (due to climate change, temporary drought, and human disturbance while harvesting Guassa grass) (Skarpe, 1990) and its encroachment over other habitats like *Festuca* grassland was also pointed out (Sillero-Zubiri and Macdonald, 1997).

The assessment of soil seedbank is very crucial for understanding the competitive ability of species, conservation planning and management of species composition and structure. Studies shows that soil seedbank provide a viable option for restoration through the establishment of native vegetation (van der Valk and Pederson, 1989). In Ethiopia, particularly in our study area, there are only scant information concerning soil seedbank (Lemenih and Teketay, 2006; Reubens *et al.*, 2007) especially for the two dominant plant species (*Helichrysum splendidum* and *Festuca macrophylla*) hereafter called the target species. This study is designed based on our observation of the current management system of the Guassa Community Conservation Area, which seems to favor the encroachment of *Helichrysum splendidum* as compared to *Festuca macrophylla.* In addition, our previous research has shown that (Steger *et al.,* 2020; 2021; 2022) the local community perceives the encroachment of *Helichrysum splendidum* as sustainability threat. These two species are by far the most dominant species in the area. However, there is a general perception that the grass (*Festuca macrophylla*) is losing competition to the shrub (*Helichrysum splendidum*). The current management of system of the area involves harvesting *Festuca macrophylla* every two-three-year cycle before the grass set seeds because the vigor of the grass decreases upon flowering (Sillero-Zubiri and Macdonald, 1997).

Therefore, based on this observation and our previous finding, we set to find out if there is a significant difference in terms of soil seedbank density between these two species. However, the studies of soil seedbank in a conservation area where the diversity and composition of species are high unavoidably involve other species in addition to the target species. Therefore, we addressed the following questions with an objective to assess whether the management system (cutting Guassa grass every two to three years and forbidding *Helichrysum spelindidum* to cut) being implemented in the conservation area is favoring one target species over the other. a) What is the status of soil seedbank of GCCA in terms of species diversity, composition and seedbank density? b) Does the soil seedbank density of *Helichrysum splendidum* and *Festuca macrophylla* species vary along aspect and altitudinal gradients? c) Does the management systems give *Helichrysum splendidum* a competitive advantage to encroach into *Festuca macrophylla* stands?

2.2. Materials and Methods

2.2.1. Description of the Study Area

Ethiopia is one of the 25 biodiversity-rich countries in the world, where two of the 36 biodiversity hotspots in the world (Brooks *et al.*, 2002; Hoffman *et al.*, 2016), namely the East Afromontane and the Horn of Africa (WCMC, 1994), trespass through its mountain and lowland areas. Ethiopia consists of three major high plateau regions divided by the Great Rift Valley and by the Abay (Blue Nile) Gorge. These three highland blocks are known as the north-western highlands, the central highlands and south-eastern highlands. The north-western highlands are the largest highland massif. The GCCA is in the central highlands at 10°15'–10° 27' N and 39° 45'–39° 49' E and is situated in an area locally known as Menz Gera Midir district (Wube *et al.*, 2021). It is found in the Amhara Regional State of North Shewa, 295 km north-east from Addis Ababa, capital city of Ethiopia (Fig 2.1). The Guassa range comprises 111 km^2 and lies at an altitude range of 3200 to 3700 m above sea level (Ashenafi, 2001).

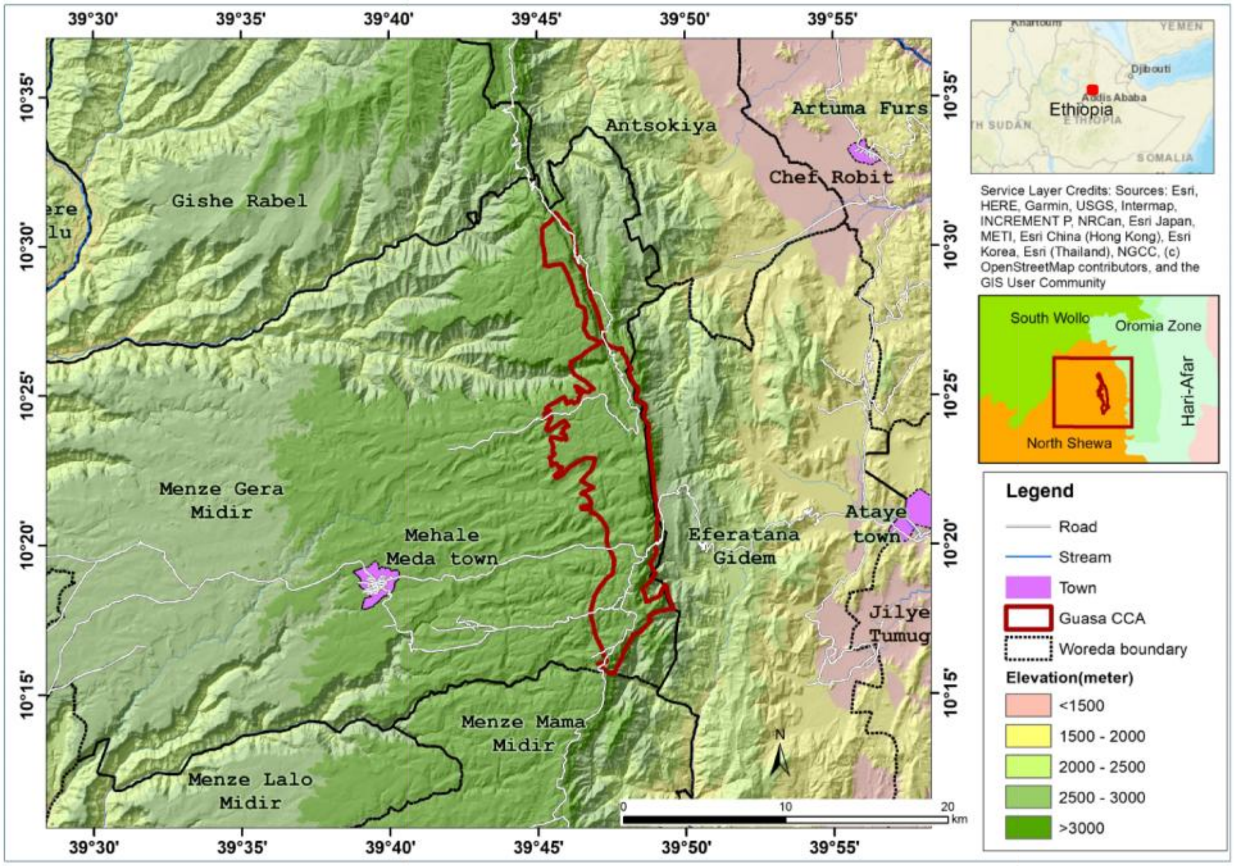


Figure 2.1. Map of the study area showing the Guassa Community Conservation Area (GCCA).

2.2.2. Climate, Soil, and Vegetation

GCCA is characterized by its plateau which crosscut by various gorges and river valleys that flow west and eastwards. It straddles the catchment basins of two major rivers in East Africa – the Abay (the Blue Nile) and the Awash, and thus its conservation is critical to the health and functioning of those headwaters (Moges, 2015). The swamps of the area increase water holding capacity and limit runoff in the rainy seasons, thus providing flow all year round. Generally, the soil of the Guassa area is deep and humic. However, on higher ground, the soil is shallow, and highly mineralized (Ashenafi and Leader-Williams, 2005).

The climate in the Guassa area varies widely due to the differences in elevation and the size of the mountain block. The annual mean rain fall is 828 mm. Temperatures are characterized by mild days and cold nights. In the drier months (December to February), daytime temperatures can rise to 25 ^{0}C, while night-time temperatures can drop to -7 ^{0}C (Simeneh, 2010; Wube *et al.*, 2021) (Fig. 2.2). The area gets its name from the "Guassa grass" *Festuca macrophylla*, which is highly valued by the local community.

GCCA is a biodiversity hotspot, containing several endemic and threatened species (Ashenafi *et al.*, 2012). The area is rich in biodiversity and contains several endemic and threatened species of flora and fauna species (Ashenafi and Leader-Williams, 2005). The vegetation of the Guassa area is characterized by high Afroalpine vegetation with different plant community types, namely: *Euryops-Alchemilla* shrubland, *Festuca* grassland, *Euryops-Festuca* grassland, *Helichrysum - Festuca* grassland, Swamp-Grassland and Erica moorland (Beyene, 2010; Simeneh, 2010). GCCA is a place for important and endemic plant species including Guassa grass (*F. macrophylla*), giant Lobelia (*Lobelia rhynchopetalum*), *Kniphofia foliosa* and *Alchemilla* species (Ashenafi and Leader-Williams 2005; Ashenafi *et al.,* 2012). There are about nine (which accounts to 23% mammal fauna of the country) endemic fauna including the Ethiopian wolf (*Canis simensis)*, gelada baboon (*Theropethicus gelada)* and Ethiopian Highland hare or Abyssinian hare (*Lepus starcki)* and about 114 (12% of 861 bird species) have been recorded in the GCCA (Ashenafi and Leader-Williams, 2005). The Guassa area is also home to the world's largest concentration of the globally endangered Ankober serin (*Serinus ankoberensis)* and the spot-breasted plover (*Vannellus melocephalus*) (Ashenafi, 2001).

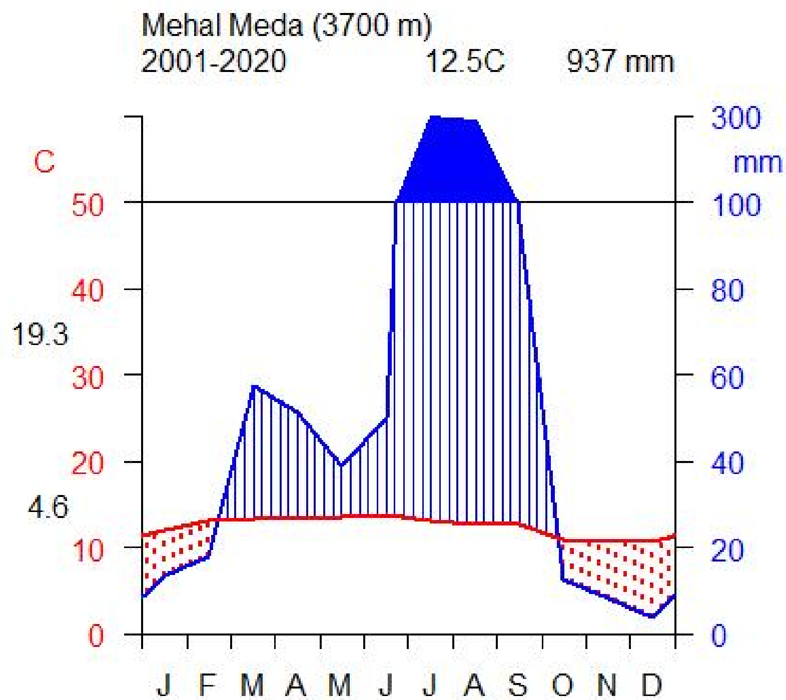


Figure 2.2. Climate diagram of the study area indicating high and low rainfall and mean monthly temperature. (Station: Mehal Meda)

2.2.3. Population and Livelihood

The human population is predominantly of Amhara ethnicity and Orthodox Christian religion. The main economic activity of the people is farming which involves mainly crop production and livestock husbandry. The community can generate income from off-farm activities such as petty trading, selling local beer (‘Tella’), liquor (‘Arekie’) and local green tea. Wool processing (known in sheep and cattle rearing) is the most common off-farm activity of the Guassa community. The area is regarded as food insecure, and in many years, parts of the population depend on the national food aid program called safety-net (Ashenafi, 2001).

The Guassa area is currently managed by nine farmers' associations, local institutions that were created throughout Ethiopia in 1975 for rural administration. The community protects the area by promulgating various regulations that restrict the use of natural resources by the communities (Ashenafi and Leader-Williams, 2005).

2.3. Soil Sampling Technique

First, we stratified the vegetation by type and purposefully selected eight blocks based on elevation (<3350 m.a.s.l/lower and >3350 m.a.s.l/upper elevation) and aspect. Each block has twenty 5m x 5m established plots, thus we have a total of 160 plots. We also categorized aspects in to four as NE, NW, SE and SW to compare the seed density in the soil for the target species along elevation gradient. The samples were taken from five subplots (1m x 1m each) (one at the center and the other four at the corners) to collect composite soil samples from the three separate layers. Within the 1m x 1m subplots, five subplots (5cm x 5cm) were established to take the soil seed bank sample. 225cm^3 of soil samples were collected from each subplot using a digger. A total of 480 soil samples (3 vertically successive layers x 160 sample plots) were collected from the three separate soil layers. Each layer had 3 cm depth (0-3 cm, 3-6 cm and 6-9 cm) following Price *et al.,* (2010), Li *et al.,* (2011) and Wang *et al.,* (2015). The litter layer was deliberately removed. This is because, the probability of predation, rain-washing seeds from the surface resulted in poorly guided to conclude restoration potential of woody species from litter layer. To capture spatial heterogeneity of seed distribution (Niknam *et al.,* 2018; Erfanzadeh *et al.,* 2020) soil samples from similar layers of the five subplots were mixed and put in one plastic bag to form composites samples and to reduce variability within the plot. The composite sample for each soil layer was again divided into five equal parts among which one (400 gm) was randomly selected for glasshouse germination.

Sampling was completed within two weeks (February 13-30, 2021) to avoid differences between habitats, and thus any temporal bias in seed availability and composition following the method used by Lopez and Ramos (2011). These samples were packed in plastic bags and transported to Addis Ababa University for glasshouse germination. The soil samples were first sieved using a mesh size of 2 mm to recover seeds of the different plant species (Daïnou *et al.,* 2011). The sieved soil samples were spread immediately in plastic trays in Addis Ababa University greenhouse for germination of the seeds. Each plastic tray (20cm x 3cm) was perforated at the bottom and plugged by cotton to facilitate proper drainage of water without losing soil. The seedling trays were kept continuously moist by daily watering following the method used by Lopez and Ramos (2011). The emerging seedlings were identified, counted and recorded. Species identification was done using local reference material (Flora of Ethiopia and Eritrea Volumes (Edwards *et al.,* 1995; Edwards *et al.,* 1997; Edwards *et al.,* 2000; Hedberg and Edwards, 1989; Hedberg *et al.,* 2003). Each of the plant specimens were pressed and deposited in the National Herbarium Ethiopia (ETH), at Addis Ababa University.

2.4. Data Analysis Techniques

All the collected data were organized in excel and checked for errors, normal distribution and homogeneity of variance before the data analysis were run (Erfanzadeh *et al.*, 2020; Yusefi *et al.*, 2023). Using SAS statistical software version 9.0.1 (SAS Institute, 2001), all the collected data was fitted into a general linear model (GLM) and were analyzed using two-way ANOVA (Analysis of variance) to determine the abundance of *Festuca macrophylla* and *Helichrysum splendidum* in the soil seed bank along altitudinal gradient. Shannon diversity index was used to determine species diversity in the soil seedbank. Fisher's least significant difference (LSD) test was employed to separate the means when significant F values were found at a significance level of $p \leq 0.05$. We calculated species abundance by totaling the number of seedlings that emerged from each sample. The composition, density and frequency of seeds in the soil were determined from the germination data recorded in the greenhouse experiment. The density of seeds was derived from the total number of seeds recovered from the soil samples.

Density is more useful in estimating the importance of a species. The sum of individuals per species is calculated in terms of species density per sampled area unit, such as hectare (Erfanzadeh *et al.,* 2020; Mueller-Dombois and Ellenberg 1974).

$$D = \frac{\text{The number of stems of a species}}{\text{Sampled area in hectar}} \times 100$$

To analyze the diversity of soil seed bank, Shannon-Wiener diversity index (H′) was used following the method used by Tesfaye *et al.*, (2010). The Shannon index, which combines species richness with relative abundance, is widely used in species diversity studies (Kent, 2011). The Shannon index expresses the relative evenness or equitability of species, gives weight to dominant species (Whittaker, 1972). Total species diversity, richness and evenness of the soil seedbank of the study area were calculated taking the pooled seeds from the plots and the three soil layers found in each block.

The values of the Shannon-wiener diversity index usually fall between 1.5 and 3.5, although in exceptional cases, the value can exceed 4.5. The value of evenness index falls between zero and one. The higher the value of evenness index, the more even the species is in their distribution within the given area.

2.5 Results

2.5.1 Species composition of soil seed banks

The total number of species recorded was 74 species, representing 55 genera and 23 families from soil samples collected. Of the identified species recorded from the seed bank, 64 (86.49%) were herbs and 10 (13.51%) were shrub plants. Families with the highest number of species were Asteraceae (18 species), Poaceae (9 species), Scrophulariaceae (6 species), Cyperaceae (5 species), and the remaining families were represented by less than four species each. Five species namely: *Thymus schimperi* (Lamiaceae, 1457 seedlings), *H. splendidum (*Asteraceae, 1136 seedlings), *Trifolium polystachyum* (Fabaceae, 843 seedlings), *Trifolium usambarense* (Fabaceae, 752 seedlings) and *Euryops pinifolius* (Asteraceae, 701 seedlings) accounted for more than 56.3 % of these seedlings (Table 2.1). From the three soil layers (i.e., 0-3 cm, 3-6 cm, 6-9 cm), high number of seedlings were recorded from soil seedbank of the upper layer (0-3 cm) (Fig 2.3).

Table 2.1. Top ranked species with their total number of seedlings in the GCCA.

Species	Family	Number of seedlings	Density (%)	Rank
Thymus schimperi Ronniger	Lamiaceae	1457	13.2	1
Helichrysum splendidum (Thumb.) Less	Asteraceae	1136	10.28	2
Trifolium polystachyum Fresen.	Fabaceae	843	7.63	3
Trifolium usambarense Taub.	Fabaceae	752	6.78	4
Euryops pinifolius A. Rich.	Asteraceae	701	6.32	5
Alchemilla ellenbecki Engl.	Rosaceae	610	5.49	6
Alchemilla abyssinica Fresen.	Rosaceae	577	5.19	7
Festuca macrophylla Hochst. ex A. Rich.	Poaceae	357	3.21	8

Urtica simensis Steudel	Urticaceae	336	3.02	9
Cyperus elegantulus Steud.	Cyperaceae	172	1.54	10

Eleven of the taxa are endemic to Ethiopia. These are: *Anchusa affinis, Cineraria abyssinica, Cynoglossum coerulem, Euryops pinifolius, F. macrophylla, kalanchoe petitiana, Kniphofia foliosa, Lobelia rhynchopetalum, Senecio schultzii, Senecio steudelii,* and *Urtica simensis.* In addition, there are also three near-endemic species to Ethiopia which are also found in Eritrea. These are: *Anchusa affinis, Plectocephalus varians* and *Thymus schimperi*. From these endemic taxa some of them like *F. macrophylla, Kniphofia foliosa, Urtica simensis* and *Cynoglossum coerulem* are stated in the IUCN Red list categories as least concern species.

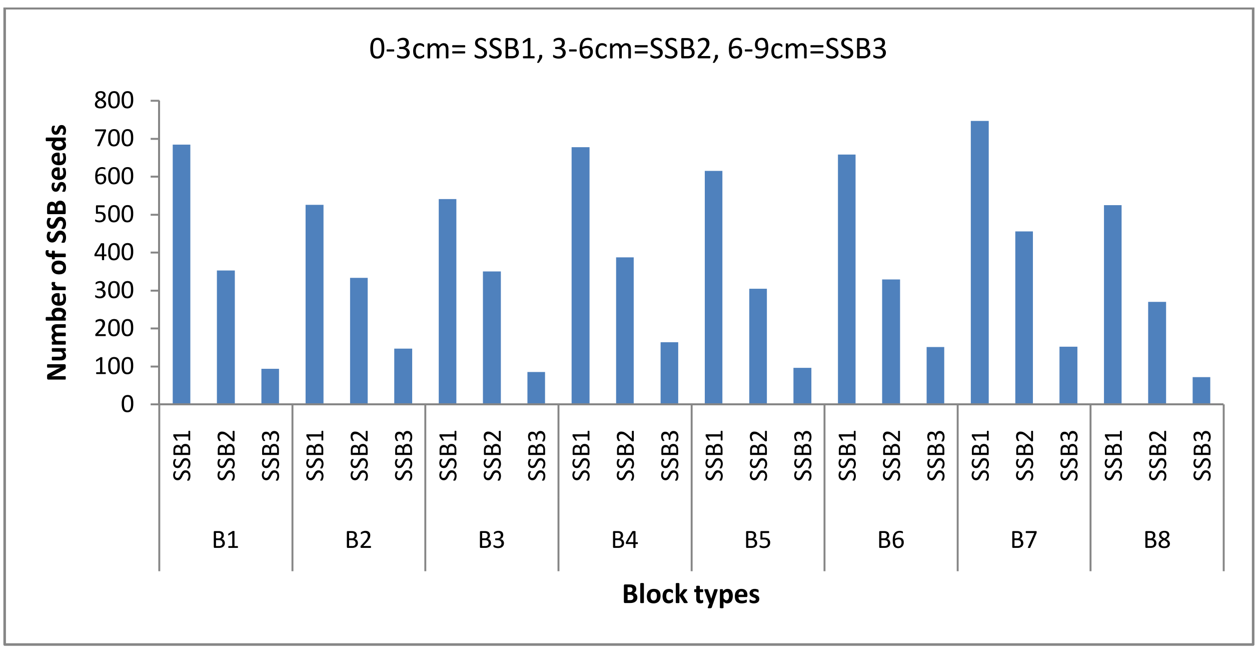


Figure 2.3. Number of seedlings recorded from soil seedbanks of the upper 9 cm soil depth collected from GCCA. Key: SSB = soil seed bank, SSB1 = 0-3 cm, SSB2 = 3-6 cm, SSB3 = 6-9 cm

2.5.2 Density of seeds in the soil

The maximum seed density was recorded in the first sampling layer (0-3 cm). Seed density and total species abundance decreases as the soil depth increases in the GCCA. The species with the highest soil seed densities in descending order include *Thymus schimperi, Helichrysum splendidum, Trifolium polystachyum, Trifolium usambarense, Euryops pinifolius,* and *Alchemilla ellenbecki* (Table 2.1).

2.5.3 Species Richness, Diversity and Evenness of Soil Seedbank

The Shannon-Wiener diversity index for the diversity of soil seed bank at the study area generally demonstrated high values for the diversity of soil seed bank as it is greater than 2.5 (Table 2.2). The Shannon evenness index (E) had no consistence value among the soil layers in the study area; but totally viewed as 0-3 cm>6-9 cm>3-6 cm. Species in the middle layer (3-6 cm) are more evenly distributed than the others whereas the species in the bottom layer (6-9 cm) are less evenly distributed. Generally, species richness decreased down the soil layers (Table 2.2).

Table 2.2. Soil seedbank species richness, diversity and evenness of GCCA.

Soil layers	Species richness (S)	Diversity Index (H')	Shannon's-Evenness (E)
0-3 cm	70	2.85	0.67
3-6 cm	53	3.05	0.72
6-9 cm	31	3.81	0.37

2.5.4 Vertical distribution of seeds in the soil seedbank

The depth distribution of the seed bank was consistent with the highest seed densities in the upper three centimeters (= 0-3 cm depth) of soil and a gradually decreasing number of species and densities of seeds with increasing soil depth. The soil seedbank density exhibited a declining trend with increasing soil depth accounting for 4934 seeds m^{-2} (0-3 cm), 2783 seeds m^{-2} (3-6 cm) and 949 seeds m^{-2} (6-9 cm). There was variation in relation to depth distribution that decreased to the lower centimeters for the sampled species (Table 2.3). Most of the species recorded in the soil seed banks had seeds in all the three different soil layers. Alternatively, there was variation in the depth distribution of seeds among different plant species. For instance, seeds of some species were recovered only from the upper three centimeters soil layers e.g., *Nepeta azurea*. On the other hand, most of the species have seeds which are distributed in all soil layers, e.g., *Alchemilla abyssinica*, *Alchemilla ellenbecki* and *Euryops pinifolius* (Table 2.3).

Table 2.3. Ten purposively selected plant species with their variation in relation to depth distribution of seeds from GCCA

Layers	**Density of seeds m^{-2}**									
	AA	AE	NA	EP	FM	HS	TS	TP	TU	US
0-3 cm	335	293	2	442	169	681	923	413	457	210
3-6 cm	234	205	0	218	134	263	408	272	208	99
6-9 cm	3	112	0	41	47	192	126	158	87	27
Total	572	610	2	701	350	1136	1457	843	752	336

(Abbreviations: AA= *Alchemilla abyssinica;* AE = *Alchemilla ellenbecki*; *NA* = *Nepeta azurea;* EP *Euryops pinifolius;* FM = *F. macrophylla;* HS = *H. splendidum;* TS = *Thymus schimperi;* TP = *Trifolium polystachyum;* TU = *Trifolium usambarense;* US = *Urtica simensis*).

2.5.5 Soil seedbank density of *Festuca macrophylla* and *Helichrysum splendidum*

From the analysis of soil seed bank, the density of *H. splendidum* was found to be higher than seeds of *F. macrophylla* in each block both along aspect and altitudinal gradients (Fig 2.4).

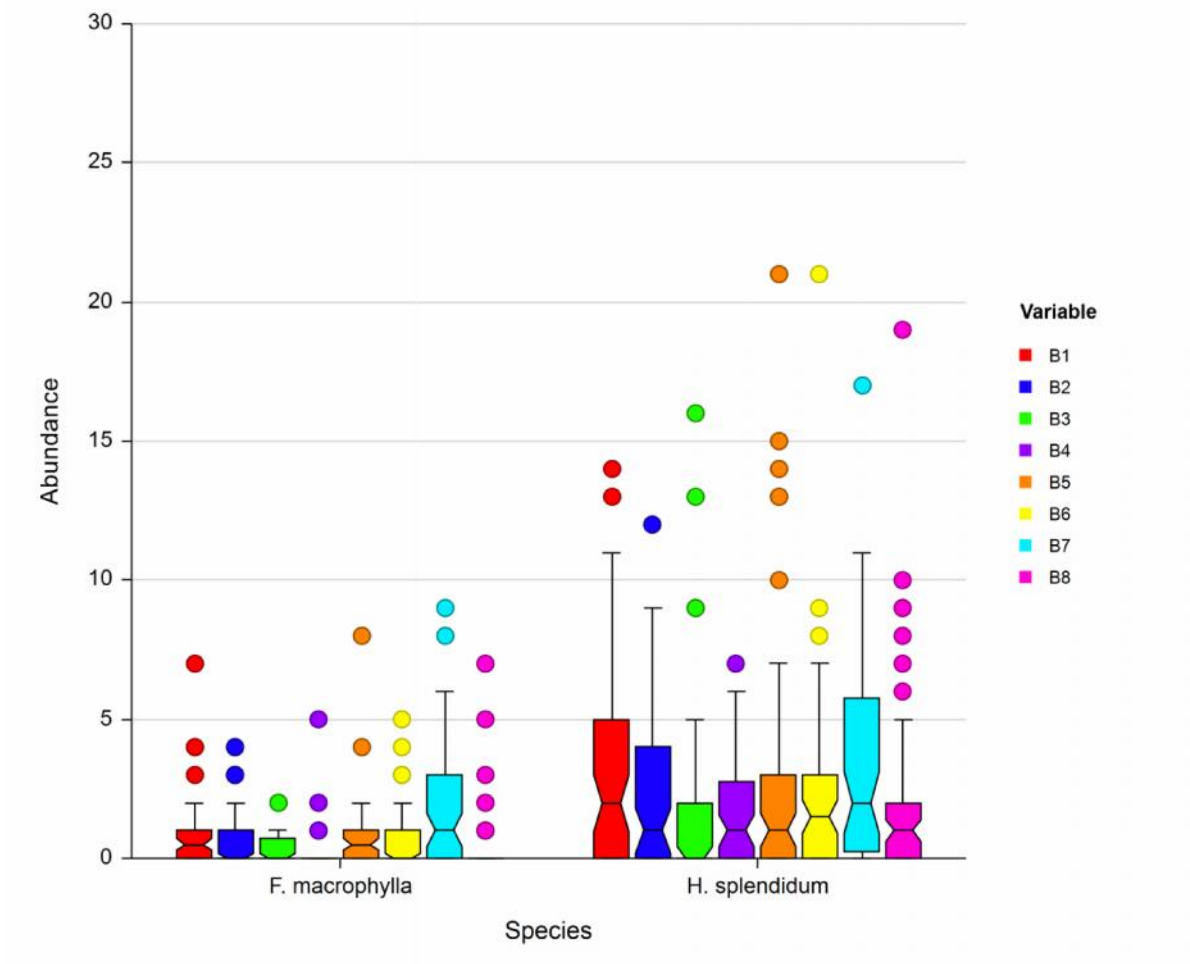


Figure 2.4. Soil seedbank status of *F. macrophylla* and *H. splendidum* collected from GCCA.

2.5.5.1 Abundance of the seeds of *Festuca macrophylla* and *Helichrysum splendidum* plant species in relation to altitude and soil depth

The abundance of the seeds of the two target species (*F. macrophylla* and *H. splendidum*) in the soil seed bank showed significant differences. The pooled abundance and altitude were negatively correlated (Two-way ANOVA: $P<0.05$), where abundance of the two species showed decreasing pattern as altitude increase in the sample plots (Fig 2.5).

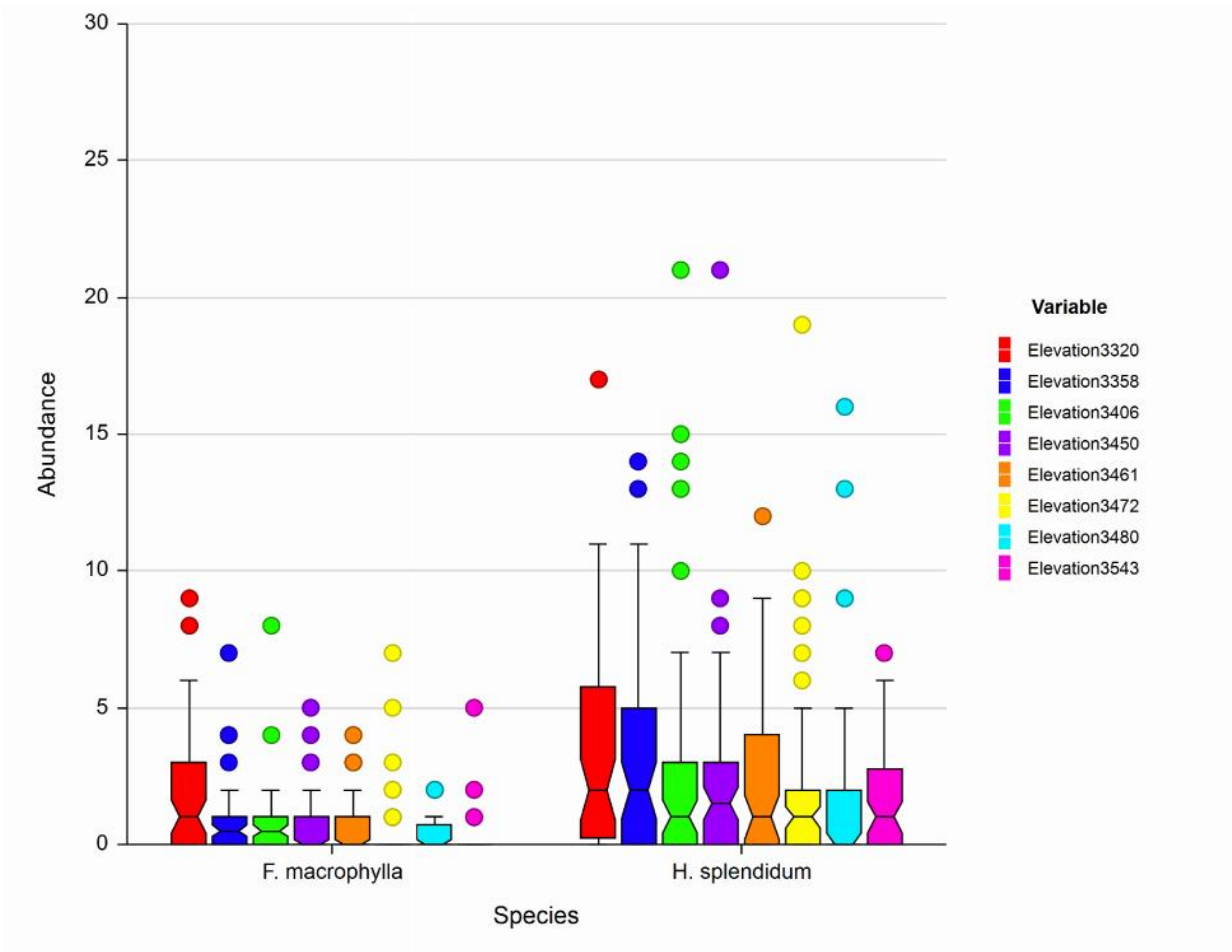


Figure 2.5. Abundance of *F. macrophylla* and *H. splendidum* along altitude in the GCCA.

Altitudinal difference had great impact on diversity and abundance of species in the study site. The lower altitude had a significant variation index compared to upper altitude gradient (Table 2.4).

Table 2.4. Interaction effect of altitude, aspect and soil depth on soil seedbank abundance of *F. macrophylla* and *H. splendidum*

Lower elevation			
Treatment	***F. macrophylla* abundance**		
Aspect*soil depth			
Aspect	**Soil depth**		
	0-3 (cm)	3-6 (cm)	6-9 (cm)
NW	18.33[bc]	5.00[d]	4.33[d]
NE	50.67[a]	24.00[b]	10.00[cd]
P. value	**0.0088**		
Treatment	***H. splendidum* abundance**		
Aspect*soil depth			
Aspect	**Soil depth**		
	0-3 (cm)	3-6 (cm)	6-9 (cm)
NW	110.33[a]	45.67[c]	36.00[cd]
NE	86.00[b]	33.33[d]	21.33[e]
p. value	**0.005**		
Upper elevation			
Treatment	***F. macrophylla* abundance**		

Aspect*soil depth			
Aspect	**Soil depth**		
	0-3 (cm)	**3-6 (cm)**	**6-9 (cm)**
SW	22.67^{a}	19.00^{ab}	14.33^{bc}
SE	20.00^{a}	13.00^{c}	9.00^{c}
P. value	**0.0052**		
Treatment	***H. splendidum* abundance**		
Aspect*soil depth			
Aspect	**Soil depth**		
	0-3 (cm)	**3-6 (cm)**	**6-9 (cm)**
SW	69.67^{a}	40.00^{c}	25.33^{d}
SE	51.33^{b}	22.67^{d}	14.67^{d}
p. value	**0.0051**		

Mean values followed by the same letters in each column and treatment showed no significant difference by LSD (p = 0.05). **KEY***:* NW=North-West, NE**=**North-East, SW=South-West, SE=South-East

2.5.5.2 Effect of aspect on the abundance of *F. macrophylla* and *H. splendidum* plant species

From the analysis done using SAS software, aspect significantly affected abundance of the two species, where both species with high abundance recorded higher at North-West and North-East direction followed by South-West and South-East direction (Table 2.5).

Table 2.5. Effect of aspect on *F. macrophylla* and *H. splendidum* abundance on lower and upper elevation of GCCA

Lower elevation		
Treatment	***F. macrophylla* abundance**	***H. splendidum* abundance**
Aspect		
NW	28.22[a]	64.00[a]
NE	17.22[b]	46.89[b]
P. value	**<.0001**	**0.0001**
Soil depth		
0-3 cm	34.50[a]	98.17[a]
3-6 cm	14.50[b]	39.50[b]
6-9 cm	7.17[b]	28.67[c]
p. value	**<0.0001**	**<0.0001**
Upper elevation		
Treatment	***F. macrophylla* abundance**	***H. splendidum* abundance**
Aspect		
SW	9.67[a]	45.00[a]
SE	7.00[b]	29.56[b]
P. value	**0.0076**	**0.0002**
Soil depth		
0-3 cm	21.33[a]	60.50[a]
3-6 cm	16.00[b]	31.33[b]
6-9 cm	11.67[c]	20.00[c]
p. value	**0.0008**	**<.0001**

Mean values followed by the same letters in each column and treatment showed no significant difference by LSD (p = 0.05). **KEY***:* NW=North-West, NE**=**North-East, SW=South-West, SE=South-East

2.5.5.3 Depth distribution of *Festuca macrophylla* and *Helichrysum splendidum* plant species in the seedbanks

Vertical distribution of soil seedbank of both *F. macrophylla* and *H. splendidum* showed similar patterns. The highest number of seed was found within the first soil layer (0-3 cm) depth, while small amount for these species were found in the bottom layers (3-6 cm and 6-9 cm). It showed decreasing trend vertically following with increasing soil depth (Tables 2.4 and 2.5).

2.6 Discussion

Densities of seeds in the samples collected from the different plots varied greatly within and between the eight blocks as well as in the three different soil layers. The species composition and density of the soil seedbanks in the study area depended on the type of plant species that existed in the conservation area. The findings of the soil seedbank study revealed that there are large quantities of seeds of herbaceous species in the soil. The predominance of herbaceous species may be attributed to the small seed size, which makes them easily incorporated into the soil to form seedbank and less prone to predation (Thompson, 1987; Guo *et al.*, 1998; Luzuriaga *et al.*, 2005). The endemic species account for about 14.86% of the total species, which is higher than the 10% endemism of the Ethiopian Flora. This implies that the area is rich in endemic species of plants. The Shannon diversity indices for the diversity of soil seed bank showed that species richness declined with altitude and along the depth. The study agrees with previous findings of unimodal relationships between altitude and plant species richness (Rahbek, 1995; Bruun *et al.*, 2006). Such relationships have been suggested as the consequence of productivity associated competitive exclusions at lower altitudes (Rosenzweig, 1971) and productivity-related dilutions of regional species pools at higher altitudes (Huston, 1999). Despite the observed declines in species richness, no species evenness pattern was observed, so that not one species appears to have become dominant as species communities became diluted at higher altitudes. Although this result partly could have been caused by a declining species pool at higher altitudes (Dalerum *et al.,* 2017), our observations support suggestions of strong abiotic regulation of plant diversity at higher altitudes (Sang, 2009), coupled with relaxed competition (Bruun *et al.,* 2006). This variation can also be attributed to the nature of the soil, slope, difference in magnitude and intensity of disturbances could add up to the variation in diversity and evenness of soil seedbank (Kellerman and Van Rooyen, 2007).

The present study revealed that *H. splendidum* had higher density of seeds in the soil than *F. macrophylla*. The possible reason for the existence of high seed of *H. splendidum* in the soil may be due to high seed production which may persist in the soil for a long period of time (Wanga *et al.,* 2005). In addition, the species may have benefited from the current management system that forbid the local community from harvesting the shrub for fire and for other purposes and therefore, enabling the continuous production of seeds.

On the other hand, low seed density of *F. macrophylla* in the soil could be attributed to the light small sized seed and frequently found on the steep slope. These small sized seeds are mostly found on the steep slopes getting to be washed by water (Looney and Gibson 1995). Moreover, *F. macrophylla* is perennial herb and produce its seed every two year and grass harvesting or cutting (disturbance by the local community may be done before it produces seed (Steger *et al.,* 2020, 2021, 2022) which may also result in low persistence seed in the soil (Levassor *et al.,* 1990; Lemenih and Teketay, 2006).

The current management system in GCCA that involves two-three years cycle of harvesting festuca grass for various uses may have led to decreasing seed production and thus less seed as compared to other species. The dominance of the grass is possibly due to vegetative reproduction instead of germination from soil seedbank.

Patterns of abundance of *F. macrophylla* and *H. splendidum* were determined against altitude and aspect. The result indicated that abundance of *F. macrophylla* and *H. splendidum* negatively correlated with altitude ($P<0.05$). This result was similar with Melese *et al.,* (2017) who found that altitude is the most significant factor that affects species abundance and distribution in Afroalpine region. A reduction in species abundance might be due to harsh climatic condition and less competition as altitude increase Melese *et al.,* (2017). According to Bruun *et al.,* (2006) as altitude increases, richness of vegetation declines because of harsh climatic condition in the upper altitude that causes restriction to species' expansion. Altitude was found to be very important in many studies in influencing the plant species distribution (Jin *et al.,* 2008; Khalik *et al.,* 2013). Altitude was the main variable that determines the vertical distribution of vegetation whereas the horizontal distribution was affected by aspect (Jin *et al.,* 2008).

Species abundance is also significantly affected by aspect. High number of *F. macrophylla* and *H. splendidum* recorded along North-West and North-East direction followed by South-West and South-East directions. The high number recorded in these directions may be attributed to the fact that seed dispersed by wind and facilitated by human activity giving an opportunity to widely disperse in the soil (Schimmel and Granstrom, 1996). But considering study area a high number of *H. splendidum* was possibility due to high disturbance pressure as a result of high population density living in the surrounding areas as compared to the other two aspects. In addition, high disturbance may favor increase in non-native species hence opened area give an opportunity to germinate seed in soil (Beyene, 2010).

Vertical distribution of seeds of a species is assumed to reflect the longevity of its seeds in the soil (Teketay and Granström, 1995). The vertical distribution of the seeds in the soil showed that most habitat types have highest seed densities in the upper three centimeters of soil and gradually decreasing densities with increasing depth. The vertical distribution of the seeds of the two target species also showed similar trend (Teketay and Granström, 1997; Argaw *et al.*, 1999; Tekle and Bekele, 2000; Senbeta and Teketay, 2001 and Wassie and Teketay, 2006). The variations of seed density in successive layers may indicate *H. splendidum* had better seed longevity in the soil than *F. macrophylla* in addition to mode of seed dispersal and seed predation. It also suggests that if the upper soil layer is degraded by soil erosion or other factors, there may be variation in soil seed bank down to 9 cm.

The finding provides further evidence that *H. splendidum* showed significant increase in GCCA. The increase in *H. splendidum* cover confirms the problem of *H. splendidum* encroachment in the GCCA. This also confers with other study in the area. For example, the high-rate expansion of *H. splendidum* and its encroachment over other habitats, like *Festuca* grassland was pointed by Sillero-Zubiri and Macdonald, (1997). The *H. splendidum* free areas would be subject to competition for various uses such as agriculture land and grazing. Previous study indicated the expansion of farming at the western edge of GCCA (Ashenafi, 2001). Generally, *H. splendidum* increment was the predominant factor for the decrease in *F. macrophylla* and causes a decline in the status of the grassland in the study area (Sillero-Zubiri and Macdonald, 1997). Commonly *H. splendidum* encroachment was one but other drivers also listed as cause for the decreased of grass land cover. Much of the Ethiopian landscape from sea level up to 4,000 m is altered by agricultural activities, deforestation and overgrazing to fit the basic needs of a growing human population (Hilman, 1993; William *et al.*, 2007).

