INVASION STATUS AND POTENTIAL MANAGEMENT OPTIONS FOR THE INVASIVE TREE SPECIES *MAESOPSIS EMINII* IN AMANI NATURE FOREST RESERVE, TANZANIA

Beatus Mwendwa

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Doctor of Philosophy in Life Sciences of the Nelson Mandela African Institution of Science and Technology

Arusha, Tanzania

March, 2021

ABSTRACT

Invasion of *Maesopsis eminii* in Amani Nature Forest Reserve was considered an ecological disaster in the 1980s. After more than 50 years have elapsed since its introduction, there is little information available on its invasion progress, germination and earlier growth behavior. The present study resurveyed 60 (20 m × 50 m) sample plots previously surveyed in 1998 and collected remote sensing data for 1997 and 2018. The effect of four shade levels (0%, 50%, 65% and 85%) on seed germination and early growth of *M. eminii* seeds were studies. Also information on the distribution of *M. eminii* species in household farms were gathered through interviews and observation. Out of 30 control plots, *M. eminii* had invaded seven new sample plots (23%) which were not invaded in 1998. Change detection analysis indicated 1108 ha of non-forest vegetation had regrown into forest over the last 20 years, particularly in the south - western region of the reserve. The study found that the average germination rate across the four different shade levels differed significantly during the dry season ($F_{(3,12)} = 48.74$, $P < 0.001$) but not during wet season ($F_{(3,12)} = 3.49$, $P = 0.051$). During the dry season, leaf chlorophyll contents were three times higher at 65% and 85% shade than at 0% shade level. Also this study found that 58% of household farms had *M eminii*. There was significant negative association (ρ = -0.49, P = <0.001) between population size of *M. eminii* in household farms and the distance from the forest reserve boundary. Majority of respondents (68%) demonstrated good understanding of *M. eminii* while it was further found positive correlation between respondents' age and knowledge on *M. eminii* invasion. (ρ = 0.49, P = <0.001). The study concludes that there is 4% increase in spatial distribution of *M. eminii* between 1998 and 2018, with higher *M. eminii* density in invaded plots than control plots. Based on this study, it is recommended that potential management options to take into account light and water availability regimes to predict susceptible forest niches and prevent further spread of *Maesopsis eminii*.

DECLARATION

I, Beatus Mwendwa do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

Beatus Mwendwa

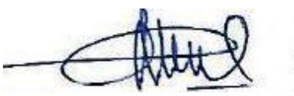
Name of Candidate and Signature **Date**

The above declaration is confirmed by

Prof. Anna Treydte

Name of Main Supervisor **Date**

Dr. Charles Kilawe



Date

Name of Co-Supervisor

COPYRIGHT

This dissertation is copyright material protected under the Berne Convention, the Copyright Act of 1999 and other international and national enactments, in that behalf, on intellectual property. It must not be reproduced by any means, in full or in part, except for short extracts in fair dealing; for researcher private study, critical scholarly review or discourse with an acknowledgement, without the written permission of the office of DVC-ARI, on behalf of both the author and the Nelson Mandela African Institution of Science and Technology.

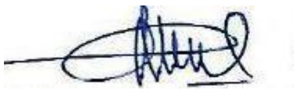
CERTIFICATION

The undersigned certifies that they have read the dissertation entitled "Potential Spread and Management Options of the Invasive Tree Species *Maesopsis eminii* in Amani Nature Forest Reserve, Tanzania" and found to be in a form acceptable for examination as a fulfillment of the requirements for the Degree of Doctor of Philosophy in Biodiversity and Ecosystem Management at Nelson Mandela African Institution of Science and Technology (NM-AIST).

Prof. Anna Treydte

Name of Main Supervisor **Date**

Dr. Charles Kilawe



Date

ACKNOWLEDGEMENTS

Glory and honor to God almighty for the strength and good health he gave me during this work.

I am profoundly thankful to my supervisors Prof. Anna C. Treydte and Dr. Charles J. Kilawe for their tireless guidance, advice and support all the time around the clock. Their invaluable and intellect supervision and guidance gave me substantial and strong latitude in both the conceptualization and the execution of this study. I also wish to express much sincere thanks to the management of Amani Nature Forest Reserve the permit, assistance and support during fieldwork.

I owe many thanks to my employer, the Institute of Adult Education for granting me study leave and financial support. I am also beholden and appreciative to the Nelson Mandela African Institution of Science and Technology through CREATES, and the Auckland Zoo Conservation Fund for financing fieldwork during this study. Their support were available at the time needed most and contributed prominently to the success and completion of this study on time.

Lastly but not least, I wish to express my sincere and heartfelt gratitude to my parents and family, my lovely wife and children for allowing me with plenty of time to concentrate on my study. Your endurance and patience during my absence as I was concentrating to this work is a great love that made me reach this far, I love you all.

DEDICATION

To my Beloved Parents Mr and Mrs Alex Mwendwa, My Lovely Wife and Children

….to the generous mind, the heaviest debt is that of gratitude…

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

ANFR	Amani Nature Forest Reserve
CABI	Centre for Agriculture and Bioscience International
CBD	Convention for Biological Diversity
CREATES	Centre for Research, Agricultural Advancement, Teaching Excellence and Sustainability
CVG	Coefficient of Velocity of Germination
DBH	Diameter at Breast Height
DMSO	Dimethyl Sulfoxide
DVC ARI	Deputy Vice Chancellor – Academic Research and innovations
EAMCEF	Eastern Arc Mountain Conservation Endowment Fund
EIA	Environmental Impact Assessment
ENVI	Environment for Visualizing Images
FGP	Final Germination Percentage
GI	Germination Index
GRI	Germination Rate Index
IBA	Important Bird Area
ICRAF	International Centre for Research in Agroforestry
IUCN	International Union for Conservation of Nature
MGT	Mean Germination Time
NM –AIST	Nelson Mandela African Institution of Science and Technology
OLI	Operational Land Imager
SD	Standard Deviation
SVN	Support Vector Machine
TM	Thematic Mapper
UNESCO	United Nations Educational, Scientific and Cultural Organization
URT	United Republic of Tanzania
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WWF	World Wildlife Fund

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

Biological invasion refers to a range expansion of species that were introduced intentionally or accidentally outside of their native or historic range, and that successfully spread in their new environment (McDougall *et al.,* 2011). It is one of the major global ecological issues that cause ecosystem degradation (Liebhold *et al.*, 2017). It is the second largest driver of biodiversity loss and declines after anthropogenic activities (Vardien *et al.,* 2012). While the awareness on the effects of invasive plants has increased (Thapa *et al.,* 2018) there is also an increasing global attention in adopting international agreements to prevent and control invasive plants (Broz *et al.*, 2007). This include a Convention on Biological Diversity, a multilateral treaty of 196 parties where under article 8(h) agreed to prevent the introduction, eradicate and control invasive species which threaten other species, habitats or ecosystems (Convention on Biological Diversity [CBD], 1992). The negative impacts of biological invasions have been widely reported and are predicted to increase even further under future climatic change conditions and human population growth (Thapa *et al.,* 2018). Invasive plant species displace native vegetation, disrupt the ecosystem while rendering the habitats less productive, economic losses in the agricultural sector, loss of ecological healthy and endangered species (May, 2007). It is estimated that a global cost caused by invasive species sums to about US$ 400 billion per year, assessed by crop damage, ecosystem function damage, loss of crop yields as well as investment into control and management methods (Borghesio, 1995).