2.7 Conclusions

Guassa Community Conservation Area is one of the protected areas in Ethiopia where the local community harvest Guassa grass for different uses and other shrubs for firewood. The result of assessment of soil seedbank of GCCA revealed that the species recorded from soil seedbank were high. A total of 74 plant species were identified from which eleven taxa are endemic and three are near endemic to Ethiopia. The soil seedbank was dominated by the herbaceous flora and in terms of seedbank distribution; the upper 0-3 cm soil has high number of species when compared with the lower 3-6 cm and 6-9 cm soil. The study showed that abundance of the two target species was significantly affected by altitude and aspect. In addition, the current management system seems to favor the expansion of *H. splendidum.*

Evidence from this study showed that there is a significant increase in the expansion of *H. splendidum* encroachment in GCCA. The aboveground result also revealed and complemented that the density of *H. splendidum* is highly abundant than *F. macrophylla*. Thus, the GCCA has experiencing encroachment by *H. splendidum*. This study also concludes that the rate of expansion of *H. splendidum* encroachment might risk the loss of other habitats (such as *Festuca* grass land, *Erica* and other shrub lands). Furthermore, since the interest of local community to protect the GCCA because of the interest in the *Festuca* grassland, if the rate of *H. splendidum* encroachment over the *Festuca* grassland continuous, it might result in a failure of interest by the local community to protect the GCCA. Thus, expansion of *H. splendidum* might result in the loss of *F. macrophylla*.

Finally, loss of such ecologically and economically valuable plant species would have great implications for the environment, biodiversity and socio-economic development of the communities. Therefore, conservation and sustainable utilization of *F. macrophylla* through different management approach such as reintroducing the “QERO” management system that has been exercised for centuries by the local community would bring a better conservation outcome especially when complimented with scientific management approach.

Chapter Three

Influence of Aspect and Elevational Gradients on the Regeneration of *Festuca macrophylla* and *Helichrysum splendidum* plant species in GCCA, Central Highlands of Ethiopia

Shambel Alemu Chengere[1], Sileshi Nemomissa[1], Bikila Warkineh Dullo[1]

[1]Department of Plant Biology and Biodiversity Management, College of Natural and computational Sciences, Addis Ababa University, Addis Ababa P.O. BOX 3434, Ethiopia; shambel.alemu@aau.edu.et; bikila.warkineh@aau.edu.et; sileshi.nemomissa@aau.edu.et

Corresponding author

E-mail: shambel.alemu@aau.edu.et; Tel.: +251-91-216-5150

Abstract

Natural regeneration is an important process that ensures the flow of genes and thus preserves the diversity of life in ecosystems. However, natural regeneration is constrained by many factors including biotic, climatic and edaphic factors. The aim of this work was to assess the effects of aspect and elevational gradient on the natural regeneration potential of two competing species in Guassa Community Conservation Area in North Central Ethiopian highlands. We stratified our study area into eight blocks based on aspect and elevational gradient and conducted shrub removal experiment on 160 plots (5m x 5m). From these plots, we conducted vegetation survey following the modified Braun-Blanquette methods every three months. We used two elevational (<3350 m.a.s.l/lower and >3350 m.a.s.l/upper elevation) and four aspect categories (northeast, northwest, southwest and southeast) to compare the seeding density of the target species and species composition studies. On these plots, all vascular plants were recorded, and the data was analyzed by two-way ANOVA using SAS statistical software version 9.0.1. In addition, we used

LSD test for mean separation test. We computed the similarities in composition, density, abundance and species similarity between soil seedbank and the aboveground vegetation. Results showed that a total of 31 species, representing 27 genera and 16 families were recorded. The families with the highest number of species were Asteraceae (18 species, 22.5%), Fabaceae (3 species, 10%), and Poaceae (3 species, 10%). Of the total families, the dicots constituted 87.5% and monocots 12.5%. Species abundance was negatively correlated with elevation ($p<0.0009$), with fewer species occurring at higher elevation. Moreover, topographical difference had a significant ($P<0.05$) impact on the abundance of *H. splendidum* and *F. macrophylla* for all the three seasons in the study area. Meanwhile, aspect significantly affected abundance of the two species ($P<0.0009$), where both species with high abundance recorded in the Northern direction followed by Southern directions. Treatments done during the study also highly influenced the recovery of vegetation species in different ways. High species similarity was also observed between below and aboveground vegetation.

Keywords: Elevation gradient, Guassa Community Conservation Area, Regeneration potential, Similarity, Species recovery

3.1. Introduction

For the management and protection of biodiversity, it is essential to have knowledge of the plant diversity and regeneration status of specific vegetation type. Natural regeneration is a key element of the dynamics of the specific ecosystem and is crucial for the conservation and preservation of biodiversity (Getachew *et al.*, 2010; Rahman *et al.*, 2011). The diversity of their species, variety, and intricate community organization are among the most significant traits of tropical and subtropical vegetation, along with regeneration (Mishra *et al.*, 2005). According to Pala *et al.*, (2012), a given species' ability to regenerate successfully depends on the structure of its overall populations as well as the availability of sufficient numbers of seedlings, saplings, and adults.

Ecosystem's species richness, population structure, and natural regeneration are all impacted by both natural and man-made activities. Invasive species, floods, fires, and storms are examples of natural causes, whereas illegal logging, excessive use of natural resources, encroachment, harvesting (overexploitation) and domestic grazing are examples of human-caused factors that can harm the natural ecosystems. The conservation of biodiversity and human use of resources in developing countries are at odds (Singh *et al.*, 2016), and degradation and destruction of habitats as a result of human activities are the main causes of global biodiversity loss (Mishra *et al.*, 2004).On the other hand, understanding the distribution and patterns of vegetation growth as well as the influencing factors in those areas is crucial and has been researched by numerous researchers (Endress and Chinea, 2001; Bai *et al.*, 2004).

Dawes and Short (1994) indicated that, the type of soil and the amount of rainfall only have little impact on the size of hill slopes, where topography is the primary governing factor for vegetation growth. Environmental variables such as elevation, aspects and soil nutrient regime contribute to determining the vegetation changes in the land where disturbance practices have been ceased (Tasser & Tappeiner, 2002). The three primary topographic parameters that regulate the distribution and patterns of vegetation in mountainous locations are elevation, aspect, and slope (Titshall *et al.*, 2000). Elevation is the most crucial of these three variables (Busing *et al.*, 1992). The microclimate, and consequently the large-scale spatial distribution and patterns of vegetation are frequently influenced by elevation, aspect, and slope (Busing *et al.*, 1993).

One particular concern in protected areas such as GCCA is shrub encroachment, which is a common phenomenon (Knapp *et al.*, 2008; Guido *et al.*, 2017), threatening conservation of global grassland ecosystems (Fogarty *et al.*, 2020). Shrub encroachment brings competition between the shrubby species and the other less competitive species such as the herbaceous plants (e.g., *Festuca* grasses). The effect of such competition is the loss of grasslands, whereas shrubs replace palatable herbaceous forage (Venter *et al.*, 2018). The displacement of other plants species by the shrubs also leads to the decline in endemic plant species richness and abundance (Eldridge *et al.*, 2011; Manish *et al.*, 2016).

Shrubs negatively affect other plant species through competition for aboveground resources, e.g., light (Bahalkeh *et al.*, 2021), and/or belowground resources such as soil nutrients (Gillet, 2008). For many expanding shrub species, encroachment occurs in areas where soils are characterized by low soil nutrient levels (Kgosikoma & Mogotsi, 2013) leads to less regeneration of grass species, because such areas have limited number of competitors (Szita & Gyo, 2021). Examples of the well-known shrub encroachers in Africa include the woody shrub species *Prosopis spp*., *Senegalia spp.* and dwarf shrubs of *Artemisia afra* Willd. in South Africa (Tiawoun *et al.*, 2022) and *Helichrysum splendidum* (Thunb.) Less in Ethiopia (Wube *et al.*, 2021; Steger *et al.*, 2022).

In Ethiopia, most of the protected areas do not have legal status and are inadequately protected. These protected areas are facing problems that could potentially deteriorate them (Teressa, 2017). Impoverished resource dependent local populations are still increasing in Ethiopia, both within and adjacent to conservation areas with high biodiversity value (EBI, 2014). The nature of community conserved areas depends on the ecological characteristics in sites, species diversity and regeneration status of species. Natural regeneration is essential for preservation and maintenance of biodiversity in community conserved areas. Depending on management objectives, it is important to maintain the process of ecosystem restoration by appropriate natural and assisted regeneration. In the conservation areas, cutting of grasses accelerates loss of seedlings and saplings as well as disturbs the natural condition of the ecosystem (Haque *et al*., 1988).

Knowledge of plant diversity and natural regeneration status of certain ecosystems provides basic information for ecosystem management and biodiversity conservation (Hossain *et al.,* 1999). Natural regeneration is a fundamental component of ecosystem dynamics and is essential for the conservation and maintenance of biological diversity (Dutta and Devi, 2013; Rahman *et al.,* 2011; Tesfaye e*t al.,* 2010), as well as for identifying priority plant species for conservation (Tyagi *et al.,* 2013). Management of regeneration is an essential component for sustainable ecosystems as it ensures future growing stocks (Level, 2010). Successful regeneration of a species can be predicted by overall population structure as well as enough seedlings, saplings and adults (Pala *et al.*, 2012; Saxena *et al.,* 1984). The presence of sufficient numbers of seedlings, saplings and adults in each population indicates that the species can be successfully regenerate (Pala *et al.,* 2012).

For the conservation and management of plant diversity in biodiversity conservation areas, information on plant diversity is considered essential because of its potential importance and implications (Kadavul and Parthasarathy, 1999). Many researchers (Ashenafi, 2001; Ashenafi *et al.,* 2005, 2012; Amessie, 2017; Steger *et al*., 2020, 2021 and 2022) have carried out various studies on GCCA but influence of aspect and elevational gradients on the regeneration of *Festuca macrophylla* and *Helichrysum splendidum* plant species were not investigated in the biodiversity conservation areas of GCCA, in the central highlands of Ethiopia.

Thus, the aim of this study was to assess the effect of aspect and elevation on the natural regeneration status (after removal experiment), composition and diversity of herbaceous species in conservation area namely GCCA. In the study site, the ground is mainly covered with herbs and shrubs. Therefore, assessing the regeneration status, composition and diversity of *Festuca macrophylla* and *Helichrysum splendidum* in the study area is highly valuable to understand the status of the conservation area and to predict future conservation strategies and design (Senbeta *et al*., 2014).

3.2. Materials and Methods

3.2.1. Description of study area

The study area is in the Amhara Regional State, North Shewa Zone, in the central portion of the Ethiopian highland massif in an area locally known as Menz Gera Midir district. It is located at a latitude of 10^0 15'–10^0 27'N and longitude 39^0 45'–39^0 49'E, 295 km north-east from Addis Ababa (capital city of Ethiopia) (Amessie, 2017). The Guassa range comprises 111 km^2 and lies at an altitude range of 3200 to 3700 m above sea level (Ashenafi, 2001).

The highland plateaus of Ethiopia formed 45 million years ago from tertiary uplift followed by volcanism and form basalt layers (Hendickx *et al*., 2014; Rosqvist, 1990). This long-term volcanic activity resulted in the building up of the northern and central highlands of Ethiopia which include GCCA. GCCA is characterized by its plateau which crosscut by various gorges and river valleys that flow west and eastwards. It straddles the catchment basins of two major rivers in East Africa – the Abay (the Blue Nile) and the Awash, and thus its conservation is critical to the health and functioning of those headwaters (Moges, 2015). The swamps of the area increase water holding capacity and limit runoff in the rainy seasons, thus providing flow all year round. Generally, the soil of the Guassa area is deep and humic. However, on higher ground, the soil is shallow, and highly mineralized (Ashenafi and Leader-Williams, 2005).

The climate in the Guassa area varies widely due to the differences in elevation and the size of the mountain block. The annual mean rain fall is 828mm. Temperatures are characterized by mild days and cold nights. In the drier months (December to February), daytime temperatures can rise to 25 ^{0}C, while night-time temperatures can drop to -7 ^{0}C (Simeneh, 2010; Amessie, 2017). The area gets its name from the "Guassa grass" *Festuca macrophylla*, which is highly valued by the local community. The Guassa area is a common property resource area managed by the community for various uses such as grazing land, essential source of income for the local community, firewood collection, and the cutting of Guassa grass for various purposes such as thatching, making household equipment, baskets, painting brushes, mattresses and shepherds' raincoats and farm implements like ropes and whips.

GCCA is a biodiversity hotspot, containing several endemic and threatened species (Ashenafi *et al*., 2012). The area is rich in biodiversity and contains several endemic and threatened species of flora and fauna species (Ashenafi and Leader-Williams, 2005). The vegetation of the Guassa area is characterized by high Afroalpine vegetation with different types of habitats, namely: *Euryops-Alchemilla* shrubland, *Festuca* grassland, *Euryops-Festuca* grassland, *Helichrysum* -*Festuca* grassland, Swamp Grassland and Erica moorland (Beyene, 2010 and Simeneh, 2010). GCCA is a place for important and endemic plant species including Guassa grass (*F. macrophylla*), giant Lobelia (*Lobelia rhynchopetalum*), *Kniphofia foliosa* and *Alchemilla* species (Ashenafi and Leader-Williams 2005; Ashenafi *et al*., 2012). There are about nine (which accounts to 23% mammal fauna of the country) endemic fauna including the Ethiopian wolf (*Canis simensis)*, gelada baboon (*Theropethicus gelada)* and Ethiopian Highland hare or

Abyssinian hare (*Lepus starcki)* and about 114 (12% of 861 bird species) have been recorded in the GCCA (Ashenafi and Leader-Williams, 2005). The Guassa area is also home to the world's largest concentration of the globally endangered Ankober serin (*Serinus ankoberensis)* and the spot-breasted plover (*Vannellus melocephalus*) (Ashenafi, 2001).

The human population is predominantly of Amhara ethnicity and Orthodox Christian religion. The main economic activity of the people is farming which involves mainly crop production and livestock husbandry. The community can generate income from off-farm activities such as petty trading, selling local beer ('Tella'), liquor ('Arekie') and local green tea. Wool processing (known in sheep and cattle rearing) is the most common off-farm activity of the Guassa community. The area is regarded as food insecure, and in many years, parts of the population depend on the national food aid program (safety-net) (Ashenafi, 2001).

The Guassa area is currently managed by a team composed of five representatives from each of the nine communities (the "Guassa Committee"), and about 20 other individuals from two government offices. The community protects the area by promulgating various regulations that restrict the use of natural resources by the communities (Ashenafi and Leader-Williams, 2005).

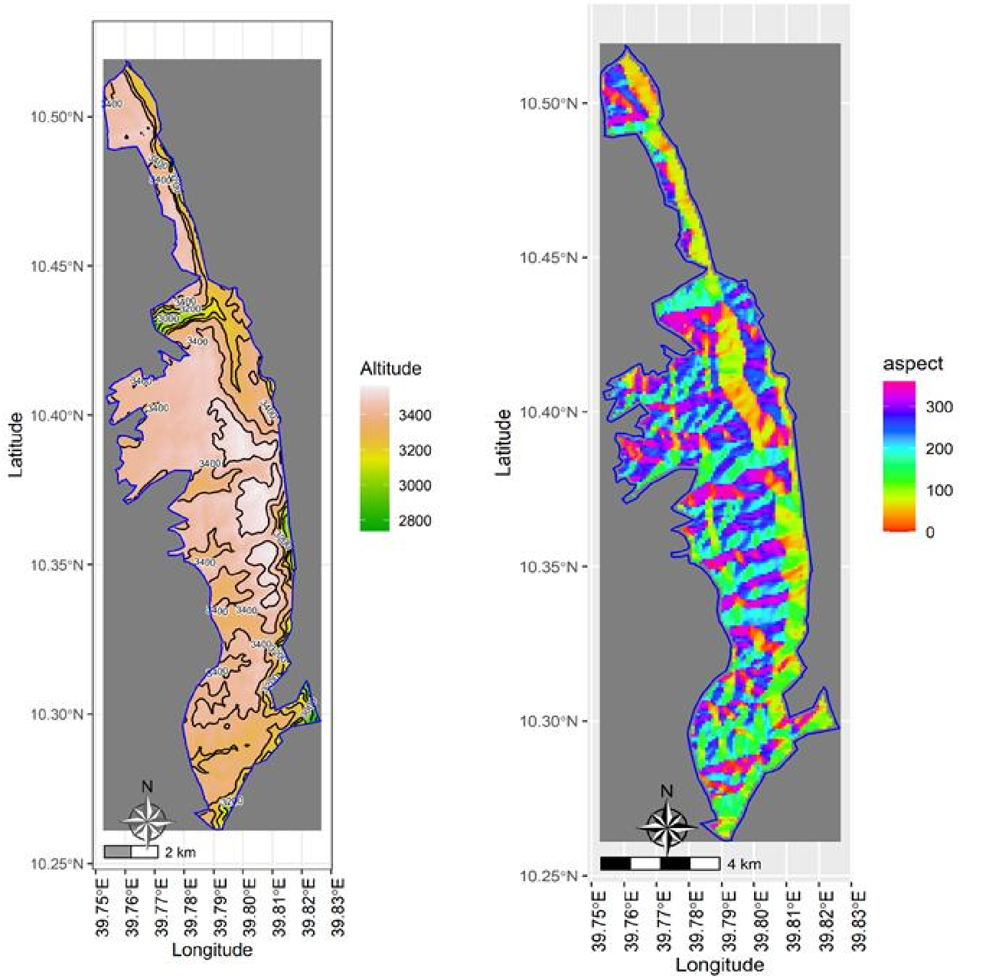


Figure 3.1. Contour and aspect map of the Guassa Community Conservation Area (GCCA).

3.3. Data Collection Procedure and Experimental Design

For shrub removal experiment, vegetation in the study area was stratified and categorized into eight blocks based on elevation and aspect. Each block has twenty 5 m x 5 m established plots; thus, we have a total of 160 plots. Vegetation data were collected from each (160) sampling plots. We used a block design that allowed us to explore removal and regrowth of shrubs across a range of environmental variability (aspect and elevation). We organized our removal according to aspect and altitudinal categories. We also categorized aspects in to four as NE, NW, SE and

SW to compare the seedling density for the target species in the elevation. Elevation in GCCA ranges from about 3,000 m – 3550 m.a.s.l with the bulk of the area falling between 3250 – 3550 m. Therefore, we further stratified these plots according to two elevational categories (<3350 m/lower and >3350 m/upper elevation) to test whether removal and subsequent regrowth will respond differently at low and high elevations.

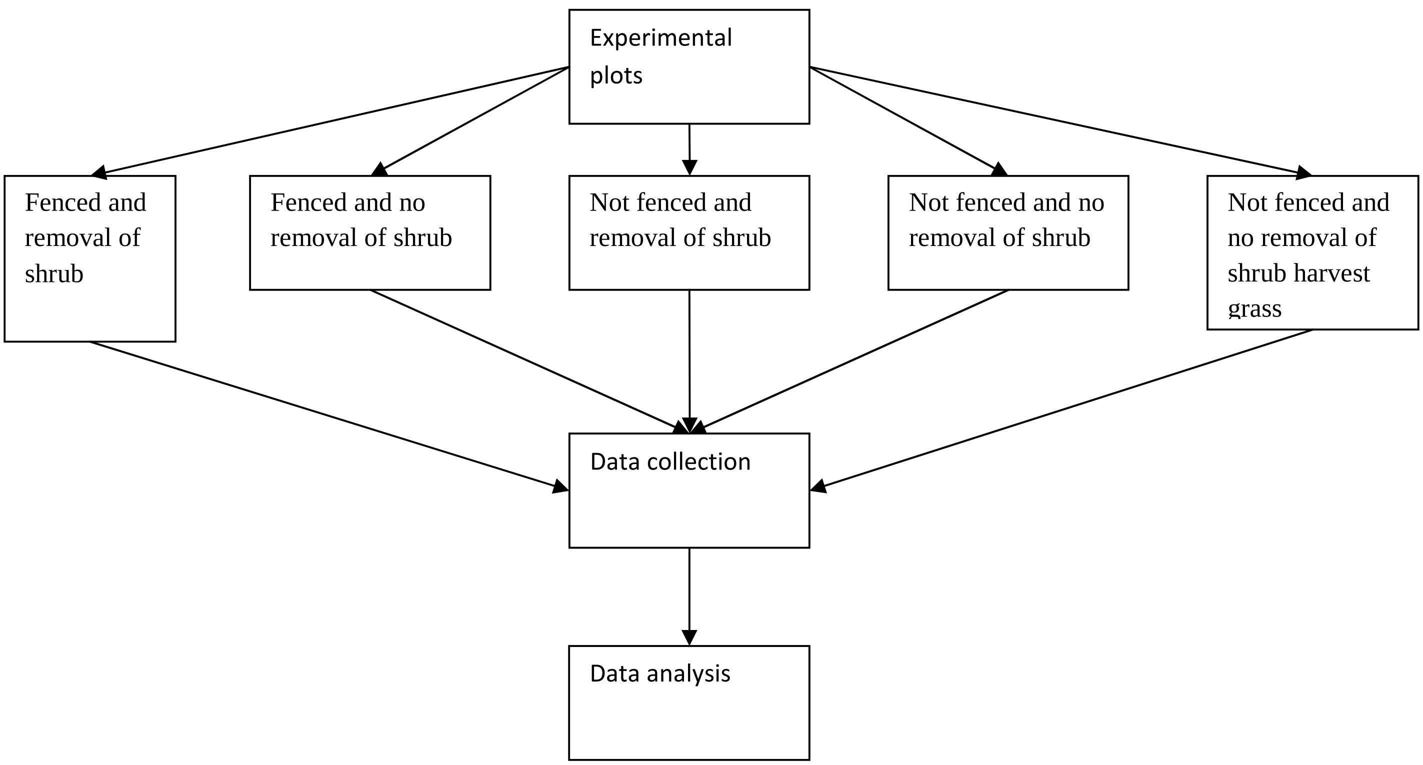


Plate 3.1. A schematic diagram of the experimental treatments showing data collection and analysis procedure.

Our experimental treatments were fenced and open plots. In each block, we have eight fenced and twelve unfenced plots. Therefore, we have a total of 160 (8 fenced plots * 8 blocks + 12 unfenced plots * 8 blocks) permanent plots from both fenced and unfenced treatments. We used meshed wire that can preclude herbivores except insects. We assumed insect herbivory is the same for both fenced and unfenced treatments.

Once we established the plots, we then classified the collected data in the experimental treatments in to two main rainy seasons (Meher) between June to September and minor rainy season (Belg) in February, March and April. Then the measurements taken during this time were categorized into five groups; 1 (Fenced remove shrub/FR), 2 (Fenced don't remove shrub/FN), 3 (Not fenced remove shrub/ NR), 4 (Not fenced don't remove shrub/NN) and 5 (Not fenced don't remove shrub harvest grass/NNH).

After that, we completely removed all the above ground *Helichrysum* biomass by up-rooting for the plots that require removal of the Helichrysum shrub and Guassa grass. Members of the local community were trained and monitored the sites every month for eighteen consecutive months. During the monitoring abundance data (count) were collected for analysis. Altitude, longitude, latitude and aspect were measured and recorded for each plots using GPS. These shrub removal experiment and subsequent data recording have been conducted for eighteen months.

3.4. Data Analysis

Before conducting the data analysis, all gathered data were organized in Excel and checked for errors, normal distribution, and homogeneity of variance. The abundance of *Festuca macrophylla* and *Helichrysum splendidum* along an altitudinal gradient was determined using SAS statistical software version 9.0.1 (SAS Institute, 2001). All the collected data was fitted into a general linear model (GLM) and analyzed using two-way ANOVA (Analysis of variance). Fisher's least significant difference (LSD) test was employed to separate the means when significant F values were found at a significance level of $p \leq 0.05$.

We calculated species abundance by totaling the number of seedlings per sample area. The composition, density, abundance and similarity between soil seedbank (data from chapter two) and aboveground vegetation in the study area were estimated. The density of seeds was calculated from the total number of seeds recovered after removal (Mueller-Dombois and Ellenberg 1974). Density is a count of the numbers of individuals of a species within the plots (Kent and Coker, 1992). It refers to the total number of stems of a species ha $^{-1}$ which was calculated by summing up all the stems across all sample plots (abundance) and translated to hectare base for all the species encountered in the study plots. Afterwards, the sum of individuals per species is calculated in terms of species density per convenient area unit, such as hectare (Mueller-Dombois and Ellenberg, 1974). It was calculated using the following formula.

$$D = \frac{\text{The number of above ground stems of a species}}{\text{Sampled area in hectar}} \times 100$$

The frequency of *Festuca macrophylla* and *Helichrysum splendidum* in all plots were also calculated. The higher the frequency, the more important the plant is in the study area. Frequency is defined as the probability or chance of finding a species in each sample area or plot. It is dependent on plot size, plant size and pattern in the vegetation (Kent and Coker, 1992).

It is calculated using the following formula:

$$F = \frac{\text{The number of plots in which species occur}}{\text{Total number of plots}} \times 100$$

Then the relative frequencies of occurrences of the two species present were calculated by using the formula:

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of species}}{\text{Total frequency of all species}} \times 100$$

The species richness of above ground vegetation and soil seedbank in each soil profile was counted (data from chapter two). Sorensen coefficient of similarity (Ss, Sorensen, 1948) was used to compare the similarity between soil seedbank compositions with the aboveground vegetation and it is given as:

$$\text{Ss} = \frac{2a}{(2a + b + c)}$$

Where, a = number of species common to both soil seed bank and aboveground vegetation; b = number of species recorded only in aboveground vegetation; and c = number of species recorded only in soil seedbank. The closer Sorensen's coefficient of similarity to 1 the more similar the sites are. This similarity coefficient was selected because it gives weight to species that exist in both sites.

3.5. Results

3.5.1. Floristic Composition of the Study Plots

Results showed that, a total of 31 species in 27 genera and 16 families were recorded from the 160 experimental plots (Table 3.1). Of the 16 plant families, Asteraceae has the highest number of species (7 species, 22.5 %) followed by Fabaceae and Poaceae represented with three species each (Table 3.1). These three families contained 42.5% of the total species recorded in the study area and the remaining 13 families were represented only by less than two species each (Table 3.2). Of the total families, the dicots constituted 87.5% and monocots 12.5%. Herbs were found to occur more abundantly (24 species, 77.42%) than shrubs (7 species, 22.58%). These numbers are the total species recoded over the experimental period from the sampled plots.

The result of species composition showed that the area contains all the five “typical” Afroalpine life-forms; namely Giant Rosette Plants (e.g., *Lobelia rhynchopetalum*), Tussock Grasses and sedges (e.g., *Agrocharis melanantha, Carex monostachya, Festuca macrophylla*), Acaulescent Rosette Plants (e.g., *Haplocarpha rueppellii*), Sclerophyllous and Dwarf-Shrubs (e.g., *Erica arborea*), and Cushion Plants (e.g., *Helichrysum splendidum*, *Helichrysum formosissimum*).

Table 3.1. List of species with their family and habit recorded from the experimental plots.

No	**Name of Species**	**Family**	**Abundance**	**Habit**
1	*Agrocharis melanantha* Hochst.	Apiaceae (Umbelliferae)	156	H
2	*Alchemilla abyssinica* Fresen.	Rosaceae	903	H
3	*Anchusa affinis* R.Br. ex. DC.	Boraginaceae	124	H
4	*Andropogon lima* (Hack.) Stapf	Poaceae	2	H
5	*Anthemis tigreensis* J. Gay ex A. Rich.	Asteraceae (Compositae)	3	H
6	*Argyrolobium ramosissimum* Bak.	Fabaceae (Leguminosae)	3	H
7	*Artemisia abyssinica* Sch. Bip. ex A. Rich.	Asteraceae (Compositae)	140	H
8	*Bartsia longiflora* Hochst.ex Benth.	Scrophulariaceae	4	SH
9	*Carduus schimperi* Sch. Bip. ex A. Rich.	Asteraceae (Compositae)	114	H
10	*Carex monostachya* A. Rich.	Cyperaceae	3	H
11	*Cynoglossum coeruleum* Hochst. ex A. DC.	Boraginaceae	3	H
12	*Cyperus elegantulus* Steud.	Cyperaceae	61	H
13	*Erica arborea* L.	Ericaceae	9	SH
14	*Euryops pinifolius* A. Rich.	Asteraceae (Compositae)	1619	SH
15	*Festuca abyssinica,* Hochst. ex A. Rich.	Poaceae (Gramineae)	28	H
16	*Festuca macrophylla* Hochst. ex A. Rich.	Poaceae (Gramineae)	4988	H
17	*Haplocarpha rueppellii (*Sci.Bip.)	Asteraceae (Compositae)	52	H
18	*Helichrysum formosissimum* Sch. Bip. ex A. Rich.	Asteraceae (Compositae)	47	H
19	*Helichrysum splendidum* (Thumb.) Less	Asteraceae	1863	SH

		(Compositae)		
20	*Hypericum revolutum* Vahl	Hypericaceae	3	SH
21	*Kalanchoe petitiana* A. Rich.	Crassulaceae	7	SH
22	*Lobelia rhynchopetalum* Hemsl.	Lobeliaceae	1	H
23	*Ranunculus multifidus* Forssk.	Ranunculaceae	4	H
24	*Rubus volkensii* Engl.	Rosaceae	19	SH
25	*Rumex abyssinica* Jacq.	Polygonaceae	13	H
26	*Rumex nepalensis* Spreng.	Polygonaceae	32	H
27	*Thymus schimperi* Ronniger	Lamiaceae	867	H
28	*Trifolium polystachyum* Fresen.	Fabaceae (Leguminosae)	223	H
29	*Trifolium usambarense* Taub.	Fabaceae (Leguminosae)	114	H
30	*Urtica simensis* Steudel	Urticaceae	73	H
31	*Verbascum sinaiticum* Benth.	Scrophulariaceae	19	H

Table 3.2. List of plant families with number of genera, species and percentage obtained from the experimental plots.

Family	**Genera**	**Species**	**Percentage**	**Classification**
Apiaceae	1	1	3.3	Dicot
Asteraceae	6	7	22.5	Dicot
Boraginaceae	2	2	6.6	Dicot
Crassulaceae	1	1	3.3	Dicot
Cyperaceae	2	2	6.6	Monocot
Ericaceae	1	1	3.3	Dicot
Fabaceae	2	3	10	Dicot
Hypericaceae	1	1	3.3	Dicot
Lamiaceae	1	1	3.3	Dicot
Lobeliaceae	1	1	3.3	Dicot
Poaceae	2	3	10	Monocot
Polygonaceae	1	2	6.6	Dicot
Ranunculaceae	1	1	3.3	Dicot
Rosaceae	2	2	6.6	Dicot
Scrophulariaceae	2	2	6.6	Dicot
Urticaceae	1	1	3.3	Dicot

3.5.2. Density and Frequency of Aboveground Vegetation

The species with the highest densities in descending order include *Festuca macrophylla*, *Helichrysum splendidum*, *Euryops pinifolius*, *Alchemilla abyssinica* and *Thymus schimperi* (Table 3.3).

The above ground density of *Helichrysum splendidum* was found to be lower than that of *Festuca macrophylla* which was the opposite result with soil seedbank density of the two species (*Helichrysum splendidum* was more abundant than that of *Festuca macrophylla*), (the soil seedbank article is apparently published and presented here as chapter two). Densities of the species per hectare are shown in (Table 3.3).

From the two species, *Festuca macrophylla* was found to be the most frequent species occurring in 93% (RF=53.76%) of all plots sampled. Whereas *Helichrysum splendidum* frequency was found to be 80.63% (RF=46.23%).

Table 3.3. Density of above ground plants in the study plots

No	Name of species	Count	Density (%)
1	*Agrocharis melanantha* Hochst.	156	1.41
2	*Alchemilla abyssinica* Fresen.	903	8.14
3	*Anchusa affinis* R.Br. ex DC.	124	1.12
4	*Andropogon lima* (Hack.) Stapf	2	0.02
5	*Anthemis tigreensis* J. Gay ex A. Rich.	3	0.03
6	*Argyrolobium ramosissimum* Bak.	3	0.03
7	*Artemisia abyssinica* Sch. Bip. ex A. Rich.	140	1.26
8	*Bartsia longiflora* Hochst.ex Benth.	4	0.04
9	*Carduus schimperi* Sch. Bip. ex A. Rich.	114	1.03
10	*Carex monostachya* A. Rich.	3	0.03
11	*Cynoglosum coeruleum* Hochst. ex A. DC.	3	0.03
12	*Cyperus elegantulus* Steud.	61	0.55

13	*Erica arborea* L.	9	0.08
14	*Euryops pinifolius* A. Rich.	1619	14.59
15	*Festuca abyssinica,* Hochst. ex A. Rich.	28	0.25
16	*Festuca macrophylla* Hochst. ex A. Rich.	4988	44.94
17	*Haplocarpha rueppellii (*Sci.Bip.)	52	0.47
18	*Helichrysum formosissimum* Sch. Bip. ex A. Rich.	47	0.42
19	*Helichrysum splendidum* (Thumb.) Less	1863	16.77
20	*Hypericum revolutum* Vahl	3	0.03
21	*kalanchoe petitiana* A.Rich.	7	0.06
22	*Lobelia rhynchopetalum* Hemsl.	1	0.01
23	*Ranunculus multifidus* Forssk.	4	0.04
24	*Rubus volkensii* Engl.	19	0.17
25	*Rumex abyssinicus* Jacq.	13	0.12
26	*Rumex nepalensis* Spreng.	32	0.29
27	*Thymus schimperi* Ronniger	867	7.81
28	*Trifolium polystachyum* Fresen.	223	2.01
29	*Trifolium usambarense* Taub.	114	1.03
30	*Urtica simensis* Steudel	73	0.66
31	*Verbascum sinaiticum* Benth.	19	0.17

3.5.3. Impact of elevation difference on *F. macrophylla* and *H. splendidum* species abundance

Vegetation pattern is determined by environmental factors that exhibit heterogeneity over space and time, such as climate, topography, and soil, as well as human disturbances**.** The distribution of the plant species growing at the study sites varied with altitudinal range (figure 3.2).

The cover abundance of the two target species (*F. macrophylla* and *H. splendidum*) in the study area was statistically significant. The pooled cover abundance and altitude were negatively correlated (Two-way ANOVA: $P<0.0009$), where abundance of these two species showed decreasing pattern as altitude increases in the sample blocks (Figure 3.2). The five most abundant species in the study area are given in Table 3.1.

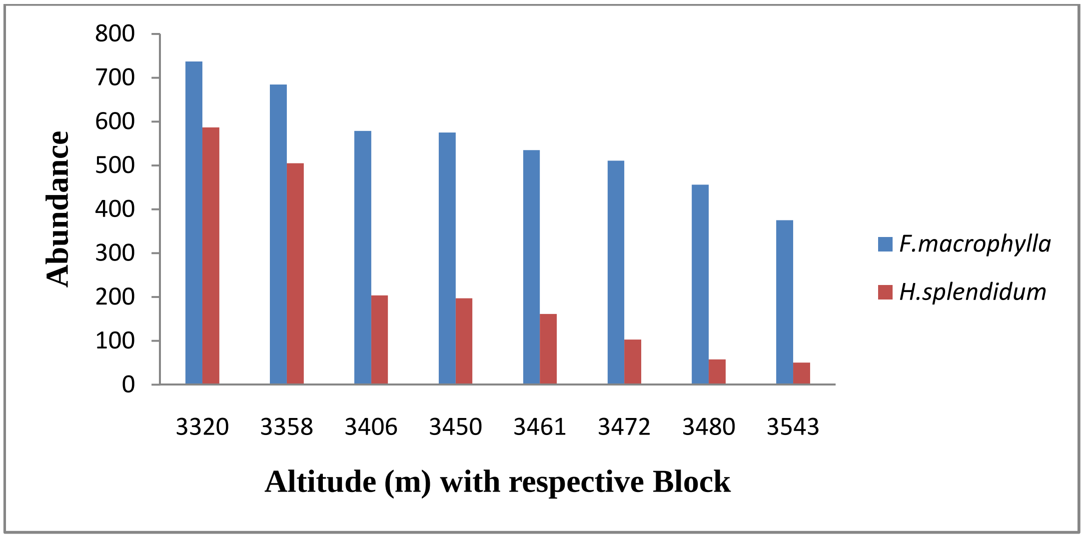


Figure 3.2. Abundance of *F. macrophylla* and *H. splendidum* along altitude gradient from the study plots.

The result done using two-way ANOVA also showed that topographical difference had a significant ($P<0.05$) impact on the cover abundance of *H. splendidum* for all the three seasons in the GCCA (Table 3.4). This indicates that the cover abundance of *F. macrophylla* and *H. splendidum* declines monotonically from the lowest to highest elevations in the study plots.

Table 3.4. Elevation-abundance relationship for *F. macrophylla* and *H. splendidum* plant species in the study plots

Elevation	**Meher1**	**Belg**	**Meher2**
F. macrophylla			
Lower elevation	11.96^{a}	5.10^{a}	19.20^{a}
Upper elevation	9.78^{b}	4.10^{b}	12.34^{b}

P- value	**	**	**
H. splendidum			
Lower elevation	8.03[a]	0.60[a]	10.0[a]
Upper elevation	1.61[b]	0.01[b]	3.01[b]
P- value	***	**	***

The numbers show the value of species abundance. The letters show significance level. Different letters have significant difference. Mean values followed by the same letters in each column and treatment showed no significant difference by LTD (p = 0.05). * donates = significant at P ≤ 0.05; ** = significant at P ≤ 0.01; *** = significant at P ≤ 0.001.

3.5.4. Effect of aspect on the abundance of *F. macrophylla* and *H. splendidum* plant species.

The result of the analysis done within each blocks shows that, aspect significantly affected abundance of the two species (Two-way ANOVA: P<0.0009), where both species with high abundance recorded highest at North-West and North-East direction followed by South-West and South-East directions (Figure 3.3).

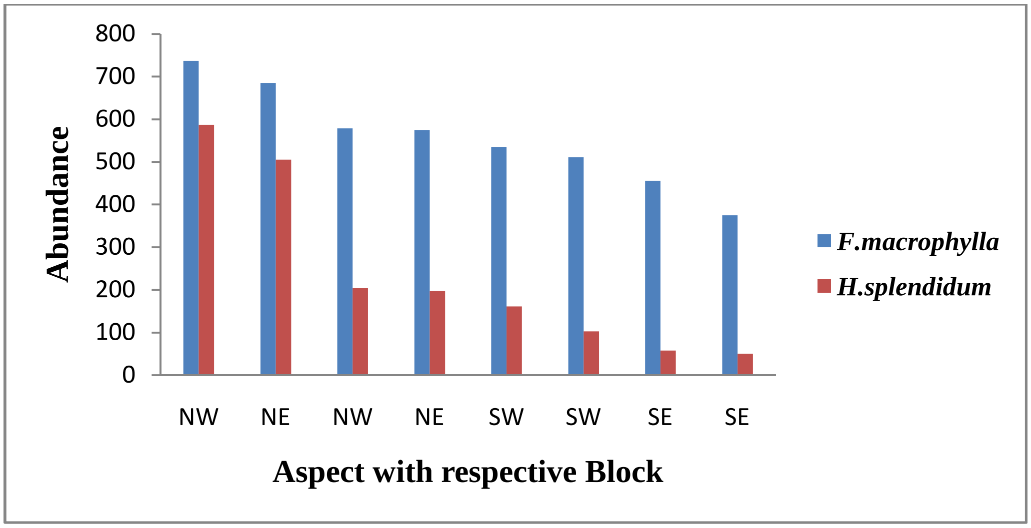


Figure 3.3. The effect of aspect on the abundance of *F. macrophylla* and *H. splendidum* plant species (**KEY***:* NW=North-West, NE**=**North-East, SW=South-West, SE=South-East**)**

On the other hand, the analysis done using Two-way ANOVA by using SAS also complement that both species with high abundance recorded in Northern direction followed by Southern direction (Table 3.5).

Table 3.5. Effect of aspect on *F. macrophylla* and *H. splendidum* abundance in the study area

Aspect	**Meher1**	**Belg**	**Meher2**
F. macrophylla			
North-West	14.30^{a}	4.76^{a}	17.00^{ab}
North-East	9.62^{a}	5.63^{a}	21.40^{a}
South-West	7.65^{b}	3.53^{b}	11.68^{b}
South-East	5.90^{b}	3.28^{b}	13.00^{b}
P- value	**	*	*
H. splendidum			
North-West	7.85^{a}	0.75^{a}	8.83^{a}
North-East	8.20^{a}	0.45^{ab}	11.18^{a}
South-West	0.73^{b}	0.00^{b}	1.98^{b}
South-East	2.50^{b}	0.03^{b}	4.05^{b}
P- value	***	*	***

The numbers show the value of species abundance. The letters show significance level. Different letters have significant difference. Mean values followed by the same letters in each column and treatment showed no significant difference by LTD (p = 0.05). * donates = significant at P ≤ 0.05; ** = significant at P ≤ 0.01; *** = significant at P ≤ 0.001.

3.5.5. Regeneration status of *F. macrophylla* and *H. splendidum* species

The five treatments done during experimental study responded to the regeneration of the two species in different ways. These indicates, after the removal experiments was done, the treatments taken impacts the recovery of vegetation and determines the cover abundance of mature vegetation and seeding stage of the existing shrub and grass species in the study area. As a result, the most seedling counts was observed for treatment 5 (plot not fenced no removal of shrub harvest grass/NNH) followed by treatment 1 (Fenced remove shrub/FR), treatment 3 (Not fenced remove shrub/ NR), treatment 2 (Fenced no removal of shrub/FN) and treatment 4 (Not fenced no removal of shrub/NN) for both target species (Table 3.6). Thus, the five treatments had a significant ($P< 0.05$) impact on regeneration status of *F. macrophylla* and *H. splendidum* species in the study area.

Table 3.6. Effect of different treatments on *F. macrophylla* and *H. splendidum* regeneration abundance among different seasons

Treatment description	**Meher1**	**Belg**	**Meher2**
Measurement			
F. macrophylla			
Fenced remove shrub/FR	15.44^{b}	4.91^{b}	19.16^{b}
Fenced no removal of shrub/FN	1.16^{d}	2.79^{bc}	5.28^{c}
Not fenced and removal of shrub/ NR	8.63^{c}	2.81^{bc}	14.19^{b}
Not fenced no removal of shrub/NN	0.88^{d}	1.00^{c}	3.78^{c}
Not fenced no removal of shrub harvest grass/NNH	28.25^{a}	11.50^{a}	36.50^{a}
P- value	***	***	***

H. splendidum			
Fenced remove shrub/FR	7.00^{ab}	0.41^{ab}	8.06^{b}
Fenced no removal of shrub/FN	3.00^{cd}	0.06^{b}	3.81^{c}
Not fenced and removal of shrub/ NR	4.41^{bc}	0.09^{b}	5.67^{bc}
Not fenced no removal of shrub/NN	1.22^{d}	0.00^{b}	2.94^{c}
Not fenced no removal of shrub harvest grass/NNH	8.47^{a}	0.97^{a}	12.03^{a}
P- value	***	**	***

The numbers show the value of species abundance. The letters show significance level. Different letters have significant difference. Mean values followed by the same letters in each column and treatment showed no significant difference by LTD (p = 0.05). * donates = significant at P ≤ 0.05; ** = significant at P ≤ 0.01; *** = significant at P ≤ 0.001.

On the other hand, the cover abundance of *H. splendidum* differed significantly between the treatments over series of time. When we compare the total cover abundance of *H. splendidum* per plots before and after removal experiment for the treatments in which the removal was conducted, the removal leads to less regeneration of *H. splendidum* in the sample plots. *Helichrysum splendidum* was more represented in the plots before the removal was done than in the plots after the removal experiment was conducted, which had less cover representation in all the plots (Figure 3.4).

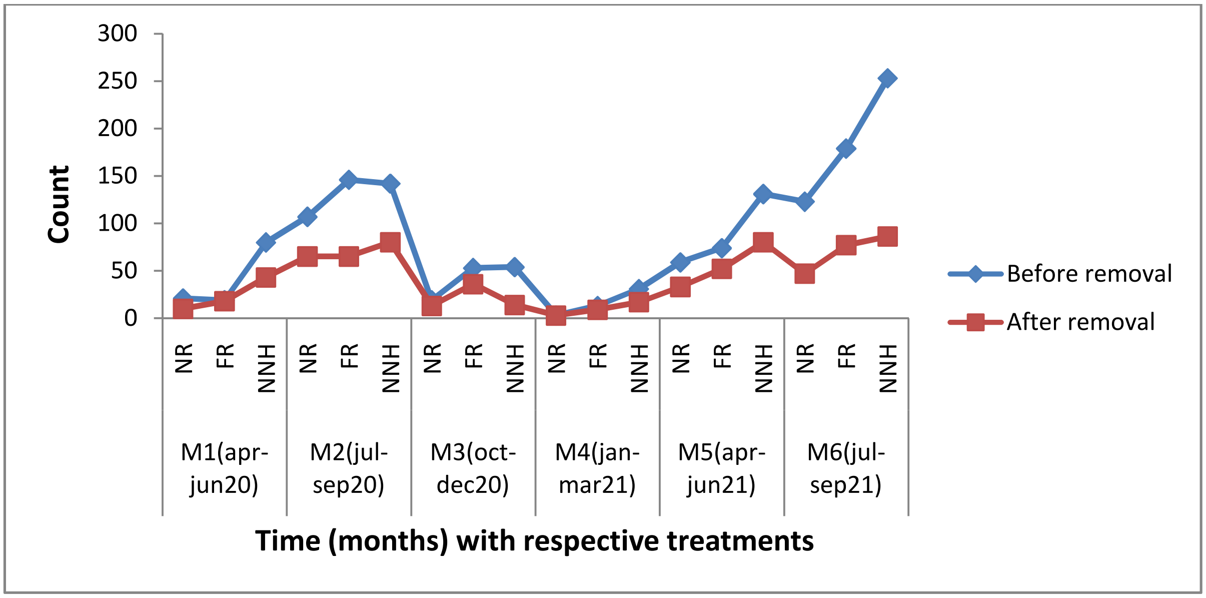


Figure 3.4. Cover abundance of *H. splendidum* before and after removal experiment under different treatments. (**KEY***:* NR= Not fenced remove shrub, FR**=** Fenced remove shrub, NNH= Not fenced don't remove shrub harvest grass, M= the three months (for the year 2020 and 2021) in which counting was conducted**)**

3.5.6. Similarity between soil seedbank and aboveground vegetation

The total number of species recorded in the aboveground vegetation was 31 and the total number of species recorded in the soil seedbank was 74 (data from chapter two). Species recorded only in soil seedbank were 44, species recorded only in the aboveground vegetation were 1, and species recorded both in soil seedbank and standing vegetation were 30 (Table 3.7). The Sorensen Similarity index was 0.6 (60% Sorenson's coefficient). The similarity of species composition found in the seedbank and aboveground vegetation was high. From the study plots, species found in the aboveground vegetation were 99% represented in the soil seedbank.

Table 3.7. Similarity between soil seedbank and aboveground vegetation

Aboveground vegetation (Abgv) (A)			
		No. of species present	No. of species absent
Soil seed bank SSB (B)	No. of species present	30	1
	No. of species absent	44	0

3.6. Discussion

The total number of regenerating species recorded in our 160 experimental plots over the study period was 31 species in 27 genera and 16 families. From these families Asteraceae was the family with high species representation (7 species, 22.5%). Tadesse (2004) stated that Asteraceae was among the richest family in the flora area (Flora of Ethiopia and Eritrea (FEE). According to Hedberg (1964), wind dispersal is one of the main mechanisms affecting long-distance dispersal for Afroalpine landscapes. Moreover, many species of Asteraceae have umbrella shape capitula that are adapted for wind dispersal (Hedberg, 1964) and increase their opportunity for the successful establishment of their populations. The study was in accordance with results of other studies, for instance, Boditi (39 species, 17%; Yineger *et al*., 2008), Komto (17 species, 9.44%; Gurmessa *et al*., 2013), Dense (20 species, 27%; Lulekal, 2014), Hugumburda-Gratkahsu (38 species, 11%; Kidane, 2016).

The result of this study indicated that densities of plant species collected from the eight blocks varied greatly. The density of *Helichrysum splendidum* was found to be lower than that of *Festuca macrophylla* which was opposite result with soil seedbank density of the two species (16.77% and 44.94% for *Helichrysum splendidum* and *Festuca macrophylla* in the above ground, and 10.28% and 3.21% for *Helichrysum splendidum* and *Festuca macrophylla* in the soil seedbank respectively). Variations in density distributions can be attributed to variations in habitat preferences of species and topographic gradients forming the degree of anthropogenic influences (Whittaker *et al*., 2003). These findings agree with Wube *et al.*, (2021), who found that the expansion of *Helichrysum splendidum* in Guassa Conservation Community area in Ethiopia was associated with land disturbance such as wood collection, soil excavation, and cultivation (Jørgensen et al., 2013; Archer *et al.*, 2017). The other possible reason for the existence of low density of *H. splendidum* could be due to the removal of *H. splendidum* which leads to suppress the shrub and promote the *Festuca* grass growth.

From the two species, *Festuca macrophylla* (RF=53.76%) was species with the highest frequency value than *Helichrysum splendidum* (RF=46.23%). Shibiru and Balcha (2004) stated that the variation in frequency among species indicates differences in site conditions, species characteristics, seed dispersal mechanisms of species, and disturbance. Likewise, Rey *et al.*, (2000) reported that the high frequency of a species always depends on factors which relate to habitat preferences, adaptation, and degree of exploitation and availability of suitable conditions for regeneration.

Patterns of abundance of *F. macrophylla* and *H. splendidum* were determined against altitudinal variation. The result indicated that abundance of *F. macrophylla* and *H. splendidum* negatively correlated with altitude ($P<0.0009$). Altitude is the most significant factor that affects species abundance and distribution in Afroalpine region (Melese *et al*., 2017). Even though, *Festuca* grass seems to perform better at higher altitude than *Helichrysum*, the lower elevation has high abundance compared to higher elevation gradient for both *F. macrophylla* and *H. splendidum* species. This could be due to top-climatic factors like season, seed dispersal, slope and elevation (Getachew *et al*., 2008). A reduction in species abundance and richness of vegetation decline at higher elevation might also be due to harsh climatic condition, less competition, environment, a regional lack of capable species, or a multitude of disturbances caused by restriction in species' expansion (Bruun *et al*., 2006; Korner, 2012; Melese *et al*., 2017; Gairola *et al.*, 2009).

Altitudinal difference had great impact on the abundance of shrub and grass species in the study area. The upper elevation had low abundance compared lower elevation gradient which had high abundance for *F. macrophylla* and *H. splendidum* plant species (Figure 3.2 and Table 3.4). This could be due to top-climatic factors like season, slope and elevation (Tadesse *et al.,* 2008). This implies altitude can act as an independent factor that affects both the environmental and conservation area sustainability. This is the major cause of the general vegetation pattern linked with other living and non-living threating factors (Otypkova *et al*., 2011; Simegn and Soromessa, 2015) and results of diversity and richness of grass species along with altitudinal difference.

Altitude was found to be very important in many studies in influencing the plant species distribution and determines the microclimate and thus large-scale spatial distribution and patterns of vegetation (Jin *et al*., 2008; Khalik *et al*., 2013). Our findings are similar to findings from mountain forests of northern China (Zhang *et al*., 2013) and sub-alpine mountainous zone in central Japan (Tsujino and Yumoto, 2013) stating that altitude has a strong influence on the structure of the vegetation in most mountains. Moreover, variations of species richness occurred among the vegetation could be attributed to the area sampled (Hill and Curan, 2003) and large range of altitude (Bekele, 1993), climate variability (Schmitt *et al*., 2013) and disturbance (Økland, 1990).

Climate, topography, aspect, inclination of slope, wind direction, soil type, and land use pattern are recognized as the major contributor to vegetation type (Maren *et al*., 2015). From our findings, vegetation growth in the GCCA area is significantly affected by aspect. High number of *F. macrophylla* and *H. splendidum* recorded along North-West and North-East direction followed by South-West and South-East directions. North-East and North-West faces are observed as the paramount habitat for the growth of plants in the study area. Furthermore, insolation and light intensity also put down a range of microclimates at the multifaceted landscape. The variation in vegetation between North and South aspects could be attributed to difference in reception of solar radiation (Ghimire *et al*., 2010; Paudel and Vetaas, 2014). Of the eight aspect categories we have (Figure 3.3), south-facing slopes receive more sunlight and become warmer. Therefore, such slopes are less favorable for plant growth. However, north-facing slopes hold moisture and remain cold as well as humid, thus supporting moisture loving plants (Nevo, 2001; Maren *et al*., 2015) which is a case in the Afroalpine vegetation of the study area. In other words, the best vegetation growth is on the shady side of the mountain where less evapotranspiration is expected. The high number recorded in north directions may be attributed to the fact that seed dispersed by wind and facilitated by human activity during Guassa harvest giving an opportunity to widely disperse (Schimmel and Granstrom, 1996).

Different measurements/treatments taken during data collection also impacted the recovery of vegetation and determines the abundance of mature vegetation and seeding stage of the existing shrub and grass species in the study area. Thus, the treatments done during experimental study responded to the regeneration of the two species in different ways. The most seedling counts was observed for treatment 5 (plot not fenced no removal of shrub and harvest grass/NNH) (Table 3.6). Germination of *H. splendidum* decreases over time when a continued removal was conducted for twenty-four months, showing less cover abundance as compared to the number of species before the removal was conducted.

Factors such as seed dispersal agents, harvesting time, encroachment and climate change had great impact on the recovery of plant species (Leul *et al*., 2010). Also, the anthropogenic activates during harvesting had a great impact on the recovery of the spices in the study area. This result agrees with the report done by Kidane *et al*., (2016) stating that anthropogenic activates during harvesting had a great impact on the recovery of the spices. All the regeneration of vegetation in the study site is highly impacted by both climatic and human factors (Kuma and Shibiru, 2015). According to the data reported by Girma (2012), the recovery and rehabilitation rate of vegetation is primarily influenced by topographical variation, site location, rate of grazing intensity, human interference and combination of all the determinant factors.

The Sorenson's similarity between the soil seedbank (data from chapter two) and above ground vegetation was relatively high (0.6). Thirty plant species (23.3 %) were represented both in the above ground vegetation and soil seed banks. From these plant species, *Haplocarpha rueppellii* was found in the above ground flora were not represented in the seed bank. The regional climate has a paramount role in similarities for species distribution patterns in Afroalpine ecosystems, especially in those with highly diverse topography (Schmitt *et al*., 2013). The higher similarity observed were because both share similar climate and altitude interval. The ecological distance between any two areas has also been noted to play an important part for differences in species composition (Mueller-Dombois and Ellenberg, 1974).

3.7. Conclusion

In this study composition, density, frequency, abundance and similarity were determined for the vegetation in the study area. The result shows that Asteraceae was found to be the most dominant family followed by Fabaceae and Poaceae. The findings of the study indicated that abundance of the two target species (*H. splendidum* and *F. macrophylla*) was significantly affected by altitude and aspect. Species abundance decreases as altitude increase. High number of *F. macrophylla* and *H. splendidum* recorded along North-West and North-East direction followed by South-West and South-East directions. Measurements/treatments done during the study also impacts the recovery of vegetation species and determines the abundance of mature vegetation and seeding stage of the existing plant species in the study area. The high similarity for species distribution pattern between seedbank and aboveground vegetation was due to similar climate and altitude interval. Finally, we recommend that the management intensity of the GCCA should receive increased attention from the responsible body for its conservation. Especially the local government (Guassa Administration) and the community should collaborate with NGO and other organizations working on Guassa area for the better management and sustainable use of this conservation area.

Article III-Published

environments

MDPI

Article

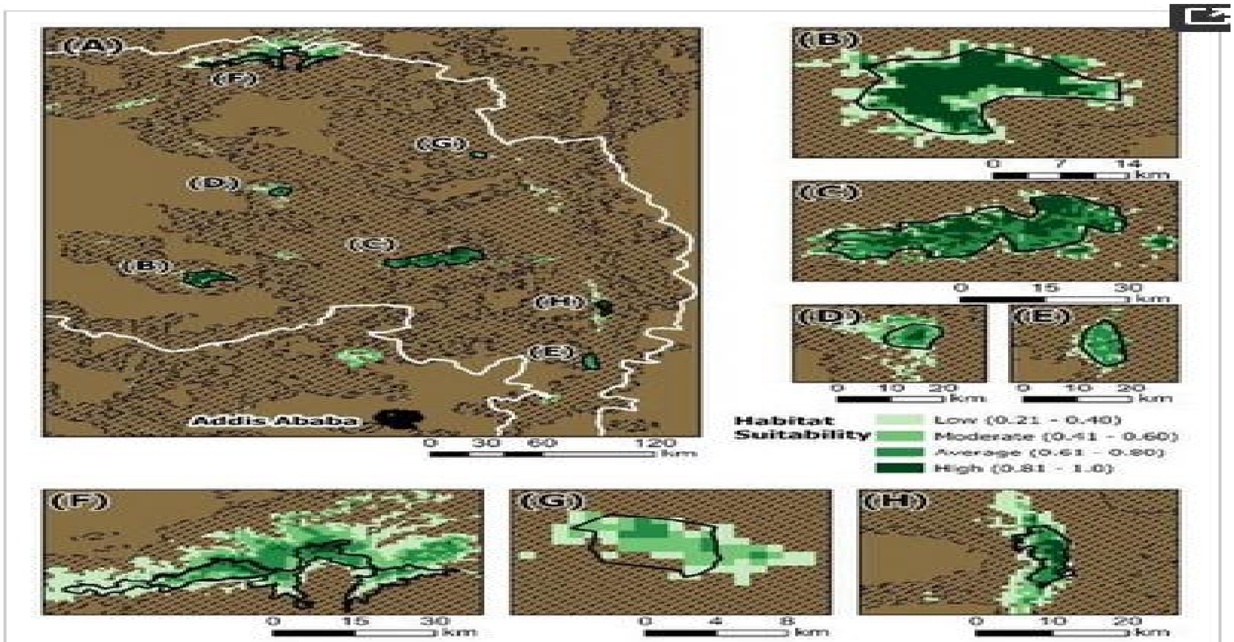
Modeling Cultural Keystone Species for the Conservation of Biocultural Diversity in the Afroalpine

Shambel Alemu Chengere [1,*], Cara Steger [2], Kflay Gebrehiwot [3], Sileshi Nemomissa [1] and Bikila Warkineh Dullo [1]

[1] Department of Plant Biology and Biodiversity Management, College of Natural and Computational Sciences, Addis Ababa University, Addis Ababa P.O. Box 3434, Ethiopia
[2] Department of Natural Resources and Environment, Cornell University, Ithaca, NY 14850, USA
[3] Department of Biology, Samara University, Semera P.O. Box 132, Ethiopia
* Correspondence: shambel.alemu@aau.edu.et; Tel.: +251-91-216-5150

Environments **2022**, *9*(12), 156; https://doi.org/10.3390/environments9120156

Received: 25 March 2022 / Revised: 29 April 2022 / Accepted: 1 May 2022 / Published: 16 December 2022



Chengere, S.A.; Steger, C.; Gebrehiwot, K.; Nemomissa, S.; Dullo, B.W. Modeling Cultural Keystone Species for the Conservation of Biocultural Diversity in the Afroalpine. *Environments* **2022**, *9*, 156. https://doi.org/10.3390/environments9120156

Chapter Four

Modeling Cultural Keystone Species for the Conservation of Biocultural Diversity in the Afroalpine

Shambel Alemu Chengere [1,*], Cara Steger [2], Kflay Gebrehiwot [3], Sileshi Nemomissa [1] and Bikila Warkineh Dullo [1]

[1]Department of Plant Biology and Biodiversity Management, College of Natural and Computational Sciences, Addis Ababa University, Addis Ababa, P.O. BOX 3434, Ethiopia; shambel.alemu@aau.edu.et; sileshi.nemomissa@aau.edu.et (S.N.); bikila.warkineh@aau.edu.et (B.W.D.)

[2]Department of Natural Resources and Environment, Cornell University, Ithaca, NY, 14850, USA; cara.steger@gmail.com

[3]Department of Biology, Samara University, Semera, P.O. BOX 132, Ethiopia; kflay77@gmail.com

*Correspondence: shambel.alemu@aau.edu.et; Tel.: +251-91-216-5150

Abstract:

Climate warming threatens the future sustainability of mountains, and tropical mountains are particularly threatened with loss of biodiversity and associated ecosystem services. Conservation biologists increasingly turn to habitat suitability models to guide the establishment and assessment of protected area networks to protect the highest number of species, yet this focus often neglects the values, attitudes, and beliefs of the people living around protected areas. If we consider protected areas as dynamic social-ecological systems, habitat suitability modeling for conservation planning must pay greater attention to the role of *biocultural diversity*, rather than biodiversity alone. Here, we describe a conservation assessment of the Afroalpine grassland ecosystem in the northern highlands of Ethiopia. We use a cultural keystone species known as Guassa grass (*Festuca macrophylla*) to focus our modeling efforts, and evaluate the potential distribution of this endemic species in relation to current national and community-based protected areas. Our model performed highly according to the area under the curve (AUC =0.96), yet nearly 80% of highly suitable Guassa habitat falls outside the range of our training data and thus must be interpreted conservatively. We found that Guassa grass distribution is primarily limited by low mean temperature in the warmest quarter (BIO10, 36.7%), high precipitation in the wettest quarter (BIO16, 21%) and low precipitation in the driest quarter (BIO17, 15.6%). As climate change causes rapid warming at high elevations and alters rainfall patterns in the Ethiopian highlands, we urge managers to carefully monitor the changing populations of Guassa grass to evaluate whether the species is experiencing an extinction debt. We also recommend four additional areas as potential community-based conservation areas, with government and NGO support for peer-to-peer communication networks. Spatially explicit modeling may be a valuable tool to determine whether these existing and proposed protected areas can sustain future populations of Guassa grass.

Keywords: Social-ecological systems, Climate change, Grassland, MaxEnt model, Community-based conservation areas, Extinction debt

4.1. Introduction

Mountain systems provide essential ecosystem services to the world, yet are disproportionately threatened by climate change (Grabherr *et al.*, 1994; IPCC 2007; Lenoir *et al.*, 2008; Loeffler *et al.*, 2011; Klein *et al.*, 2019). Mountains occupy ~30% of the global land mass (Sayre *et al.*,

2018) and may contain up to 28% of the world's human population (Karagulle *et al.*, 2017) yet support an astonishing 85% of the world's amphibian, bird, and mammal species (Rahbek *et al.*, 2019). Mountains contribute approximately twice as much total runoff to the world's freshwater supply than would be expected based on their share of surface area, and serve as particularly critical "water towers" in arid and semi-arid climates (Viviroli *et al.*, 2007). Hydrological processes in mountains are already being altered by global environmental change, with continued changes expected in the timing, volume, and variability of water (Loeffler *et al.*, 2011). Climate warming threatens the future sustainability of mountain systems as most species ranges continue to shift upward in elevation (Parmesan & Yohe, 2003; Hickling *et al.,* 2006), increasing competitive pressures on mountain species with as yet unknown consequences (Thuiller *et al.*, 2006; Bakkenes *et al.,* 2002; Thomas *et al.*, 2004; Hagedorn *et al.*, 2019). Warming appears to be amplified at higher elevations, causing more rapid and disproportionately intense change for mountains compared to lowlands (Pepin *et al.,* 2015).

Tropical mountains are particularly threatened with loss of biodiversity due to their high baseline levels of diversity (Rahbek *et al.,* 2019), endemism (Gehrke & Linder, 2014) and rarity (Enquist *et al.,* 2002; Stévart *et al.*, 2019). In Africa, the Afroalpine ecosystem occurs over 3,000 meters above sea level and is confined to a mosaic of mountains and plateaus that form isolated "sky-islands" separated by extensive savannas, semi-deserts, agricultural areas, and other social-ecological barriers (Mairal *et al.*, 2021). The highlands of Ethiopia occupy an estimated 658,551 km^2 (58.2% of the country), based on our calculations using the Albers Equal Area Conic projection and the Karagulle *et al.,* (2017) mountain delineation. Nearly half of these highlands are "high mountains" that can support Afroalpine vegetation (Yalden & Largen, 1992; Brochmann *et al.,* 2021). The highlands support the livelihoods of millions of Ethiopians and provide water to hundreds of millions of additional downstream users (e.g., by providing over 70% of the Nile River flow, Conway, 2005). The Ethiopian highlands are severely threatened by climate and land use change (Stévart *et al.,* 2019). Despite their ecological and economic importance, and the imminent threats they face from global environmental change, our calculations place only 15% of the high mountains of Ethiopia within protected areas.

Conservation biologists are increasingly turning to habitat suitability models, also known as species distribution models, to guide the establishment and assessment of protected area networks (Anderson & Martinez-Meter, 2004; Pauli *et al.,* 2007; Arcos *et al.,* 2012; Guisan *et al.,* 2013; Fajardo *et al.,* 2014). Referred to as systematic conservation planning (Guisan *et al.,* 2013) or regional conservation planning (Ferrier, 2002) this two-step process typically involves modeling distributions of large numbers of species (hundreds to thousands) or species assemblages and then using algorithms to select locations that maximize biodiversity representation with as little land as possible (Pawar *et al.,* 2007; Kremen *et al.,* 2008; Fajardo *et al.,* 2014). These conservation planning processes are often considered a more time- and cost-effective approach than modeling individual species (Ferrier, 2002). However, this focus on protecting the highest level of biological diversity ignores the values, attitudes, and beliefs of the people living in or around protected areas. The failures of top-down “fortress conservation” are well-documented (Brockington, 2002; West *et al.,* 2006), and even efforts in community-based conservation have often fallen short of their people-oriented goals (Berkes, 2007). Despite these challenges, there is increasing agreement that we must consider protected areas as dynamic social-ecological systems (Palomo *et al.,* 2014; Cumming *et al.,* 2015; Brueckner-Irwin *et al.,* 2019).

We argue that habitat suitability modeling for conservation planning must pay greater attention to the role of biocultural diversity, rather than biodiversity alone, to realize the benefits of a social-ecological approach to protected area design and evaluation. Biocultural diversity has been defined as the 'diversity of life in all its manifestations-biological, cultural and linguistic-which are interrelated within a complex socio-ecological adaptive system' (Maffi, 2005). It refers to the interconnectedness of human cultures and the biophysical environments in which they exist (Maffi, 2005; Kassam, 2008; Hanspach *et al.*, 2020). Early efforts to integrate biocultural diversity into conservation planning focused on standardization and measurement of cultural diversity (i.e., through language, ethnicity, or religion) for protected area conservation (Harmon, 1992; Loh & Harmon, 2005). An analysis of the diversity of language and vascular plants found that mountains have some of the highest rates of biocultural diversity when examined at a global scale (Stepp *et al.*, 2005). However, these indicators are less useful for examining biocultural diversity at a local scale; when cultural diversity might take the form of diverse social constructions of meaning that require qualitative inquiry and whose complexity cannot be adequately or ethically represented in a scientific model (Taylor, 2005; Crane, 2010). While ethnographic understanding of culture is needed to analyze biocultural diversity at a local scale, there is still a role for modeling to extend this understanding to broader scales. For example, cultural keystone species are "species whose existence and symbolic value are essential to the stability of a cultural group over time" (Cristancho & Vining, 2004). Cultural keystone species are often irreplaceable, embedded within social-ecological systems where they are thought to play critical roles in maintaining cultural or ecological stability at a local level (Garibaldi & Turner, 2004). We propose that habitat suitability modeling might focus on the distributions of cultural keystone species (Garibaldi & Turner, 2004) as surrogates for broader scale biocultural diversity (Ferrier *et al.*, 2002; Cristancho & Vining, 2004).

In this paper, we focus our efforts on a conservation assessment of the Afroalpine grassland ecosystem that uses a cultural keystone species to drive our modeling efforts and evaluate the potential distribution of this species in relation to current national and community-based protected areas. The endemic Guassa grass (*Festuca macrophylla*) is thought to have evolved around 290-300 thousand years ago in the northern highlands of Ethiopia (Mairal *et al.*, 2021), during a time of rapid technological and cultural evolution amongst early humans (McBrearty & Brooks, 2000; Ambrose, 2001). Contrary to long-held beliefs that high elevations were inhospitable to early humans, stone tools dating to the same era have been found in the Ethiopian highlands (Vogelsang *et al.*, 2018; Ossendorf *et al.*, 2019). This shared evolutionary heritage of humans and Guassa grass is compelling, as the Guassa grass has become a cultural keystone species for modern people living in the Ethiopian highlands – so much so that the first community conservation area in Ethiopia was named in its honor (Ashenafi & Leader-Williams, 2005). The Guassa grass is celebrated for its length and strength, and used to thatch roofs, construct ropes, plaster walls, and craft a wide variety of other cultural items such as mattresses and parkas (Steger *et al.*, 2020). Ecologically, the Guassa grass shares functional traits with other tussock grasses in the tropical alpine zone, contributing to carbon sequestration, freshwater supply and regulation, and supporting highly diverse flora and fauna (Myers *et al.*, 2000; Mosquera *et al.*, 2015).

The purpose of this paper is to access the habitat suitability of Guassa grass across the Ethiopian highlands, and to evaluate the current extent of suitable Guassa habitat contained within protected areas as a measure of biocultural diversity protection in the Afroalpine.

4.2. Methods

4.2.1. Area of Study

Three protected areas currently serve as strongholds for the Guassa grass and associated Afroalpine vegetation in the northern Ethiopian highlands (Figure 4.1) and all three are located in the Amhara Region of Ethiopia. Simien Mountains National Park (SMNP; 486 km^2) was established in 1969 primarily to protect the endemic Walia ibex (*Capra walia).* The SMNP is home to Ethiopia's highest peak, Mount Ras Dejen (4540 m). The climate of SMNP is characterized by frequent frosts, occasional high-altitude snowfall, and frequent hailstorms (Hurni, 1988). The daily mean temperature varies between a minimum of 1.5 °C and a maximum of 14.6 °C (Hurni & Stahli, 1982). Precipitation in SMNP follows a unimodal rainfall pattern with high average annual rainfall (around 1500 mm). In 1978 SMNP was listed as a World Heritage Site; however, it became a World Heritage Site in Danger in 1997 due to increased anthropogenic pressure and declines in iconic species such as the Walia ibex. The number of tourists to the SMNP has increased in recent years, which has enhanced conservation funding while also presenting new challenges for regulating tourist impacts on the environment (EWCA, 2015). The SMNP can be divided into three distinct vegetation belts. The montane forest belt, the transitional ericaceous belt and the uppermost Afroalpine belt (Nemomissa & Puff, 2001; Puff & Nemomissa, 2005). The montane forest belt is rich in species with large trees such as *Prunus africana*, *Hagenia abyssinica* and *Olea europaea* (Jacob *et al.*, 2017). The transitional ericaceous belt includes the shrubs *Erica arborea* and *Hypericum revolutum* in low altitudes (Nievergelt *et al.,* 1998). The Afroalpine zone contain Afroalpine grasslands scattered with giant lobelias (*Lobelia rhynchopetalum*) and various types of low and tall grass steppes (*F. macrophylla*, *Carex monostachya*) and wetlands (Hurni & Stahli, 1982; Gebremedhin *et al.*, 2016). In addition to the Walia ibex, SMNP is home to several endemic species such as Ethiopian wolf (*Canis simensis*) and Gelada baboon (*Theropithecus gelada*) many of which are endangered due to habitat fragmentation and destruction due to anthropogenic impact (Yihune *et al.,* 2009; Alemayehu *et al.*, 2011).

Guassa Community Conservation Area (GCCA; 111 km^2) and Abune Yosef Community Conservation Area (AYCCA; 46 km^2) are both community conservation areas with rich histories of traditional environmental management (Ashenafi & Leader-Williams, 2005; Eshete *et al.*, 2015; Steger *et al.*, 2020). GCCA was officially recognized by the Ethiopian government in 2012 and AYCCA in 2014. Both community conservation areas were created in collaboration with Frankfurt Zoological Society and were largely promoted as protected areas for the endemic and endangered Ethiopian wolf (*Canis simensis*). Both areas have a bimodal precipitation regime, with short rains in the early spring (February to April) and long rains in (June to September) (Ashenafi, 2001). The mean monthly minimum temperature of GCCA was 5°C, and the maximum was 20°C, while at AYCCA they were 4°C and 26°C, respectively (Gebrehiwot *et al.*, 2018). The vegetation of GCCA and AYCCA is characterized by high Afroalpine plant species such as the genera *Alchemilla*, *Helichrysum*, *Senecio*, *Carex, Festuca,* and the endemic giant *Lobelia* (*Lobelia rhynchopetalum*) and *Kniphofia foliosa*. Both areas are also rich in biodiversity and contain several endemic species of fauna, including Ethiopian wolf (*Canis* *simensis*) and Gelada baboon (*Theropithecus gelada*) (Ashenafi & Leader-Williams, 2005; Gebrehiwot *et al.,* 2018).

The altitude of GCCA varies from (3200 - 3700 m.a.s.l). The climate also varies widely due to the differences in elevation and size of mountain block (Ashenafi, 2001). Temperatures are characterized by mild days and cold nights. In the drier months (December to February), daytime temperatures can rise to 25°C, while night-time temperatures can drop to -7°C. The area gets its name from the "Guassa grass" *Festuca macrophylla*, which is highly valued by the local community. The GCCA is currently managed by nine farmers' associations, local institutions that were created throughout Ethiopia in 1975 for rural administration. However, the area has been managed according to a traditional management system known as Qero for at least 400 years (Ashenafi & Leader-Williams, 2005). The community protects the area through various regulations that control the access of natural resources by the communities (Fisher *et al.,* 2014).
Prolonged volcanic activity has led to the creation of high mountains in northern Ethiopia that include some of the highest peaks such as Abune Yosef (Billi, 2015), which reaches 4284 m.a.s.l. The soils are predominantly Andosols and Vertisols (Gebrehiwot *et al.,* 2018). Elevations above 3500 m.a.s.l are considered potential Afroalpine grasslands; however, because much of this land has been turned into agricultural land, these grasslands can only be found above 3700 m.a.s.l. In the region around AYCCA, agricultural practices are not uncommon at an altitude of almost 3800 m.a.s.l. (Gebrehiwot *et al.,* 2021).

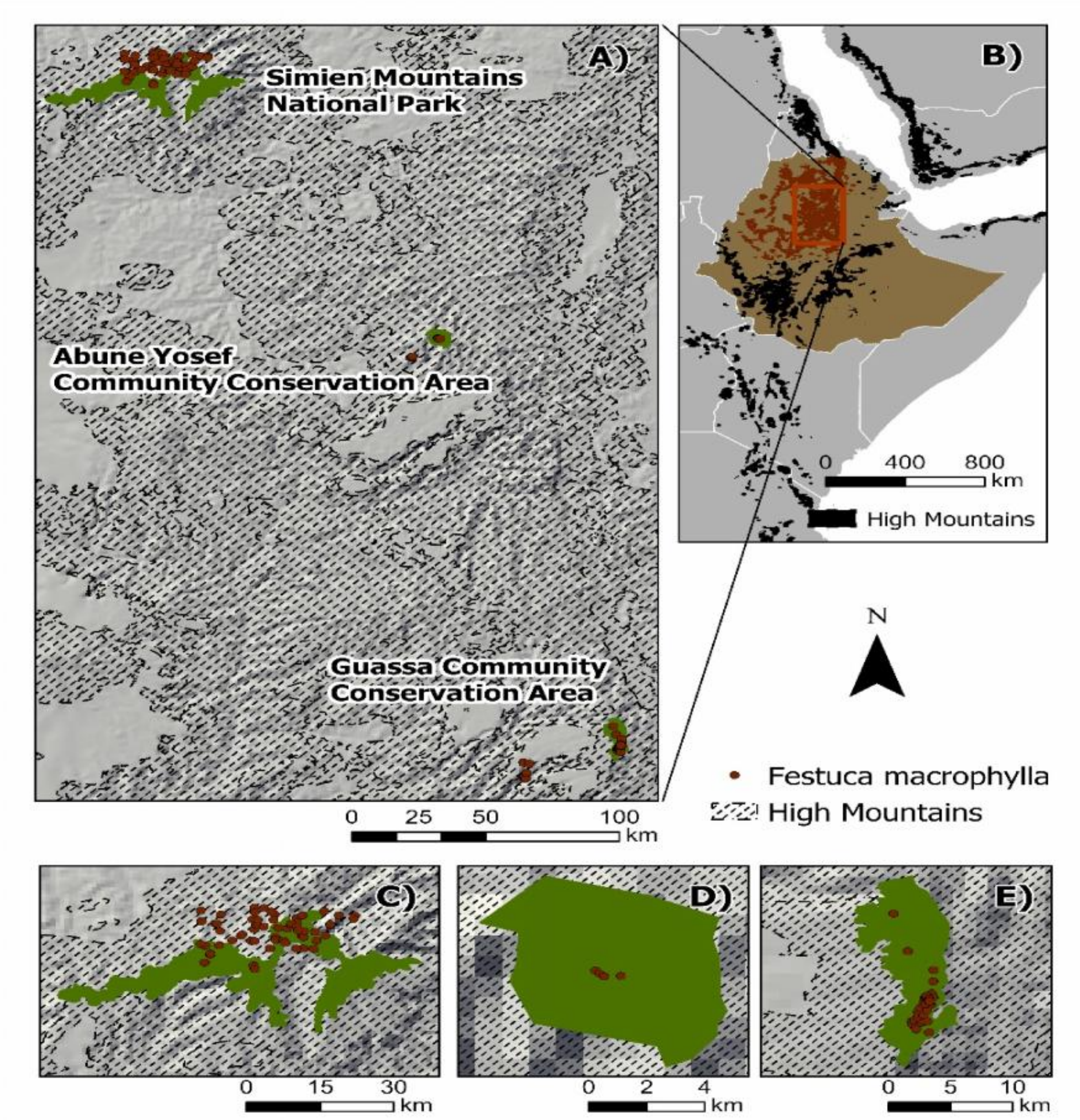


Figure 4.1. Map depicting A) three protected areas where Guassa grass (*F. macrophylla*) is currently found, B) the location of these areas in the country of Ethiopia and the broader Horn of Africa context, C) the distribution of Guassa grass observations in Simien Mountains National Park, D) the distribution of Guassa grass observations in Abune Yosef Community Conservation Area, and E) the distribution of Guassa grass observations in Guassa Community Conservation Area.

4.2.2. Species occurrence data

We compiled a dataset of 119 occurrence points (Fig.4.1) from a range of sources. Data were collected during field visits to the Guassa Community Conservation area in 2016, 2018, and 2020 (n=48) and Abune Yosef Community Conservation Area in 2017 and 2018 (n=11). Furthermore, occurrence data were retrieved from the Global Biodiversity Information Facility (GBIF) collected for the Natural History Museum of Oslo in 2007 (n=6) and specimens of the National Herbarium of Ethiopia (n=19), and various other published sources including GBIF and JSTOR (n=35).

4.2.3. Environmental predictors

Twenty-four variables were used for predicting suitable habitats of Guassa grass. The 19 bioclimatic variables and average annual solar radiation data were downloaded from WorldClim (www.worldclim.org) at ~1 km^2 (30 arc second) resolution (Hijmans *et al.*, 2005). Furthermore, elevation, aspect (sine and cosine), slope, and topographic position index variables at 1 km^2 were derived from a 250 m GMTED digital elevation model (Amatulli *et al.*, 2018). The variables were processed to the spatial extent of the northern highlands of Ethiopia, and calculated correlations between variables using Band Statistics in ArcGIS Pro 2.8. The variables were removed until there were no correlations > 0.7 and retained 11 predictors ($r < 0.7$) with the highest ecological relevance to the Guassa grasses (Elith & Leathwick, 2009; Merow *et al.*, 2013).

4.2.4. Model selection

We used the software MaxEnt (Phillips *et al.*, 2006; Phillips & Dudik, 2008) due to the opportunistic nature of our dataset, composed of presence-only locations. MaxEnt consistently performs well compared to other modeling approaches (Elith *et al.,* 2006), and has been used in across a wide range of ecological conditions in global (Tittensor *et al.*, 2009) to highly local (Williams *et al.,* 2009) applications. For example, Maxent has shown promise as a conservation planning and management tool when predicting suitable habitat for threatened, endemic, and endangered species (Kumar & Stohlgren, 2009; Abdelaal *et al.,* 2019), anticipating the spread of invasive species (Evangelista *et al.,* 2008; Wakie *et al.,* 2014), and forecasting potential impacts of climate change (Davis *et al.,* 2012; Evangelista *et al.,* 2013).

The background area of the model exerts a strong influence on the final predictions in MaxEnt (Elith *et al.,* 2011; Merow *et al.,* 2013). Merow *et al.,* (2013) and Saupe *et al.,* (2012) recommend selecting a background sample that reflects only the environmental conditions where the species is equally likely to reach via dispersal. As the Guassa grass is endemic to the northern highlands of Ethiopia, we restricted our background sample to only the high mountains in the Ethiopian massif, which at 154,600 km^2 occupies roughly half the land in the northwest corner of the country (Fig.4.1). Furthermore, other Afroalpine areas may have been suitable habitats but its history limited its distribution to the northern mountains. This restriction is not only more ecologically realistic, but it has the further benefit of focusing the model at a scale that is more relevant to managers (Elith *et al.,* 2011).

We evaluated model performance using the area under the receiver-operating characteristic curve (AUC). We tested a range of regularization coefficients but found that the default of 1 yielded the highest AUC and most realistic prediction patterns (Merow *et al.,* 2013). The regularization parameter balances overfitting with generalizability in the model, and previous research has shown the default value of 1 is not always optimal for all species (Phillips & Dudik, 2008; Elith *et al.,* 2010; Anderson & Gonzalez, 2011). We fitted each model on the full dataset using 10-fold cross-validation to estimate predictive performance on the withheld 10% of data (Elith *et al.*, 2010). We used a jackknife test to evaluate the relative contributions of each environmental predictor and to rank variable importance for Guassa grass habitat suitability. As a result of this testing, we further refined our environmental variables to only the six which showed strong (>5%) contribution to the predictions and useful ecological insight (Table 4.1). This additional reduction in predictor variables yielded the most parsimonious model without materially impacting the AUC. We selected the logistic output for the model, as it produced a more conservative estimate of probability of Guassa grass occurrence than the default cloglog transformation at high values (Phillips *et al.*, 2017). We classified the predicted output into five categories: unsuitable (0-0.2), low suitability (0.21-0.40), moderate suitability (0.41-0.6), suitable (0.61-0.8), and highly suitable (0.81-1.0) habitats.

Table 4.1. Six environmental predictors, their ecological significance for modeling suitable habitat for Guassa grass (*F. macrophylla*), and their percent contribution to final model predictions.

Variable	**Description**	**Ecological Significance**	**Percent Contribution**
BIO10	Mean temperature of the warmest quarter	Afroalpine vegetation is found in cold climates (Brochmann, *et al.*, 2021)	36.7
BIO16	Total precipitation of wettest quarter	The wettest months are typically June through September. Afroalpine vegetation is found in wet conditions (Ashenafi *et al.*, 2012).	21

BIO17	Total precipitation of driest quarter	The driest months are typically December through February. Desiccation stress and fire occurrence during these months are thought to favor grasses over shrubs in the Afroalpine (Wesche, 2003)	15.6
SLOPE	Rate of change of elevation in magnitude	Guassa grass is thought to prefer steep to moderately steep slopes (Ashenafi, 2001)	9.9
BIO2	Mean diurnal range - Mean of monthly (max temp - min temp)	Afroalpine vegetation has evolved under conditions of high daily temperature fluctuations, known as 'summer every day and winter every night' (Hedberg, 1964). Diurnal fluctuations are typically greater during the dry season	9.4
BIO19	Total precipitation of coldest quarter	Afroalpine vegetation is thought to persist in areas of low temperature and high moisture (Ashenafi, 2001; Buytaert *et al.*, 2011)	7.4

4.3. Results

The average test AUC across the 10 replicate model runs was 0.96 (SD +/- 0.02). The most important predictor was BIO10 (mean temperature of the warmest quarter) with a contribution of 36.7%, followed by BIO16 (precipitation of wettest quarter) at 21%, BIO17 (precipitation of driest quarter) at 15.6%, slope at 9.9%, BIO2 (mean diurnal range) at 9.4%, and BIO19 (precipitation of the coldest quarter) at 7.4%. The marginal response curves illustrate the species-environment relationship defined by the model, where mean temperatures in the warmest quarter below 15°C support higher probabilities of Guassa grass presence (Fig.4.2a). A sharp distinction between wet and dry seasons appears to also be a critical ecological factor in suitable Guassa grass habitat, as high precipitation in the wet season (>730 mm) and low precipitation in the dry season (<15 mm) were the next most influential variables (Fig.4.2b and 4.2c). Our results suggest that Guassa grass is more suited to higher slopes (above 15%), and to a mean diurnal range of roughly 12-15°C (Fig.4.2d and 4.2e). Finally, precipitation in the coldest quarter appears to exert a small influence on our predictions, with higher Guassa grass habitat probability between 100-600 mm (Fig.4.2f).