Inspite of being key biological resources, forest ecosystems have been increasingly infested by both woody and herbaceous invasive plants (Kohli, 2009; Liebhold *et al.*, 2017). Various hypothesis and predictors have been put forth describing biological invasion in forest ecosystems. Fine (2002) mentioned propagule pressure, forest disturbances and functional diversity as main determining factors for invisibility of tropical forests by exotic plants. Furthermore, Bradley *et al.* (2010) mentioned two fundamental reasons for biological invasion risk associated with global climatic change which are creating of novel environments and high resource availability such as temperature, rainfall, carbon dioxide and Nitrogen deposition. Invasive plants in forests profoundly alter ecosystem properties causing massive economic impacts on forest resources. Some of these invasive plant species have cascading impacts such as alteration of tree species composition, changes in forest succession, declines in biological diversity, and alteration of nutrient, carbon and water cycles (Liebhold *et al.,* 2017). The problem of invasive plant species is being experienced worldwide, both in economically developed nations as well as in developing countries. In India for example, *Leucaena leucocephala*, which was planted as a fodder crop in agroforestry systems due to its prolific natural regeneration in open gaps, quickly became a problematic invasive tree species (Binggeli, 1989). In sub-Saharan Africa, invasive plants have increased rapidly in numbers, with dire consequences not only on agriculture, livestock productivity and water security, but also for fisheries, wildlife conservation and human health (Broz *et al.,* 2007). The spread of invasive plant species is affecting livelihoods, particularly in rural areas, aggravating poverty and hampering economic development, while at the same time irreversibly compromising biological diversity (Boy & Witt, 2005). In Ethiopia, for instance, the evergreen mesquite shrub (*Prosopis juliflora*) has formed impenetrable shrubby thickets, invading watercourses, lowering the water-table and, hence, starving other plants of moisture and nutrients, creating what is known as "green deserts" (Abdulahi *et al.*, 2017). As another example, *Lantana camara*, now considered the most destructive of all widespread terrestrial invasive plants, is present in no fewer than 60 countries across sub-Saharan Africa (Shackleton *et al.*, 2017).

In Tanzania, like in other parts of the world, there has been a substantial increase in biological invasions caused of invasive plant species since the 1960s (Lyimo *et al.,* 2009). Many of these species have severely disrupted forest ecosystem processes, thereby hampering the provisioning of ecosystem services that societies depend upon (Chamier *et al.*, 2012). Reasons for invasive species success over native indigenous species have been well documented, which include the absence of natural predators, rapid vegetative growth, prolific seed production (Binggeli, 1989), high seed germination rate, effective seed invasive dispersal mechanisms, tolerance to drought, pest and stress and their rapid maturation to a seed-producing stage contribute to their success in new areas (International Centre for Research in Agroforestry [ICRAF], 1992). Forest-threatening invasive plant species such as *Maesopsis eminnii, Cedrela odorata, Prosopis juliflora, Lantana camara and Acacia mearnsii* have been reported to replace their native counterparts (Eastern Arc Mountain Conservation Endowment Fund [CMEAMF], 2007; Epila *et al.,* 2017). Kilawe *et al.* (2018) mentioned *Maesopsis eminii* in the East Usambara Mountains as a highly aggressive invasive species, widely distributed in natural forests and could spread rapidly.

The introduction of *Maesopsis eminii* in East Usambara Mountains is poorly reported, particularly due to unavailability of records. However, Geddes (1998) and Wood (1966) states that the aggressive tree species was introduced to the East Usambara mountain range from Bukoba district by Germans around 1910s for plant experimental growth. Large scale planting in the 1960s and 1970s to fill logged forest gaps helped this species spread into the endemic rich natural forests. In Amani Nature Forest Reserve (ANFR) *M. eminii* was observed to have fast growth rates and prolific seed production, which impoverished the understory scrub and herb vegetation of the forests ecosystem and alternated the canopy structure and species composition (Musila, 2006). However, it is reported that the same species is native in Lake Victoria basin, northern parts of Tanzania in Bukoba and Ukerewe districts (Hall, 1993). While various studies such as Hall (1993), Hamilton and Bensted (1989) and International Union for Conservation of Nature [IUCN] (2000) provided previous status of *M. eminii* in ANFR, there is no updated information on the current spatial distribution of *M. eminii,* which is crucial for management of the invasive species.

1.2 Statement of the Problem

Various studies and reports show that *M. eminii* has spread and established relatively dense stands are now found in ANFR and nearby forest reserves such as Nilo Nature Forest Reserve and Mlinga forest (Binggeli, 1989; Epila *et al.,* 2017; Geddes, 1998). The invasive tree species is also becoming dominant species in agroforestry systems while pausing potential threat to the diversity of indigenous, especially endemic, flora in the sub montane forest of the eastern arc mountains. Binggeli and Hamiltonn (1993) and Hall *et al.* (2011) noted that 15% of gaps in ANFR contained *M. eminii* with floristically impoverished understory vegetation, little regeneration of primary forest trees and poor animal and plant diversity including that of the soil fauna. The invasion and spread of *M. eminii* in ANFR has raised recent concerns that it may dominate a significant area of the forest and impacts biodiversity and other ecosystem services (Hall *et al.,* 2011). While considerable research has been done on the ecology, spread, potential threat and effect of *M. eminii* from 1980 to 2010 in the study area, there is no updated information on the current spread over the last twenty years. After more than 50 years have elapsed since the species was first been introduced in the reserve, there is yet little information available on its invasion progress particularly after gazettment of the forest as Nature forest reserve in 1997. Furthermore, little is known about the current biophysical factors, which aid the invasiveness of the *M. eminii* species in ANFR reserve and other East Usambara mountain blocks.