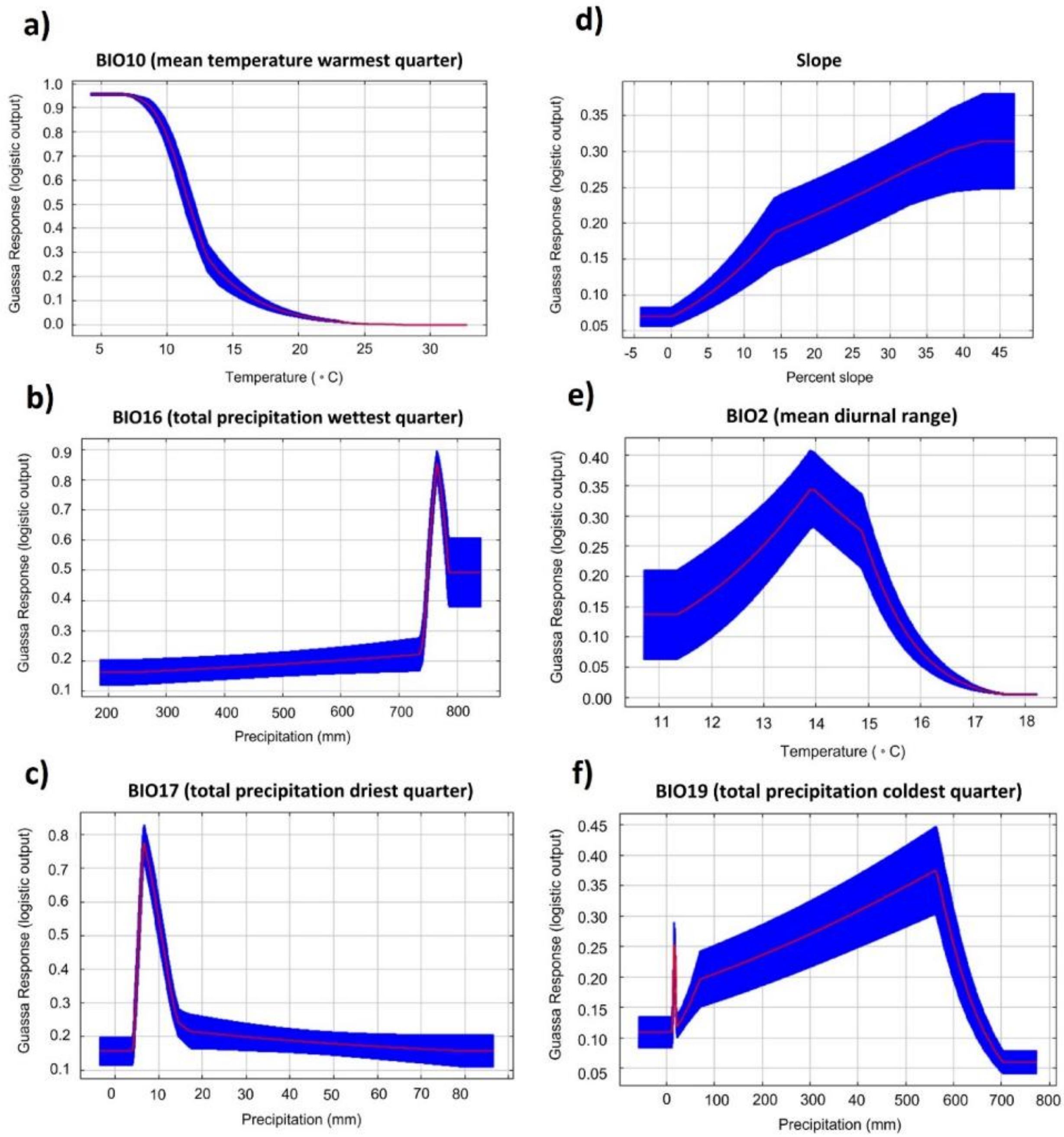


Figure 4.2. Marginal response curves showing how each environmental variable impact the final model prediction for suitable Guassa grass habitat. Each curve shows how the predicted probability of Guassa presence changes as each variable increases (with all other variables held at their mean value).

Our results estimated 591 km^2 of highly suitable habitat for Guassa grass, less than half of one percent of the total northern highlands land area. Only 53 km^2 (8.9%) of highly suitable Guassa grass habitat and 170 km^2 (18.3%) of suitable Guassa habitat currently falls within a protected area. Notably, 294 km^2 (49.7%) of the highly suitable habitat is in South Wollo, and 177 km^2 (30%) of the highly suitable habitat is located on Mount Choke (Table 4. 2). These areas are the most dissimilar to our predictor variable training range, and Mount Choke in particular is completely outside the training range of one or more of our environmental predictor variables. Therefore, both of these estimates should be treated with strong caution, and likely represent an overestimate of highly suitable Guassa grass habitat. A total of 930 km^2 were identified as suitable habitat (0.6% of the northern highlands), and 1,069 km^2 of moderately suitable habitat (0.7% of the northern highlands). The vast majority of the northern highlands are either low suitability (2,040 km^2) or unsuitable (149,629 km^2) Guassa grass habitat.

Table 4.2. Three existing protected areas and four proposed protected areas, describing the land area that falls within each class of suitable Guassa grass habitat and what percent of the protected area that covers.

Name	Unsuitable	Low Suitability	Moderate Suitability	Suitable	Highly Suitable
Existing Protected Areas					
Simien Mountains National Park	81 km^2 (16.5%)	113 km^2 (23.0%)	132 km^2 (26.9%)	134 km^2 (27.3%)	31 km^2 (6.3%)
Guassa	6 km^2	7 km^2	15 km^2	30 km^2	22 km^2

Community Conservation Area	(7.5%)	(8.8%)	(18.8%)	(37.5%)	(27.5%)
Abune Yosef Community Conservation Area	14 km^2 (29.8%)	8 km^2 (17.0%)	19 km^2 (40.4%)	6 km^2 (12.8%)	0 km^2 (0%)
Potential Protected Areas					
Mount Choke	21 km^2 (6.6%)	49 km^2 (15.5%)	35 km^2 (11.0%)	35 km^2 (11.0%)	177 km^2 (55.8%)
South Wollo	59 km^2 (8.1%)	40 km^2 (5.5%)	59 km^2 (8.1%)	278 km^2 (38.1%)	294 km^2 (40.3%)
Mount Guna	6 km^2 (6.7%)	6 km^2 (6.7%)	33 km^2 (37.1%)	34 km^2 (38.2%)	10 km^2 (11.2%)
Ankober	7 km^2 (6.1%)	8 km^2 (7.0%)	30 km^2 (26.3%)	65 km^2 (57.0%)	4 km^2 (3.5%)

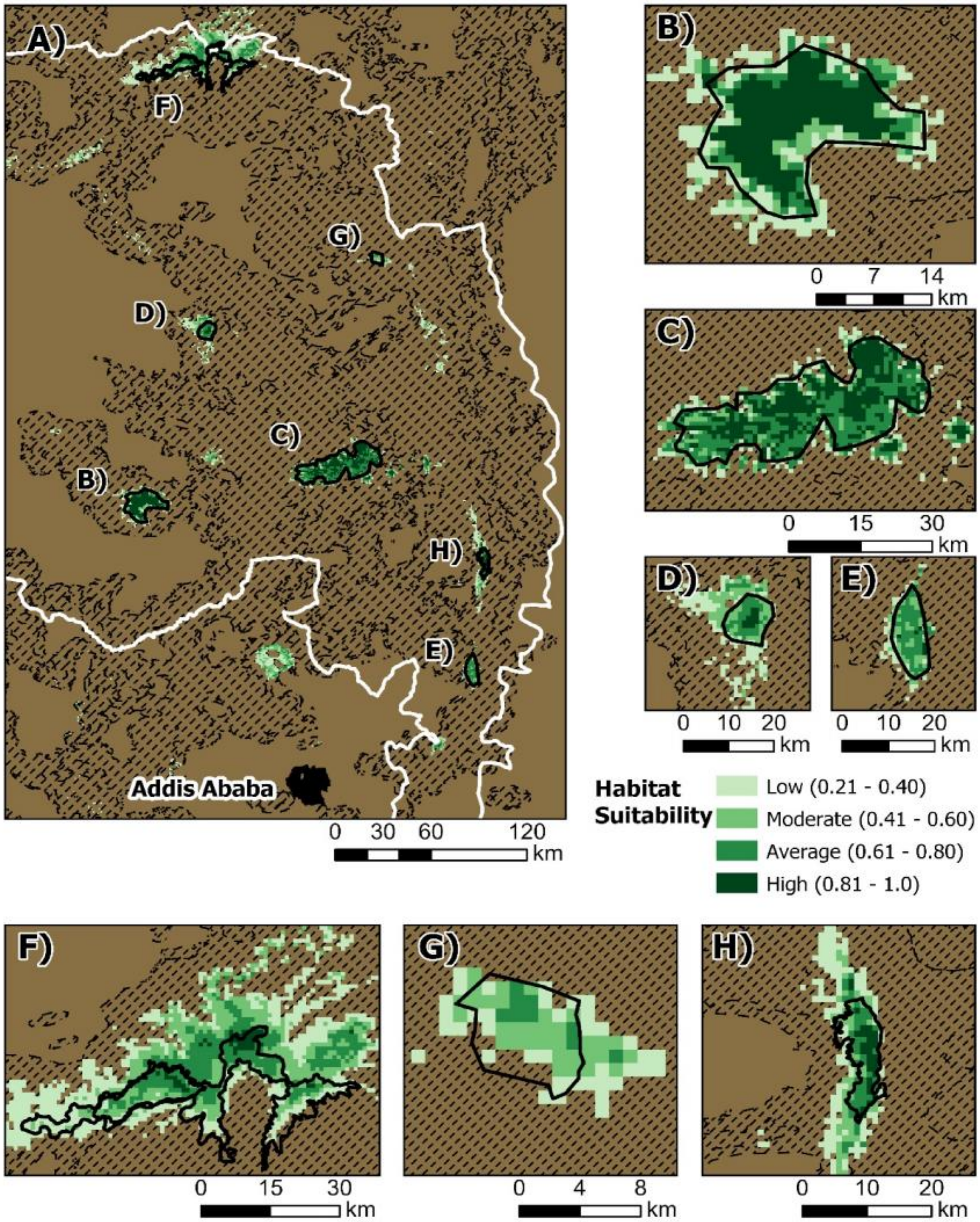


Figure 4.3. Map of Guassa grass habitat suitability, showing the distribution of habitat A) throughout the state of Amhara (outlined in white), B) on Mount Choke, C) in South Wollo, D) on Mount Guna, E) around Ankober, F) in and around Simien Mountains National Park, G) in and around Abune Yosef Community Conservation Area, and H) in and around Guassa

Community Conservation Area. Boundaries for B, C, D, and E indicate potential protected areas, while F, G, and H represent existing protected areas.

4.4. Discussion

4.4.1. Evaluating the extinction debt of Guassa grass

Climate change threatens the equilibrium of Afroalpine vegetation as warming temperatures at high elevations allow for new species to colonize and/or dominate (Kidane *et al.,* 2019), driving others to extinction (Chala *et al.,* 2016). The expansion of agriculture and rangelands to support additional human communities on what was once considered inhospitable lands further restricts available land for Afroalpine vegetation (Ashenafi, 2001). Our results indicate that Guassa grass will be sensitive to these warming temperatures as the ideal habitat for the grasses lies in areas with average maximum temperatures under 15°C. Our results also suggest that Guassa grass distribution is attuned to seasonal precipitation patterns, and there is mounting evidence that early spring rains are declining or disappearing across the Ethiopian highlands (Rosell, 2011; Fashing *et al.,* 2014; Groth *et al.,* 2020).

These habitat modifications may already be causing an extinction debt for Guassa grass, which is the idea that there is a time lag whereby extinctions can occur over a considerable amount of time following perturbation (Tilman *et al.,* 1994; Brooks *et al.,* 1999; Ferraz *et al.,* 2003). Extinction debt is thought to be "paid off" faster in landscapes like the Afroalpine that have small, isolated patches (Kuussaari *et al.,* 2009). In grasslands, it is estimated that extinction debt occurs when less than 10% of the original grassland area remains (Cousins, 2009). While we have qualitative knowledge of declining Guassa grass habitat from local ecological knowledge in the GCCA (Steger *et al.,* 2020), there are no quantitative historical datasets that would allow us to evaluate whether current Guassa grass habitat has exceeded this 10% threshold or not.

Without access to historical data, one of the most promising ways to empirically assess extinction debt is through spatially explicit modeling for single species (Kuussaari *et al.*, 2009; DeAngelis & Yurek, 2017). Data on population growth rates across reference sites can be integrated into metapopulation models, which often take the form of patch occupancy models, cellular automata, and individual- or agent-based models (Carroll *et al.*, 2004; Bulman *et al.*, 2007). These models can then be used to inform protected area management. For example, these models can identify minimum viable metapopulation sizes based on the required habitat area for populations to persist over 95% of model simulations (Bulman *et al.*, 2007). We propose that spatially explicit modeling would be a valuable tool to determine whether existing and proposed protected area networks would sustain future populations of Guassa grass. However, extensive habitat surveys and demographic data are still needed before such models can occur. A critical barrier to collecting this data is the lack of funding for basic vegetation monitoring.

4.4.2. A community-based conservation network for Afroalpine biocultural diversity

Our results indicate there is extremely limited suitable habitat for Guassa grass, and even our estimates are likely slightly inflated. We therefore propose four additional areas that should be considered for establishment as protected areas. However, we recognize that many conservation activities in Ethiopia have fallen short of their goals (Admassie, 2000), even when they were nominally community-based initiatives (Ashenafi, 2001). Therefore, we stress that the locations in Figure 3 are intended as starting points for community-centered investigations into their suitability as protected areas. In some places, like the Choke Mountains, these conversations have already started (UNDP, 2019). Though the two community conservation areas in our study have only been officially recognized by the government for ~10 years, the Indigenous management of these areas has persisted for hundreds of years, particularly in GCCA. We therefore propose that establishing a series of community-based conservation areas with strong peer-to-peer networks of communication and resource exchange is preferable to the creation of government-administered national parks.

A persistent shortcoming of community-based conservation is the lack of motivation and empowerment of local communities to take ownership over the area (DeCaro & Stokes, 2008; Gebrehiwot *et al.*, 2021). Granting communities official land tenure plays a critical role in overcoming this barrier, as people hesitate to spend time managing an area that might be taken away from them (Laperye, 2010; Steger *et al.*, 2020). However, community motivation has also been shown to lag when the conservation narrative focuses too strongly on wildlife protection, and discounts or ignores cultural values (Marks, 2001; Silva & Mosimane, 2014). Meanwhile, community-based conservation that celebrates cultural knowledge and values has been shown to promote joint social and ecological benefits (Sheppard *et al.*, 2010; Dyer *et al.*, 2014). The cultural relationship between the people in Amhara Regional State and the Guassa grass is therefore a unique and valuable characteristic of this area that can be leveraged for greater community empowerment towards conservation.

Effective community-based conservation areas require nested levels of governance that connect institutions both laterally and vertically (Ostrom *et al.*, 2002). Nongovernmental organizations have a key role to play, largely through start-up funding, technical training, and institutional support for knowledge sharing across individual community-based conservation areas (Seixas & Berkes, 2010; Galvin *et al.*, 2018). A study of community-based conservation areas in the Oromia region of Ethiopia demonstrated that local governments are also expected to be active participants in community-based conservation areas and are especially needed to support collective action over individual rights (Dixon, 2008). This focus on collective action should also strive to overcome problems of unequal distribution of benefits and reduced social capital, which are widespread issues in African community-based conservation (Galvin *et al.*, 2018).

4.5. Conclusion

In this paper, we sought to model the habitat suitability of Guassa grass (*F. macrophylla*) across the northwestern Ethiopian highlands, evaluating the current extent of Guassa grass habitat that is currently contained within protected areas. Our results indicate very limited areas of suitable habitat for Guassa grass, leading us to define only four additional regions for consideration as protected areas. Thus, we discussed concerns over the future persistence of the Guassa grass as continued habitat modification, climate change, and species invasion threatens these isolated sky-islands. The Guassa grass is a cultural keystone species for certain areas within the Amhara Regional State, and we propose that building a network of community-based conservation areas with strong peer to peer learning, open communication, and resource sharing may facilitate the future protection of the bioculturally diverse Afroalpine.

Chapter Five

Predicting the current and future distribution of *Helichrysum splendidum* (Thunb.) Less., and *Euryops pinifolius* A. Rich., for the conservation of *Festuca macrophylla* Hochst. ex A. Rich. under the changing climate scenarios in Ethiopian highlands

Shambel Alemu Chengere[1], Sileshi Nemomissa[1], Bikila Warkineh Dullo[1]

[1]Department of Plant Biology and Biodiversity Management, College of Natural and computational Sciences, Addis Ababa University, Addis Ababa P.O. BOX 3434, Ethiopia; shambel.alemu@aau.edu.et; bikila.warkineh@aau.edu.et; sileshi.nemomissa@aau.edu.et

Corresponding author

E-mail: shambel.alemu@aau.edu.et

Tel.: +251-91-216-5150

Abstract

The impact of climatic change on the distribution of species is currently the hottest topic in ecology. The adaptive ranges of plant species may alter because of ongoing climate changes. This study looks at the distribution of three plant species, *Festuca macrophylla*, *Helichrysum splendidum* and *Euryops pinifolius*, and their probable future suitable environments. We used MaxEnt model to forecast the suitable habitats for these species in the present and the future. For the years 2050 and 2070, the middle (RCP 4.5) and extreme (RCP 8.5) climate change scenarios were considered. To analyze our data, we combined a total of 19 Bioclimatic data and 3 environmental variables with 48, 51 and 53 occurrence data of *Festuca macrophylla*, *Helichrysum splendidum* and *Euryops pinifolius*, respectively. The effects of elevation, solar radiation index (SRI) and topographic position index (TPI) on suitable habitats of these species were tested using linear model in R. Our result shows elevation, topographic location index, warmest quarter precipitation (Bio18) and precipitation seasonality (Bio15) has a substantial impact on the existing and potential habitats for these species. The habitat suitability distributions for the three species under the current and future climate scenario were primarily found in the central highlands, northern and north-western Ethiopia. According to the future climatic scenario, there is a decreasing trend from less suitable to highly suitable regions in the comparative relative area between the various categories of suitable habitat. Hence, *Festuca macrophylla* is facing conservation challenges because of these shrub invasions and its distribution is limited to the central parts of the country. We recommend managers to carefully monitor the declining of this grass to evaluate whether the species is experiencing an extinction debt. The results of this study will be valuable for conservation planning, monitoring and sustainably using *Festuca macrophylla* and its management should consider the effect of climate change.

Key words: Bioclimatic variables, Climate change, Ethiopia, Habitat suitability, Maximum entropy (MaxEnt), Species distribution models (SDMs)

5.1 Introduction

According to Perrings and Halkos (2015) and Serdeczny *et al.*, (2016), continuous habitat degradation and climate change together constitute a serious threat to biodiversity in sub-Saharan Africa. Continuous evaluation of species niche performance using predictive statistical models is essential for effective conservation in the face of a species diversity problem (Austin, 2006).

Environmental factors (such as elevation, precipitation, temperature, water, soil, and surface humidity) have a considerable impact on how plants are distributed. Because of this, ecology has traditionally placed a strong emphasis on the examination of species-environment relationships (He *et al.*, 2007). Plant-environment interactions and their effects on plant growth have been brought to light by researchers (Scheper *et al.,* 2013). Environmental factors influence plant distribution as well as their composition and uses, according to studies (Jochum *et al.,* 2007) plant species are often highly sensitive to their environment and increases in temperature likely profoundly affect their ecology.

The rate of global climate change today is unprecedented. Particularly, manmade greenhouse gas emissions are the primary causes of global warming (Aizebeokhai, 2009). By the end of the 21st century, the world's temperature is expected to rise by 1.8 to 4 °C, according to the Intergovernmental Panel on Climate Change (IPCC, 2008). It has changed the dynamics and composition of communities as well as the range reduction and growth of many different plants (IPCC, 2008). Due to extraordinary climate change, plant species are currently changing and disappearing at an alarming rate (Larsen *et al.,* 2011).

According to Chhetri *et al.,* (2018), not every species reacts to climate change in the same manner. For instance, a lack of adequate dispersal capacity limits the ability of plant species to adjust to climatic change (Dagnino *et al.,* 2020). Due to their small ecological niche and localized distribution, mountain plants are particularly vulnerable to climate change (Essl *et al.,* 2009). The extent of these species' distribution range has a direct impact on how resilient it is to climate change (Purvis *et al.,* 2000). For species that are naturally confined to specific environments, the range is extremely sensitive to anthropogenic pressure and, generally speaking, climate change scenarios. Accordingly, a plant species' susceptibility to extinction is closely correlated with the size of their habitats and their capacity to expand or contract their range (Purvis *et al.,* 2000). As a result, a plant species' vulnerability to extinction is directly correlated with the size of its habitat range and the effectiveness of its range shift (Purvis *et al.,* 2000). Determining the size of a species' suitable habitat range is crucial for creating an effective management strategy (Fourcade *et al.*, 2014).

The development of modeling and geographic information systems (GIS) has led to the widespread use of ecological theories and GIS techniques in the areas of ecology and conservation (Guisan and Zimmermann, 2000; Warren *et al.*, 2008; Brito *et al.*, 2009). The MaxEnt (maximum entropy) species distribution model (SDM), one of these models, is a widely used instrument for examining potential geographic distributions of organisms (Guisan *et al.*, 2002).

Helichrysum splendidum and *Euryops pinifolius* are the two most prevalent shrub species in the Ethiopian highlands that naturally thrive in Afroalpine environments. The less value that is being obtained by the local community helps these shrubs to expand in the conservation area and they are being considered as invaders by the local community leads them to be a challenge for conservation area. On the other hand, *Festuca macrophylla* one of the endemic Afroalpine grass, which is highly valued by the local communities for different purposes (detail in chapters 2, 3 and 4) is currently being encroached by these shrubs leading to loss of a valuable resource and a decline in the quantity and quality of the product, are the subjects of the current study's model prediction analysis.

Helichrysum splendidum is well known in many areas of Ethiopia and characteristically is a fast-growing shrub, perennial with woody base; grow up to 1m high and canopy measure up to 1m in diameter (Tadesse, 2004; Mashigo *et al*., 2015). It is Characterized by its gray color leaf, presence of woolly structure on stem (important for reducing water loss), aromatic smell, bright yellow flower which are long lasting, extensive root systems (extended below the root zone of other plants) (Pooley, 2003). Further both morphological and physiological factors such as high reproductive efficiency, small leaf areas to limit transpiration and allelopathic effect help *Helichrysum splendidum* to become successful and able to grow at a wide range of altitudes from 2500-4300 meter above sea level (Hae, 2016). Essential oil extracted from this plant used to inhibit both fungal and bacterial activity (Chagonda *et al*., 1999) and also used in cosmetics industries.

Euryops pinifolius is a shrub 30-100 cm high, glabrous except for tufts of loose hairs in leaf axils. Branches leafy in upper parts, leafless in below with prominent leaf scars. It is montane grass-land with *Lobelia*, *Helichrysum, Haplocarpha* on thin soil over rocks, between rocks at cliff margins, and able to grow at a range of altitudes from 3200-3700 m.a.s.l (Tadesse, 2004).

Presently, persistent human-induced degradation is affecting the Afroalpine vegetation of Ethiopia that is the natural habitat of the target species (Shumi *et al.,* 2019). This vegetation area is experiencing settlement encroachment, deforestation due to agricultural development, firewood gathering, charcoal manufacture, grazing land needs by farmers and other livelihood activities (Gole *et al.,* 2009; Tadese *et al.,* 2021). Currently, the local community considers these shrubs as invaders that decline the productivity of *Festuca macrophylla* and GCCA is having conservation challenges for these shrubs. Therefore, it is necessary and important to predict how global climate change will impact the potentially suitable climatic distribution of these plants in Ethiopia.

Moreover, studying the current and future distribution of plant species and examining the key environmental factors that affect their natural distribution can help us to see if the current and future distributions of these plants overlap with our target species – *Festuca macrophylla* for better management. To know the overall distribution trends and to protect *Festuca macrophylla* from invading shrubs, it is important to examine important environmental variables affecting their natural distribution. Thus, our objectives were to: to identify the potential distribution of *Festuca macrophylla, Helichrysum splendidum* and *Euryops pinifolius* in Ethiopia; to predict suitable habitat distribution for these species; and identify the environmental factors associated with these species habitat distribution for the conservation of *Festuca macrophylla*.

5.2. Materials and Methods

5.2.1. Target species and occurrence data

We obtained data on the geographic locations of *Festuca macrophylla, Helichrysum splendidum* and *Euryops pinifolius* from field observation using Garmin GPS, the National Herbarium of Ethiopia, ETH, Addis Ababa University, the Global Biodiversity Information Facility (http://www.gbif.org) database and published literatures. A total of 48, 51 and 53 valid presence records of *Festuca macrophylla, Helichrysum splendidum* and *Euryops pinifolius* were collected respectively and used for training and testing the MaxEnt modelling algorithm (Figure 5.1). All records for latitude/longitude were imported into Microsoft Excel and saved as “CSV” file format constructing the SDMs.

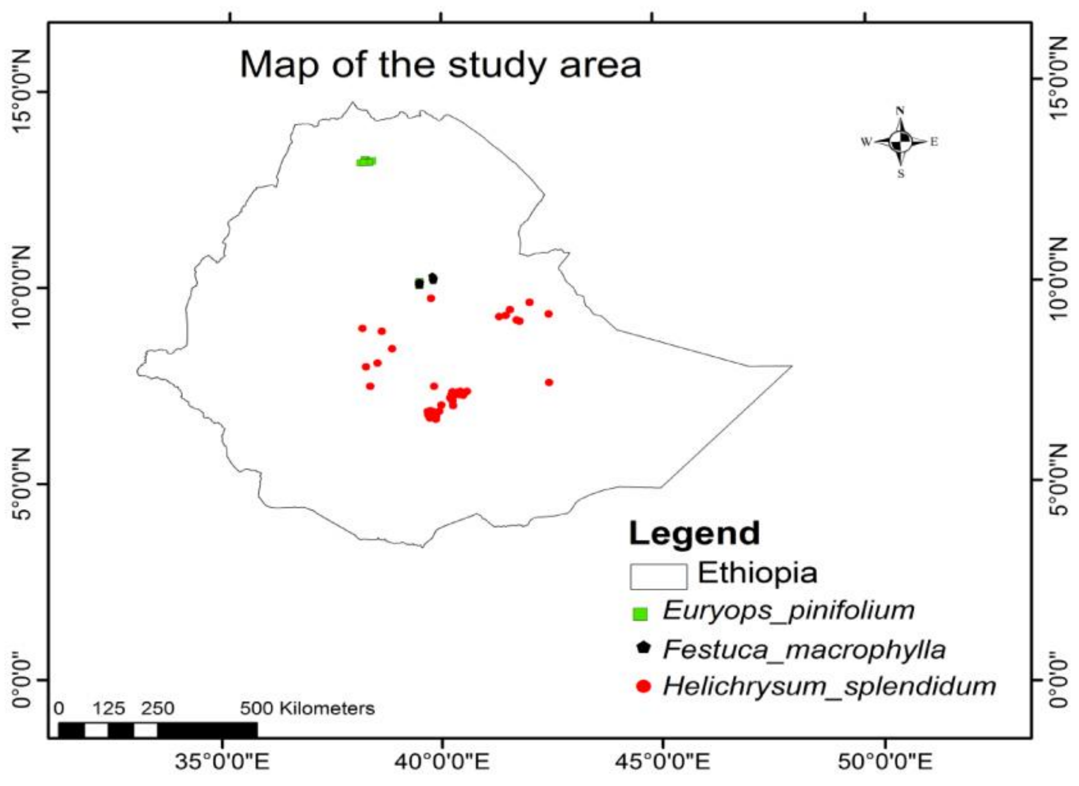


Figure 5.1. Spatial distribution of occurrence records of *Festuca macrophylla, Helichrysum splendidum* and *Euryops pinifolius* in Ethiopia.

5.2.2 Environmental variables

The Bioclimatic variables (Bio1-Bio19) were downloaded from WorldClim database (www.worldclim.org/bioclim) at spatial resolutions of 30 arc seconds (~1km) which uses interpolation based on observed representative data over the period from 1950 to 2000 (Hijmans *et al.*, 2005). Elevation, topographic position index (TPI) (combined indices for slope, aspect and altitude) and solar radiation indexes (SRI) were predictor variables used for modelling in the current study. These three variables were chosen based on their biological relevance to plant species distributions and the global Bioclimatic variables (Keating *et al.*, 2007; Mukherjee *et al.*, 2013) (Table 5.1). Through limiting soil moisture and hydrological processes, the TPI is a significant role in the distribution of natural resources (Mukherjee *et al.,* 2013; Loritz *et al.,* 2019). For projective vegetation modeling, it has been a deciding element (Kumar *et al.,* 2000). The amount of direct solar radiation that strikes an arbitrarily oriented piece of the earth's surface as a function of its aspect, slope, and latitude is theoretically proportional to the SRI, which was also chosen for this study (Keating *et al.,* 2007).

In case of future climate change predictions, the 19 bioclimatic variables were obtained for Representative concentration pathways (RCPs). RCPs are four greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change (IPCC) in its AR5 (Remya *et al*., 2015). These pathways are used in climate modeling and research to describe four possible future climates, all of which are considered possible depending on how many greenhouse gases are emitted in the future. The IPCC used range reports of forcing levels linked with emission scenarios in different published literatures for the RCP adoption (IPCC, 2008). The four RCPs are RCP2.6, RCP4.5, RCP6.0 and RCP8.5 (named after the potential radiative forcing value in 2100) relative to the pre-industrial values (+2.6, +4.5, +6.0 and +8.5 W/m2, respectively) (Weyant *et al.,* 2009). Thus, we used Representative concentration pathways (RCPs): RCP 4.5 and RCP 8.5 for the year 2050, and RCP 4.5 and RCP 8.5 for the year 2070, where the years 2050 and 2070 were considered average GHG emissions for the years 2041–2060 and 2061–2080, respectively (Griffies *et al.,* 2011). The environmental variables were then georeferenced, translated to Ascii files, and processed to the same spatial resolution of 30-second latitude/longitude (about 1 km^2 at ground level).

5.2.3 Data analysis

Using Pearson's pairwise correlation matrix analysis (Table 5.1), the multicollinearity of the 22 predictor variables was compared before the model was run. The jackknife test was used to assess each variable's contribution to the simulation in accordance with Worthington's (Worthington *et al.,* 2016) method, and 11 variables were eliminated because of their lack of contribution (percent contribution = 0) (Table 5.2). To reduce the effects of multi-collinearity and over-fitting of the model, pair wise correlations were cross checked and highly correlated variables were excluded with a Pearson's ($r \leq 0.70$, as per the default in MaxEnt software) (Wang *et al.,* 2018). Thus, to model the present and future distributions of *Festuca macrophylla*, *Helichrysum splendidum* and *Euryops pinifolius* in Ethiopia, 11 variables were kept (Table 5.2). To measure the significance of the environmental variables, it is crucial to consider their % contribution and permutation importance.

Table 5.1. Environmental variables used for the habitat suitability prediction modelling.

Variable code	**Variable name**	**Unit**
BIO1	Annual mean temperature	^{0}C
BIO2	Mean diurnal range	^{0}C
BIO3	Isothermality	^{0}C
BIO4	Temperature seasonality	^{0}C
BIO5	Max temperature of warmest month	^{0}C
BIO6	Min temperature of coldest month	^{0}C
BIO7	Temperature annual range	^{0}C
BIO8	Mean temperature of wettest quarter	^{0}C
BIO9	Mean temperature of driest quarter	^{0}C
BIO10	Mean temperature of warmest quarter	^{0}C
BIO11	Mean temperature of coldest quarter	^{0}C
BIO12	Annual precipitation	^{0}C

BIO13	Precipitation of wettest month	mm
BIO14	Precipitation of driest month	mm
BIO15	Precipitation seasonality	mm
BIO16	Precipitation of wettest quarter	mm
BIO17	Precipitation of driest quarter	mm
BIO18	Precipitation of warmest quarter	mm
BIO19	Precipitation of coldest quarter	mm
Ele	Elevation	m
Sri	Solar radiation index	-
Tpi	Topographic position index	-

5.2.4 Modeling procedure and performance evaluation

The maximum entropy model (Maxent version 3.4.1) was used to evaluate current and future potential habitats for the two species which was obtained from http://www.cs.princeton.edu/ and it is freely downloadable. It requires only species presence data and environmental variable layers for the study area. The presence data for the three species were saved in csv document. The running parameters were as follows. The species occurrence information for model calibration was divided into a training set (75% of total occurrence records selected randomly) and the random test percentage was fixed to be 25, that is, allowing MaxEnt to withhold 25% of the presence data to be used randomly to evaluate the model performance and keeping aside 75% for training the model (Phillips *et al.,* 2006).

MaxEnt was set to run the model 10 times and then average the results from all models created (Choudhury *et al.,* 2016). MaxEnt was set to maximum iterations = 500, convergence threshold = 0.00001, a maximum number of background points = 10,000, replicate run type = subsample, linear and quadratic binary features (Peng *et al.*, 2019), output format = logistic (Antúnez *et al.*, 2018). The Jackknife test was used to evaluate the relative contribution of each predictor variable in the modelling (Phillips *et al.*, 2004). After running the model and to retain the maximum predictive information, we imported the predicted suitability into five habitat class levels: unsuitable habitat (0-38%), less suitable habitat (38-54%), moderately suitable habitat (54%-69%), suitable habitat (69%-85%), and highly suitable habitat (85%-100%).

The model's power of predicting the species distribution was measured by area under the curve (AUC) value which is obtained from receiver-operating characteristic (ROC) (Phillips *et al.*, 2006). AUC is a threshold-independent index that measures the ability of the MaxEnt model to discriminate background into a high probability of presence from absence in the modelling algorithm. The AUC were checked, and jackknife was used in measuring variable importance. It generates an estimate of probability of presence of the species that varies from 0 to 1, where 0 being the lowest and 1 the highest probability. AUC = 0.5 corresponds to random prediction and AUC < 0.5 shows even worse than random prediction (Phillips *et al.*, 2004). The AUC values were rated as poor (0.5–0.6), fair (0.6–0.7), good (0.7–0.8), very good (0.8–0.9) and excellent (AUC>0.9) (Swets, 1988) and if AUC ≥ 0.9 it shows a robust model.

Since the AUC values of all the future years/scenario cases were higher than 0.90, (AUC for the three species were found to be between 0.959 and 0.994) the model was robust enough to discriminate the background into presence and absence classes for these species with high accuracy.

Table 5.2. Environmental variables removed and retained for Species distribution models

Model name	**Environmental variables**
Complete	bio1, bio2, bio3, bio4, bio5, bio6, bio7, bio8, bio9, bio10, bio11, bio12, bio13, bio14, bio15, bio16, bio17, bio18, bio19, , elev, sri and tpi
Uncorrelated	bio2, bio3, bio4, bio11, bio15, bio17, bio18, bio19, elev, sri and tpi
Year 2050 (RCP 4.5, RCP 8.5)	bio2, bio3, bio4, bio11, bio15, bio17, bio18, bio19, elev, sri and tpi
Year 2070 (RCP 4.5, RCP 8.5)	bio2, bio3, bio4, bio11, bio15, bio17, bio18, bio19, elev, sri and tpi

5.2.5 Ecological factor optimization

The test for multicollinearity was conducted by using cross-correlations among environmental variables. This was done to minimize the impact of multicollinearity and over fitting of the model. Then, only variables with a Spearman correlation coefficient of less than 0.7 were selected, which included: bio2, bio3, bio4, bio11, bio15, bio17, bio18, bio19, elev, sri and tpi (Table 5.2). In addition, ecological variables: elevation, topographic position index (TPI) and solar radiation indexes (SRI) that determine species distribution were used for modeling the current study.

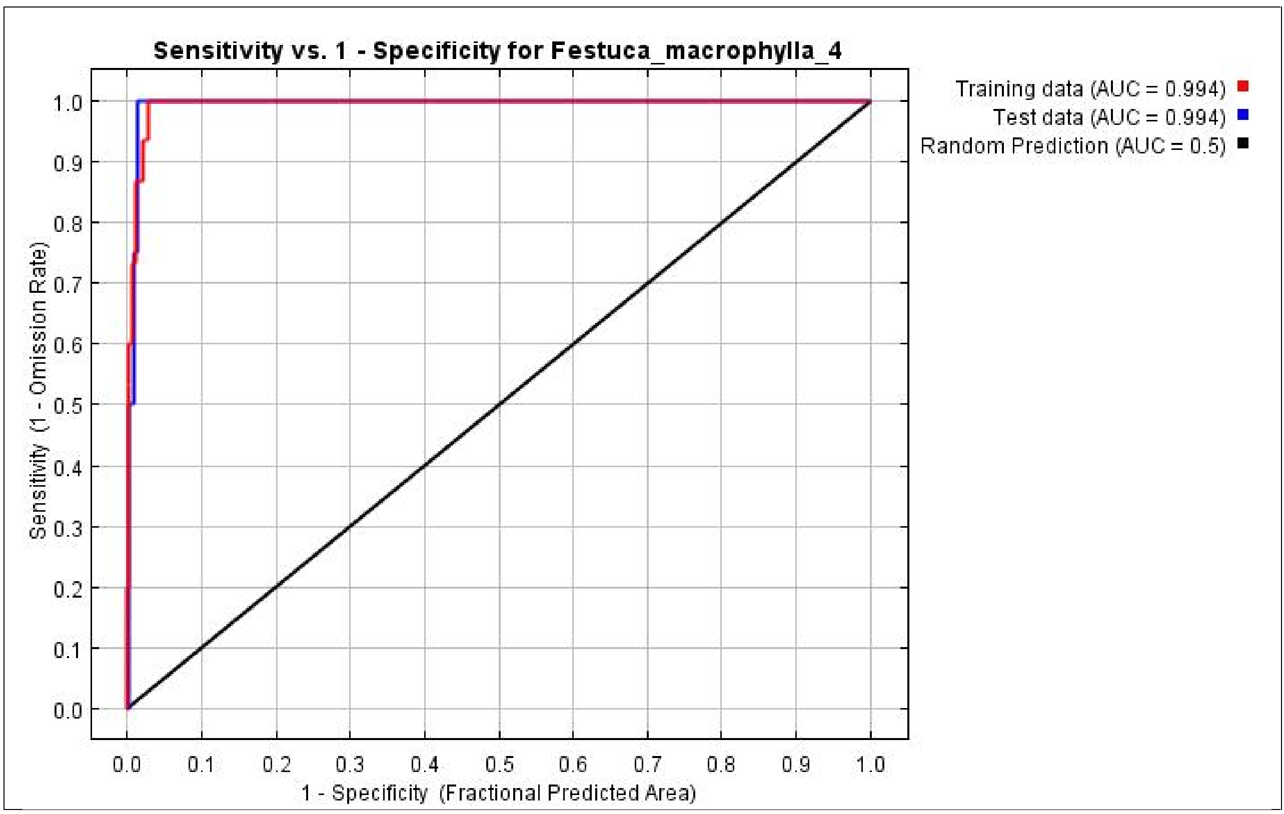
5.3 Results

5.3.1 Model performance and contributions of variables

According to the results of the spatial SDM studies (Table 5.3), the two species' distribution modeling (both for the current and future scenario) has been considerably influenced by Elevation, Mean temperature of coldest quarter (Bio11) and topographic position index environmental variables. The two factors that most influence the spread of *Festuca macrophylla* are elevation and Bio11. The two factors that most influence the spread of *Euryops pinifolius* are

Bio11 and topographic position index. Whereas Bio11 and elevation influence the spread of *Helichrysum splendidum.*

The AUC values obtained from the ROC curves were used to evaluate the performance of the model. An AUC of high values led to better results that notably differed from the random predictions. In this study, the accuracy of prediction of *Festuca macrophylla*, *Helichrysum splendidum* and *Euryops pinifolius* during the current period was found to be "excellent" (AUC mean = 0.994, 0.959 and 0.994) respectively (Figure 5.2 and Table 5.4).



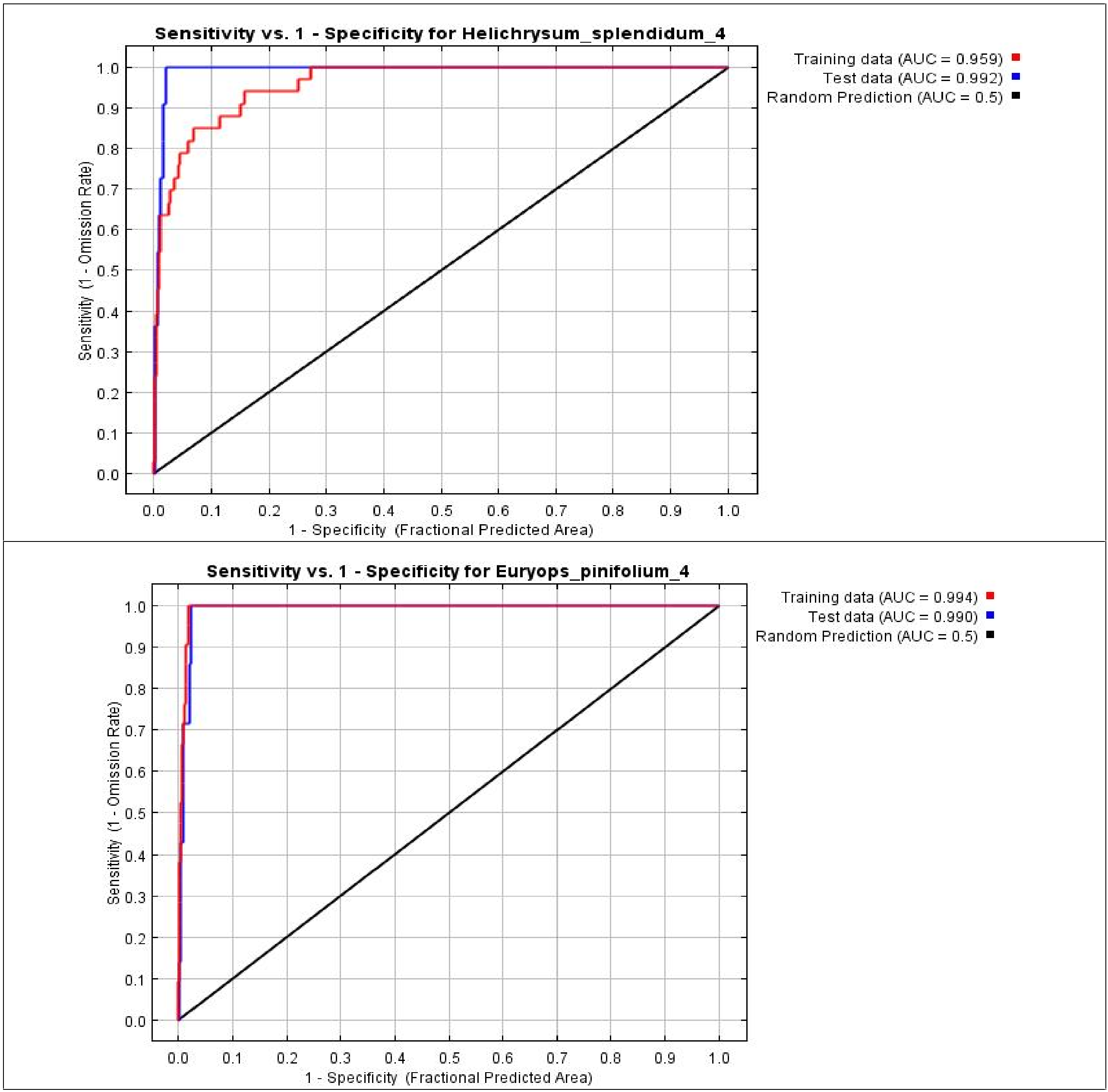
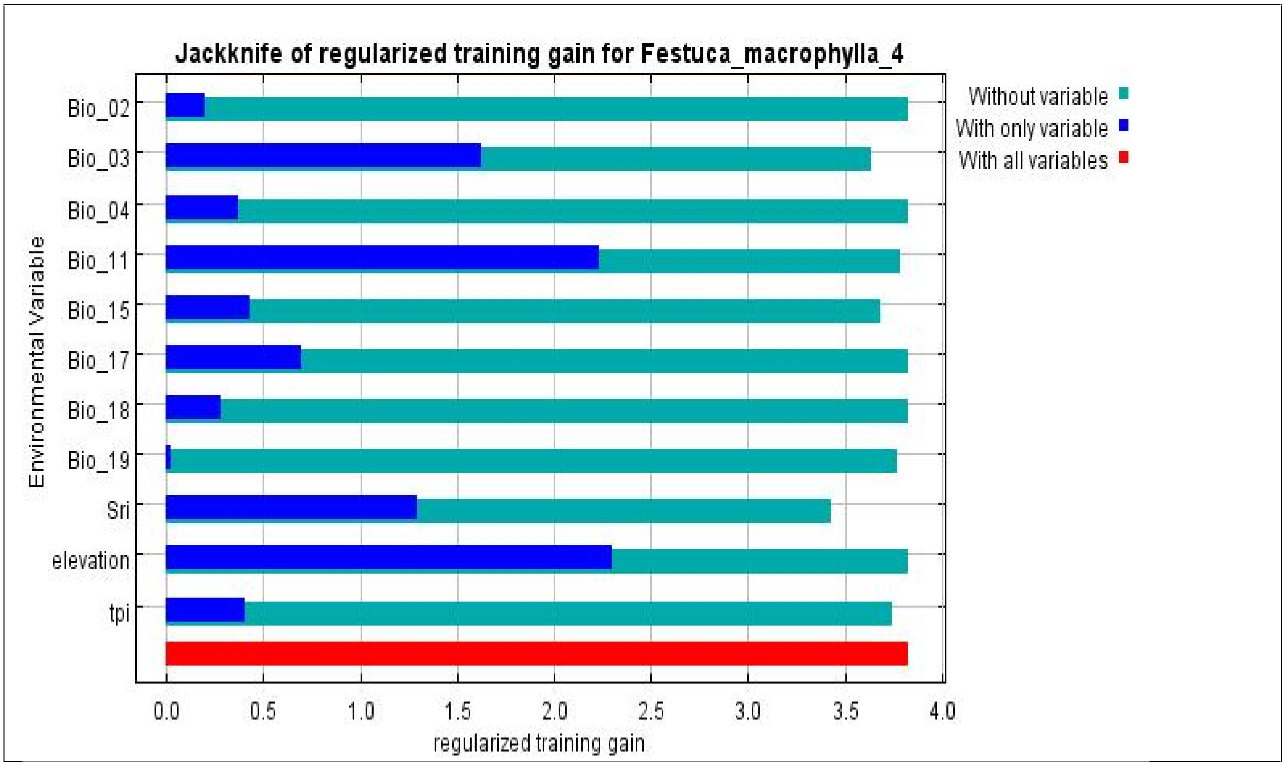


Figure 5.2. ROC curve and AUC value under the current period for *Festuca macrophylla*, *Helichrysum splendidum* and *Euryops pinifolius*

5.3.2 Habitat suitability mapping under current climate scenario (1970−2000)

The model's internal jackknife test of variable importance showed that elevation, Bio11, Bio03 and SRI were the four most important predictors for *Festuca macrophylla*. Whereas Bio11, topographic position index, elevation and Bio15 were the four most important predictors of *Euryops pinifolius* habitat distribution. Likewise, the internal jackknife test of variable importance showed that Bio11, elevation, Bio18 and Bio17 were the four most important predictors of *Helichrysum splendidum* habitat distribution indicated on the model (Figure 5.3). These variables presented the higher gain (that is, contained most information) compared to other variables.



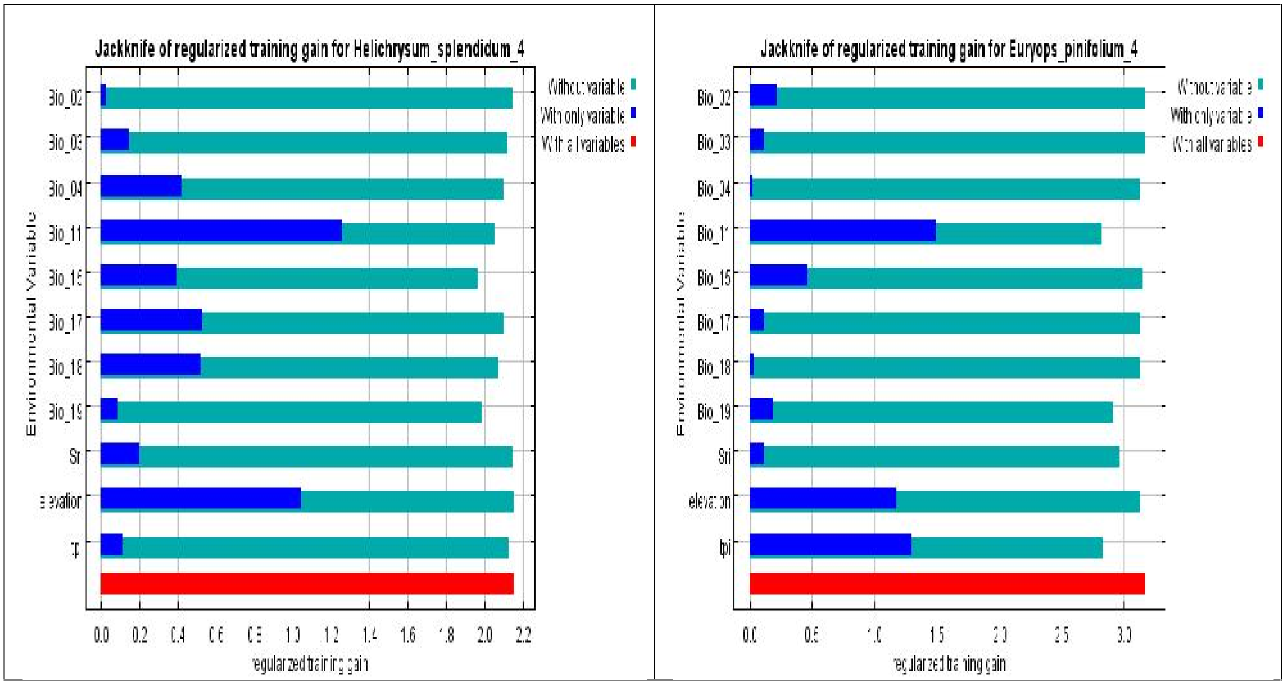


Figure 5.3. Jackknife of regularized training gain for *Festuca macrophylla*, *Helichrysum splendidum* and *Euryops pinifolius* under current climate.

Festuca macrophylla, *Helichrysum splendidum* and *Euryops pinifolius* distributions of the various habitat suitability categories (less suitable, suitable, moderately suitable, and highly suitable) were concentrated predominately in central highlands, northern and north-western parts of the Ethiopian highlands. Only 0.095% of Ethiopia's total land area was predicted by the model to fall within ranges of highly favorable locations for *Festuca macrophylla* (Figure 5.4A). While 2.36% and 1.07% of Ethiopia's total land area was predicted by the model to fall within ranges of highly suitable locations for *Helichrysum splendidum* (Figure 5.4B) and *Euryops pinifolius*, (Figure 5.5C) respectively.

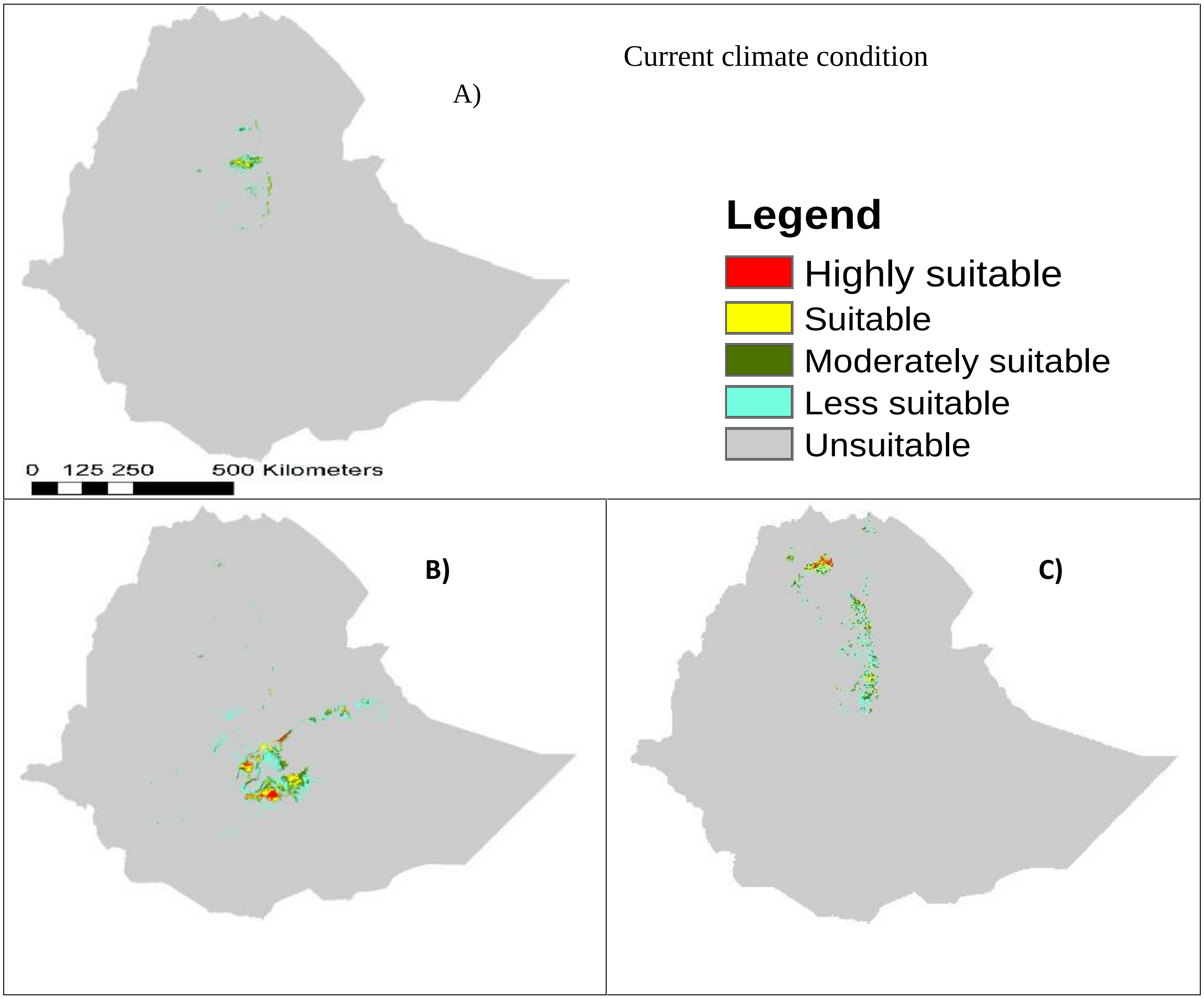


Figure 5.4. Current Suitable habitats of: **A)** *Festuca macrophylla*, **B)** *Helichrysum splendidum* and **C)** *Euryops pinifolius*

5.3.3 Predicting habitat suitability distribution under future climate change scenarios

The predicted future potentially suitable climatic distributions of *Festuca macrophylla*, *Helichrysum splendidum* and *Euryops pinifolius* under RCP 4.5 and RCP 8.5 climate change scenarios for the year 2050 and 2070 are shown in Figures 5.8 and 5.9 and Table 5.3.

The model prediction showed that only 0.22% and 0.30% of the total areas of Ethiopia is modeled to lie under highly suitable areas for *Festuca macrophylla* in 2050s under RCP 4.5 and RCP 8.5 respectively. Similarly, only 0.35% and 0.20% of the total area was identified as the highly suitable habitats for *Festuca macrophylla* in 2070s under RCP 4.5 and RCP 8.5 respectively (Figure 5.5).

Species distribution maps shows that in the 2050, projections of RCP 4.5, and RCP 8.5 scenarios of the study area identified the highly suitable habitats for *Helichrysum splendidum* which were (1.43%, and 1.36%) respectively. Similarly, the projections for highly suitable habitats of *Helichrysum splendidum* in the year 2070 scenarios of RCP 4.5, and RCP 8.5 were (1.26% and 1.28%) respectively (Figure 5.6).

Looking for similar scenarios for *Euryops pinifolius*, the highly suitable habitats were (2.96% and 2.67%) in the year 2050 (under RCP 4.5 and RCP 8.5) and (2.80% and 2.26%) in the year 2070 (RCP 4.5 and RCP 8.5) respectively (Figure 5.7). According to each scenario, the comparative relative area between the various types of suitable habitat exhibits a decreasing tendency from less suitable to highly suitable places (Table 5.3).

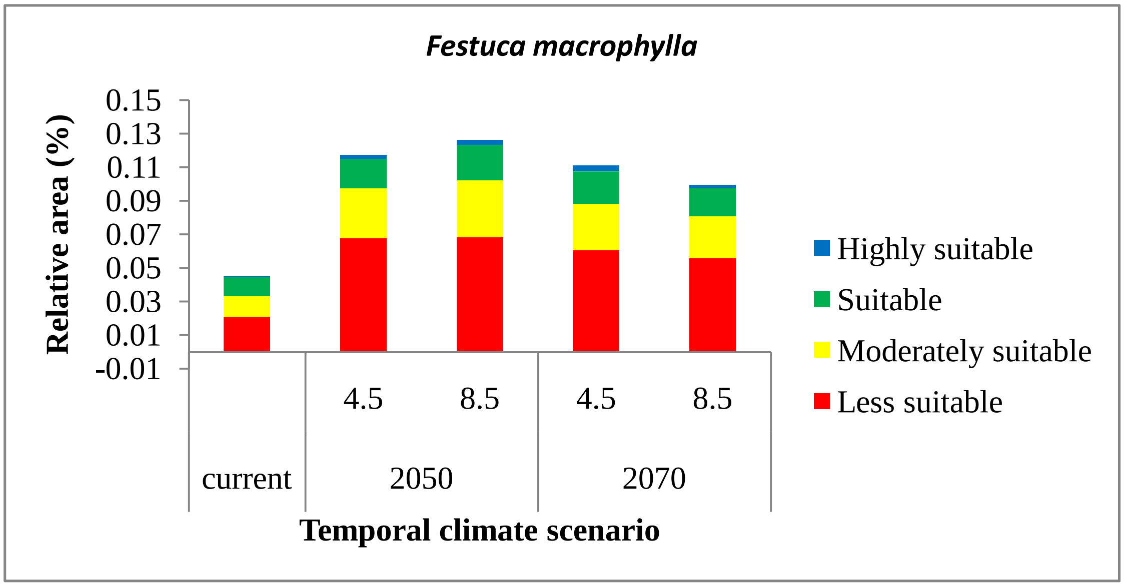


Figure 5.5. Graph showing a comparative summary of predicted relative suitable area for *Festuca macrophylla* under current climate condition and future climate scenarios.

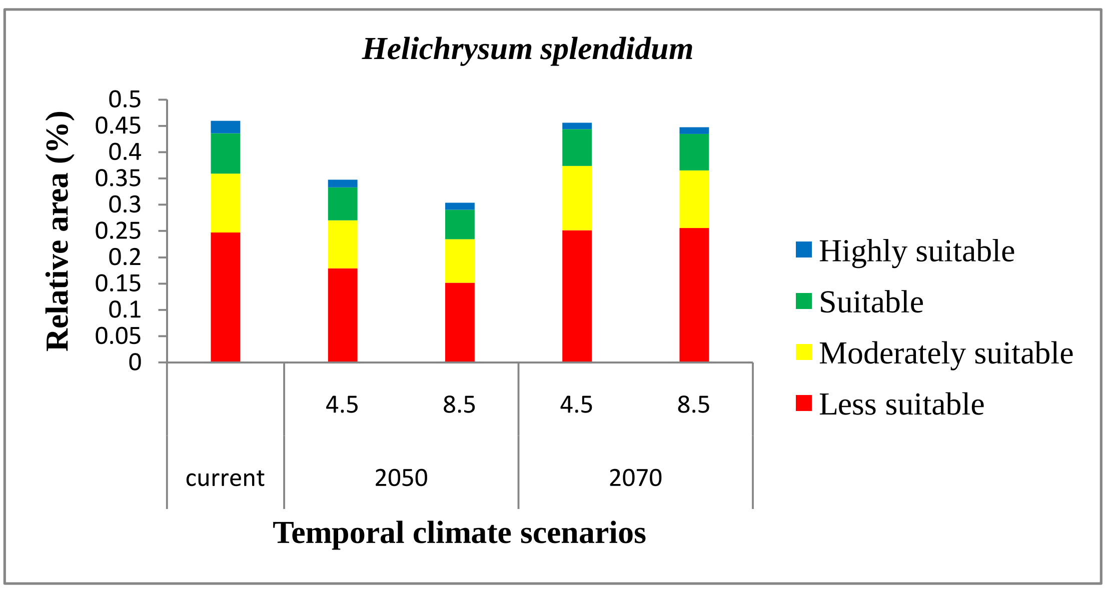


Figure 5.5. Graph showing a comparative summary of predicted relative suitable area for *Helichrysum splendidum* under current climate condition and future climate scenarios.

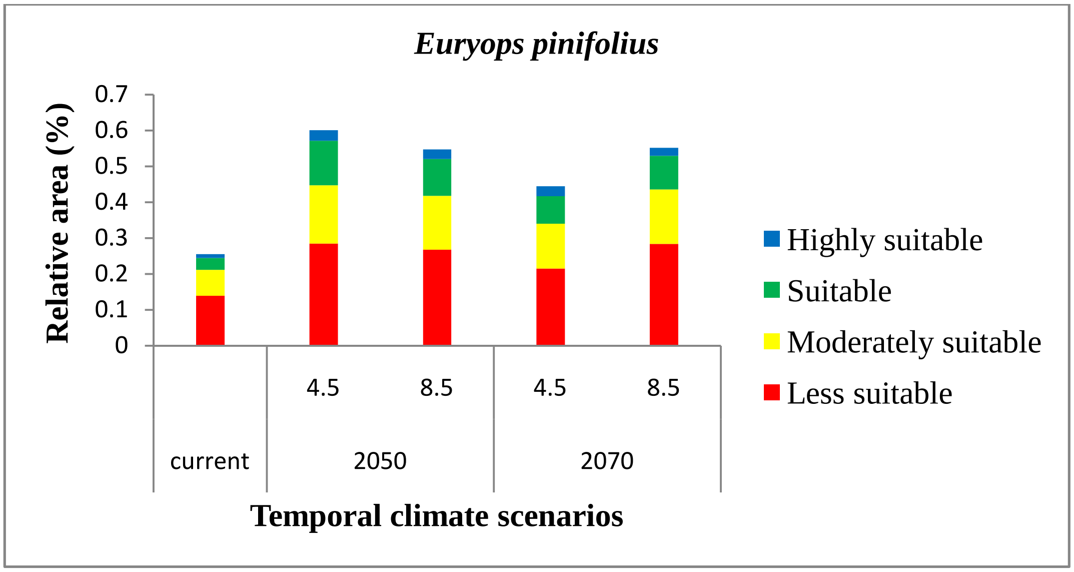


Figure 5.6. Graph showing a comparative summary of predicted relative suitable area for *Euryops pinifolius* under current climate condition and future climate scenarios.

Table 5.3. Predicted suitable areas (%) for *Euryops pinifolius* and *Helichrysum splendidum* under current and future climatic conditions

Category for *Euryops pinifolius*		**Less suitable (0.38-0.54)**	**Moderately suitable (0.54-0.69)**	**Suitable (0.69-0.85)**	**Highly suitable (0.85-1)**
Current	Area (ha)	791,321.6412	406,532.7153	189,856.2774	61,001.05884
	Cover (%)	0.001	0.0007	0.0003	0.0001
RCP 4.5 2050	Area (ha)	1,613,270.721	920,599.8908	702,908.1787	168,027.8819
	Cover (%)	0.002	0.001	0.001	0.0002
RCP 8.5 2050	Area (ha)	1,515,296.76	849,615.3022	582,005.9414	151,698.8884
	Cover (%)	0.002	0.001	0.001	0.0002
RCP 4.5 2070	Area (ha)	1,217,821.416	709,338.2487	435,214.2118	158,805.8078
	Cover (%)	0.002	0.001	0.0007	0.0002
RCP 8.5 2070	Area (ha)	1,609,463.443	858,752.7701	529,888.5319	128,432.1877
	Cover (%)	0.002	0.001	0.0009	0.0002

Category for *Helichrysum splendidum*		**Less suitable (0.38-0.54)**	**Moderately suitable (0.54-0.69)**	**Suitable (0.69-0.85)**	**Highly suitable (0.85-1)**
Current	Area (ha)	1,399,047.863	634,969.4128	436,737.1231	133,931.5897
	Cover (%)	0.002	0.001	0.0007	0.0002
RCP 4.5 2050	Area (ha)	1,013,497.481	517,197.6043	357,376.5223	81,560.36161
	Cover (%)	0.001	0.0009	0.0006	0.0001
RCP 8.5 2050	Area (ha)	857,991.3144	468,549.0483	317,442.4033	77,160.84003
	Cover (%)	0.001	0.0008	0.0005	0.0001
RCP 4.5 2070	Area (ha)	1,426,037.235	693,601.4984	393,672.5753	71,576.83187
	Cover (%)	0.002	0.001	0.0006	0.0001
RCP 8.5 2070	Area (ha)	1,449,811.573	621,517.0295	392,403.4825	72,845.92463
	Cover (%)	0.002	0.001	0.0006	0.0001

On the other hand, the potential spatial distribution of each generated model for future distribution of the three species performed "excellent". The potential spatial distribution of each generated model for future distribution of *Festuca macrophylla* in RCP 4.5, and RCP 8.5 in the year (2050 and 2070, Figures 5.8 and 5.9) performed "excellent", with high AUC values 0.983%_0.993 and 0.983%_0.992%, respectively (Table 5.4). The future distribution of *Euryops pinifolius* in RCP 4.5, and RCP 8.5 in the year (2050 and 2070, Figures 5.5 and 5.9) performed "excellent", with high AUC values 0.977%_0.981 and 0.974%_0.980%, respectively (Table 5.4). Similarly, the potential spatial distribution of each generated model for future distribution of *Helichrysum splendidum* in RCP 4.5, and RCP 8.5 in the year (2050 and 2070, Figure 5.8 and

5.9) performed “excellent”, with high AUC values 0.967%-0.982 and 0.970%-0.976%, respectively (Table 5.4). This result shows that the simulations have high reliability and can also be used to analyze the impact of climate change on the distribution of *Festuca macrophylla*, *Euryops pinifolius* and *Helichrysum splendidum* in Ethiopia.

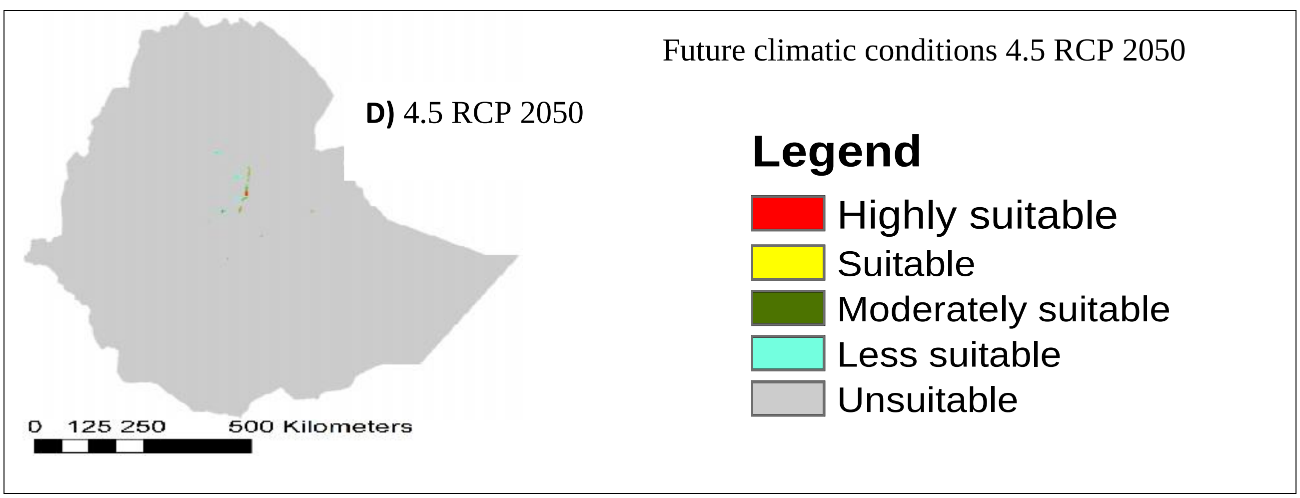
Table 5.4. AUC Values of modeling *Festuca macrophylla*, *Euryops pinifolius* and *Helichrysum splendidum* habitat distribution from two different RCP scenarios (RCPs 4.5 and 8.5) in two future periods (2050 and 2070).

Festuca macrophylla **Periods**		**AUC mean**	**AUC mean Standard Deviation**
Current		0.994	0.001
2050	RCP4.5	0.993	0.007
	RCP8.5	0.983	0.003
2070	RCP4.5	0.992	0.006
	RCP8.5	0.983	0.012
Helichrysum splendidum **Periods**		**AUC mean**	**AUC mean Standard Deviation**
Current		0.959	0.041
2050	RCP4.5	0.967	0.044
	RCP8.5	0.982	0.027
2070	RCP4.5	0.976	0.033
	RCP8.5	0.970	0.029
Euryops pinifolius **Periods**		**AUC mean**	**AUC mean Standard Deviation**
Current		0.994	0.001
2050	RCP4.5	0.981	0.009
	RCP8.5	0.977	0.006
2070	RCP4.5	0.974	0.009
	RCP8.5	0.980	0.011

5.4. Discussion

The distribution of plant species' possible suitable habitats depends on ecological factors that are related to the environment or the climate. Designing conservation strategies in the face of climate change necessitates an understanding of such spatial distributions for endemic plants such as

Festuca macrophylla. In this study, we showed the distributions of the suitable habitats that would be suited for *Festuca macrophylla*, *Helichrysum splendidum* and *Euryops pinifolius* species under the current climate and two future climate change scenarios (i.e., RCP 4.5 and RCP 8.5 by 2050 and 2070). Our prediction model revealed that under the future climate change scenarios (RCP 4.5 and RCP 8.5 of 2050 and 2070), there are spatial and elevational shifts in the distributions of the potential suitable habitats of *Helichrysum splendidum* and *Euryops pinifolius* plant species outside of their current ranges. Most of these distributions are found in the country's northern and north-western highlands (Figures 5.4 and 5.5). But the distribution of *Festuca macrophylla* is limited only to the central part of Ethiopia. The expansion of these two shrubs (*Helichrysum splendidum* and *Euryops pinifolius)* and their habitat modifications may already be causing an extinction debt for *Festuca macrophylla*, which is the idea that there is a time lag whereby extinctions can occur over a considerable amount of time following perturbation (Brooks *et al.*, 1999; Ferraz *et al.*, 2003).



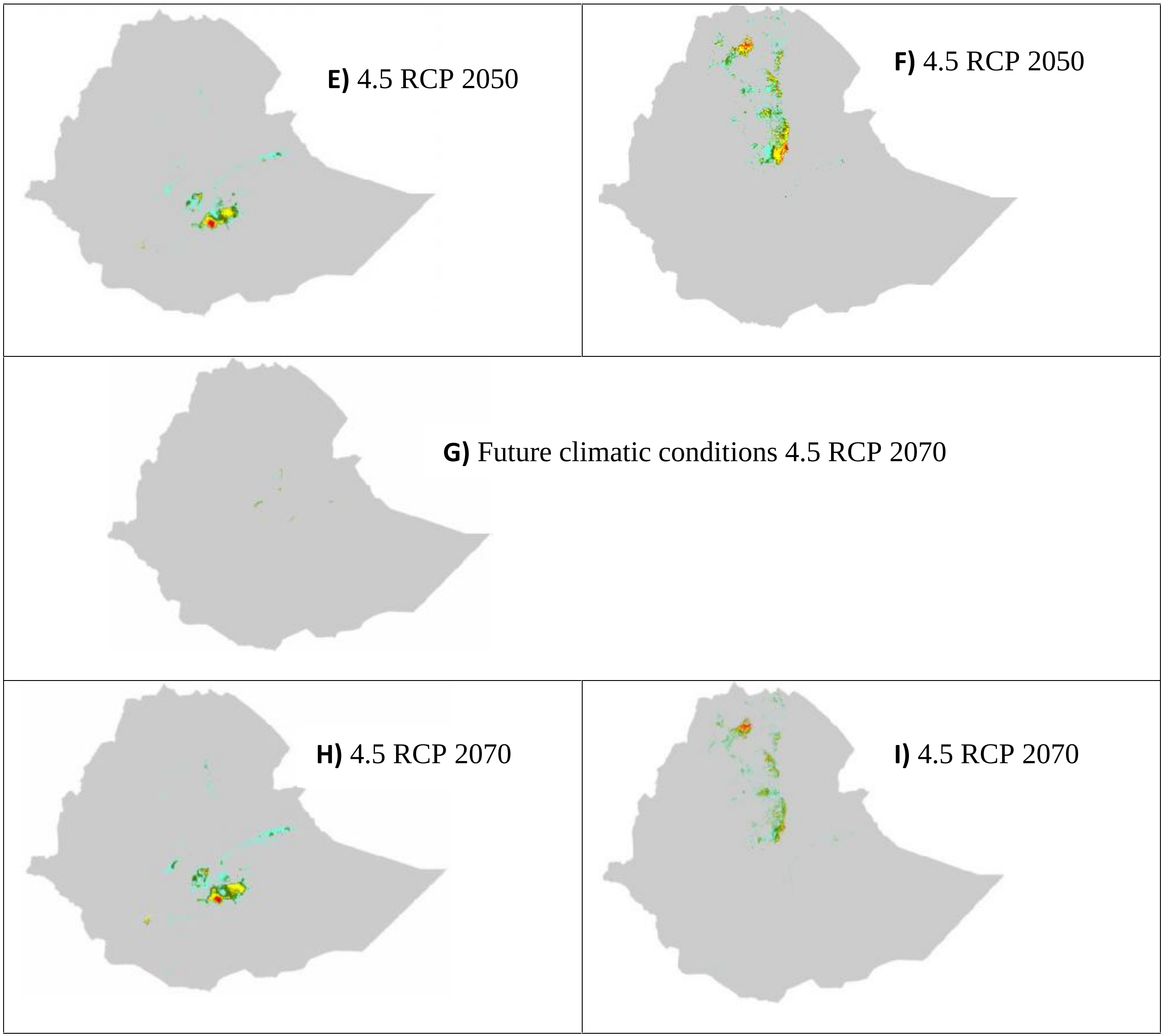


Figure 5.8. Future Suitable habitats of: *Festuca macrophylla* (D and G), *Helichrysum splendidum* (E and H) and *Euryops pinifolius* (F and I): future 2050 (D, E and F) and 2070 (G, H and E) periods with 4.5 RCP scenarios

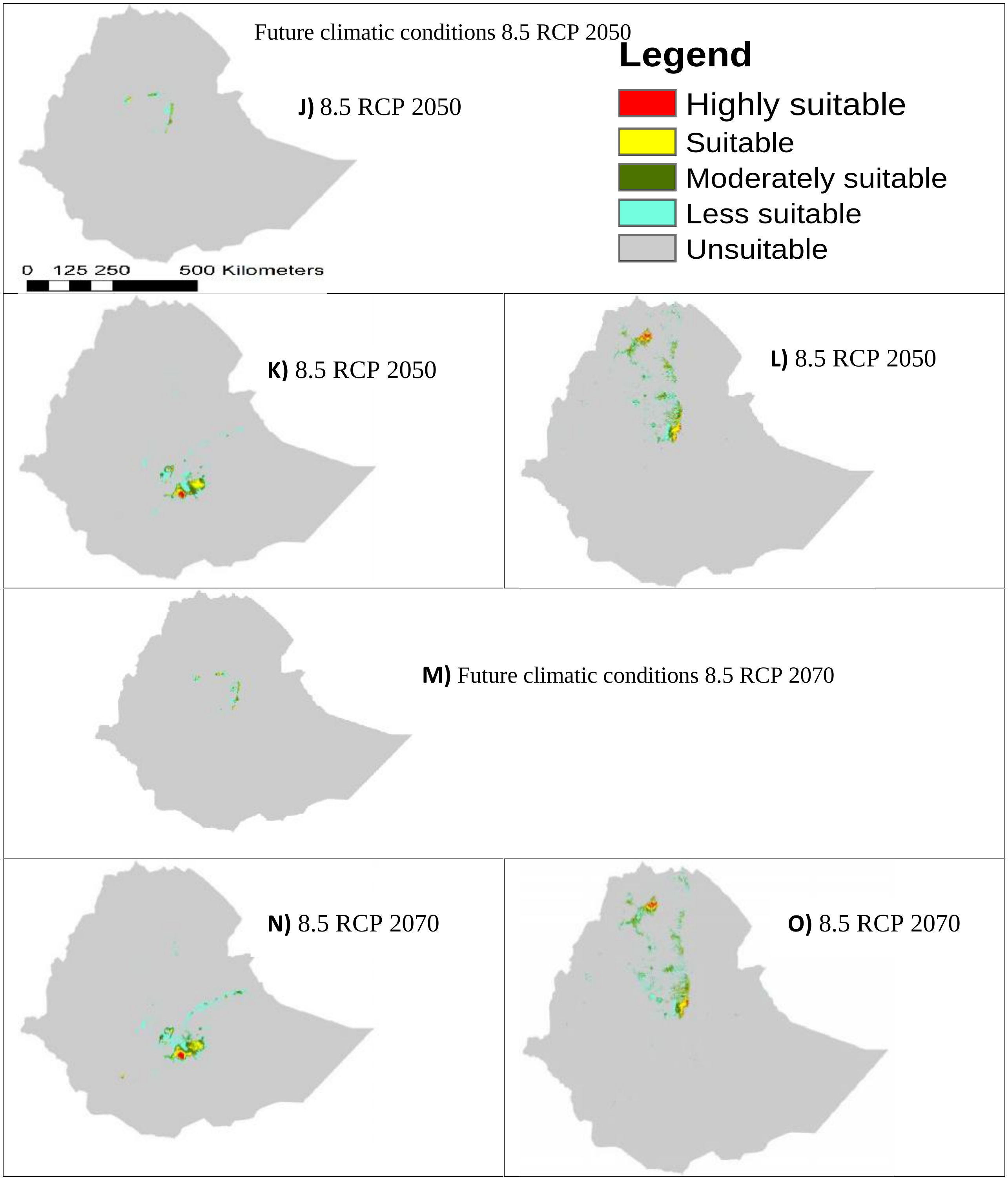


Figure 5.9. Future Suitable habitats of: *Festuca macrophylla* (J and M), *Helichrysum splendidum* (K and N) and *Euryops pinifolius* (L and O): future 2050 (J, K and L) and 2070 (M, N and O) periods with 8.5 RCP scenarios

5.4.1 The distributions of the suitable habitats under current climate scenario (1970–2000)

From the analysis of the model's output, the distribution of these three species are significantly predicted by the Mean temperature of coldest quarter (Bio11) and elevation, two of the model's 11 environmental variables that were taken into consideration. This result is consistent with earlier research, which showed that elevation is one of the major variables regulating plant development and dispersion as well as photosynthetic capacity (Teramura, 1983; Madronich *et al.,* 1998). Elevation and anthropogenic may determine the level of vulnerability of these plants (Elsen *et al.,* 2020). Additionally, Gebrewahid *et al.,* (2020) found how precipitation from the environmental variables such as Mean temperature of coldest quarter (Bio11) impacted the distribution ranges of various species.

It is projected that the distributions of the different categories of habitats that are suitable for these plants under the current climate were found predominately in the central highlands, northern and north-western regions of Ethiopia. Accordingly, these plants are currently found in these locations naturally (Agize and Zouwen, 2016; Debebe *et al.*, 2018) but shifting under future climate change scenarios.

Although the model predicted that only 0.095%, 2.36% and 1.07% of Ethiopia's total land area would fall within ranges of highly favorable area for *Festuca macrophylla* (Figure 5.5), *Helichrysum splendidum* (Figure 5.6) and *Euryops pinifolius* (Figure 5.7), respectively, the probabilities of occurrence are in range-restricted areas. These species may be sensitive to climate change because of their limited geographic range of distribution (Purvis *et al.*, 2000). As compared to the shrubs *Festuca macrophylla* has less suitable and is restricted to the central part of the country. This indicates that the shrubs are expanding their area to the northern and western regions, while *Festuca* is limited to central part of the country. This result agrees with the finding by Kidane *et al.,* (2019), who stated that climate change threatens the equilibrium of Afroalpine vegetation as warming temperatures at high elevations allow for new species to colonize and/or dominate and driving others to extinction. Our results indicate there is extremely limited suitable habitat for Guassa grass than the shrubs. These habitat modifications by shrubs may already be causing an extinction debt for *Festuca macrophylla*, which is the idea that there is a time lag whereby extinctions can occur over a considerable amount of time (Ferraz *et al.*, 2003).

The degree of sensitivity of certain plant species may depend on topography factors (such as elevational gradients) and human activity in addition to the additive effects of climate change (Elsen *et al.,* 2020). Particularly, anthropogenic causes have seriously endangered Ethiopia's richness of plant species (Aerts *et al.,* 2011). Other human influences that contribute to the destruction of the habitats of plant species include illegal settlements, deforestation caused by agricultural development, firewood gathering, and charcoal manufacture (Gole *et al.,* 2009; Tadese *et al.,* 2021).

In this study, it is expected that because of climate change, the distribution of *Festuca macrophylla*, *Helichrysum splendidum* and *Euryops pinifolius* will change along altitudinal gradients. The qualitative knowledge of declining Guassa grass habitat from local ecological knowledge in the GCCA (Steger *et al.,* 2020) and the encroachment of shrubs to the conservation area may lead this valuable grass to extinction. It is predicted that the ranges of these species will shift in the direction of their suitable habitat niches (González-Moreno *et al.,* 2015), which is supported by earlier studies that found distribution shifts in mountainous areas have been occurring along elevational gradients (Chen *et al.*, 2011; Elsen *et al.*, 2020).

5.4.2 The distributions of the suitable habitats under future climate scenarios (2050 and 2070)

According to the prediction model, in both climate scenarios, the ecosystems of the central highlands, northern and north-western Ethiopia will serve as refugia for *Helichrysum splendidum* and *Euryops pinifolius* in the 2050s and 2070s. But the distribution of *Festuca macrophylla* is limited to the central highlands. Here, the overall pattern of the model's output from the present to the 2070s demonstrates that, despite declines under a high GHG emission scenario (RCP 8.5) for these species in the 2070s, global warming tends to dictate the highly suitable areas *Festuca macrophylla*, *Helichrysum splendidum* and *Euryops pinifolius*. Comparatively speaking, *Helichrysum splendidum* and *Euryops pinifolius* shown more range expansion with climate change than *Festuca macrophylla*, which demonstrated a species-specific response to climate change (Jensen, 2003; Chhetri *et al.*, 2018). In concordance with this, Cao *et al.*, (2004) reported that global warming encourages the extension of some plant species' distribution ranges.

The model's results showed that the likely future occurrences of these two shrub species' highly suitable habitats, particularly under the RCP 8.5 scenario, are outside of their current adaptive ranges (Figures 5.8 and 5.9). But *Festuca macrophylla* is restricted to central highlands. This hypothetical situation demonstrates categorically how species can vary their geographic ranges in response to climate change (Chen *et al.*, 2011). However, after experiencing the strains of global warming, the species may either fill the realized niches or they may endure and adapt to the climate change rather than changing their geographic ranges (Jezkova *et al.,* 2016; Carlin *et al.,* 2021).

5.5 Conclusion

In this paper, we wanted to model the habitat suitability of Guassa grass (*Festuca macrophylla)*, *Helichrysum splendidum* and *Euryops pinifolius* in the central highlands of Ethiopia, to evaluate the current and future extent of habitat suitability class. The results of the prediction models demonstrated that elevation and Mean temperature of coldest quarter (Bio11) have had significant impacts on the modeling of the distribution of these plant species. The central, northern and north-western part of the country are the main suitable area for the three species and will be expected to remain suitable during 2050 and 2070 under RCP 4.5 and RCP 8.5 future climate scenarios. Elevation and Mean temperature of coldest quarter (Bio11) were found to be significant predictor variables for their distributions and three of these species share common suitable areas under these two variables. Our results indicate there is very limited suitable habitat for *Festuca macrophylla* as compared to *Helichrysum splendidum* and *Euryops pinifolius.* Thus, there are concerns over the future persistence of the *Festuca macrophylla* as continued *Helichrysum splendidum* and *Euryops pinifolius* invasion, habitat modification and climate change threaten the GCCA. Therefore, regular monitoring of this conservation area may be important to reduce the impacts of shrub encroachments to this economically and ecologically valuable community conservation area for future protection. Finally, this study highlights the importance of taking into consideration the scenarios of the impacts of climate change in designing conservation strategies for *Festuca macrophylla* plant species.

Chapter Six

6. General Discussion, Conclusion and Recommendations

6.1 General Discussion

In this study, we investigated the soil seed bank analysis in the GCCA (chapter 2), Influence of Aspect and Elevational Gradients on the Regeneration of *Festuca macrophylla* and *Helichrysum splendidum* plant species in GCCA, Central Highlands of Ethiopia (chapter 3), assessment of the suitable habitats of cultural keystone species using MaxEnt under climate change (chapter 4), and investigated the current and future distribution of *Festuca macrophylla, Helichrysum splendidum* and *Euryops pinifolius* in the central highlands of Ethiopia (chapter 5). This work could help in making decisions about the most beneficial community conservation area management strategies in the face of pressing ecological, anthropogenic and climate change pressures.