In addition, no management plan exists yet for *M. eminii* in ANFR. In its 2016 – 2021 Forest Management Plan, the ANFR has a well-documented invasive species management strategy (United Republic of Tanzania [URT], 2017). The strategy lists existing invasive plants including *Maesopsis eminii, Castila elastica, Cordia alliodora, Psidium cattleianum*, *Melia azederach*, *Lantana camara* and others. Invasive control methods and management principles entail prevention, early detection and rapid response, control and monitoring, but a lack of funds, inadequate legislation/regulations and lack of information on the ecology and management best practices of invasive species are challenges that must be overcome (URT, 2017). To contribute to addressing these challenges, particularly knowledge on the ecology and management best practices of *M. eminii,* this study devises information on the species' population dynamics and distribution as well as potential management options to mitigate further spread of *M. eminii.*

1.3 Rationale of the Study

In Tanzania, like in other parts of the world, there has been a substantial increase in biological invasions caused of invasive plant species since the 1960s (Lyimo *et al.,* 2009). Many of these species have severely disrupted forest ecosystem processes, thereby hampering the provisioning of ecosystem services that societies depend upon (Chamier *et al.,* 2012). Forest-threatening invasive plant species such as *Maesopsis eminnii, Cedrela odorata, Prosopis juliflora, Lantana camara and Acacia mearnsii* have been reported to replace their native counterparts (CMEAMF, 2007; Epila *et al.*, 2017). Kilawe *et al.* (2018) mentioned *Maesopsis eminii* in the East Usambara Mountains as a highly aggressive invasive species, widely distributed in natural forests and could spread rapidly. In Amani Nature Forest Reserve (ANFR) *M. eminii* was observed to have fast growth rates and prolific seed production, which impoverished the understory scrub and herb vegetation of the forests ecosystem and alternated the canopy structure and species composition (Musila, 2006). However, it is reported that the same species is native in Lake Victoria basin, northern parts of Tanzania in Bukoba and Ukerewe districts (Hall, 1993). To contribute to knowledge on the ecology and management best practices of *M. eminii,* this study devises information on the species' population dynamics and distribution as well as potential management options to mitigate further spread of *M. eminii.*

1.4 Research Objectives

1.4.1 General Objective

The study examined the invasion dynamics and management options of the invasive tree species *Maesopsis eminii* in Amani Nature Forest Reserve.

1.4.2 Specific Objectives

The specific objectives of the study included:

(i) To quantify the current spatial distribution of invasive tree species *Maesopsis eminii*.

(ii) To evaluate changes in spatio-temporal distribution of *Maesopsis eminii* over the last 20 years.

(iii) To determine biophysical factors that promote the invasiveness of *Maesopsis eminii* in the study area.

(iv) To investigate sustainable strategies and options for management of the invasive tree species *Maesopsis eminii*.

1.5 Research Questions

To quantify the current spatial distribution of the invasive tree species *Maesopsis eminii*, the following questions were asked:

(i) What is the current spatial distribution and population structure of *Maesopsis eminii* in the study area?

(ii) What is the extent of *Maesopsis eminii* distribution in farms adjacent to Amani Nature Forest Reserve?

(iii) What is the difference in woody plant species richness and diversity in sites with and without *Maesopsis eminii?*

To evaluate changes in the spatio-temporal distribution of *Maesopsis eminii* over the last 20 years, the following questions were asked:

(i) What are the forest cover changes that took place between 1998 and 2018?

(ii) Where are the new sites invaded by *Maesopsis eminii* in the last 20 years located?

To determine biophysical factors that promote the invasiveness of *Maesopsis eminii* in the study area, the following questions were asked:

(i) Does the natural light level influence germination and growth of *Maesopsis eminii* seeds?

(ii) Does germination and growth of *Maesopsis eminii* seeds differ between wet and dry seasons?

To devise sustainable strategies and options for management of the invasive tree species *Maesopsis eminii*, the following questions were asked:

(i) What is the level of knowledge and understanding about *Maesopsis eminii* among local communities that live adjacent to the Amani Nature Forest Reserve?

(ii) What are the available mechanisms for detection and control of the invasive tree species *Maesopsis eminii* in the forest reserve?

(iii) How has the management of ANFR been working to restore, rehabilitate and prevent the spread of *Maesopsis eminii*?

1.6 Significance of the Study

This study evaluated the potential distribution of the tree species *M. eminii* in Amani Nature Forest Reserve in the Eastern Arc Mountain in Tanzania. Furthermore, the current pattern, density and distribution of invasion of *M. eminii* in the forest reserve over the last 20 years were assessed. The ecological hotspot that has been newly invaded and the extent of spread across in household farms in community adjacent forest reserve were also identified. According to Hernández *et al.* (2014) and Thapa *et al.* (2018), understanding the extent of spread of invasive species across spatial and temporal scales is central to the management of biological invasions and biodiversity conservation. Also the extent of invasion of *M. eminii* in household farms and community understanding and perspectives towards invasive species *M. eminii* and its impacts was explored.

The findings of the study uncovered important information on the current problem of invasive tree species *M. eminii* and can be used in devising sustainable management options. The study findings can also be used to propose sustainable management options and strategies for identifying gaps, needs, technical implementation and raising awareness on invasive tree species prevention and management in the country. The findings as well inform various aspects management programs and by determine areas that are susceptible to establishment of invasive species and identifying the environmental variables important to species presence and colonization, thus allowing forest managers to develop proactive management approaches. Furthermore, the study provided a framework on how to approach biodiversity loss and inform appropriate management and conservation strategies for the Eastern Arc Mountain. This can contribute in addressing solutions on adaptability, resilience to disturbance and to a broader range of biogeographic conditions and environmental controls. This provides contributions and suggestions on prompt actions needed to control the invasive species through sustained benefits of native species and biodiversity in the study area.

1.7 Delineation of the Study

In the course of interpreting results of this study, there are some limitations, which should not be overlooked. This study re-surveyed only 60 sample plots (33%) out of 181 permanent vegetation sample plots in the entire forest reserve. Re-surveying larger forest areas (larger sample size) would have provided a more comprehensive information on the distribution and recruitment of *M. eminii* in the forest reserve. The small sample size surveyed was due to time and financial resources constraints. However, it was assumed that 33% of the entire plot number is sufficient to highlight the processes and trends observed during this PhD project. Apart from that, the Landsat satellite imagery used during forest vegetation classification provided relatively medium spatial resolution (30 m) and temporal resolution of 16 days. The medium resolution characteristics of the Landsat images limited a more fine vegetation classification, reduction in the mixed pixel problem and vegetation classification accuracies as compared to higher resolution data such as SPOT High Resolution Visible (HRV), recently SPOT High Resolution Geometric (HRG) or the Sentinel. However, since this study focused on one species only that usually occurs in dense, rather mono-specific stands it was assumed that the resolution was sufficient to provide changes in forest vegetation cover in 2018 and 1998.