In the past, common property resource regimes supporting a variety of indigenous groups were common in Ethiopia. The "Qero" system in the Guassa area was an indigenous common property resource management system that was established based on the existing indigenous land tenure system. This indigenous resource management system known as "Qero" in the GCCA the Central Highlands of Ethiopia successfully protected resources used by the local community as well as significant endemic and threatened biodiversity (Ashenafi, 2001). The Qero system in the GCCA has continued since 1975 to protect local livelihoods, as well as endemic and threatened biodiversity, including Guassa grass (*Festuca macrophylla*) and an important population of the Ethiopian wolf (*Canis simensis*), the world's most endangered canid (Ashenafi, 2001; Ashenafi *et al.*, 2005). The Ethiopia's 1975 Agrarian Reform led to the transformation of the Qero system, which had functioned in the GCCA and exhibited all the traits of a traditional common property resource management system, into a new system for GCCA, which is to still in operation. The Qero system was then formally replaced by the Guassa Committee, which took over the management of the Guassa area. The newly established Guassa Committee is now in charge of managing the GCCA (Berkes, 2007).

Lack of local community empowerment and motivation to take ownership of the area is a recurring weakness of community-based conservation area (DeCaro & Stokes, 2008; Gebrehiwot *et al.*, 2021). Official land tenure grants to communities are essential to overcoming this obstacle since people are reluctant to invest time in managing land that may be taken away from them (Laperye, 2010; Steger *et al.*, 2020). However, it has also been demonstrated that when the conservation narrative minimizes or ignores cultural values in favor of wildlife protection, community motivation lags (Marks, 2001; Silva & Mosimane, 2014). In the meantime, it has been shown that community-based conservation that honors cultural knowledge and values fosters positive social and ecological effects (Sheppard *et al.*, 2010; Dyer *et al.*, 2014).

Effective community-based conservation areas require nested levels of governance that connects different institutions both horizontally and vertically (Ostrom *et al.*, 2002). Non-governmental organizations have a key role to play through funding, technical training, and institutional support for knowledge sharing across individual community-based conservation areas (Seixas & Berkes, 2010; Galvin *et al.*, 2018). Thus, collective action should also strive to overcome problems of unequal distribution of benefits and reduced social capital, which are widespread issues in African community-based conservation (Galvin *et al.*, 2018).

The Guassa Area is home to significant Afroalpine biodiversity, including numerous endemic and rare flora and fauna species, and it is a designated Ethiopian Highland Biodiversity Hotspot by Conservation International. The local communities' means of subsistence heavily depends on the area's natural resources. Even if a more contemporary form (that consists of Guassa committee, district and local administration) of the system has been restored, the area is threatened by development initiatives, internal and external human population growth, shrub encroachment, drought, climate changes, and agricultural expansion (Ashenafi, 2001).

The results of this study suggest that *Helichrysum splendidum* significantly increased in GCCA. *Helichrysum splendidum* increased in cover abundance due to the management practice that allows the harvest of grass every two-three year while firewood collection or cutting of shrubs and trees in the area is still forbidden in this conservation area. This phenomenon may have led to the creating of an ‘ecological vacuum’ for *Helichrysum splendidum* to increase in cover abundance at the expense of *Festuc*a grass. This intensive harvest strongly reduces grass cover (Porensky *et al.,* 2020) and leaving a competitive advantage for shrub species to establish (Bond, 2008). *Helichrysum splendidum* encroachment might also be related to a pioneer/invasive plant species trait, i.e., being able to establish itself in non-*Helichrysum splendidum* places such grasslands and Erica moorlands areas (Orban *et al.,* 2021). The invasion of *Helichrysum splendidum* in the GCCA is confirmed by the overall increase in *Helichrysum splendidum* cover abundance. This concurs with related research stating that *Helichrysum splendidum* has been encroaching on other ecosystems including *Festuca* grassland at a rapid rate, Sillero-Zubiri and Macdonald (1997).

According to our observation and the local community perception, the expansion of *Helichrysum splendidum* was the main cause of the decline in *Festuca* grass. This concurs with earlier research conducted by many academics (Sillero-Zubiri and Macdonald (1997; William *et al.,* 2005). Sillero-Zubiri and Macdonald (1997) stated that *Helichrysum splendidum* encroachment results in a reduction in the status of the grassland in the study area. In general, encroachment by *Helichrysum splendidum* was one factor, but other factors were also cited as contributing to the decline in grassland cover. For example, Hilman (1993) and William *et al.*, (2005) claimed that agricultural practices, deforestation, and overgrazing have significantly changed much of Ethiopia's terrain from sea level up to 4,000 m in order to meet the basic demands of a growing human population.

Climate change affects species distribution potential in a way that it either enables species to occupy/encroach certain area or leads others to extinction. In this regard, species distribution modeling is important to identify key environmental variables that help a given species to fall in either of the options. As a result of climate change, and because of their increased risk of extinction, rare and endemic species (such as *Festuca macrophylla*) are given priority in global conservation efforts (Salam *et al.,* 2022). In this case, we found that there is a very little amount of suitable habitat for endemic Guassa grass (*Festuca macrophylla*), a culturally important species, as compared to the shrubs (*Helichrysum splendidum* and *Euryops pinifolius*), based on the results of the habitat suitability model (chapters 4 and 5). Since warming temperatures at high elevations enable new species to colonize and/or dominate (Kidane *et al.*, 2019), driving others to extinction (Chala *et al.*, 2016), climate change threatens the balance of Afroalpine vegetation.

The expansion of agriculture and rangelands to support additional human communities on what was once considered inhospitable lands further restricts available land for Afroalpine vegetation (Ashenafi, 2001). As the best habitat for the grasses is found in regions with average maximum temperatures under 15 ^{0}C, our findings suggested that Guassa grass will be vulnerable to these warming temperatures. According to the theory that there is a time lag whereby extinctions can happen over a significant amount of time after perturbation, these habitat changes may already be contributing to an extinction debt for Guassa grass (Tilman *et al.*, 1994; Brooks *et al.*, 1999; Ferraz *et al.*, 2003).

Using Maxent software, an SDM tool that has been deemed suitable for modelling rare and endemic species (Phillips *et al.*, 2006), we also evaluated the habitat suitability of *Helichrysum splendidum* and *Euryops pinifolius* under changing climate scenarios that are reportedly encroaching and decreasing the productivity of endemic *Festuca macrophylla* in the GCCA. *Festuca macrophylla* is currently restricted to Ethiopia's Afroalpine vegetation type. The model showed that central highlands are the main suitable habitat for *Festuca macrophylla.* Whereas, central highlands, south-eastern, west, west-eastern are the main suitable habitats for *Helichrysum splendidum.* Similarly, the central highlands, northern and north-western parts of Ethiopia are the main suitable habitat for *Euryops pinifolius* and will stay suitable during 2050 and 2070 under RCP 4.5 and RCP 8.5 future climatic scenarios. These three species co-occur in their native ranges (in the central highlands) under current climate scenario. But, because of climate change, there will be a range shift for the two shrubs under future climate scenarios.

According to the model, the future possible occurrences of highly suitable habitats of *Helichrysum splendidum* and *Euryops pinifolius* species will be outside the current adaptive ranges (Figures 5.8 and 5.9). This scenario shows that the species will shift their geographic ranges following climate change (Chen *et al.*, 2011). Thus, climate change is expected to cause a shift in the distribution of *Helichrysum splendidum* and *Euryops pinifolius*, while *Festuca macrophylla* will be restricted in its native habitat. Thus, future suitable habitats for these three species are greatly impacted by: elevation, Mean temperature of coldest quarter (Bio11) and topographic position index (TPI). This is in line with prior studies (Teramura, 1983; Madronich *et al.,* 1998) that identified environmental variables as one of the key factors affecting plant growth, distribution, and photosynthetic capacity. The effect of these environmental variables on modifying the distribution ranges of various species was also noticed by Gebrewahid *et al.*, (2020).

The local community's desire to protect the GCCA has a strong connection to *Festuca* grass. They have conserved this cultural key stone species for domestic purposes, including as animal feed and thatching for roofs (detail in chapter 2). *Festuca* grass has therefore long been the source of community interest in helping to preserve the GCCA (Ashenafi, 2001; Leader-Williams *et al.,* 2005). Additionally, as the local community's interest in protecting the GCCA from its interest in the *Festuca* grassland, a failure on the part of the community to protect the GCCA may occur if the rate of *H. splendidum* encroachment over the *Festuca* grassland continues. Thus, *F. macrophylla* may disappear because of *H. splendidum* invasion (considered by the local community as nuisance to the conservation area) after some time.

In comparison to other shrub species, the GCCA's current management system, which entails a two- to three-year cycle of *Festuca* grass harvesting, may have resulted in less seed production (because harvesting takes place before seed production by the grass) and consequently less seed germination. Apparently, the dominance of the grass cover abundance is possibly due to vegetative reproduction instead of germination from soil seedbank. Thus, to address the interest of the local community, better management approach that revise the harvesting period and let this grass to produce more seed should be introduced.

6.2 General Conclusion

The findings of this study indicated that *Helichrysum splendidum* invasion had increased significantly in the study area. The expansion of *Helichrysum splendidum* in the GCCA was found to be relatively higher than that of other species (such as *Euryops pinifolius*), according to the findings from soil seedbank. *Helichrysum splendidum* has therefore been invading the GCCA. This study also concludes that *Festuca macrophylla* may be at risk of extinction due to the rate at which *Helichrysum splendidum* is encroaching and as a result of climate change.

Altitude and aspect had a substantial impact on the abundance of the two target species (*H. splendidum* and *F. macrophylla*). As altitude increases, there are fewer species to be found. These elevational variations in plant abundance may be the result of microclimate, topographic diversity, and/or management strategies. The North-West and North-East direction recorded the highest number of *F. macrophylla* and *H. splendidum*, followed by the South-West and South-East directions. The measurements and treatments made during the study have a significant impact on the species' ability to recover and determine the amount of mature vegetation and the stage of seeding of the study area's plant species. For the treatment in which removal experiment was conducted, germination of *H. splendidum* decreases over time showing less cover abundance as compared to the number of species before the removal. The high similarity for species distribution pattern between seedbank and aboveground vegetation was due to similar climate and altitude variation in the study area.

We model the habitat suitability of *F. macrophylla* throughout the highlands of northwest Ethiopia while assessing the current extent of *F. macrophylla* habitat that is currently contained within protected areas. Only four additional regions were identified for consideration as protected areas because of our findings, which showed that there are extremely few areas that are suitable habitat for *F. macrophylla*. As a result, there are concerns regarding the Guassa grass' prolonged survival considering the threats posed by ongoing habitat modification, climate change, and shrub invasion to these isolated sky-islands.

According to the potential habitat suitability class done for the three species, *Festuca macrophylla* is restricted to small geographic ranges (only to the central highlands) as compared with *Helichrysum splendidum* and *Euryops pinifolius.* This limited geographic range may indicate that this species is vulnerable to climate change. The model demonstrated that central highlands, south-eastern, west, west-eastern, northern, and north-western parts of Ethiopia are currently the main suitable habitat for *Helichrysum splendidum* and *Euryops pinifolius* and will stay suitable during 2050 and 2070 under RCP 4.5 and RCP 8.5 future climatic scenarios. This indicates the two shrubs abundance and cover is increasing at the expense of *Festuca macrophylla* and urges regular monitoring of this conservation area will be important to reduce the impacts of shrub encroachments to this economically and ecologically valuable community conservation area for future protection.

6.3 Recommendations

The Guassa community depends on the resource in the Guassa area for their survival and livelihoods. These communities residing close to the Guassa area who are using the resource should take major responsibility for its protection at the same time. Then, other stakeholders should take their part accordingly. Hence, the following recommendations are drawn from the results of the study.

- The expansion of *Helichrysum splendidum* in the GCCA was found to be relatively higher than *Festuca macrophylla* and therefore been invading the area. Thus, rigorous and continued removal (by up-rooting) would decrease germination of *Helichrysum splendidum* over time, and intern increases *Festuca macrophylla* population and reduces its risk of extinction over long period of time.

- Over the past times, the intensive harvest of *Festuca macrophylla* has been taken place every two-three year. This harvesting period strongly reduces grass cover, because; it will not give a chance for the grass to produce seed. Hence, management practice by the Guassa committee that allows the opening and closing time for the harvest of the grass every two-three year should be modified to four-five years as new law. This will give the grass enough time to have good regeneration potential and also better chance for seed production.
- In GCCA, firewood collection, and cutting of shrubs and trees for different uses is legally forbidden. But these activities should be practically allowed to create the ecological space for *Festuca macrophylla* to increase in cover abundance and intern increases its competitive advantages over *Helichrysum splendidum* such as for resources and dispersal agents.
- The effects of climate change on plant species habitat suitability and range shifts should be considered as one of biodiversity indicator or criteria in formulating conservation strategies especially in community conservation areas.
- Finally, but certainly not least, the researcher urges more study by scholars from the nearby universities such as Debre Birehan, Wollo and Addis Ababa University, on the prospects for MGCCA's sustainability. This could be done to investigate the advantages and opportunities of shrubs like *Helichrysum* spp. (for essential oil extraction e.g., anti-fungi, anti-allergic; cosmetics such as shampoos, lotions, etc.), so that the expansion of

these shrubs into the protected area could be minimized by changing the challenges into opportunity.

Chapter Seven

7.1 References

Abdelaal, M., Fois, M., Fenu, G., Bacchetta, G. (2019). Using MaxEnt modeling to predict the potential distribution of the endemic plant Rosa arabica Crép. in Egypt. Ecological informatics, 50, *pp.68-75.*

Adger, W. N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D. R., & Naess, L. O. (2009). Integrated solutions for biodiversity, climate change and poverty. *Clim. Chang*, 5, 1-100.

Admassie, Y. (2000). Twenty years to nowhere. Property rights, land management and conservation in Ethiopia. Red Sea Press, Trenton, New Jersey, USA.

Aerts, R., Hundera, K., Berecha, G., Gijbels, P., Baeten, M., Van Mechelen, M., ... & Honnay, O. (2011). Semi-forest coffee cultivation and the conservation of Ethiopian Afromontane rainforest fragments. Forest Ecology and Management, 261(6), 1034-1041.

Agize, M., & Zouwen, L. (2016). Spice and medicinal plants production and value chain analysis from South-West Ethiopia. Journal of Pharmacy and Alternative Medicine, 10, 126-144.

Ahmed, A. A. (2013). Diversity and distribution of the afroalpine flora of eastern Africa with special reference to the taxonomy of the genus Pentaschistis (Poaceae) (Doctoral dissertation, Kenyatta University).

Alemayehu, K., Dessie, T., Gizaw, S., Haile, A., Mekasha, Y. (2011). Population dynamics of Walia ibex (*Capra walie*) at Simen Mountains National Park, Ethiopia. *Afr J Ecol* 49:292–300. doi:10.1111/j.1365-2028.2011.01264.

Alemu B, Garedew E, Eshetu Z, Kassa H. Land use and land cover changes and associated driving forces in north western lowlands of Ethiopia. International research journal of agricultural science and soil science. 2015 Jan;5(1):28-44.

Alexander, J. M., Lembrechts, J. J., Cavieres, L. A., Daehler, C., Haider, S., Kueffer, C., ... & Seipel, T. (2016). Plant invasions into mountains and alpine ecosystems: current status and future challenges. *Alpine Botany*, *126*, 89-103. https://doi.org/10.1007/s00035-016-0172-8

Amatulli, G., Domisch, S., Tuanmu, M.-N., Parmentier, B., Ranipeta, A., Malczyk, J., Jetz, W. (2018). A suite of global, cross-scale topographic variables for environmental and biodiversity modeling. Scientific Data volume 5, Article number: 180040. DOI: doi:10.1038/sdata.2018.40.

Ambrose, S.H. (2001). Paleolithic technology and human evolution. *Science*, *291*(5509), pp.1748-1753.

Amessie, G. (2014). Opportunities and challenges of community based natural resource management in Menz Guassa community conservation area, Ethiopia. *Unpublished MA thesis, Addis Ababa University, Ethiopia*, 29.

Amessie, G. (2017). Opportunities and Challenges of Community Based Natural Resource Management in Menz-Guassa Community Conservation Area, Ethiopia.

Anderson, R. P., Gonzalez, I. (2011). Species-specific tuning increases robustness to sampling bias in models of species distributions: an implementation with MaxEnt. – Ecol. Model. 222: 2796–2811.

Anderson, R.P., Martınez-Meyer, E. (2004). Modeling species' geographic distributions for preliminary conservation assessments: an implementation with the spiny pocket mice (Heteromys) of Ecuador. *Biological conservation*, *116*(2), pp.167-179.

Angassa A, Oba G. Relating long-term rainfall variability to cattle population dynamics in communal rangelands and a government ranch in southern Ethiopia. Agricultural systems. 2007 Jun 1;94(3):715-25.

Antúnez, P., Suárez-Mota, M. E., Valenzuela-Encinas, C., & Ruiz-Aquino, F. (2018). The potential distribution of tree species in three periods of time under a climate change scenario. Forests, 9(10), 628.

Archer S, Schimel DS, Holland EA. Mechanisms of shrubland expansion: land use, climate or CO2?. Climatic change. 1995 Jan;29(1):91-9.

Archer, S. R., Andersen, E. M., Predick, K. I., Schwinning, S., Steidl, R. J., & Woods, S. R. (2017). Woody plant encroachment: causes and consequences. *Rangeland systems: Processes, management and challenges*, 25-84.

Arcos, J.M., Bécares, J., Villero, D., Brotons, L., Rodríguez, B., Ruiz, A. (2012). Assessing the location and stability of foraging hotspots for pelagic seabirds: an approach to identify marine Important Bird Areas (IBAs) in Spain. *Biological conservation*, *156*, pp.30-42.

Argaw M, Teketay D, Olsson M. Soil seed flora, germination and regeneration pattern of woody species in an Acacia woodland of the Rift Valley in Ethiopia. Journal of Arid Environments. 1999 Dec 1;43(4):411-35.

Ashenafi, Z. T. (2001). Common property resource management of an Afro-alpine habitat supporting a population of the critically endangered Ethiopian Wolf (Canis simensis). *PhD thesis, University of Kent*.

Ashenafi, Z. T., & Leader-Williams, N. (2005). Indigenous common property resource management in the Central Highlands of Ethiopia. *Human Ecology*, *33*(4), 539-563.

Ashenafi, Z. T., Coulson, T., Sillero-Zubiri, C., & Leader-Williams, N. (2005, May). Behaviour and ecology of the Ethiopian wolf (Canis simensis) in a human-dominated landscape outside protected areas. In *Animal Conservation forum* (Vol. 8, No. 2, pp. 113-121). Cambridge University Press.

Ashenafi, Z. T., Leader-Williams, N., & Coulson, T. (2012). Consequences of human land use for an Afro-alpine ecological community in Ethiopia. *Conservation and Society*, *10*(3), 209-216.

Ashenafi, Z.T., Leader-Williams, N. (2005). Indigenous common property resource management in the central highlands of Ethiopia. Hum. *Ecol*. 33 (4), 539–563.

Augustine DJ, Mcnaughton SJ. Regulation of shrub dynamics by native browsing ungulates on East African rangeland. Journal of Applied Ecology. 2004 Feb;41(1):45-58.

Austin, M. (2006). Species distribution models and ecological theory: a critical assessment and some possible new approaches. Ecological modelling, 200(1-2), 1-19.

Bahalkeh, K., Abedi, M., Dianati Tilaki, G. A., & Michalet, R. (2021). Fire slightly decreases the competitive effects of a thorny cushion shrub in a semi-arid mountain steppe in the short term. *Applied Vegetation Science*, *24*(2), e12575. https://doi.org/10.1111/avsc.12575

Bai, Y., Broersma, K., Thompson, D., & Ross, T. J. (2004). Landscape-level dynamics of grassland-forest transitions in British Columbia. *Journal of Range Management*, *57*(1), 66-75.

Bakkenes, M., Alkemade, J.R.M., Ihle, F., Leemans, R., Latour, J.B. (2002). Assessing effects of forecasted climate change on the diversity and distribution of European higher plants for 2050. *Global change biology*, *8*(4), pp.390-407.

Batllori, E., & Gutiérrez, E. (2008). Regional tree line dynamics in response to global change in the Pyrenees. *Journal of Ecology*, *96*(6), 1275-1288.

Bekele M. (2003). Forest property rights, the role of the state, and institutional exigency: the Ethiopian experience, 0073-0073.

Bekele, T. (1993). Vegetation ecology of remnant Afromontane forests on the central plateau of Shewa, Ethiopia. Sv. växtgeografiska sällsk.

Berg, M. P., Kiers, E. T., Driessen, G., Van Der HEIJDEN, M. A. R. C. E. L., Kooi, B. W., Kuenen, F., ... & Ellers, J. (2010). Adapt or disperse: understanding species persistence in a changing world. Global Change Biology, 16(2), 587-598.

Berkes, F. (2007). Community-based conservation in a globalized world. *Proceedings of the National academy of sciences*, *104*(39), pp.15188-15193.

Betemariam, E. A. (2011). Forest diversity in fragmented landscapes of northern Ethiopia and implications for conservation (Doctoral dissertation, Universitäts-und Landesbibliothek Bonn).

Bewket W. Land cover dynamics since the 1950s in Chemoga watershed, Blue Nile basin, Ethiopia. Mountain research and development. 2002 Aug;22(3):263-9.

Beyene, H. (2010). Population Estimate and Structure of the Gelada Baboon, Theropithecus Gelada, in the Guassa Community Conservation Area, Central Ethiopia.

Billi, P. (2015). Geomorphological landscapes of Ethiopia. In: Billi, P. (Ed.), Landscapes and Landforms of Ethiopia, World Geomorphological Landscapes. *Springer Science+Business Media*, Dordrecht.

Biniyam, A., & Tefera, Z. (2011). Trek like the locals on the scenic Guassa Plateau Travel Guide book. *Frankfurt Zoological society, Ethiopia*.

Bond, W. J. (2008). What limits trees in C4 grasslands and savannas?. *Annual review of ecology, evolution, and systematics*, *39*, 641-659.

Brandt, J. S., Haynes, M. A., Kuemmerle, T., Waller, D. M., & Radeloff, V. C. (2013). Regime shift on the roof of the world: Alpine meadows converting to shrublands in the southern Himalayas. *Biological Conservation*, *158*, 116-127.

Briggs JM, Knapp AK, Blair JM, Heisler JL, Hoch GA, Lett MS, McCarron JK. An ecosystem in transition: causes and consequences of the conversion of mesic grassland to shrubland. BioScience. 2005 Mar 1;55(3):243-54.

Brito, J. C., Acosta, A. L., Álvares, F., & Cuzin, F. (2009). Biogeography and conservation of taxa from remote regions: An application of ecological-niche based models and GIS to North-African Canids. *Biological Conservation*, *142*(12), 3020-3029.

Brochmann, C., Gizaw, A., Chala, D., Kandziora, M., Eilu, G., Popp, M., Pirie, MD., Gehrke, B. (2021). History and evolution of the afroalpine flora: in the footsteps of Olov Hedberg. *Alp Botany* (2021). https://doi.org/10.1007/s00035-021-00256-9.

Brockington, D. (2002). Fortress conservation: the preservation of the Mkomazi Game Reserve, Tanzania. *Indiana University Press*.

Brooks, T. M., Mittermeier, R. A. and Mittermeier, C.G. (2002). Habitat Loss and Extinction inthe Hotspots of Biodiversity. *Conservation Biology* **16(4)**: 909-923.

Brooks, T.M., Pimm, S.L., Oyugi, J.O. (1999). Time lag between deforestation and bird extinction in tropical forest fragments. *Conservation Biology*, *13*(5), pp.1140-1150.

Brueckner-Irwin, I., Armitage, D., Courtenay, S. (2019). Applying a social-ecological well-being approach to enhance opportunities for marine protected area governance. *Ecology and Society*, *24*(3).

Bruun, H. H., Moen, J., Virtanen, R., Grytnes, J. A., Oksanen, L., & Angerbjörn, A. (2006). Effects of altitude and topography on species richness of vascular plants, bryophytes and lichens in alpine communities. *Journal of Vegetation Science*, *17*(1), 37-46.

Bulman, C.R., Wilson, R.J., Holt, A.R., Bravo, L.G., Early, R.I., Warren, M.S., Thomas, C.D. (2007). Minimum viable metapopulation size, extinction debt, and the conservation of a declining species. *Ecological Applications*, *17*(5), pp.1460-1473.

Busing, R. T., White, P. S., & MacKenzie, M. D. (1993). Gradient analysis of old spruce–fir forests of the Great Smoky Mountains circa 1935. *Canadian Journal of Botany*, *71*(7), 951-958.

Buytaert, W., Cuesta Camacho, F., Tobón, C. (2011). Potential impacts of climate change on the environmental services of humid tropical alpine regions. *Global Ecology and Biogeography*, *20*(1), pp.19-33.

Cao, M., Prince, S. D., Small, J., & Goetz, S. J. (2004). Remotely sensed interannual variations and trends in terrestrial net primary productivity 1981–2000. Ecosystems, 7, 233-242.

Carlin, T., Bufford, J., Hulme, P., & Godsoe, W. (2021). Global assessment of climatic niche shifts in three Rumex species.

Carroll, C., Noss, R.F., Paquet, P.C., Schumaker, N.H. (2004). Extinction debt of protected areas in developing landscapes. *Conservation Biology*, *18*(4), pp.1110-1120.

Chagonda L. S., Makanda C., and Chalchat J. C. (1999).Essential oils of four wild and semi wild plants from Zimbabwe: *Colospermum mopane* (Kirk ex Benth.) Kirk ex Leonard, *Helichrysum splendidum* (Thunb.) Less., *Myrothamnus flabellifolia* (Welw.) and *Tagetes minuta* L. J. Essent. Oil Res. 11:573-578

Chala, D., Brochmann, C., Psomas, A.,Ehrich, D., Gizaw, A., Masao, C. A., Bakkestuen, V., Zimmermann,N. E. (2016), Good- bye to tropical alpine plant giants under warmerclimates? Loss of range and genetic diversity in *Lobelia rhynchopetalum. Ecology and Evolution*, 6: 8931–8941.doi: 10.1002/ece3.2603.

Chen, I. C., Hill, J. K., Ohlemüller, R., Roy, D. B., & Thomas, C. D. (2011). Rapid range shifts of species associated with high levels of climate warming. Science, 333(6045), 1024-1026.

Chhetri, P. K., Gaddis, K. D., & Cairns, D. M. (2018). Predicting the suitable habitat of treeline species in the Nepalese Himalayas under climate change. Mountain Research and Development, 38(2), 153-163.

Choudhury, M. R., Deb, P., Singha, H., Chakdar, B., & Medhi, M. (2016). Predicting the probable distribution and threat of invasive Mimosa diplotricha Suavalle and Mikania micrantha Kunth in a protected tropical grassland. Ecological Engineering, 97, 23-31.

Conservation Press, Cambridge, UK.

Conway, D. (2005). From headwater tributaries to international river: Observing and adapting to climate variability and change in the Nile basin. *Global Environmental Change*, *15*(2), pp.99-114.

Cory Merow, Matthew J. Smith and John A. Silander, Jr. (2013). A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. *Ecography* 36: 001–012, 2013, doi: 10.1111/j.1600-0587.2013.07872.x.

Cousins, S.A. (2009). Extinction debt in fragmented grasslands: paid or not? *Journal of Vegetation Science*, *20*(1), pp.3-7.

Crane, T.A. (2010). Of models and meanings: Cultural resilience in social–ecological. *Ecology and Society*, *15*(4).

Cristancho, S., Vining, J. (2004). Culturally defined keystone species. *Hum Ecol* Rev.11:153–64.

Cumming, G.S., Allen, C.R., Ban, N.C., Biggs, D., Biggs, H.C., Cumming, D.H., De Vos, A., Epstein, G., Etienne, M., Maciejewski, K., Mathevet, R. (2015). Understanding protected area resilience: a multi-scale, social-ecological approach. *Ecological Applications*, *25*(2), pp.299-319.

Dagnino, D., Guerrina, M., Minuto, L., Mariotti, M. G., Médail, F., & Casazza, G. (2020). Climate change and the future of endemic flora in the South Western Alps: relationships between niche properties and extinction risk. Regional Environmental Change, 20, 1-12.

Daïnou K, Bauduin A, Bourland N, Gillet JF, Fétéké F, Doucet JL. Soil seed bank characteristics in Cameroonian rainforests and implications for post-logging forest recovery. Ecological Engineering. 2011 Oct 1;37(10):1499-506.

Dalle, G., Maass, B. L., & Isselstein, J. (2006). Encroachment of woody plants and its impact on pastoral livestock production in the Borana lowlands, southern Oromia, Ethiopia. *African Journal of Ecology*, *44*(2), 237-246.

Dalerum F, de Vries JL, Pirk CW, Cameron EZ. Spatial and temporal dimensions to the taxonomic diversity of arthropods in an arid grassland savannah. Journal of Arid Environments. 2017 Sep 1;144:21-30.

Davis, A.P., Gole, T.W., Baena, S., Moat, J. (2012). The impact of climate change on indigenous arabica coffee (*Coffea arabica*): predicting future trends and identifying priorities. *PloS one*, *7*(11), p.e47981.

Dawes, W. R., & Short, D. (1994). The significance of topology for modeling the surface hydrology of fluvial landscapes. *Water Resources Research*, *30*(4), 1045-1055.

DeAngelis, D.L., Yurek, S. (2017). Spatially explicit modeling in ecology: a review. *Ecosystems*, *20*(2), pp.284-300.

Debebe, E., Dessalegn, T., & Melaku, Y. (2018). Chemical constituents and antioxidant activities of the fruits extracts of Piper capense. Bulletin of the Chemical Society of Ethiopia, 32(1), 167-174.

DeCaro, D., Stokes, M. (2008). Social psychological principles of community based conservation and conservancy motivation: attaining goals within an autonomy supportive environment. *Conservation Biology*, *22*(6), pp.1443-1451.

Dullinger, S., Gattringer, A., Thuiller, W., Moser, D., Zimmermann, N. E., Guisan, A., ... & Hülber, K. (2012). Extinction debt of high-mountain plants under twenty-first-century climate change. Nature climate change, 2(8), 619-622.

Dutta, G., & Devi, A. (2013). Plant diversity, population structure, and regeneration status in disturbed tropical forests in Assam, northeast India. *Journal of Forestry Research*, *24*(4), 715-720.

Dyer, J., L. C. Stringer, A. J. Dougill, J. Leventon, M. Nshimbi, F. Chama, A. Kafwifwi, J. I. Muledi, J.-M. K. Kaumbu, M. Falcao, S. Muhorro, F. Munyemba, G. M. Kalaba, and S. Syampungani. (2014). Assessing participatory practices in community-based natural resource management: experiences in community engagement from southern Africa. *Journal of Environmental Management* 137:137-145. http://dx.doi.org/10.1016/ j.jenvman.2013.11.057.

Edwards S, Demissew S, Hedberg I. Flora of Ethiopia and Eritrea: Hydrocharitaceae to Arecaceae. The National Herbarium, Addis Ababa University; 1997.

Edwards S, Tadese M, Hedberg I. Flora of Ethiopia and Eritrea vol. 2, Part 2: canellaceae to euphorbiaceae. AAU; 1995.

Edwards S, Tadesse M, Demissew S, Hedberg I. Flora of Ethiopia and Eritrea. Magnoliaceae to Flacourtiaceae (vol. 2:1). Department of Systematic Botany, Uppsala, Sweden: The National Herbarium, Addis Ababa, Ethiopia. 2000, pp. 332.

Eldridge, D. J., Bowker, M. A., Maestre, F. T., Roger, E., Reynolds, J. F., & Whitford, W. G. (2011). Impacts of shrub encroachment on ecosystem structure and functioning: towards a global synthesis. *Ecology letters*, *14*(7), 709-722. https://doi.org/10.1111/j.1461-0248.2011.01630.x

Elith, J. and Leathwick, J.R. (2009) Species distribution models: ecological explanation and prediction across space and time. *Annual Review of Ecology*, *Evolution and Systematics*, 40, 677– 697.

Elith, J., Graham, C.H., Anderson, R.P. et al. (2006) Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, 29, 129–151.

Elith, J., Kearney, M., Phillips, S.J. (2010). The art of modeling range-shifting species. *Methods in Ecology and Evolution*, 1, 330–342.

Elith, J., Phillips, S. J., Hastie, T., Dudík, M., Chee, Y. E., Yates, C. J. Yates. (2011). A statistical explanation of MaxEnt for ecologists. – Divers. *Distrib*. 17: 43–57.

Elsen, P. R., Monahan, W. B., & Merenlender, A. M. (2020). Topography and human pressure in mountain ranges alter expected species responses to climate change. Nature Communications, 11(1), 1974.

Endress, B. A., & Chinea, J. D. (2001). Landscape Patterns of Tropical Forest Recovery in the Republic of Palau 1. *Biotropica*, *33*(4), 555-565.

Engedasew, A. (2010). Human -Wildlife Conflict Involving Ethiopian Wolf (Canis simensis) and Gelada Baboon (Theropithicus gelada) In and Around guassa Community Comservation area, North shoa, Ethiopia.MSc thesis.

Enquist, C.A.F. (2002). Predicted regional impacts of climate change on the geographical distribution and diversity of tropical forests in Costa Rica. *J. Biogeogr*. 29, 519e553.

Erfanzadeh R, Hazhir S, Jafari M. Effect of cushion plants on the soil seed bank in overgrazed semiarid regions. Land Degradation & Development. 2020 May 15;31(8):990-1000.

Erfanzadeh R, Shayesteh Palaye AA, Ghelichnia H. Shrub effects on germinable soil seed bank in overgrazed rangelands. Plant Ecology & Diversity. 2020 Mar 3;13(2):199-208.

Eshetu Z, Högberg P. Reconstruction of forest site history in Ethiopian highlands based on 13C natural abundance of soils. AMBIO: A Journal of the Human Environment. 2000 Mar;29(2):83-9.

Ethiopian Biodiversity Institute (2014). Ethiopia‟s Fifth National Report to the Convention on Biological Diversity. Addis Ababa, Ethiopia.

Ethiopian Biodiversity Institute (2022). National Ecosystem Assessment of Ethiopia. Syntheses of the Status of Biodiversity and Ecosystem Services, and Scenarios of Change. Addis Ababa, Ethiopia.

Evangelista, P., Young, N., Burnett, J. (2013). How will climate change spatially affect agriculture production in Ethiopia? Case studies of important cereal crops. *Climatic change*, *119*(3), pp.855-873.

Evangelista, P.H., Kumar, S., Stohlgren, T.J., Jarnevich, C.S., Crall, A.W., Norman III, J.B., Barnett, D.T. (2008). Modelling invasion for a habitat generalist and a specialist plant species. *Diversity and Distributions*, *14*(5), pp.808-817.

EWCA, (2015). State of conservation report of the world natural Heritage site, Simen Mountains National Park (Ethiopia). Ethiopian Wildlife Conservation Authority, Addis Ababa, Ethiopia.

Fajardo, J., Lessmann, J., Bonaccorso, E., Devenish, C., Munoz, J. (2014). Combined use of systematic conservation planning, species distribution modelling, and connectivity analysis reveals severe conservation gaps in a megadiverse country (Peru). *PLoS One*, *9*(12), p.e114367.

Fang J, Chen A, Peng C, Zhao S, Ci L. Changes in forest biomass carbon storage in China between 1949 and 1998. Science. 2001 Jun 22;292(5525):2320-2.

Fashing, P. J., Nguyen, N., Venkataraman, V. V., Kerby, J. T. (2014). Gelada feeding ecology in an intact ecosystem at Guassa, Ethiopia: variability over time and implications for theropith and hominin dietary evolution. *American Journal of Physical Anthropology* 155(1):1-16. https://doi.org/10.1002/ajpa.22559.

Ferraz, G., Russell, G.J., Stouffer, P.C., Bierregaard, R.O., Pimm, S.L., Lovejoy, T.E. (2003). Rates of species loss from Amazonian forest fragments. *Proceedings of the National Academy of Sciences*, *100*(24), pp.14069-14073.

Ferrier, S., Watson, G., Pearce, J., Drielsma, M. (2002) Extended statistical approaches to modeling spatial pattern in biodiversity: the north-east New South Wales experience. I. Species-level modeling. *Biodiv. Conserv*. 11: 2275–2307.

Fischer, A., Wakjira, D. T., Weldesemaet, Y. T., Ashenafi, Z. T. (2014). On the interplay of actors in the co-management of natural resources - a dynamic perspective. *World Development* 64:158-168. https://doi.org/10.1016/j.worlddev.2014.05.026.

Fogarty, D. T., Roberts, C. P., Uden, D. R., Donovan, V. M., Allen, C. R., Naugle, D. E., ... & Twidwell, D. (2020). Woody plant encroachment and the sustainability of priority conservation areas. *Sustainability*, *12*(20), 8321. https://doi.org/10.3390/su12208321

Fortunel, C., Paine, C. T., Fine, P. V., Kraft, N. J., & Baraloto, C. (2014). Environmental factors predict community functional composition in Amazonian forests. *Journal of Ecology*, *102*(1), 145-155.

Fourcade, Y., Engler, J. O., Rödder, D., & Secondi, J. (2014). Mapping species distributions with MAXENT using a geographically biased sample of presence data: a performance assessment of methods for correcting sampling bias. PloS one, 9(5), e97122.

Friis, I. B., Demissew, S., & Breugel, P. V. (2010). Atlas of the potential vegetation of Ethiopia. Det Kongelige Danske Videnskabernes Selskab.

Gairola, S., Ghildiyal, S. K., Sharma, C. M., & Suyal, S. (2009). Species richness and diversity along an altitudinal gradient in moist temperate forest of Garhwal Himalaya. *Am J Sci*, *5*, 119-128.

Galvin, K.A., Beeton, T.A., Luizza, M.W. (2018). African community-based conservation. *Ecology and Society*, *23*(3).

Garibaldi, A., Turner, N. (2004). Cultural keystone species: implications for ecological conservation and restoration. *Ecology and society*, *9*(3).

Gashaw T, Dinkayoh T. Land use/land cover dynamics in Hulet Wogedamea Kebele, northern Ethiopia. Current Research in Agricultural Sciences. 2015;2(1):36-41.

Gebrehiwot, K., Desalegn, T., Woldu, Z., Demissew, S., & Teferi, E. (2018). Soil organic carbon stock in Abune Yosef afroalpine and sub-afroalpine vegetation, northern Ethiopia. *Ecological Processes*, *7*(1), 1-9. https://doi.org/10.1186/s13717-018-0117-9.

Gebrehiwot, K., Teferi, E., Woldu, Z., Fekadu, M., Desalegn, T., Demissew S. (2021). Dynamics and drivers of land cover change in the Afroalpine vegetation belt: Abune Yosef mountain range, Northern Ethiopia. Environment, *Development and Sustainability* 23:10679–10701.

Gebremedhin, B., Flagstad, Ø., Bekele, A., Chala, D., Bakkestuen, V., Boessenkool, S., ... Epp, L. S. (2016). DNA Metabarcoding Reveals Diet Overlap between the Endangered Walia Ibex and Domestic Goats - Implications for Conservation. *PLoS ONE* 11(7): e0159133. https://doi.org/10.1371/journal.pone.0159133.

Gebrewahid, Y., Abrehe, S., Meresa, E., Eyasu, G., Abay, K., Gebreab, G., ... & Darcha, G. (2020). Current and future predicting potential areas of Oxytenanthera abyssinica (A. Richard) using MaxEnt model under climate change in Northern Ethiopia. Ecological Processes, 9(1), 1-15.

Gehrke, B., Linder, H.P. (2014). Species richness, endemism and species composition in the tropical Afroalpine flora. Alp Bot 124:165–177. https:// doi. org/ 10. 1007/ s00035-014- 0132-0.

Gerard, F., Petit, S., Smith, G., Thomson, A., Brown, N., Manchester, S., ... & Feranec, J. (2010). Land cover change in Europe between 1950 and 2000 determined employing aerial photography. *Progress in Physical Geography*, *34*(2), 183-205.

Ghimire, B., Mainali, K. P., Lekhak, H. D., Chaudhary, R. P., & Ghimeray, A. K. (2010). Regeneration of Pinus wallichiana AB Jackson in a trans-Himalayan dry valley of north-central Nepal. *Himalayan Journal of Sciences*, *6*(8), 19-26.

Gillet, F. (2008). Plant Competition. *Encyclopedia of Ecology, Five-Volume Set*, 2783–2793. https://doi.org/10.1016/B978-008045405-4.00218-4

Girma E., Tesfay, G., Bauer, H., Ashenafi, Z. T., de Iongh, H., & Marino, J. (2015). Community Resource Uses and Ethiopian Wolf Conservation in Mount Abune Yosef. *Environmental Management*, 56, pp.684–694.

Girma, A. (2012). Plant communities, species diversity, seedling bank and resprouting in Nandi forests, Kenya.

Gizaw, A., Kebede, M., Nemomissa, S., Ehrich, D., Bekele, B., Mirré, V., ... & Brochmann, C. (2013). Phylogeography of the heathers Erica arborea and E. trimera in the afro-alpine 'sky islands' inferred from AFLPs and plastid DNA sequences. *Flora-Morphology, Distribution, Functional Ecology of Plants*, *208*(7), 453-463.

Gole, T. W., Feyera, S., Kassahun, T., & Fite, G. (2009). Yayu coffee forest biosphere reserve nomination form. Ethiopian MAB National Committee, Addis Ababa.

González-Moreno, P., Diez, J. M., Richardson, D. M., & Vilà, M. (2015). Beyond climate: disturbance niche shifts in invasive species. Global Ecology and Biogeography, 24(3), 360-370.

Grabherr, G., Gottfried, M., Pauli, H. (1994). Climate effects on mountain plants. Nature 369, 448.

Griffies SM, Winton M, Donner LJ, Horowitz LW, Downes SM, Farneti R, Gnanadesikan A, Hurlin WJ, Lee H, Liang Z, Palter JB, Samuels BL, Wittenberg AT, Wyman BL, Yin J, Zadeh N (2011). The GFDL CM3 coupled climate model: characteristics of the ocean and sea ice simulations. J Climate 24:3520–3544.

Groth, J., Ide, T., Sakdapolrak, P., Kassa, E. and Hermans, K., (2020). Deciphering interwoven drivers of environment-related migration–A multisite case study from the Ethiopian highlands. *Global Environmental Change*, *63*, p.102094.

Guido, A., Salengue, E., & Dresseno, A. (2017). Effect of shrub encroachment on vegetation communities in Brazilian forest-grassland mosaics. *Perspectives in Ecology and Conservation*, *15*(1), 52–55. https://doi.org/10.1016/j.pecon.2016.11.002

Guisan A, Zimmermann NE (2000). Predictive habitat distribution models in ecology. Ecol. Modell. 135: 147–186.

Guisan, A., Edwards Jr., T.C., Hastie, T., (2002). Generalized linear and generalized additive models in studies of species distributions: setting the scene. Ecol. Model. 157 (2), 89-100.

Guisan, A., Tingley, R., Baumgartner, JB., Naujokaitis-Lewis, I., Sutcliffe, PR., Tulloch, AI., Regan, TJ., Brotons, L., McDonald-Madden, E., Mantyka-Pringle, C., Martin, TG., Rhodes, JR., Maggini, R., Setterfield, SA., Elith, J., Schwartz, MW., Wintle, BA., Broennimann, O., Austin, M., S., …Buckley, YM. (2013). Predicting species distributions for conservation decisions. *Ecol Lett*. 16(12):1424-35. doi: 10.1111/ele.12189.

Guo Q, Rundel PW, Goodall DW. Horizontal and vertical distribution of desert seed banks: patterns, causes, and implications. Journal of arid environments. 1998 Mar 1;38(3):465-78.

Gurmessa, F., Soromessa, T., & Kelbessa, E. (2013). Floristic Composition and Community Analysis of Komto Afromontane Moist Forest, East Wollega Zone, West Ethiopia. *Science, Technology and Arts Research Journal*, *2*(2), 58-69.

Hae, M. E. (2018). Invasive plant species in Lesotho's rangelands: Species characterization and potential control measures. *United Nations University Land Restoration Training Programme [final project]*. http://www.unulrt.is/static/fellows/document/Hae2016.pdf

Hagedorn, F., Gavazov, K. and Alexander, J.M. (2019). Above-and belowground linkages shape responses of mountain vegetation to climate change. *Science*, *365*(6458), pp.1119-1123.

Hanspach, J., Haider, L.J., Oteros-Rozas, E., Olafsson, A.S., Gulsrud, N.M., Raymond, C.M., Torralba, M., Martín-López, B., Bieling, C., Garcia-Martin, M., Albert, C. (2020). Biocultural approaches to sustainability: A systematic review of the scientific literature. *People and Nature*.

Haque, S. M. S., & Alam, M. S. (1988). Some aspects of practicing the clear felling followed by artificial regeneration system in the Cox's Bazar Forest Division. *Chittagong University Studies, Part II: Science*, *12*(2), 87-95.

Harmon, D. (1992). Indicators of the world's cultural diversity. In *Fourth World Congress on National Parks and Protected Areas, Caracas, Venezuela, February* (pp. 1-33).

Hedberg I, Edwards S, Nemomissa S. Flora of Ethiopia and Eritrea Apiaceae to Dipsacaceae. (vol. 4:1). Department of Systematic Botany, Uppsala, Sweden: The National Herbarium, Addis Ababa, Ethiopia. 2003, pp. 352.

Hedberg I, Edwards S. Flora of Ethiopia and Eritrea. Pittosporaceae to Araliaceae. (vol. 3). Department of Systematic Botany, Uppsala, Sweden: The National Herbarium, Addis Ababa, Ethiopia. 1989, pp. 659.

Hedberg, O. (1957). *Afroalpine vascular plants: a taxonomic revision* (Doctoral dissertation, Acta Universitatis Upsaliensis).

Hedberg, O. (1964) Features of Afroalpine plant ecology. *Acta Phytogeographica Suecica* **49:** 1-144.

Hendickx, H., Jacob, M., Frankl, A., Guyassa, E., Nyssen, J., 2014. Quaternary glacial and periglacial processes in the Ethiopian Highlands in relation to the current afro-alpine vegetation. Zeitschrift für Geomorphol. 1e21. https://doi.org/10.1127/0372-8854/2014/0128.

Hickling, R., Roy, D.B., Hill, J.K., Fox, R., Thomas, C.D. (2006). The distributions of a wide range of taxonomic groups are expanding polewards. *Global change biology*, *12*(3), pp.450-455.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. – *Int. J. Climatol*. 25: 1965–1978.

Hill, J. L., & Curran, P. J. (2003). Area, shape and isolation of tropical forest fragments: effects on tree species diversity and implications for conservation. *Journal of biogeography*, *30*(9), 1391-1403.

Hillman JC. Ethiopia: Compendium of wildlife conservation information. Ethiopian Wildlife Conservation Organisation; 1993.

Hoffman, M., Koenig, K., Bunting, G., Costanza, J., & Williams, K. J. (2016). Biodiversity hotspots (version 2016.1). *Zenodo https://doi. org/10.5281/zenodo*, *3261807*. Accessed:19/9/2022.

Hossain, M. K., Azad, A. K., & Alam, M. K. (1999). Assesment of Natural Regeneration Status in a Mixed Tropical Forest at Kaptai of Chittagong Hill Tracts (South) Forest Division. *Chittagong University Journal of Science*, *23*(1), 73-80.

Hurni, H. (1988). Degradation and conservation of the resources in the Ethiopian highlands. Mt Res Dev 8:123–130. doi:10.2307/3673438.

Hurni, H., Stahli P. (1982). Simen Mountains, Ethiopia Vol II: Climate and the dynamics of altitudinal belts from the last cold period to the present day. Geographische Gesellschaft Bern und Geographica Bernensia 7, Bern, Switzerland.

Huston MA. Local processes and regional patterns: appropriate scales for understanding variation in the diversity of plants and animals. Oikos. 1999 Sep 1:393-401.

IPCC (2008). Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies. Intergovernmental Panel on Climate Change, Geneva, 132 pp.

IPCC Climate Change, (2013). The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Changed Summary for Policymakers. IPCC, Geneva,Switzerland, 2013.

IPCC, (2007). Climate change: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom.

Jackson RB, Banner JL, Jobbágy EG, Pockman WT, Wall DH. Ecosystem carbon loss with woody plant invasion of grasslands. Nature. 2002 Aug 8;418(6898):623-6.

Jacob, M., Frankl, A., Hurni, H., Lanckriet, S., Ridder, M., Guyassa, E., Beeckman, H., Nyssen J. (2017). Land cover dynamics in the Simien Mountains (Ethiopia), half a century after establishment of the National Park. Reg *Environ Change* 17:777–787. dio:10.1007/s10113-016-1070-8.

Janowiak, M. K., Iverson, L. R., Fosgitt, J., Handler, S. D., Dallman, M., Thomasma, S., Hutnik, B., Swanston, C. W. (2017). Assessing stand-level climate change risk using forest inventory data and species distribution models. *Journal of Forestry*, *115*(3), 222-229.

Jensen, M. N. (2003). Consensus on ecological impacts remains elusive. Science, 299(5603), 38-38.

Jezkova, T., Jaeger, J. R., Oláh-Hemmings, V., Jones, K. B., Lara-Resendiz, R. A., Mulcahy, D. G., & Riddle, B. R. (2016). Range and niche shifts in response to past climate change in the desert horned lizard Phrynosoma platyrhinos. Ecography, 39(5), 437-448.

Jin, X.M., Zhang, Y.-K., Schaepman, M.E., Clevers, J.G.P.W., Su, Z. (2008). Impact of elevation and aspect on the spatial distribution of vegetation in the Qilian Mountain area with remote sensing data. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, Part B7 37, pp. 1385-1390.

Jochum, G. M., Mudge, K. W., & Thomas, R. B. (2007). Elevated temperatures increase leaf senescence and root secondary metabolite concentrations in the understory herb Panax quinquefolius (Araliaceae). *American Journal of Botany*, *94*(5), 819-826.

Jørgensen, R. H., Meilby, H., & Kollmann, J. (2013). Shrub expansion in SW Greenland under modest regional warming: disentangling effects of human disturbance and grazing. *Arctic, Antarctic, and Alpine Research*, *45*(4), 515-525.

Kadavul, K., & Parthasarathy, N. (1999). Plant biodiversity and conservation of tropical semi-evergreen forest in the Shervarayan hills of Eastern Ghats, India. *Biodiversity & Conservation*, *8*(3), 419-437.

Karagulle, D., Frye, C., Sayre, R., Breyer, S., Aniello, P., Vaughan, R., Wright, D. (2017). Modeling global Hammond landform regions from 250-m elevation data. *Transactions in GIS*, *21*(5), pp.1040-1060.

Kassam, K.A. (2008). Diversity as if nature and culture matter: Bio-cultural diversity and Indigenous peoples.

Keating, K. A., Gogan, P. J., Vore, J. M., & Irby, L. R. (2007). A simple solar radiation index for wildlife habitat studies. The Journal of wildlife management, 71(4), 1344-1348.

Kellerman MJ, Van Rooyen MW. Seasonal variation in soil seed bank size and species composition of selected habitat types in Maputaland, South Africa. Bothalia. 2007 Aug 18;37(2):249-58.

Kent M. Vegetation description and data analysis: a practical approach. John Wiley & Sons; 2011 Nov 14.

Kent, M. and Coker, P. (1992). Vegetation Description and Analysis. A practical approach. John Wiley and Sons, New York. pp. 363.

Kgosikoma, O. E., & Mogotsi, K. (2013). Understanding the causes of bush encroachment in Africa: The key to effective management of savanna grasslands. *Tropical Grasslands-Forrajes Tropicales*, *1*(2), 215–219. https://doi.org/10.17138/tgft(1)215-219

KHALIK KA, El-Sheikh M, El-Aidarous A. Floristic diversity and vegetation analysis of wadi Al-Noman, Mecca, Saudi Arabia. Turkish Journal of Botany. 2013;37(5):894-907.

Khalik, K. A., El-Sheikh, M. & El-Aidarous, A. (2013). Floristic diversity and vegetation analysis of wadi Al-Noman, Mecca, Saudi Arabia. *Turkish Journal of Botany*, *37*(5), 894-907.

Kidane, L., Nemomissa, S., & Woldu, Z. (2016). The effects of disturbance on the population structure and regeneration potential of five dominant woody species–in Hugumburda-Gratkhassu National Forest Priority Area, North-eastern Ethiopia. *African journal of ecology*, *54*(1), 20-28.

Kidane, Y., Stahlman, R., Beierkuhnlein, C. (2019). Dead end for endemic plant species? A biodiversity hotspot under pressure. *Global Ecology and Conservation*, DOI: 10.1016/j.gecco.e00670.

Kindu M, Schneider T, Teketay D, Knoke T. Land use/land cover change analysis using object-based classification approach in Munessa-Shashemene landscape of the Ethiopian highlands. Remote sensing. 2013 May 15;5(5):2411-35.

Klein, J. A., Tucker, C. M., Steger, C. E., Nolin, A., Reid, R., Hopping, K. A., Yager, K. (2019). An Integrated community and ecosystem-based approach to disaster risk reduction in mountain systems. *Environmental Science & Policy*, 94, 143–152.

Knapp, A. K., Briggs, J. M., Collins, S. L., Archer, S. R., Bret-Harte, M. S., Ewers, B. E., Peters,D. P., Young, D. R., Shaver, G. R., Pendall, E., & Cleary, M. B. (2008). Shrub encroachmentin North American grasslands: Shifts in growth form dominance rapidly alters control ofecosystem carbon inputs. *Global Change Biology*, *14*(3), 615–623.https://doi.org/10.1111/j.1365-2486.2007.01512.x

Knox, E. B., & Palmer, J. D. (1995). Chloroplast DNA variation and the recent radiation of the giant senecios (Asteraceae) on the tall mountains of eastern Africa. *Proceedings of the National Academy of Sciences*, *92*(22), 10349-10353.

Körner, C. (2012). Alpine treelines: functional ecology of the global high elevation tree limits. *Springer Science & Business Media*.

Kremen, C., Cameron, A., Moilanen, A., Phillips, S.J., Thomas, C.D., Beentje, H., Dransfield, J., Fisher, B.L., Glaw, F., Good, T.C. and Harper, G.J. (2008). Aligning conservation priorities across taxa in Madagascar with high-resolution planning tools. *Science*, *320*(5873), pp.222-226.

Kuma, M., & Shibru, S. (2015). Floristic Composition, Vegetation Structure, and Regeneration Status of Woody Plant Species of Oda Forest of Humbo Carbon Project, Wolaita, Ethiopia. *Journal of Botany*, *2015*.

Kumar, P., Verdin, K. L., & Greenlee, S. K. (2000). Basin level statistical properties of topographic index for North America. Advances in water resources, 23(6), 571-578.

Kumar, S., Stohlgren, T.J. (2009). Maxent modeling for predicting suitable habitat for threatened and endangered tree Canacomyrica monticola in New Caledonia. *Journal of Ecology and the Natural Environment*, *1*(4), pp.094-098.

Kuussaari, M., Bommarco, R., Heikkinen, R.K., Helm, A., Krauss, J., Lindborg, R., Öckinger, E., Pärtel, M., Pino, J., Rodà, F., Stefanescu, C. (2009). Extinction debt: a challenge for biodiversity conservation. *Trends in ecology & evolution*, *24*(10), pp.564-571.

Lapeyre, R. (2010). Community-based tourism as a sustainable solution to maximise impacts locally? The Tsiseb Conservancy case, Namibia. *Development Southern Africa*, *27*(5), pp.757-772.

Larsen, T. H., Brehm, G., Navarrete, H., Franco, P., Gomez, H., Mena, J. L., ... & Canhos, V. (2011). Range shifts and extinctions driven by climate change in the tropical Andes: synthesis and directions. Climate change and biodiversity in the tropical Andes, 47-67.

Lemenih M, Teketay D. Changes in soil seed bank composition and density following deforestation and subsequent cultivation of a tropical dry Afromontane forest in Ethiopia. Tropical Ecology. 2006;47(1):1-2.

Lenoir, J., G_egout, J.C., Marquet, P.A., De, R.P., Brisse, H. (2008). A significant upward shift in plant species optimum elevation during the 20th century. *Science* 320, 1768e1771.

Lett MS, Knapp AK, Briggs JM, Blair JM. Influence of shrub encroachment on aboveground net primary productivity and carbon and nitrogen pools in a mesic grassland. Canadian Journal of Botany. 2004 Sep 1;82(9):1363-70.

Lett MS, Knapp AK. Woody plant encroachment and removal in mesic grassland: production and composition responses of herbaceous vegetation. The American Midland Naturalist. 2005 Apr;153(2):217-31.

Levassor C, Ortega M, Peco B. Seed bank dynamics of Mediterranean pastures subjected to mechanical disturbance. Journal of Vegetation Science. 1990 Jun;1(3):339-44.

Level, F. W. P. A. (2010). Tree growth relationships and silvicultural tools to assist stand management in private native spotted gum dominant forests in Queensland and northern New South Wales.

Li Q, Fang H, Cai Q. Persistent soil seed banks along altitudinal gradients in the Qilian Mountains in China and their significance for conservation management. African Journal of Agricultural Research. 2011 May 18;6(10):2329-40.

Loeffler, J., Anschlag, K., Baker, B., Finch, O.D., Diekkrueger, B., Wundram, D., Schroeder, B., Pape, R. and Lundberg, A. (2011). Mountain ecosystem response to global change. *Erdkunde*, pp.189-213.

Loh J, Harmon D. (2005). A global index of biocultural diversity. *Ecol. Indic*. 5(3):231–41.

Looney PB, Gibson DJ. The relationship between the soil seed bank and above-ground vegetation of a coastal barrier island. Journal of Vegetation Science. 1995 Dec;6(6):825-36.

López-Toledo L, Martínez-Ramos M. The soil seed bank in abandoned tropical pastures: source of regeneration or invasion? Revista mexicana de biodiversidad. 2011 Jun;82(2):663-78.

Loritz, R., Kleidon, A., Jackisch, C., Westhoff, M., Ehret, U., Gupta, H., & Zehe, E. (2019). A topographic index explaining hydrological similarity by accounting for the joint controls of runoff formation. Hydrology and Earth System Sciences, 23(9), 3807-3821.

Luzuriaga AL, Escudero A, Olano JM, Loidi J. Regenerative role of seed banks following an intense soil disturbance. Acta Oecologica. 2005 Jan 1;27(1):57-66.

Madronich, S., Mckenzie, R. L., Björn, L. O., & CALDWELL, M. M. (1998). Changes in biologically active ultraviolet radiation reaching the Earth’s surface. Photochemical & Photobiological Sciences Official Journal of the European Photochemistry Association & the European Society for Photobiology 46, 5–19.

Maestre FT, Bowker MA, Puche MD, Belén Hinojosa M, Martínez I, García-Palacios P, et al. Shrub encroachment can reverse desertification in semi-arid Mediterranean grasslands. Ecology letters. 2009 Sep;12(9):930-41.

Maffi, L. (2005). Linguistic, cultural, and biological diversity. *Annu. Rev. Anthropol.*, *34*, pp.599-617.

Mairal, M., Namaganda, M., Gizaw, A., Chala, D., Brochmann, C. and Catalán, P. (2021). Multiple mountain-hopping colonization of sky-islands on the two sides of Tropical Africa during the Pleistocene: The afroalpine Festuca grasses. *Journal of Biogeography*.

Manish, K., Telwala, Y., Nautiyal, D. C., & Pandit, M. K. (2016). Modelling the impacts of future climate change on plant communities in the Himalaya: a case study from Eastern Himalaya,India. *Modeling Earth Systems and Environment*, *2*(2). https://doi.org/10.1007/s40808-016-0163-1

Måren, I. E., Karki, S., Prajapati, C., Yadav, R. K., & Shrestha, B. B. (2015). Facing north or south: Does slope aspect impact forest stand characteristics and soil properties in a semiarid trans-Himalayan valley?. *Journal of arid environments*, *121*, 112-123.

Marks, S. A. (2001). Back to the future: some unintended consequences of Zambia's community-based wildlife program (ADMADE). *Africa Today* 48(1):121-141. http://dx.doi. org/10.2979/AFT.2001.48.1.120.

Mashigo, M., Combrinck, S., Regnier, T., Du Plooy, W., Augustyn, W., & Mokgalaka, N. (2015). Chemical variations, trichome structure and antifungal activities of essential oils of Helichrysum splendidum from South Africa. *South African Journal of Botany*, *96*, 78-84.

McBrearty, S., and Brooks, A.S. (2000). The revolution that wasn't: a new interpretation of the origin of modern human behavior. *Journal of human evolution*, *39*(5), pp.453-563.

Melese, G. T., Tsegay, B. A., & Kassa, G. M. (2017). Effects of environmental variables on the patterns of plant community distribution in the afro-alpine vegetation of simien mountains national park, ethiopia. *Journal of Biotechnology International*, *10*(1), 8-21.

Mesfin Tadesse (2004). Asteraceae (Compositae). In: Hedberg I, Friis I, Edwards S (eds) Flora of Ethiopia and Eritrea. 4(1). *The National Herbarium, Addis Ababa University, Addis Ababa & Uppsala.*

Mishra, B. P., Tripathi, O. P., Tripathi, R. S., & Pandey, H. N. (2004). Effects of anthropogenic disturbance on plant diversity and community structure of a sacred grove in Meghalaya, northeast India. *Biodiversity & Conservation*, *13*(2), 421-436.

Mishra, B. P., Tripathi, O. P., & Laloo, R. C. (2005). Community characteristics of a climax subtropical humid forest of Meghalaya and population structure of ten important tree species. *Tropical Ecology*, *46*(2), 241-252.

Moges, E. (2015). Population Structure, Behavioural Ecology and Habitat Vulnerability of Gelada (Theropithecus gelada) in Guassa Community Protected Area, Ethiopia.

Molla MB. Land use/land cover dynamics in the central rift valley region of Ethiopia: Case of Arsi Negele District. African Journal of Agricultural Research. 2015 Jan 29;10(5):434-49.

Molla, E. L. (2014). *Plant Diversity and Ethnobotanical Study of Medicinal Plants in Ankober District, North Shewa Zone of Amhara Region, Ethiopia* (Doctoral dissertation, Addis Ababa University).

Montané F, Casals P, Taull M, Lambert B, Dale MR. Spatial patterns of shrub cover after different fire disturbances in the Pyrenees. Annals of Forest Science. 2009 Sep 1;66(6):1-8.

Montane F, Romanya J, Rovira P, Casals P. Aboveground litter quality changes may drive soil organic carbon increase after shrub encroachment into mountain grasslands. Plant and Soil. 2010 Dec;337:151-65.

Mosquera, G.M., Lazo, P.X., Célleri, R., Wilcox, B.P., Crespo, P. (2015). Runoff from tropical alpine grasslands increases with areal extent of wetlands. *Catena*, *125*, pp.120-128.

Mueller-Dombois, D. and Ellenberg, H. (1974). Aims and methods of vegetation ecology. John Wiley, New York.

Mukherjee, S., Mukherjee, S., Garg, R. D., Bhardwaj, A., & Raju, P. L. N. (2013). Evaluation of topographic index in relation to terrain roughness and DEM grid spacing. Journal of Earth System Science, 122, 869-886.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A., Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, *403*(6772), pp.853-858.

National ecosystem assessment of Ethiopia (2022). Syntheses of the Status of Biodiversity and Ecosystem Services, and Scenarios of Change, Ethiopian Biodiversity Institute, Addis Ababa, Ethiopia.

Nemomissa, S., Puff, C. (2001). Flora and vegetation of the Simen Mountains National Park, Ethiopia. *Biologiske Skrifter (Denmark)*.

Nevo, E. (2001). Evolution of genome–phenome diversity under environmental stress. *Proceedings of the National Academy of Sciences*, *98*(11), 6233-6240.

Nievergelt B., Good, T., Guttinger, R. (1998). A survey of the flora and fauna of the Simen Mountains National Park. Walia (special issue), Zurich.

Niknam P, Erfanzadeh R, Ghelichnia H, Cerdà A. Spatial variation of soil seed bank under cushion plants in a subalpine degraded grassland. Land Degradation & Development. 2018 Jan;29(1):4-14.

Oba G, Post E, Syvertsen PO, Stenseth NC. Bush cover and range condition assessments in relation to landscape and grazing in southern Ethiopia. Landscape ecology. 2000 Aug;15:535-46.

Odland, A., & Birks, H. J. B. (1999). The altitudinal gradient of vascular plant richness in Aurland, western Norway. *Ecography*, *22*(5), 548-566.

Økland, R. H. (1990). Vegetation ecology: theory, methods and applications with reference to Fennoscandia. *Sommerfeltia*, *1*(s1), 1-238.

Orbán, I., Szitár, K., Kalapos, T., & Körel-Dulay, G. (2021). The role of disturbance in invasive plant establishment in a changing climate: insights from a drought experiment. *Biological Invasions*, *23*, 1877-1890.

Ossendorf, G., Groos, A.R., Bromm, T., Tekelemariam, M.G., Glaser, B., Lesur, J., Schmidt, J., Akçar, N., Bekele, T., Beldados, A., Demissew, S. (2019). Middle Stone Age foragers resided in high elevations of the glaciated Bale Mountains, Ethiopia. *Science*, *365*(6453), pp.583-587.

Ostrom, E., T. Dietz, N. Dolšak, P. C. Stern, S. Stonich, and E. U. Weber. (2002). The drama of the commons. *National Academy Press*.

Otýpková, Z., Chytrý, M., Tichý, L., Pechanec, V., Jongepier, J. W., & Hájek, O. (2011). Floristic diversity patterns in the White Carpathians biosphere reserve, Czech Republic. *Biologia*, *66*(2), 266-274.

Pala, N. A., Negi, A. K., Gokhale, Y., Bhat, J. A., & Todaria, N. P. (2012). Diversity and regeneration status of Sarkot Van Panchyat in Garhwal Himalaya, India. *Journal of Forestry Research*, *23*(3), 399-404.

Palomo, I., Montes, C., Martin-Lopez, B., González, J.A., Garcia-Llorente, M., Alcorlo, P., Mora, M.R.G. (2014). Incorporating the social–ecological approach in protected areas in the Anthropocene. *BioScience*, *64*(3), pp.181-191.

Parmesan, C., Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421, 37–42. https://doi.org/10.1038/nature01286.

Paudel, S., & Vetaas, O. R. (2014). Effects of topography and land use on woody plant species composition and beta diversity in an arid Trans-Himalayan landscape, Nepal. *Journal of Mountain Science*, *11*(5), 1112-1122.

Pauli, H., Gottfried, M., Reiter, K., Klettner, C., Grabherr, G. (2007). Signals of range expansions and contractions of vascular plants in the high Alps: observations (1994–2004) at the GLORIA *master site Schrankogel, Tyrol, Austria. *Glob. Chang. Biol*. 13, 147–156. https://doi.org/10.1111/j.1365-2486.2006.01282.x.

Pecchi, M., Marchi, M., Burton, V., Giannetti, F., Moriondo, M., Bernetti, I., Bindi, M., Chirici, G. (2019). Species distribution modelling to support forest management. A literature review. *Ecological Modelling*, *411*, 108817.

Pepin, N., Bradley, R. S., Diaz, H. F., Baraer, M., Caceres, E. B., Forsythe, N., Fowler, H., Greenwood, G., Hashmi, M. Z., Liu, X. D., Miller, J. R., Ning, L., Ohmura, A., Palazzi, E., Rangwala, I., Schöner, W., Severskiy, I., Shahgedanova, M., Wang, M. B., Yang, D. Q. (2015). Elevation-dependent warming in mountain regions of the world. *Nature Climate Change, 5*(5), 424-430. https://doi.org/10.1038/nclimate2563.

Perrings, C., & Halkos, G. (2015). Agriculture and the threat to biodiversity in sub-Saharan Africa. Environmental Research Letters, 10(9), 095015.

Phillips, S. (1995). Poaceae (Gramineae). In: Hedberg I, Edwards S (eds) Flora of Ethiopia and Eritrea, Vol. 7. The National Herbarium, Addis Ababa University, Addis Ababa & Uppsala, Sweden, pp 3–6.

Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. Ecological modelling, 190(3-4), 231-259.

Phillips, S. J., Dudík, M., & Schapire, R. E. (2004). A maximum entropy approach to species distribution modeling. In Proceedings of the twenty-first international conference on Machine learning (p. 83).

Phillips, S.J., Anderson, R.P., Dudík, M., Schapire, RE., Blair, M.E. (2017). Opening the black box: an open-source release of Maxent. *Ecography*, 40(7): 887–893. DOI: https://doi.org/10.1111/ecog.03049.

Phillips, S.J., Dudik, M. (2008) Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography*, 31, 161–175.

Phillipson, A. (2010). *Separating Commodity Fact from Commodity Fiction* (Doctoral dissertation, Imperial College London).

Pôças, I., Cunha, M., Marcal, A. R., & Pereira, L. S. (2011). An evaluation of changes in a mountainous rural landscape of Northeast Portugal using remotely sensed data. *Landscape and Urban Planning*, *101*(3), 253-261.

Pooley, E (2003). Mountain Flowers: A Field Guide to the Flora of the Drakensberg and Lesotho, 1st ed. *The Flora Publications Trust*. Durban. 222–225.

Porensky, L. M., McGee, R., & Pellatz, D. W. (2020). Long-term grazing removal increased invasion and reduced native plant abundance and diversity in a sagebrush grassland. *Global Ecology and Conservation*, *24*, e01267.

Price JN, Wright BR, Gross CL, Whalley WR. Comparison of seedling emergence and seed extraction techniques for estimating the composition of soil seed banks. Methods in Ecology and Evolution. 2010 Jun;1(2):151-7.

Puff, C., Nemomissa, S. (2005). Plants of the Simen: A flora of the Simen Mountains and surroundings, northern Ethiopia. Meise: National Botanic Garden.

Purvis, A., Gittleman, J. L., Cowlishaw, G., & Mace, G. M. (2000). Predicting extinction risk in declining species. Proceedings of the royal society of London. Series B: Biological Sciences, 267(1456), 1947-1952.

Rahbek C. The elevational gradient of species richness: a uniform pattern?. Ecography. 1995 Jun 1:200-5.

Rahbek, C., Borregaard, M.K., Colwell, R.K., Dalsgaard, B.O., Holt, B.G., Morueta-Holme, N., Nogues-Bravo, D., Whittaker, R.J., Fjeldså, J. (2019). Humboldt's enigma: What causes global patterns of mountain biodiversity? *Science*, *365*(6458), pp.1108-1113.

Rahman, M., Khan, M., Arfin, A. S., Roy, B., & Fardusi, M. (2011). Assessment of natural regeneration status and diversity of tree species in the biodiversity conservation areas of Northeastern Bangladesh. *Journal of Forestry Research*, *22*(4), 551-559.

Remya K, Ramachandran A, Jayakumar S (2015). Predicting the current and future suitable habitat distribution of Myristica dactyloides Gaertn. using MaxEnt model in the Eastern Ghats, India. Ecol Eng 82:184–188. https://doi.org/10.1016/j.ecoleng.2015.04.053.

Reubens B, Heyn M, Gebrehiwot K, Hermy M, Muys B. Persistent soil seed banks for natural rehabilitation of dry tropical forests in northern Ethiopia. Tropicultura. 2007;25(4):204.

Rey, P.J., Julio, M., Alcantara, M., 2000. Recruitment dynamics of a fleshy-fruited plant (*Olea europaea*): Connecting patterns of seed dispersal to seedling establishment. J. Ecol. 88 (4), 622–633. https://doi.org/10.1046/j.1365-2745.2000.00472.x.

Robi, M. K., & Edris, E. M. (2017). Distribution, abundance, and population status of four indigenous threatened tree species in the Arba Minch Natural Forest, Southern Ethiopia. *Int. J. Nat. Resourc. Ecol. Manag*, *2*, 1-8.

Rosell, S. (2011). Regional perspective on rainfall change and variability in the central highlands of Ethiopia, 1978–2007. *Applied Geography*, *31*(1), pp.329-338.

Rosenzweig ML. Paradox of enrichment: destabilization of exploitation ecosystems in ecological time. Science. 1971 Jan 29;171(3969):385-7.

Rosqvist, G. (1990). Quaternary glaciations in Africa. *Quaternary Science Reviews*, *9*(2-3), 281-297.

Salam, N., A. Reshi, Z., & Shah, M. A. (2022). Habitat suitability modelling for Lagotis cashmeriana (ROYLE) RUPR., a threatened species endemic to Kashmir Himalayan alpines. Geology, Ecology, and Landscapes, 6(4), 241-251.

Sang W. Plant diversity patterns and their relationships with soil and climatic factors along an altitudinal gradient in the middle Tianshan Mountain area, Xinjiang, China. Ecological Research. 2009 Mar;24:303-14.

Saupe, E.E., Barve, V., Myers, C.E., Soberón, J., Barve, N., Hensz, C.M., Peterson, A.T., Owens, H.L. and Lira-Noriega, A. (2012). Variation in niche and distribution model performance: the need for a priori assessment of key causal factors. *Ecological Modelling*, *237*, pp.11-22.

Saxena, A. K., Singh, S. P., & Singh, J. S. (1984). Population structure of forests of Kumaun Himalaya: implications for management. *Journal of Environmental Management*, *19*(4), 307-324.

Sayre, R., Frye, C., Karagulle, D., Krauer, J., Breyer, S., Aniello, P., Wright, D.J., Payne, D., Adler, C., Warner, H., VanSistine, D.P. (2018). A new high-resolution map of world mountains and an online tool for visualizing and comparing characterizations of global mountain distributions. *Mountain Research and Development*, *38*(3), pp.240-249.

Scheper, J., Holzschuh, A., Kuussaari, M., Potts, S. G., Rundlöf, M., Smith, H. G., & Kleijn, D. (2013). Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss–a meta-analysis. *Ecology letters*, *16*(7), 912-920.

Schimmel, J., & Granstrom, A. (1996). Fire severity and vegetation response in the boreal Swedish forest. *Ecology*, *77*(5), 1436-1450.

Schirmel, J., Mantilla-Contreras, J., Blindow, I., & Fartmann, T. (2011). Impacts of succession and grass encroachment on heathland Orthoptera. *Journal of Insect Conservation*, *15*, 633-642.

Schmitt, C. B., Senbeta, F., Woldemariam, T., Rudner, M., & Denich, M. (2013). Importance of regional climates for plant species distribution patterns in moist Afromontane forest. *Journal of Vegetation Science*, *24*(3), 553-568.

Seixas, C. S., F. Berkes. (2010). Community-based enterprises: the significance of partnerships and institutional linkages. *International Journal of the Commons* 4(1):183-212. http://dx.doi.org/10.18352/ijc.133.

Senbeta F, Teketay D. Regeneration of indigenous woody species under the canopies of tree plantations in Central Ethiopia. Tropical Ecology. 2001;42(2):175-85.

Senbeta, F., Schmitt, C., Woldemariam, T., Boehmer, H. J., & Denich, M. (2014). Plant diversity, vegetation structure and relationship between plant communities and environmental variables in the Afromontane Forests of Ethiopia. *SINET: Ethiopian Journal of Science*, *37*(2), 113-130.

Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., ... & Reinhardt, J. (2016). Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. Regional Environmental Change, 17, 1585-1600.

Sheppard, D. J., Moehrenschlager, A., McPherson, J. M., Mason, J. J. (2010). Ten years of adaptive community-governed conservation: evaluating biodiversity protection and poverty alleviation in a West African hippopotamus reserve. *Environmental Conservation* 37:270-282. http://dx.doi.org/10.1017/ S037689291000041X.

Shibru, S., & Balcha, G. (2004). Composition, Structure and regeneration status of woody species in Dindin Natural Forest, Southeast Ethiopia: An implication for conservation. *Ethiopian Journal of Biological Sciences*, *3*(1), 15-35.

Shumi, G., Rodrigues, P., Schultner, J., Dorresteijn, I., Hanspach, J., Hylander, K., ... & Fischer, J. (2019). Conservation value of moist evergreen Afromontane forest sites with different management and history in southwestern Ethiopia. Biological conservation, 232, 117-126.

Sillero-Zubiri C, Macdonald D. Ethiopian wolf: status survey and conservation action plan.

Silva, J.A., Mosimane, A. (2014). “How could I live here and not be a member?”: Economic versus social drivers of participation in Namibian conservation programs. *Human Ecology*, *42*(2), pp.183-197.

Simegn, T. Y., & Soromessa, T. (2015). Carbon stock variations along altitudinal and slope gradient in the forest belt of Simen Mountains National Park, Ethiopia. *American Journal of Environmental Protection*, *4*(4), 199-201.

Simeneh, G. (2010). Habitat use and diet of golden jackal (Canis aureus) and human-carnivore conflict in Guassa community conservation area, Menz. *Addis Ababa, Ethiopia: Addis Ababa University*.

Singh, S., Malik, Z. A., & Sharma, C. M. (2016). Tree species richness, diversity, and regeneration status in different oak (Quercus spp.) dominated forests of Garhwal Himalaya, India. *Journal of Asia-Pacific Biodiversity*, *9*(3), 293-300.

Skarpe C. Shrub layer dynamics under different herbivore densities in an arid savanna, Botswana. Journal of Applied Ecology. 1990 Dec 1:873-85.

Sørensen, T. (1948). A method of establishing groups of equal amplitude in plant sociology based on similarity of species and its application to analyses of the vegetation on Danish commons. *Kongelige Danske Videnskabernes Selskab* **5 (4):** 1–34.

Steger, C., Boone, R. B., Dullo, B. W., Evangelista, P., Alemu, S., Gebrehiwot, K., & Klein, J. A. (2022). Collaborative agent-based modeling for managing shrub encroachment in an Afroalpine grassland. *Journal of Environmental Management*, *316*, 115040.

Steger, C., Gebrehiwot, K., Chengere, S. A., Marinkovich, J., Dullo, B. W., Zewde, S. W., & Klein, J. A. (2021). Mental models of a social-ecological system facilitate social learning among a diverse management team. *Environmental Science & Policy*, *122*, 127-138.

Steger, C., Nigussie, G., Alonzo, M., Warkineh, B., Van Den Hoek, J., Fekadu, M., Evangelista, P.H., Klein, J.A. (2020). Knowledge coproduction improves understanding of environmental change in the Ethiopian highlands. *Ecol. Soc*. 25 (2), 2.

Stepp, J.R., Castaneda, H., Cervone, S. (2005). Mountains and biocultural diversity. *Mountain research and development*, *25*(3), pp.223-227.

Stévart, T., Dauby, G., Lowry, P.P., Blach-Overgaard, A., Droissart, V., Harris, D.J., Mackinder, B.A., Schatz, G.E., Sonké, B., Sosef, M.S., Svenning, J.C. (2019). A third of the tropical African flora is potentially threatened with extinction. *Science advances*, *5*(11), p.eaax9444.

Støa, B., Halvorsen, R., Stokland, J. N., & Gusarov, V. I. (2019). How much is enough? Influence of number of presence observations on the performance of species distribution models. Sommerfeltia, 39(1), 1-28.

Szita, K., & Gyo, K. (2021). The role of disturbance in invasive plant establishment in a changing climate: *insights from a drought experiment*. *8,* 1877–1890. https://doi.org/10.1007/s10530-021-02478-8

Tadese, S., Soromessa, T., Bekele, T., & Meles, B. (2021). Biosphere Reserves in the Southwest of Ethiopia. Advances in Agriculture. https://doi.org/10.1155/2021/1585149.

Tadesse, G., Bekele, T., & Demissew, S. (2008). Dryland woody vegetation along an altitudinal gradient on the eastern escarpment of Welo, Ethiopia. *SINET: Ethiopian Journal of Science*, *31*(1), 43-54.

Tadesse, M (1994). Flora of Ethiopia and Eritrea Volume 4, part 2: Asteraceae (Compositae). *The National Herbarium, Addis Ababa University, Addis Ababa & Uppsala.*

Tadesse, M (2004). Asteraceae (Compositae). In: Hedberg I, Friis I, Edwards S (eds) Flora of Ethiopia and Eritrea. **4**(1). *The National Herbarium, Addis Ababa University, Addis Ababa & Uppsala.*

Tasser, E., & Tappeiner, U. (2002). Impact of land use changes on mountain vegetation. *Applied vegetation science*, *5*(2), 173-184.

Taylor, P.J. (2005). *Unruly complexity*. University of Chicago Press.

Tefera MM. Land-use/land-cover dynamics in Nonno district, central Ethiopia. Journal of Sustainable development in Africa. 2011;13(1):123-41.

Tegene B. Land-cover/land-use changes in the derekolli catchment of the South Welo Zone of Amhara Region, Ethiopia. Eastern Africa Social Science Research Review. 2002;18(1):1-20.

Teketay D, Granström A. Germination ecology of forest species from the highlands of Ethiopia. Journal of tropical ecology. 1997 Nov;13(6):805-31.

Teketay D, Granström A. Soil seed banks in dry Afromontane forests of Ethiopia. Journal of vegetation Science. 1995 Dec;6(6):777-86.

Tekle K, Bekele T. The role of soil seed banks in the rehabilitation of degraded hillslopes in Southern Wello, Ethiopia 1. Biotropica. 2000 Mar;32(1):23-32.

Teramura, A. H. (1983). Effects of ultraviolet-B radiation on the growth and yield of crop plants. Physiologia Plantarum, 58(3), 415-427.

Teressa, D. K. (2017). Ethiopia: Changes from “People out Approach” protected area management to participatory protected area management? Insight from Ethiopian protected areas. *IOSR Journal of Environmental Science, Toxicology and Food Technology, 11*, 49-55.

Tesfaye, G., Teketay, D., Fetene, M., & Beck, E. (2010). Regeneration of seven indigenous tree species in a dry Afromontane forest, southern Ethiopia. *Flora-Morphology, Distribution, Functional Ecology of Plants*, *205*(2), 135-143.

Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F., De Siqueira, M.F., Grainger, A., Hannah, L., Hughes, L. (2004). Extinction risk from climate change. *Nature*, *427*(6970), pp.145-148.

Thompson K. Seeds and seed banks. New phytologist. 1987 May;106:23-34.

Thuiller, W. (2004). Patterns and uncertainties of species' range shifts under climate change. *Global change biology*, *10*(12), pp.2020-2027.

Thuiller, W., Broennimann, O., Hughes, G., Alkemade, J.R.M., Midgley, G.F., Corsi, F. (2006). Vulnerability of African mammals to anthropogenic climate change under conservative land transformation assumptions. *Global Change Biology*, *12*(3), pp.424-440.

Thuiller, W., Lavorel, S., Araújo, M.B., Sykes, M.T., Prentice, I.C. (2005). Climate change threats to plant diversity in Europe. *Proceedings of the National Academy of Sciences*, *102*(23), pp.8245-8250.

Tiawoun, M. A. P., Malan, P. W., & Comole, A. A. (2022). Composition and structural patterns ofencroaching woody plant species along riparian zones of the Molopo River, North-West Province, South Africa. *South African Journal of Botany*, *147*, 652–658.https://doi.org/https://doi.org/10.1016/j.sajb.2022.02.039

Tilman, D., May, R.M., Lehman, C.L., Nowak, M.A. (1994). Habitat destruction and the extinction debt. *Nature*, 371(6492), pp.65-66.

Titshall, L. W., O'Connor, T. G., & Morris, C. D. (2000). Effect of long-term exclusion of fire and herbivory on the soils and vegetation of sour grassland. *African Journal of Range and Forage Science*, *17*(1-3), 70-80.

Tittensor, D.P., Baco, A.R., Brewin, P.E., Clark, M.R., Consalvey, M., Hall-Spencer, J., Rowden, A.A., Schlacher, T., Stocks, K.I., Rogers, A.D. (2009) Predicting global habitat suitability for stony corals on seamounts. *Journal of Biogeography*, 36, 1111–1128.

Trew, B. T., & Maclean, I. M. (2021). Vulnerability of global biodiversity hotspots to climate change. Global Ecology and Biogeography, 30(4), 768-783.

Tsujino, R., & Yumoto, T. (2013). Vascular plant species richness along environmental gradients in a cool temperate to sub-alpine mountainous zone in central Japan. *Journal of plant research*, *126*(2), 203-214. https://doi.org/10.1007/s10265-012-0520-8.

Tyagi, J. V., Qazi, N., Rai, S. P., & Singh, M. P. (2013). Analysis of soil moisture variation by forest cover structure in lower western Himalayas, India. *Journal of forestry research*, *24*(2), 317-324.

UNDP. 2019. Community and regional leadership dialogue on protecting Choke Mountain. Availableonline:https://www.et.undp.org/content/ethiopia/en/home/presscenter/articles/2019/community-and-regional-leadership-dialogue-on-protecting-choke-m0.html (accessed on 21 December 2021).

UNEP-WCMC and IUCN (2021). Protected Planet: The World Database on Protected Areas (WDPA) [Online], October 2021, Cambridge, UK: UNEP-WCMC and IUCN. Available at: www.protectedplanet.net.

Van Auken OW. Causes and consequences of woody plant encroachment into western North American grasslands. Journal of environmental management. 2009 Jul 1;90(10):2931-42.