Another limitation was the short duration of the study, which was about 12 months. As a result, it could not be possible to follow long-term germination and growth of *M. eminii* seeds under different treatments and environmental conditions. This could have provided more information about germination and growth characteristics of the invasive species under different biophysical factors such as topography, soils, elevation and in mixture with other native tree seeds. However, at least my study covered 2 seasons, the wet and dry season, which provides a picture of *M. eminii* seeds performance over the entire growing season. Also, it was not possible to find comparative studies on germination, growth, spread vectors and other physiological characteristics from areas where *M. eminii* is not invasive as there is a lack of literature. Further, due to time and financial constraints it was not possible to visit Bukoba district and Lake Victoria regions where *M. eminii* is native. Hence, it is recommended for further studies that compare the species' behavior in both sites.

Despite the limitations, the outcomes of my study are highly useful in establishing long-term trends and invasion progress of *M. eminii* in the study area. Furthermore, the study reports on distribution of *M eminii* to household farms extending information to previous studies such as Dawson *et al.* (2009) and Hall *et al.* (2011). In addition, information on germination behavior and earlier growth of *M. eminii* can now inform management strategies on the initial seedling stage as the most important timing.

CHAPTER TWO

LITERATURE REVIEW

2.1 Invasive Species Overview

Ecologists and conservation biologists define the terminology invasive species differently. For example, Boy and Witt (2005) define invasive species as non-native species which when introduced into the environments, which they do not belong, are able to become successfully established, transform and dominate the habitat of their adoptive homes. Definition by the CBD (1992) explains invasive plant species as those species whose introduction in a new environment threatens the local biological diversity, while the IUCN describes invasive species as those species which are established in natural or semi-natural ecosystems or habitat, they change and threatens native biological diversity (IUCN, 2000). Simberloff (2013) reported that an invasive plant can either be exotic (a plant living outside its native distribution range) or native to the area (due to change in functional traits and habitat range following emerging of favorable conditions). Another definition provided by Chornesky and Randall (2003) states that, invasive species are non-native species that are established in new habitat, expand and causes ecological and economic harm while threatening human health.

In all authors and definitions, distinguishing features describing invasive species include introduction and colonization to the new habitat, replacing indigenous plant and animal communities. The invasion process of invasive species comprises of three main steps, which are the introduction stage from source of origin, establishment in the recipient region and range expansion in the recipient region (Colautti & MacIsaac, 2004; Simberloff, 2013). The introduction of alien invasive species is facilitated by various factors such as transnational trade and travel such as seed contaminants, ballast, horticultural trade and dispersal along regional transport ways such as roadsides, canals and railways (Gioria & Pyšek, 2017). Furthermore, as argued by Kohli (2009) disturbance and other landscape features play a main role in the establishment and spread of invasive plant species. Mechanism for successfully colonization of invasive species is described as both bio geographical and taxonomic phenomena (Colautti & MacIsaac, 2004) as well as physiological and functional characteristics (Binggeli & Hamiltonn, 1993; Mwendwa *et al.*, 2019). Many invasive species are tolerant, opportunistic, hard generalists and are able to adapt to a broad range of physical conditions, while exploiting variety of foods and nutrients (Boy & Witt, 2005). Never the less, absence of natural enemy such as parasites, predators, unfavorable climate and diseases that in origin habitat would keep their population in check, to a great extent facilitates their prosper.

2.2 Impact of Invasive Species in Forest Ecosystems

Forests are key natural biological resources in the world that provide essential ecosystem services (Liebhold *et al.,* 2017). They serve as an important reservoir of biological biodiversity, harboring the majority of land terrestrial species (CBD, 1992). Forests play important roles in global nutrient, water and essential element cycling. Furthermore, forests gives important human and ecological goods and services such as carbon sink to mitigate impacts of climate, water catchment for rivers, market resources to both rural and urbanized societies such as fiber, fuel, herbal medicine and food. Despite being very important biological resources, forest ecosystems are susceptible and impacted by invasive species. The impacts of invasive plant species on forest ecosystems have been mainly on both ecosystem functions, processes and services. Ecological processes at an ecosystem level usually influence plant and animal wellbeing that ultimately affects the whole ecosystem health. Kohli (2009) highlighted that invasive species have resulted in to species extinctions more than human-caused climate change and are the second leading cause of species extinctions after habitat degradation. Invasive species is one of the major reasons of biodiversity loss and are blamed for much of native species deterioration and ecosystem degradation (Brooks *et al.*, 2000).

The invasion of forest ecosystems by invasive plant species has resulted on to modification of native species abundance and survival, nutrient cycling, hydrology, fire regime as well as normal energy budgets (Mack *et al.,* 2000; Wilcove *et al.,* 1998). Invasive species further induce changes of tree species composition, alteration of forest succession, degradation of biological diversity and changing nutrients and water cycles. For example, in Ethiopia, the evergreen shrub (*Prosopis juliflora*) has formed impenetrable thickets which invade water sources, lowering the level of water-table, as a result starving other plants of moisture content and nutrients forming what is known as “green deserts” (Boy & Witt, 2005; Mehari, 2015). As another example, *Lantana camara*, is now considered the most destructive invasive species of all widespread terrestrial plants, which found distributed in more than 60 countries in Africa (Shackleton *et al.,* 2017). The invasive species produces dense thickets, which have a negative impact on native plants and is highly toxic, contributing to the poisoning of people, livestock and other animals (Vardien *et al.,* 2012).

Furthermore, forest ecosystems harbors high diversity of insects and bird species, which serve very important ecosystem process and functioning particularly dispersal and pollination. According to Keast (2000) invasive species have been reported to alter bird and insects richness and composition hence resulting on to the net effect of impaired ecosystem functioning. In addition to that, invasive plants pause considerable costs generated on forest ecosystem estimated in terms of ecosystem function damage, crop damage, loss of crop yields as well as resources allocated into prevention, control and management methods (Borghesio, 1995; Chornesky & Randall, 2003). For example, an invasive tree species *Azadirachta indica* has been reported to invade Saadani National Park in Tanzania replacing indigenous native species hampering income from tourism (Dos Santos & Kiwango, 2010). As another example, Chamier *et al.* (2012) reported that Eucalyptus species when planted near water bodies are said to affect both surface and ground water availability for other plant and animal species as well as community households. Generally, invasive species particularly plants are known to deprive natural forest ecosystems, disrupt ecological processes and undermine the delivery of essential ecological processes and services.