Van Auken OW. Shrub invasions of North American semiarid grasslands. Annual review of ecology and systematics. 2000 Nov;31(1):197-215.

VAN DER VARK AG. Seed banks and the management and restoration of natural vegetation. Ecology of soil seed banks. 1989:329-61. In: M.A. Leck, V.T. Parker and R.L. Simpson (eds.). Ecology of Soil Seed Banks. Academic Press, San Diego.

Van Proosdij, A. S., Sosef, M. S., Wieringa, J. J., & Raes, N. (2016). Minimum required number of specimen records to develop accurate species distribution models. Ecography, 39(6), 542-552.

Venter, Z. S., Cramer, M. D., & Hawkins, H. J. (2018). Drivers of woody plant encroachment over Africa. *Nature Communications*, *9*(1), 1–7. https://doi.org/10.1038/s41467-018-04616-8

Viviroli, D., Dürr, H.H., Messerli, B., Meybeck, M., Weingartner, R. (2007). Mountains of the world, water towers for humanity: Typology, mapping, and global significance. *Water resources research*, *43*(7).

Vogelsang, R., Bubenzer, O., Kehl, M., Meyer, S., Richter, J., Zinaye, B. (2018). When hominins conquered highlands—an acheulean site at 3000 m asl on mount dendi/Ethiopia. *Journal of Paleolithic Archaeology*, *1*(4), pp.302-313.

Wakie, T.T., Evangelista, P.H., Jarnevich, C.S., Laituri, M. (2014). Mapping current and potential distribution of non-native Prosopis juliflora in the Afar region of Ethiopia. *PloS one*, *9*(11), p.e112854.

Wang J, Huang L, Ren H, Sun Z, Guo Q. Regenerative potential and functional composition of soil seed banks in remnant evergreen broad-leaved forests under urbanization in South China. Community Ecology. 2015 Jun;16(1):86-94.

Wang SM, Zhang X, Li Y, Zhang L, Xiong YC, Wang G. Spatial distribution patterns of the soil seed bank of Stipagrostis pennata (Trin.) de Winter in the Gurbantonggut Desert of north-west China. Journal of Arid Environments. 2005 Oct 1;63(1):203-22.

Wang, R.L., Li, Q., He, S.S., Liu, Y., Wang, M.T., Jiang, G. (2018). Modeling and mapping the current and future distribution of *Pseudomonas syringae pv. actinidiae* under climate change in China. PloS One 13 (2), e0192153.

Warren, D. L., Glor, R. E., & Turelli, M. (2008). Environmental niche equivalency versus conservatism: quantitative approaches to niche evolution. *Evolution*, *62*(11), 2868-2883.

Wassie A, Teketay D. Soil seed banks in church forests of northern Ethiopia: Implications for the conservation of woody plants. Flora-Morphology, Distribution, Functional Ecology of Plants. 2006 Jan 2;201(1):32-43.

WCMC (1994). Biodiversity Data Sourcebook. World Conservation Monitoring Centre.

Wehn, S., Pedersen, B., & Hanssen, S. K. (2011). A comparison of influences of cattle, goat, sheep and reindeer on vegetation changes in mountain cultural landscapes in Norway. *Landscape and urban planning*, *102*(3), 177-187.

Wesche, K. (2003). The importance of occasional droughts for afroalpine landscape ecology. *Journal of Tropical Ecology*, *19*(2), pp.197-208.

West, P., Igoe, J., Brockington, D. (2006). Parks and peoples: the social impact of protected areas. *Annu. Rev. Anthropol.*, *35*, pp.251-277.

Weyant, J., Azar, C., Kainuma, M., Kejun, J., Nakicenovic, N., Shukla, P. R., ... & Yohe, G. (2009). Report of 2.6 versus 2.9 Watts/m2 RCPP evaluation panel. Integrated Assessment Modeling Consortium.

Whittaker RH. Evolution and measurement of species diversity. Taxon. 1972 May;21(2-3):213-51.

Whittaker, R. J., Willis, K. J., & Field, R. (2003). Climatic-energetic explanations of diversity. In *Macroecology: Concepts and Consequences: 43rd Symposium of the British Ecological Society* (Vol. 43, p. 107). Cambridge University Press.

Williams VL, Witkowski ET, Balkwill K. The use of incidence-based species richness estimators, species accumulation curves and similarity measures to appraise ethnobotanical inventories from South Africa. Biodiversity and Conservation. 2007 Aug;16:2495-513.

Williams, J.N., Seo, C.W., Thorne, J., Nelson, J.K., Erwin, S., O'Brien, J.M., Schwartz, M.W. (2009) Using species distribution models to predict new occurrences for rare plants. Diversity and Distributions, 15, 565–576.

Wodaj, H., Kelbessa, E., & Woldu, Z. (2016). Floristic composition and herbaceous aboveground dry weight biomass of Afroalpine vegetation in Guassa Community Conservation Area, North Shewa, Ethiopia. *Int Res J Biol Sci*, *5*(1), 26-36.

Woldemichael, L. K., Bekele, T., & Nemomissa, S. (2010). Vegetation composition in Hugumbirda-Gratkhassu national forest priority area, South Tigray. *Momona Ethiopian Journal of Science*, *2*(2), 27-48.

Woldu, Z., Edward, S., Demissie, A., Bekele, T., & Haase, G. (1999). Forests in the vegetation types of Ethiopia and their status in the geographical context. In: *forest genetic resources- conservation: principles strategies and action* (eds. Edwards, S., Demissie, A., Bekelle, Y. & Haase, G.). Addis Ababa, Ethiopia.

World Conservation Monitoring Centre (1994). Biodiversity Data Sourcebook. *World Conservation Press*, Cambridge, UK.

World Conservation Monitoring Centre Biodiversity Data Sourcebook. World Conservation Press, Cambridge, UK. 1994.

Worthington, T.A., Zhang, T., Logue, D.R., Mittelstet, A.R., Brewer, S.K., (2016). Landscape and flow metrics affecting the distribution of a federally-threatened fish: improving management, model fit, and model transferability. Ecol. Model. 1-18.

Wube, S., Lemessa, D., & Dullo, B. W. (2021). Factors driving the expansion of Helichrysum splendidum in Menz-Guassa community conservation area of the Afroalpine ecosystem of Ethiopia. *East African Journal of Sciences*, *15*(1), 17–24.

Yalden, D., Largen, M. (1992). The endemic mammals of Ethiopia. *Mammal Rev.*, 22, 115–150.

Yihune, M., Bekele, A., Tefera, Z. (2009). Human-wildlife conflict in and around the Simen Mountains National Park, Ethiopia. *Ethiop J Sci* 32:57–64.

Yineger, H., Kelbessa, E., Bekele, T., & Lulekal, E. (2008). Floristic composition and structure of the dry afromontane forest at Bale Mountains National Park, Ethiopia. *SINET: Ethiopian Journal of Science*, *31*(2), 103-120.

Yusefi H, Erfanzadeh R, Esmailzadeh O. Effect of wild boar disturbances on the soil seed bank in alpine plant communities. Land Degradation & Development. 2023 Feb 28;34(4):1225-34.

Yusuf H, Treydte AC, Demissew S, Woldu Z. Assessment of woody species encroachment in the grasslands of Nechisar National Park, Ethiopia. African Journal of Ecology. 2011 Dec;49(4):397-409.

Zhang, W., Huang, D., Wang, R., Liu, J., & Du, N. (2016). Altitudinal patterns of species diversity and phylogenetic diversity across temperate mountain forests of northern China. *PloS one*, *11*(7), e0159995.

Chapter Eight

8.1 Appendices

Appendix Table 2. 1. List of soil seed bank species obtained via germination from GCCA.

S. No	Scientific name of species with authority name(s)	Family name	Habit
1	*Aeonium leucoblepharum* A. Rich.	Crassulaceae	H
2	*Agrocharis melanantha* Hochst.	Apiaceae	H
3	*Agrostis gracilifolia* C. E. Hubb	Poaceae	H
4	*Agrostis quinqueseta* (Hochst. ex Steud.) Hochst.	Poaceae	H
5	*Alchemilla abyssinica* Fresen.	Rosaceae	H
6	*Alchemilla ellenbecki* Engl.	Rosaceae	H
7	*Alchemilla kiwuensis* Engl.	Rosaceae	H
8	*Anchusa affinis* R. Br. Ex DC.	Boraginaceae	H
9	*Andropogon lima* (Hack.) stapf	Poaceae	H
10	*Andropogon amethystinus* Steud.	Poaceae	H
11	*Anthemis tigreensis* J. Gay ex A. Rich.	Asteraceae	H
12	*Argyrolobium ramosissimum* Bak.	Fabaceae	H
13	*Argyrolobium rupestre* (E. Mey.) Walp.	Fabaceae	H
14	*Artemisia abyssinica* Sch. Bip. Ex A. Rich.	Asteraceae	H
15	*Bartsia londiflora* Hochst.ex Benth.	Scrophulariaceae	SH
16	*Carduus schimperi* Sch. Bip. Ex A. Rich.	Asteraceae	H
17	*Carex conferta* Hochst.ex Benth.	Cyperaceae	H
18	*Carex monostachya* A.Rich	Cyperaceae	H
19	*Cineraria abyssinica* Sch. Bip. Ex A. Rich.	Asteraceae	H
20	*Conyza pyropappa* Sch. Bip. Ex A. Rich.	Asteraceae	SH
21	*Conyza stricta* Willd	Asteraceae	H
22	*Crassula alba* Forssk.	Crasulaceae	H
23	*Cynoglosum amplifolium* Hochst.ex Benth.	Boraginaceae	H
24	*Cynoglosum coeruleum* Hochst.ex Benth.	Boraginaceae	H
25	*Cyperus elegantulus* Steud.	Cyperaceae	H

26	*Cyperus rigidifolius* Steud.	Cyperaceae	H
27	*Dicrocephala chrysanthemifolia* DC.	Asteraceae	H
28	*Dipsacus pinnatifidus* Steud. ex A. Rich.	Dipsacaceae	H
29	*Epilobium stereophyllum* Fresen.	Onagraceae	H
30	*Erica arborea* L.	Ericaceae	SH
31	*Erica tenuipilosa* (Engl. ex Alm & Fries) Cheek	Ericaceae	SH
32	*Erigeron alpines* L.	Asteraceae	H
33	*Euryops pinifolius* A. Rich.	Asteraceae	SH
34	*Festuca abyssinica* Hochst.ex Benth.	Poaceae	H
35	*Festuca macrophylla* Hochst.ex Benth.	Poaceae	H
36	*Festuca richardii* E.B. Alexeev	Poaceae	H
37	*Galium simense* Fresen.	Rubiaceae	H
38	*Hebenstretia angolensis* Rolfe.	Scrophulariaceae	SH
39	*Hedbergia abyssinica* (Hochst.ex Benth.)	Scrophulariaceae	H
40	*Helichrysum formosissimum* Sch. Bip. Ex A. Rich.	Asteraceae	H
41	*Helichrysum stenopterum* DC.	Asteraceae	H
42	*Helichrysum forsskahilii* (J.F. Gmel.) Hilliard & Burtt	Asteraceae	H
43	*Helichrysum splendidum* (Thumb.) Less	Asteraceae	SH
44	*Helictotrichon elongatum* (Hochst. ex. A. Rich.) C. E. Hubb.	Poaceae	H
45	*Hesperantha petitiana* (A. Rich.) Baker	Iridaceae	H
46	*Hypericum revolutum* Vahl	Hypericaceae	SH
47	*Isolepis costata* A. Rich.	Cyperaceae	H
48	*kalanchoe petitiana* A. Rich	Crassulaceae	SH
49	*Kniphofia foliosa* Hochst.	Asphodelaceae	H
50	*Lobelia rhynchopetalum* Hemsl.	Lobeliaceae	H
51	*Luzula abyssinica* Parl.	Juncaceae	H
52	*Nepeta azurea* R.Br. ex Benth.	Lamiaceae	H
53	*Pimpinella oreophila* Hook.	Apiaceae	H
54	*Plectocephalus varians* (A.Rich.) C. Jeffrey ex. Cufod.	Asteraceae	H
55	*Ranunculus multifidus* Forssk.	Ranunculaceae	H

56	*Rhabdotosperma scrophularifolia* (Hochst. ex A. Rich.) Hartle	Scrophulariaceae	H
57	*Rubus volkensii* Engl.	Rosaceae	SH
58	*Rumex abyssinicus* Jacq.	Polygonaceae	H
59	*Rumex nepalensis* Spreng.	Polygonaceae	H
60	*Rytidosperma subulata* (A. Rich.) Cope	Poaceae	H
61	*Salvia merjamie* Forssk.	Lamiaceae	H
62	*Satureja pseudosimensis* Brenan	Lamiaceae	H
63	*Scabiosa columbaria* L.	Dipsacaceae	H
64	*Senecio ragazi* Chiov.	Asteraceae	H
65	*Senecio schulzii* Hochst. ex. A. Rich.	Asteraceae	H
66	*Senecio steudelii* Sch. Bip. ex A. Rich.	Asteraceae	H
67	*Senecio subsessilis* Oliv. & Hiern	Asteraceae	H
68	*Swertia kilimandscharica* Engl.	Gentianaceae	H
69	*Thymus schimperi* Ronniger	Lamiaceae	H
70	*Trifolium polystachyum* Fresen.	Fabaceae	H
71	*Trifolium usambarense* Taub.	Fabaceae	H
72	*Urtica simensis* Steudel	Urticaceae	H
73	*Verbascum sinaiticum* Benth.	Scrophulariaceae	H
74	*Veronica glandulosa* Hochst .ex Benth.	Scrophulariaceae	H

(Note: H = Herb, SH = Shrub)

Appendix Table 2. 2. List of plant families with number of genera, species and percentage obtained from GCCA.

Family	Genera	Species	Percentage
Apiaceae	2	2	2.7
Asphodelaceae	1	1	1.4
Asteraceae	12	18	24.3
Boraginaceae	2	3	4.1
Crassulaceae	3	3	4.1
Cyperaceae	3	5	6.8
Dipsacaceae	2	2	2.7
Ericaceae	1	2	2.7
Fabaceae	2	4	5.4
Gentianaceae	1	1	1.4

Hypericaceae	1	1	1.4
Iridiaceae	1	1	1.4
Juncaceae	1	1	1.4
Lamiaceae	4	4	5.4
Lobeliaceae	1	1	1.4
Onagraceae	1	1	1.4
Poaceae	5	9	12.2
Polygonaceae	1	2	2.7
Ranunculaceae	1	1	1.4
Rosaceae	2	4	5.4
Rubiaceae	1	1	1.4
Scrophulariaceae	6	6	8.1
Urticaceae	1	1	1.4

Appendix Table 2. 3. The densities of seeds (number of seeds m^{-2}) recovered from the three different layers of the samples collected from GCCA.

S.No	SPECIES NAME	SOIL LAYERS			
		0 – 3 cm	3-6 cm	6-9 cm	Total
1	*Aeonium leucoblepharum* A. Rich.	42	33	0	75
2	*Agrocharis melanantha* Hochst.	40	18	4	62
3	*Agrostis gracilifolia* C. E. Hubb	53	36	7	96
4	*Agrostis quinqueseta* (Hochst. ex Steud.) Hochst.	74	69	1	144
5	*Alchemilla abyssinica* Fresen.	335	234	3	572
6	*Alchemilla ellenbecki* Engl.	293	205	112	610
7	*Alchemilla kiwuensis* Engl.	85	57	1	143
8	*Anchusa affinis* R.Br. ex DC.	25	21	0	46
9	*Andropogon lima* (Hack.) Stapf	30	31	1	62
10	*Andropogon amethystinus* Steud.	35	24	1	60
11	*Anthemis tigreensis* J. Gay ex A. Rich.	64	53	11	128
12	*Argyrolobium ramosissimum* Bak.	40	30	1	71
13	*Argyrolobium rupestre* (E. Mey.) Walp.	14	14	4	32
14	*Artemisia abyssinica* Sch. Bip. ex A. Rich.	10	13	0	23
15	*Bartsia longiflora* Hochst.ex Benth.	1	2	2	5
16	*Carduus schimperi* Sch. Bip. ex A. Rich.	2	6	2	10
17	*Carex conferta* Hochst. ex A. Rich	1	3	1	5
18	*Carex monostachya* A. Rich.	15	12	2	29
19	*Cineraria abyssinica* Sch. Bip. ex A. Rich.	37	32	28	97
20	*Conyza pyrrhopappa* Sch. Bip. ex A. Rich.	10	11	0	21
21	*Conyza stricta* Willd	9	5	3	17
22	*Crassula alba* Forssk.	5	7	1	13
23	*Cynoglosum amplifolium* Hochst. ex A. DC.	18	21	1	40

24	*Cynoglosum coeruleum* Hochst. ex A. DC.	20	17	9	46
25	*Cyperus elegantulus* Steud.	99	49	19	167
26	*Cyperus rigidifolius* Steud.	81	51	11	143
27	*Dicrocephala chrysanthemifolia* DC.	4	5	2	11
28	*Dipsacus pinnatifidus* Steud. ex A. Rich.	3	15	6	24
29	*Epilobium stereophyllum* Fresen.	6	8	0	14
30	*Erica arborea* L.	11	2	7	20
31	*Erica tenuipilosa* (Engl. ex Alm & Fries) Cheek	1	0	0	1
32	*Erigeron alpinus* L.	4	4	2	10
33	*Euryops pinifolius* A. Rich.	442	218	41	701
34	*Festuca abyssinica,* Hochst. ex A. Rich.	31	14	1	46
35	*Festuca macrophylla* Hochst. ex A. Rich.	169	134	47	350
36	*Festuca richardii* E.B.Alexeev	0	1	0	1
37	*Galium simense* Fresen.	6	6	0	12
38	*Hebenstretia angolensis* Rolfe.	4	5	0	9
39	*Hedbergia abyssinica* (Hochst. ex Benth.	1	0	1	2
40	*Helichrysum formosissimum* Sch. Bip. ex A. Rich.	4	2	3	9
41	*Helichrysum stenopterum* DC.	9	6	3	18
42	*Helichrysum forsskahlii* (J.F. Gmel.) Hilliard& Burtt	8	5	4	17
43	*Helichrysum splendidum* (Thumb.) Less	681	263	192	1136
44	*Helictotrichon elongatum* (Hochst. ex. A. Rich.) C. E. Hubb.	5	4	2	11
45	*Hesperantha petitiana* (A. Rich.) Baker	4	3	3	10
46	*Hypericum revolutum* Vahl	25	14	3	42
47	*Isolepis costata* A. Rich.	7	2	3	12
48	*kalanchoe petitiana* A. Rich.	10	4	4	18
49	*Kniphofia foliosa* Hochst.	0	1	0	1
50	*Lobelia rhynchopetalum* Hemsl.	1	0	0	1
51	*Luzula abyssinica* Parl.	2	1	0	3
52	*Nepeta azurea* R.Br. ex Benth.	2	0	0	2
53	*Pimpinella oreophila* Hook.	1	1	1	3
54	*Plectocephalus varians* (A.Rich.) C. Jeffrey ex. Cufod.	1	2	0	3
55	*Ranunculus multifidus* Forssk.	4	2	0	6
56	*Rhabdotosperma scrophularifolia* (Hochst. ex A. Rich.) Hartle	2	2	0	4
57	*Rubus volkensii* Engl.	5	1	0	6
58	*Rumex abyssinicus* Jacq.	2	1	0	3
59	*Rumex nepalensis* Spreng.	1	1	0	2
60	*Rytidosperma subulata* (A. Rich.) Cope	2	1	0	3
61	*Salvia merjamie* Forssk.	4	1	0	5

62	*Satureja pseudosimensis* Brenan	2	1	0	3
63	*Scabiosa columbaria* L.	1	2	0	3
64	*Senecio ragazi* Chiov.	2	1	0	3
65	*Senecio schulzii* Hochst. ex. A. Rich.	2	1	0	3
66	*Senecio steudelii* Sch. Bip. ex A. Rich.	3	2	0	5
67	*Senecio subsessilis* Oliv. & Hiern	1	1	0	2
68	*Swertia kilimandscharica* Engl.	6	1	1	8
69	*Thymus schimperi* Ronniger	923	408	126	1457
70	*Trifolium polystachyum* Fresen.	413	272	158	843
71	*Trifolium usambarense* Taub.	457	208	87	752
72	*Urtica simensis* Steudel	210	99	27	336
73	*Verbascum sinaiticum* Benth.	7	3	0	10
74	*Veronica glandulosa* Hochst .ex Benth.	7	1	0	8
	Total				8666

Appendix Table 2. 4. Density and frequency of species collected from GCCA.

S. No	Scientific name	Seedlings count	Number of plots in which spp. occur	Density	Frequency
1	*Aeonium leucoblepharum* A. Rich.	76	35	0.68	21.87
2	*Agrocharis melanantha* Hochst.	62	35	0.55	21.87
3	*Agrostis gracilifolia* C. E. Hubb	96	42	0.86	26.25
4	*Agrostis quinqueseta* (Hochst. ex Steud.) Hochst.	144	53	1.29	33.13
5	*Alchemilla abyssinica* Fresen.	577	94	5.19	58.75
6	*Alchemilla ellenbecki* Engl.	610	129	5.49	80.63
7	*Alchemilla kiwuensis* Engl.	144	58	1.29	36.25
8	*Anchusa affinis* R.Br. ex DC.	46	21	0.41	13.23
9	*Andropogon lima* (Hack.) Stapf	62	31	0.55	19.38
10	*Andropogon amethystinus* Steud.	61	25	0.54	15.63
11	*Anthemis tigreensis* J. Gay ex A. Rich.	128	50	0.15	31.25
12	*Argyrolobium ramosissimum* Bak.	71	35	0.63	44.38
13	*Argyrolobium rupestre* (E. Mey.) Walp.	33	18	0.29	11.25
14	*Artemisia abyssinica* Sch. Bip. ex A. Rich.	23	12	0.20	7.50
15	*Bartsia longiflora* Hochst.ex Benth.	5	3	0.04	1.88
16	*Carduus schimperi* Sch. Bip. ex A. Rich.	10	5	0.09	3.13
17	*Carex conferta* Hochst. ex A. Rich	5	2	0.04	1.25
18	*Carex monostachya* A. Rich.	29	10	0.26	6.25
19	*Cineraria abyssinica* Sch. Bip. ex A. Rich.	98	33	0.88	20.63

20	*Conyza pyrrhopappa* Sch. Bip. ex A. Rich.	21	11	0.18	6.88
21	*Conyza stricta* Willd	17	7	0.15	4.38
22	*Crassula alba* Forssk.	13	7	0.11	4.38
23	*Cynoglosum amplifolium* Hochst. ex A. DC.	41	23	0.36	14.38
24	*Cynoglosum coeruleum* Hochst. ex A. DC.	46	19	0.41	11.88
25	*Cyperus elegantulus* Steud.	172	46	1.54	28.75
26	*Cyperus rigidifolius* Steud.	146	42	1.31	26.25
27	*Dicrocephala chrysanthemifolia* DC.	11	5	0.09	3.13
28	*Dipsacus pinnatifidus* Steud. ex A. Rich.	24	9	0.21	5.63
29	*Epilobium stereophyllum* Fresen.	14	8	0.12	5.00
30	*Erica arborea* L.	20	11	0.18	6.88
31	*Erica tenuipilosa* (Engl. ex Alm & Fries) Cheek	2	2	0.01	1.25
32	*Erigeron alpinus* L.	10	6	0.09	3.75
33	*Euryops pinifolius* A. Rich.	702	104	6.32	65.00
34	*Festuca abyssinica*, Hochst. ex A. Rich.	46	22	0.41	13.75
35	*Festuca macrophylla* Hochst. ex A. Rich.	357	110	3.21	68.75
36	*Festuca richardii* E.B.Alexeev	1	1	0.01	0.63
37	*Galium simense* Fresen.	12	6	0.10	3.75
38	*Hebenstretia angolensis* Rolfe.	9	5	0.08	3.13
39	*Hedbergia abyssinica* (Hochst. ex Benth.	2	2	0.01	1.25
40	*Helichrysum formosissimum* Sch. Bip. ex A. Rich.	9	5	0.08	3.13
41	*Helichrysum stenopterum* DC.	18	9	0.16	5.63
42	*Helichrysum forsskahlii* (J.F. Gmel.) Hilliard& Burtt	17	8	0.15	5.00
43	*Helichrysum splendidum* (Thumb.) Less	1142	147	10.28	91.88
44	*Helictotrichon elongatum* (Hochst. ex. A. Rich.) C. E. Hubb.	11	6	0.09	3.75
45	*Hesperantha petitiana* (A. Rich.) Baker	10	6	0.09	3.75
46	*Hypericum revolutum* Vahl	42	20	0.37	12.50
47	*Isolepis costata* A. Rich.	12	8	0.10	5.00
48	*kalanchoe petitiana* A. Rich.	18	10	0.16	6.25
49	*Kniphofia foliosa* Hochst.	1	1	0.01	0.63
50	*Lobelia rhynchopetalum* Hemsl.	1	1	0.01	0.63

51	*Luzula abyssinica* Parl.	3	3	0.02	1.88
52	*Nepeta azurea* R.Br. ex Benth.	2	2	0.01	1.25
53	*Pimpinella oreophila* Hook.	3	2	0.02	1.25
54	*Plectocephalus varians* (A.Rich.) C. Jeffrey ex. Cufod.	3	2	0.02	1.25
55	*Ranunculus multifidus* Forssk.	6	2	0.05	1.25
56	*Rhabdotosperma scrophularifolia* (Hochst. ex A. Rich.) Hartle	4	3	0.03	1.88
57	*Rubus volkensii* Engl.	6	5	0.05	3.13
58	*Rumex abyssinicus* Jacq.	3	3	0.02	1.88
59	*Rumex nepalensis* Spreng.	2	2	0.01	1.25
60	*Rytidosperma subulata* (A. Rich.) Cope	3	2	0.02	1.25
61	*Salvia merjamie* Forssk.	5	4	0.04	2.50
62	*Satureja pseudosimensis* Brenan	3	2	0.02	1.25
63	*Scabiosa columbaria* L.	3	2	0.02	1.25
64	*Senecio ragazi* Chiov.	3	2	0.02	1.25
65	*Senecio schulzii* Hochst. ex. A. Rich.	3	2	0.02	1.25
66	*Senecio steudelii* Sch. Bip. ex A. Rich.	5	3	0.04	1.88
67	*Senecio subsessilis* Oliv. & Hiern	2	2	0.01	1.25
68	*Swertia kilimandscharica* Engl.	8	8	0.07	5.00
69	*Thymus schimperi* Ronniger	1466	160	13.20	100
70	*Trifolium polystachyum* Fresen.	847	142	7.63	88.75
71	*Trifolium usambarense* Taub.	753	144	6.78	90.00
72	*Urtica simensis* Steudel	336	79	3.02	49.38
73	*Verbascum sinaiticum* Benth.	10	4	0.09	2.50
74	*Veronica glandulosa* Hochst .ex Benth.	8	4	0.07	2.50

Appendix Table 4. 1. Occurrence data for *Festuca macrophylla*

Lat	Long	species
12.04267	39.08709	Festuca macrophylla Hochst. ex A.Rich.
12.04182	39.08789	Festuca macrophylla Hochst. ex A.Rich.
12.04216	39.09026	Festuca macrophylla Hochst. ex A.Rich.
12.04317	39.09028	Festuca macrophylla Hochst. ex A.Rich.
12.04692	39.09351	Festuca macrophylla Hochst. ex A.Rich.
12.04672	39.09402	Festuca macrophylla Hochst. ex A.Rich.
12.04754	39.09573	Festuca macrophylla Hochst. ex A.Rich.
12.12882	39.18124	Festuca macrophylla Hochst. ex A.Rich.

12.1276	39.18259	Festuca macrophylla Hochst. ex A.Rich.
12.12645	39.18395	Festuca macrophylla Hochst. ex A.Rich.
12.12664	39.18931	Festuca macrophylla Hochst. ex A.Rich.
10.24551	39.47224	Festuca macrophylla Hochst. ex A.Rich.
10.17224	39.47338	Festuca macrophylla Hochst. ex A.Rich.
10.24319	39.47459	Festuca macrophylla Hochst. ex A.Rich.
10.18154	39.47482	Festuca macrophylla Hochst. ex A.Rich.
10.1722	39.4783	Festuca macrophylla Hochst. ex A.Rich.
10.17563	39.47912	Festuca macrophylla Hochst. ex A.Rich.
10.19503	39.4831	Festuca macrophylla Hochst. ex A.Rich.
10.20019	39.48335	Festuca macrophylla Hochst. ex A.Rich.
10.24022	39.4937	Festuca macrophylla Hochst. ex A.Rich.
10.40389	39.779658	Festuca macrophylla Hochst. ex A.Rich.
10.36796	39.79	Festuca macrophylla Hochst. ex A.Rich.
10.30054	39.792725	Festuca macrophylla Hochst. ex A.Rich.
10.29846	39.793181	Festuca macrophylla Hochst. ex A.Rich.
10.29641	39.794481	Festuca macrophylla Hochst. ex A.Rich.
10.30197	39.794942	Festuca macrophylla Hochst. ex A.Rich.
10.29442	39.795881	Festuca macrophylla Hochst. ex A.Rich.
10.29292	39.796103	Festuca macrophylla Hochst. ex A.Rich.
10.30419	39.797075	Festuca macrophylla Hochst. ex A.Rich.
10.30964	39.797408	Festuca macrophylla Hochst. ex A.Rich.
10.30599	39.798128	Festuca macrophylla Hochst. ex A.Rich.
10.31344	39.799247	Festuca macrophylla Hochst. ex A.Rich.
10.29946	39.799783	Festuca macrophylla Hochst. ex A.Rich.
10.30282	39.800294	Festuca macrophylla Hochst. ex A.Rich.
10.31743	39.801111	Festuca macrophylla Hochst. ex A.Rich.
10.30626	39.801572	Festuca macrophylla Hochst. ex A.Rich.
10.30003	39.801844	Festuca macrophylla Hochst. ex A.Rich.
10.32213	39.802136	Festuca macrophylla Hochst. ex A.Rich.
10.31103	39.803922	Festuca macrophylla Hochst. ex A.Rich.
10.30044	39.804306	Festuca macrophylla Hochst. ex A.Rich.
10.28996	39.805644	Festuca macrophylla Hochst. ex A.Rich.
10.31664	39.806936	Festuca macrophylla Hochst. ex A.Rich.
10.32739	39.807672	Festuca macrophylla Hochst. ex A.Rich.
10.33894	39.808619	Festuca macrophylla Hochst. ex A.Rich.
10.32358	39.808642	Festuca macrophylla Hochst. ex A.Rich.
10.3498	39.809075	Festuca macrophylla Hochst. ex A.Rich.
10.32367	39.802998	Festuca macrophylla Hochst. ex A.Rich.
10.32395	39.803107	Festuca macrophylla Hochst. ex A.Rich.
10.31718	39.803233	Festuca macrophylla Hochst. ex A.Rich.
10.3243	39.803252	Festuca macrophylla Hochst. ex A.Rich.

10.32455	39.803383	Festuca macrophylla Hochst. ex A.Rich.
10.3251	39.803785	Festuca macrophylla Hochst. ex A.Rich.
10.32128	39.80536	Festuca macrophylla Hochst. ex A.Rich.
10.32181	39.805449	Festuca macrophylla Hochst. ex A.Rich.
10.32252	39.805602	Festuca macrophylla Hochst. ex A.Rich.
10.32221	39.805625	Festuca macrophylla Hochst. ex A.Rich.
10.32061	39.805729	Festuca macrophylla Hochst. ex A.Rich.
10.31876	39.805842	Festuca macrophylla Hochst. ex A.Rich.
10.31996	39.805884	Festuca macrophylla Hochst. ex A.Rich.
13.307	38.109	Festuca macrophylla Hochst. ex A.Rich.
13.3084	38.1354	Festuca macrophylla Hochst. ex A.Rich.
13.331	38.1753	Festuca macrophylla Hochst. ex A.Rich.
13.335	38.1783	Festuca macrophylla Hochst. ex A.Rich.
13.347	38.20031	Festuca macrophylla Hochst. ex A.Rich.
13.399	38.2007	Festuca macrophylla Hochst. ex A.Rich.
13.388	38.2015	Festuca macrophylla Hochst. ex A.Rich.
13.3583	38.2039	Festuca macrophylla Hochst. ex A.Rich.
13.357	38.2082	Festuca macrophylla Hochst. ex A.Rich.
13.3981	38.219	Festuca macrophylla Hochst. ex A.Rich.
13.383	38.239	Festuca macrophylla Hochst. ex A.Rich.
13.375	38.2803	Festuca macrophylla Hochst. ex A.Rich.
13.3637	38.281	Festuca macrophylla Hochst. ex A.Rich.
13.381	38.2908	Festuca macrophylla Hochst. ex A.Rich.
13.3312	38.291	Festuca macrophylla Hochst. ex A.Rich.
13.301	38.293	Festuca macrophylla Hochst. ex A.Rich.
13.3284	38.2931	Festuca macrophylla Hochst. ex A.Rich.
13.343	38.294	Festuca macrophylla Hochst. ex A.Rich.
13.3412	38.315	Festuca macrophylla Hochst. ex A.Rich.
13.28525	38.118383	Festuca macrophylla Hochst. ex A.Rich.
13.28798	38.118817	Festuca macrophylla Hochst. ex A.Rich.
13.26	38.2	Festuca macrophylla Hochst. ex A.Rich.
13.25135	38.20225	Festuca macrophylla Hochst. ex A.Rich.
13.3285	38.240917	Festuca macrophylla Hochst. ex A.Rich.
13.34907	38.2625	Festuca macrophylla Hochst. ex A.Rich.
13.3917	38.1001	Festuca macrophylla Hochst. ex A.Rich.
13.3661	38.1008	Festuca macrophylla Hochst. ex A.Rich.
13.3606	38.127	Festuca macrophylla Hochst. ex A.Rich.
13.3609	38.1309	Festuca macrophylla Hochst. ex A.Rich.
13.3429	38.1363	Festuca macrophylla Hochst. ex A.Rich.
13.3201	38.1597	Festuca macrophylla Hochst. ex A.Rich.
13.31904	38.1953	Festuca macrophylla Hochst. ex A.Rich.
13.3711	38.197	Festuca macrophylla Hochst. ex A.Rich.

13.31901	38.2014	Festuca macrophylla Hochst. ex A.Rich.
13.37001	38.2071	Festuca macrophylla Hochst. ex A.Rich.
13.3531	38.2188	Festuca macrophylla Hochst. ex A.Rich.
13.30091	38.2301	Festuca macrophylla Hochst. ex A.Rich.
13.39009	38.233	Festuca macrophylla Hochst. ex A.Rich.
13.32106	38.2407	Festuca macrophylla Hochst. ex A.Rich.
13.3508	38.2458	Festuca macrophylla Hochst. ex A.Rich.
13.3575	38.2703	Festuca macrophylla Hochst. ex A.Rich.
13.3604	38.2703	Festuca macrophylla Hochst. ex A.Rich.
13.30106	38.2798	Festuca macrophylla Hochst. ex A.Rich.
13.3533	38.281	Festuca macrophylla Hochst. ex A.Rich.
13.32011	38.3175	Festuca macrophylla Hochst. ex A.Rich.
13.38101	38.3597	Festuca macrophylla Hochst. ex A.Rich.
13.38013	38.3901	Festuca macrophylla Hochst. ex A.Rich.
13.2666	38.107817	Festuca macrophylla Hochst. ex A.Rich.
13.3112	38.1003	Festuca macrophylla Hochst. ex A.Rich.
13.36591	38.10236	Festuca macrophylla Hochst. ex A.Rich.
13.38271	38.1379	Festuca macrophylla Hochst. ex A.Rich.
13.37001	38.23699	Festuca macrophylla Hochst. ex A.Rich.
13.3201	38.256	Festuca macrophylla Hochst. ex A.Rich.
13.31492	38.259	Festuca macrophylla Hochst. ex A.Rich.
13.34483	38.283	Festuca macrophylla Hochst. ex A.Rich.
13.30001	38.31231	Festuca macrophylla Hochst. ex A.Rich.
13.39101	38.33201	Festuca macrophylla Hochst. ex A.Rich.
13.33275	38.33386	Festuca macrophylla Hochst. ex A.Rich.
13.35911	38.3431	Festuca macrophylla Hochst. ex A.Rich.
13.37308	38.387	Festuca macrophylla Hochst. ex A.Rich.

Appendix Table 5. 1. Occurrence data for *Euryops pinifolius*

Latitude	Longitude
10.17079	39.47512
10.17101	39.47495
10.17134	39.47471
10.17199	39.47448
10.17229	39.47405
10.17265	39.48118
10.17337	39.47356
10.17382	39.47346
10.17429	39.47353
10.17484	39.48202

10.17529	39.47355
10.17577	39.47339
10.18017	39.47338
10.18088	39.47343
10.18153	39.47334
10.18167	39.47413
10.19313	39.48064
10.19336	39.48127
10.19365	39.48131
10.19431	39.47586
10.19445	39.47554
10.19478	39.47539
10.20087	39.47509
10.20545	39.47535
10.20599	39.47581
10.26168	39.48155
10.22168	39.48221
10.23306	39.48301
10.23127	39.48117
10.24031	39.47405
10.1722	39.47863
10.17224	39.47338
10.17563	39.47912
10.18154	39.47482
10.19503	39.48431
10.20019	39.48335
10.24022	39.49237
10.24319	39.47459
10.24551	39.47224
13.33312	38.29361
13.34132	38.31485
13.32814	38.29311
13.38613	38.23749
13.35823	38.20319
13.34513	38.29264
13.36537	38.28231
13.37308	38.38817
13.39811	38.21349
13.38448	38.20015
13.32501	38.25636
13.33401	38.29733
13.31721	38.10033

13.33215	38.17823

Appendix Table 5. 2. Occurrence data for *Helichrysum splendidum*

Latitude	Longitude
6.91667	39.78333
6.76667	39.75321
6.81667	39.85201
6.93244	39.73412
8.53333	38.85121
8.06667	38.25331
6.81667	39.81667
9.05712	38.16667
6.71667	39.85304
6.76667	39.75401
6.92103	39.93333
6.91002	39.76667
6.83275	39.68333
9.23333	41.78333
6.91667	39.66667
6.75213	39.71667
9.83333	39.75128
8.98333	38.61667
9.26667	41.71667
6.76667	39.75216
6.76667	39.75154
8.53333	38.85329
6.91667	39.71667
6.80285	39.85871
7.43333	40.41667
7.33333	40.48333
7.35218	40.21667
7.42137	40.23333
7.35169	40.38333
7.41667	40.35289
7.41667	40.41667
7.56667	38.35241
7.41209	40.41667
7.35258	40.41246
7.56667	38.35201
7.35279	40.38333

7.56667	39.81667
9.35391	41.31522
9.38333	41.46667
9.41162	42.45661
7.65241	42.45317
7.43159	40.56667
8.16667	38.51667
7.18333	40.23333
7.41667	40.41667
7.26667	40.18333
9.52681	41.56667
9.71667	42.01667
7.06667	40.25318
7.08333	39.98135
7.23333	40.23333

Appendix 6. List of pictures taken during field data collection and glasshouse germination

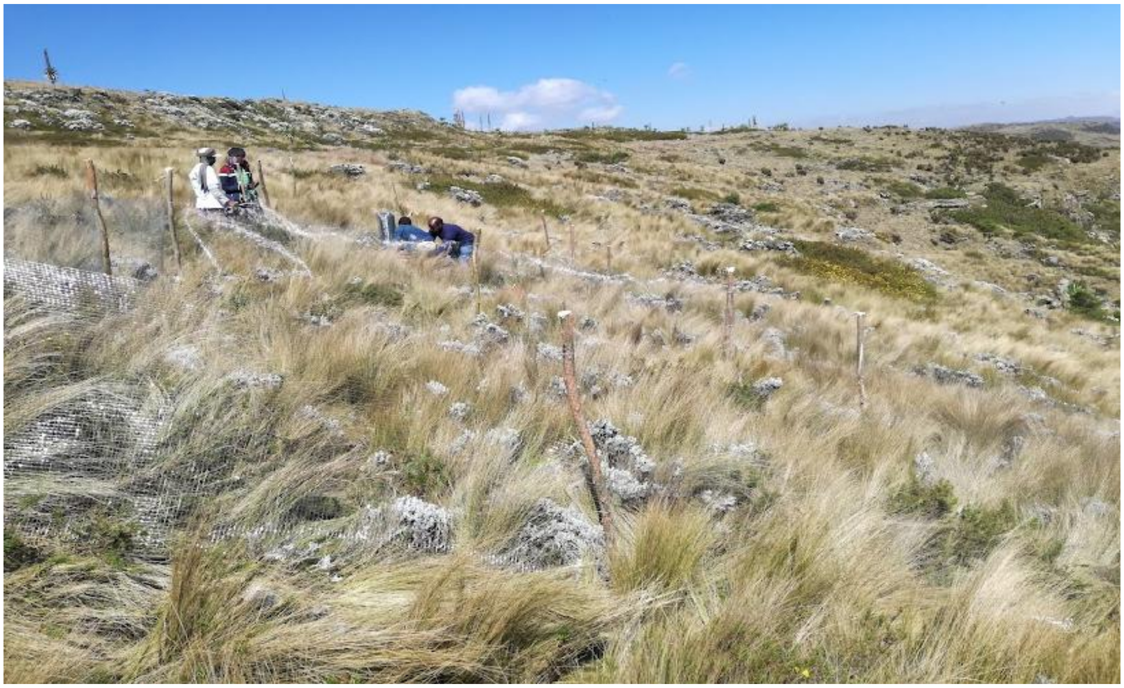
Training the community on the monitoring experimental plots (Photo: Shambel Alemu, 2019)

Selection of possible experimental site with my supervisor Dr. Bikila Warkineh (Photo: Shambel Alemu, 2019)

Experimental plot establishment (Photo: Shambel Alemu, 2020)

Partial view of GCCA (Photo: Shambel Alemu, 2020)

Fixing plots with mashed wire (Photo: Shambel Alemu, 2020)



Shrub removal activity (Photo: Shambel Alemu, 2020)

Shrub removal activity (Photo: Shambel Alemu, 2020)

Fenced plots ready for shrub removal (Photo: Shambel Alemu, 2020)

Soil samples collected for glasshouse germination (Photo: Shambel Alemu, 2020)

Soil samples ready for transportation for glasshouse germination (Photo: Shambel Alemu, 2020)

Soil samples ready to be transferred to pots in the glasshouse (Photo: Shambel Alemu, 2020)

Soil seedbank germination in the glasshouse (Photo: Shambel Alemu, 2021)

Seedbank growth progress (Photo: Shambel Alemu, 2021)

Seedbank growth progress (Photo: Shambel Alemu, 2022)

Seedbank growth progress (Photo: Shambel Alemu, 2022)