2.3 Invasive Plants Institutional Management Framework

Despite serious threats imposed by invasive plant species to ecosystems functioning, process and community livelihood, the problem is inadequately addressed in the regulations, policies and legislations (Ngondya *et al.,* 2017). The Plant Protection act of 1997, The Forest Act No 7 of 2002, National Forest Policy 1998, and the Forest Regulations of 2003, which govern conservation and management of forests in Tanzania mainland, do not address directly the problem of invasive species. The plant protection act set provisions to prevent the introduction and spread of harmful organisms to ensure sustainable plant protection and to regulate exports and imports of plants. The forest act of 2002, section 18(2) (c) directs on undertaking of an environmental impact assessment before construction of road or pipelines in protected forests as these might have negative impacts to native plants including introduction and spread of invasive plants. Lyimo *et al.* (2009) and Ngondya *et al.* (2017) highlighted that the main drawback of most Tanzania biodiversity conservation legislations is that they do not discourse important elements of biological invasions including procedures for assessment of imported foreign species and measures to be undertaken in case of an unlawful importation of exotic invasive species.

The National Environmental Act of 2004, policy and its regulations provides for legal and institutional basis for management of the environment and natural resources in Tanzania. However, the act lightly addresses the issue of invasive species by setting out prevention and control measures. Part VI (section 81-103) of the Act outlines the process of Environmental Impact Assessment (EIA) for projects that are likely to affect ecosystem functioning in the course of implementing construction and industrial projects. Furthermore, in the Environmental Impact Assessment and Audit regulations of 2005, section 12 (f), it is insisted that the undertaking of EIA should focus on protection of the ecological processes, productivity, capacity and their maintenance in natural systems. In the first schedule, the regulations requires compulsory EIA for projects, which are likely to have major adverse environmental impacts determining the extent, scale and consequence of the impacts while directing appropriate mitigation measures. The areas mentioned include agriculture, fisheries, forestry, range management and wildlife projects, which are likely to introduce new species.

Overall it is reported that, in Tanzania's natural resources and environmental conservation legislations and policies, there are inadequate approaches towards management and control of the invasive species (Ngondya *et al.*, 2016). This weakness may explain the insufficient attention, priority and resources directed to the management of invasive species and their increased rate of introduction and spread. For an effective and successful invasive species management strategy, Boy and Witt (2005), United States Department of Agriculture [USDA] (2013) and the National Invasive Species Strategy (2019) proposed four key elements which are: a) Prevention, b) Detection, c) Control and Management, d) Restoration and Rehabilitation (Fig. 1). According to the framework, the elements are not distinct from each other; instead they overlap to form an integrated adaptive approach for addressing and managing invasive species.

Prevention involves all actions that focus to stop introduction in an area and establishment of invasive species in the forests, waterways, agricultural fields, rangelands, grasslands and others. Tobin (2018) suggested that prevention is an effective management strategy that stops invasive plants from arriving in an area in the first place.

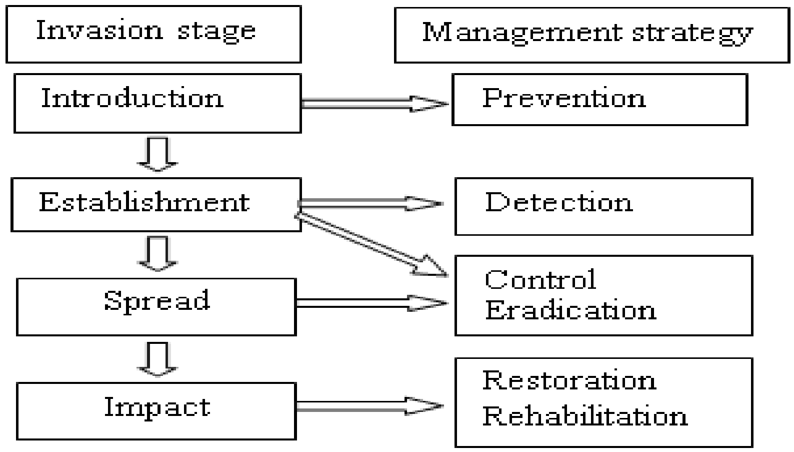


Figure 1: Framework indicating management strategy for invasive species based on invasion stage (Tobin, 2018; USDA, 2013)

In the event that prevention fails and invasive species arrives, timely detection process becomes important as it provide base for rapid response, eradication and control of the invasive species. Detection element in the model entails sighting, identification and monitoring of newly arriving invasive species (Boy & Witt, 2005). Once the invasive species has been detected, control and management becomes applicable. In control and management, the stage involves direct eradication of the invasive species, containment or management in order to mitigate further spread and impacts (Boy & Witt, 2005; USDA, 2013).

Integrated control mechanisms of invasive species combines various methods such as manual, chemical, mechanical, and biological methods which focuses to reduce the density and abundance of infestations caused by invasive species, and to keep harmful impacts down within manageable limits (Boy & Witt, 2005; Ngondya *et al.,* 2017). Restoration and rehabilitation strategy focuses to lessen or reverse adverse ecosystem effects caused by invasive species. According to Chazdon (2008) and Derak *et al.* (2018) restoration and rehabilitation revert ecological degradation caused by invasive species while improving ecosystem health, functions and productivity and reduces vulnerability to new infestations. As insisted by Boy and Witt (2005) management of invasive species at impact stage without follow up restoration and rehabilitation actions is most likely to fail. Restoration and rehabilitation programs aim to substitute native species that have been replaced by invasive species. This can be done with variety of plantings and reseeding that help restore the natural composition, processes and functioning of the ecosystem.

2.4 The East Usambara Mountain

The East Usambara Mountain (Fig. 2) is one of the 13 separate mountain blocks forming ancient Eastern Arc and Coastal forests of Tanzania (Burgess *et al.*, 2007). The East Usambara are range of mountains extending to the northeastern region of Tanzania topped by the tropical rainforests and grassland. The mountain range are composed of ancient crystalline rocks composed of granulates, gneiss and amphibolite believed to exist for about 30 million years that are believed to have once connected to the Congo basin and West Africa (EAMCEF, 1999; Hokkanen, 2002). The mountain range are 1200 km^2, from 4^o 48" to 5^o 13" and from 38^o32" to 38^o48", only 40 km from the Indian Ocean (Hall *et al.*, 2011; Hamilton & Bensted, 1989).

The East Usambara mountain contain two Nature Forest Reserves, Nilo and Amani and other 12 Forest Reserves namely Derema, Segoma, Kwamgumi, Bamba, Kambai, Semdoe, Manga, Mtai, Mlinga, Mlungui and Longuza forest plantation (Hamilton & Bensted, 1989). This is in addition to other four Village Forest Reserves found in Mfundia, Kizee, Handei and Kizangata (EAMCEF, 1999; Gereau *et al.*, 2016). The proximity of East Usambara to the Indian Ocean provides high rainfall reaching to 3000 mm per year and long-term stable climatic conditions for at least the past 30 million years (Burgess *et al.*, 2007; Lovett, 1998). The high rainfall, long-term stable climate and fragmentation of the East Usambara Mountain have resulted in forests that are both oldest, most stable and high biodiversity forest ecosystems.

The East Usambara, like other forest blocks of the Eastern Arc Mountain forests is very important locally, nationally and internationally due to its high biodiversity, ecological values, livelihood services and exceptionally high degree of endemic plants and animals (Hamilton & Bensted, 1989; Kijazi *et al.*, 2014; Lovett, 1998). The mountain is renowned for its extraordinary richness for nature, place for biological and botanical studies and for the multi natural-related socio economic projects.

In 2000 the East Usambara Mountain was designated as the man and biosphere reserve (BR) by the United Nations Educational, Scientific and Cultural Organization [UNESCO] (Kijazi *et al.*, 2014), that is a conservation and development area recognized internationally under UNESCO's Man and Biosphere programme.

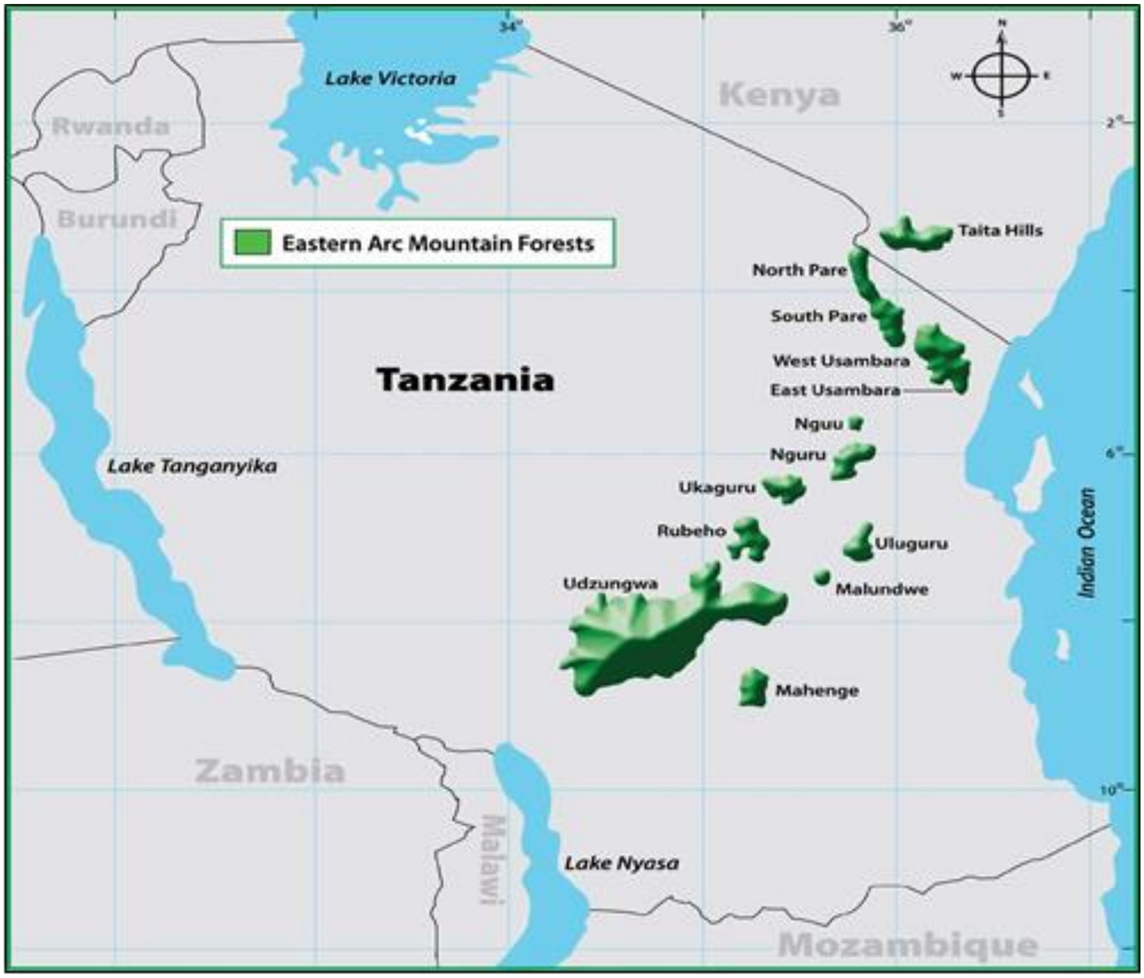


Figure 2: Location of East Usambara Block in the Eastern Arc Mountains (EAMCEF, 1999)

According to the programme, the goal of the East Usambara as a man and biosphere reserve is to conserve forest biodiversity, maintenance of ecosystem functions, provide place for learning of natural and scientific systems and traditional forms of land-use, sharing of knowledge and solutions to natural resources problems (Hokkanen, 2002). Other biosphere reserves recognized by UNESCO in Tanzania are the Serengeti Ngorongoro ecosystem and Lake Manyara National Park. The East Usambara is categorized as the globally important biodiversity hotspot for high conservation priority by the Conservation International (Brooks *et al.*, 2000; Turner *et al.*, 2007). That is, the reserve is listed as one of 36 global biodiversity hotspots which conserve world's 50% of endemic plant species and 42% of endemic land vertebrates (Hrdina & Romportl, 2017).

According to the Conservation International, in order for an area to qualify as a World's Biodiversity hotspot, it has to meet two main quantitative identification criteria which are: a) The area must harbour at least 1500 of the vascular plant species being endemic to that area, b) The area has to have lost at least 70 % of its original primary habitat (Brooks *et al.,* 2000; Hamilton & Bensted, 1989; Hrdina & Romportl, 2017). While the East Usambara has such high level of biodiversity, restricted range birds, significant number of globally threatened species and significant populations of birds (Gereau *et al.,* 2016), it has been subjected to a major degradation caused by big expansion of peasant agriculture and large scale logging operations hence suffered loss of ecological habitat.

The World Wildlife Fund (WWF) considers the East Usambara and other Eastern Arc Mountain blocks as the Global - 200 priority eco-regions (Burgess *et al.,* 2007). These are the global recognized ecological regions of the world that possess unique values in terms of biodiversity of animals, plants, as well as non-species biodiversity values such as the migrations of large numbers of mammals and birds and presence of ancient species groups. Also, the Bird Life International has identified the area as Important Bird Area (IBA), one of the regions of the world that are of extraordinary importance for the conservation of avian species and hence of high importance for bird conservation (Hokkanen, 2002; Kijazi *et al.,* 2014; Miller, 2013).

It is estimated that overall the East Usambara contains 71 species of vertebrate species which are near-endemic to the Eastern Arc Mountain, where among these, about half are found in the lowland Coastal Forests (Lovvet, 1998). The majority of these species are forest-dependent while the few remaining depend on non-forest habitats. Besides providing ecosystem services East Usambara mountain provides plants for economic value, medicinal value, water catchment services for agricultural domestic, and industrial use to major rivers of coastal regions such as Ruvu and Pangani while supporting livelihood needs for local people along adjacent communities (Burgess *et al.,* 2007). However, despite the potential values of the bio reserve, the current spread of *M. eminii* in the East Usambara, particularly in Amani Nature Forest Reserve, endangers this biodiversity hotspot and forest ecosystem (Tennigneit & Bongers, 2008; Bingeli & Hamilton, 1993).

2.5 *Maesopsis eminii* Overview

2.5.1 Botanical Description of *Maesopsis eminii*

Maesopsis eminii (Common name: Umbrella tree) is an angiosperm large African rain forest tree species which is in the family Rhamnaceae, including many extremely drought-tolerant species (Verbeeck *et al.,* 2017). Locally, *M. eminii* is known as Muzizi (Swahili), Muhumula (Haya), Muhesi (Sambaa/Chaga), Msira (Kerewe), Musizi (Luganda) (Epila *et al.,* 2017; Hamilton & Bensted, 1989). It is a semi-deciduous tree which grows up to 45 m tall with definite bole to about 2/3 of the height and has a pale grey bark, deeply fissured with inner bark deep red (Ani & Aminah, 2006). It branches horizontally with flat crown when young and turns round with age. Leaves *of M. eminii* are simple, dentate, sub opposite or alternate and with an obovoid drupe fruit 20-35 x 10-18 mm in size with serrate margins (Mugasha, 1981). Drupe fruit change from green to yellow to purple-black when mature (Fig. 3); flowering and fruiting begin when the trees are about 4-6 years old, a fruit is produced every year and seed production is normally abundant (Binggeli & Hamiltonn,1993; Hamilton & Bensted, 1989; Viisteensaari *et al.,* 2000). Fischer's turaco (*Tauraco fischeri*), hornbills (*Bycanistes bucinator*), fruit bats (*Eidolon helvum*) and blue monkey (*Cercopithecus mitis*) feed on *M. eminii* fruits (drupes) and are the dispersal agents for the species (Epila *et al.,* 2017).

Maesopsis eminii seeds germinates at higher rates, successfully (Fig. 4) and grows well in disturbed areas with canopy gaps of at least 300 square meters (Kilawe *et al.,* 2018). Similarly, Cordeiro *et al.* (2004) found that the greatest proportion of experimental seeds of *M. eminii* germinated in large tree-fall gaps and along forest edges, where there is more light and bare humus soil is available hence enhancing germination of *M. eminii* seeds. The *M. eminii* is extremely competitive in forest gaps as well as secondary forests and disturbed areas. It survives well on poor soils and growing faster than many coniferous trees, which has accounted for its broad use in afforestation enrichment, plantation forestry, ecological restoration and agroforestry practices (Ani & Aminah, 2006; Josh *et al.,* 2015; Orwa *et al.,* 2009).

Figure 3: ***Maesopsis eminii*** **seeds in Amani Nature Forest Reserve (Field survey, 2018)**

In the East Usambara Mountains, *M. eminii* was used for enrichment planting and restoration to fill forest gaps and extensively deforested areas after expansion of peasant's agricultural activities and large-scale forest harvesting operations in the 1960's (Geddes, 1998; Hall, 1995). Binggeli (1989) reported that preference of *M. eminii* was due to its quick growth rate and short felling cycle of about 40 years instead of 80 years for other hard wood native trees. In other parts of Tanzania, the species is extensively used in household farms and agroforestry as shade and border tree and for timber production due to its high growth rate (Hall, 2010). Outside Tanzania, *M. eminii* has been widely used through the tropics in timber plantations and as a key component in agroforestry (Hall, 2010). Reports indicate the use of *M. eminii* as a shade tree in banana, cocoa, coffee, and cardamom plantations in Uganda, Kenya, Congo, India, Ghana and Indonesia (Hall, 2010).

Figure 4: Seedlings of *Maesopsis eminii* near mother tree (left) and *Maesopsis eminii* sapling thriving in an open forest gap in Amani Nature Forest Reserve (Field survey, 2018)

2.5.2 Ecology and Distribution of *Maesopsis eminii*

Maesopsis eminii is regarded as a typical guineo-congolian species which is widely distributed in central and eastern Africa lowland forests. Genus Maesopsis is considered to be a complex of four species: *M. berchemioides*, *M. eminii*, *M. stuhlmannii* and *M. tessmannii* native to tropical Africa (Centre for Agriculture and Bioscience International [CABI], 2019). The species berchemioides are found from Sierra Leone to Congo Republic, while from the Democratic Republic of Congo to Central African Republic to east and south to Angola and Zambia the species *M. eminii* is dominant. While little is known about the specific distribution of species *M. stuhlmannii* and *M. tessmannii* (Epila *et al.*, 2017; Hall, 1993). Outside of Africa, *M. eminii* has been reported to be introduced by human and disseminated successful across the tropical belt (Fig. 5) in Australia, Philippines, Bangladesh, Brazil, Costa Rica, Fiji, India, Malaysia, Samoa, Solomon Islands, Hawaii, Puerto Rico and Indonesia. In these areas, the species is widely afforested in timber plantations such as in Puerto Rico and Fiji, as a shade tree for coffee plantations in India and Indonesia and elsewhere in Asia as an agroforestry tree (Epila *et al.*, 2017; Hall, 2010).

Figure 5: Global map indicating distribution of *Maesopsis eminii* (yellow mark) across the tropical belt (CABI, 2019)

The species is an early successional type, which easily adapt and colonize forest gaps and edges. Within the area of natural distribution, *M. eminii* is found in the lowlands and extending into sub-montane forest up to 1800 m altitude. The species grows naturally in riverine forests, rainforests, lowland, swampy forests and submontane forests (Binggeli, 1989; Dawson *et al.*, 2009). Naturally, *M. eminii* is a pioneer and subclimax forest species, which is capable to live for about 150 years (Binggeli & Hamilton, 1993). *Maesopsis eminii* in plantations it is normally planted in the lowland and grows well at altitudes from 600 to 900 m and mean annual rainfall ranging from 1200 to 3600 mm (Mugasha, 1980). It is capable of tolerating drought for up to 6 months and a wide range of difficult conditions while growing well on moist, deep, and fertile sandy loam soils with a neutral to acidic pH (Ani & Aminah, 2006). However, it has been revealed that *Maesopsis eminii* is prone to attacks by Lepidoptera species such *as Eagris decastigma*, *Charaxes achaemenes*, *Charaxes lactetinctus*, beetles such as *Monohammus scabiosus*, fungi species mainly *Fusarium solani* and Volutella species and browsing animals such as elephants, termites and spider mites (Eggeling, 1947; Orwa *et al.*, 2009).

2.6 Invasion of *Maesopsis eminii* in Amani Nature Forest Reserve

Maesopsis eminii is native to Tanzania and its natural range is limited to the rain forest of Bukoba District and some of the islands of Lake Victoria (Geddes, 1998). However, various studies have indicated *Maesopsis eminii* as one of the very successful invasive tree species in Amani Nature Forest Reserve (Binggeli, 1989; Binggeli & Hamiltonn, 1993; Hulme *et al.*, 2013). Binggeli and Hamilton (1993) presumed that this aggressive tree species was introduced to the East Usambara Mountain by Germans around the 1910s for plant experimental growth studies and to nurse and shade growing native tree species such as *Cephalosphaela usambarensis, Pneumonia Buchananii and Berchemedia kweo*. Large scale planting in the 1960s and 1970s to fill logged forest gaps created a massive seed source of *M. eminii* which contributed this species to spread into various parts of the forests due to its fast growth rate and massive seed production (Hall, 1995; Hamilton & Bensted, 1989). This invasive tree is becoming a dominant species in natural forestry and also in household agroforestry fields in the East Usambara Mountains (Hall *et al.,* 2011). Invasion of *M. eminii* in the reserve has lead to impoverished understory vegetation and alternated canopy structure and species composition (Musila, 2006). However, not much is known on its invasion progress and biophysical factors contributing to its successful invasion, which must be identified in order to inform sustainable

control and management options.

Figure 6: High density *Maesopsis eminii* stand near Kwamkoro station in Amani Nature Forest Reserve (Field Survey, 2018)

Apart from the East Usambara mountains, *M. eminii* invasion has also been reported in Ngezi forest in Pemba island and Puerto Rico (Hall, 2010). Various eco physiological studies has been conducted to shed light on the aggressive nature *of M. eminii*. Epila *et al.* (2017b) and Hubeau *et al.* (2019) demonstrated contribution of adaptive physiological responses particularly active phloem loading properties as well as drought-induced cavitation and hydraulic capacitance in successful invasion and colonization of *M. eminii* species. According to Epila *et al.* (2017b) Hydraulic capacitance linked to anatomy and leaf-water relocation characteristics is one of the crucial eco physiological features for drought survival strategies of *M. eminii.* This crucial position of physiological and structural properties has been reported to explain the unique characteristics of *M. eminii* such as drought-deciduous leaves, pioneer characteristics, ability to tolerate drought, invasive nature, fast growth capability and high light demand (Eggeling, 1947; Epila *et al.,* 2017; Epila *et al.,* 2018; Hubeau *et al.,* 2019). Despite of the broad eco-physiological studies, there is no clear information on the factors for *M. eminii* invasion only in East Usambara, Pemba and Puerto Rico islands.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

Amani Nature Forest Reserve (ANFR) is located along 5°14’10’’ to 5°04’30’’ S and 38°30’34’’ to 38°40’06’’ E at 190 masl to 1130 m.a.s.l within northeastern Tanzania (Fig. 7). The Nature Reserve, situated at the foothills of the East Usambara Mountains and forms the largest single block of forest with 8360 ha in size (Hall *et al.,* 2011). It is a catchment of Sigi River with sub-montane forest vegetation, lowland and plantation forests that were gazetted as a nature and biosphere reserve in 1997 (Frontier Tanzania, 2001). Its proximity to the Indian Ocean ensures high annual rainfall ranging from 600 mm to 3000 mm and relatively stable mean temperature ranging from 15^{o}C to 23^{o}C (EAMCEF, 2013). Both of the sub-montane and lowland forests of the Amani Nature Forest Reserve is part of a “biodiversity hotspot”, named by Conservation International and an Endemic Bird Area (EBA) (Stattersfield *et al.,* 1998). Amani Nature Forest Reserve contains 71 species of vertebrates, which are near-endemic to the Eastern Arc Mountains, and of these, nearly half are found in the lowland Coastal Forests (Mugasha *et al.,* 2000). The reserve also form part of the East Usambara mountain which consists of 3450 different vascular plant taxa of which 64 are strictly endemic (URT, 2017).

Maesopsis eminii has accounted for more than 6% of large trees in pristine forest, 30% in secondary forest and 50% in agroforestry systems of this area (Hall *et al.,* 2011). The spread of *M. eminii* into the forest impoverishes the understory scrub and herb vegetation, altering the canopy structure and species composition, thereby modifying the regeneration environment of native species (Burgess *et al.,* 2007). It further changes fauna species composition, and elevates soil pH (Binggeli, 1989; Binggeli & Hamiltonn, 1993; Burgess *et al*., 2005; Dawson *et al.,* 2009; Hall, 1993). In agroforestry systems surrounding the forest reserve, the invasive species is used as shade tree in cardamom (*Elettaria cardamomum*), cinnamon (*Cinnamomum verum*), tea (*Camellia sinensis*) and cocoa (*Theobroma cacao*) plantations (Epila *et al.,* 2017; Hall *et al.,* 2011). The Forest Reserve is surrounded by twenty villages (URT, 2017), with almost half of the population located in the villages south and south-west of the reserve and about 10% living in two enclaves in the forest (Frontier Tanzania, 2001; Shoo & Songorwa, 2013; URT, 2017; Fig. 1). Communities bordering the ANFR practice small holder agriculture and cash crops (Engh, 2011). A recent survey has indicated persistent problems of timber harvesting and pole cutting, even though the people are aware of the forest conservation needs (URT, 2017).

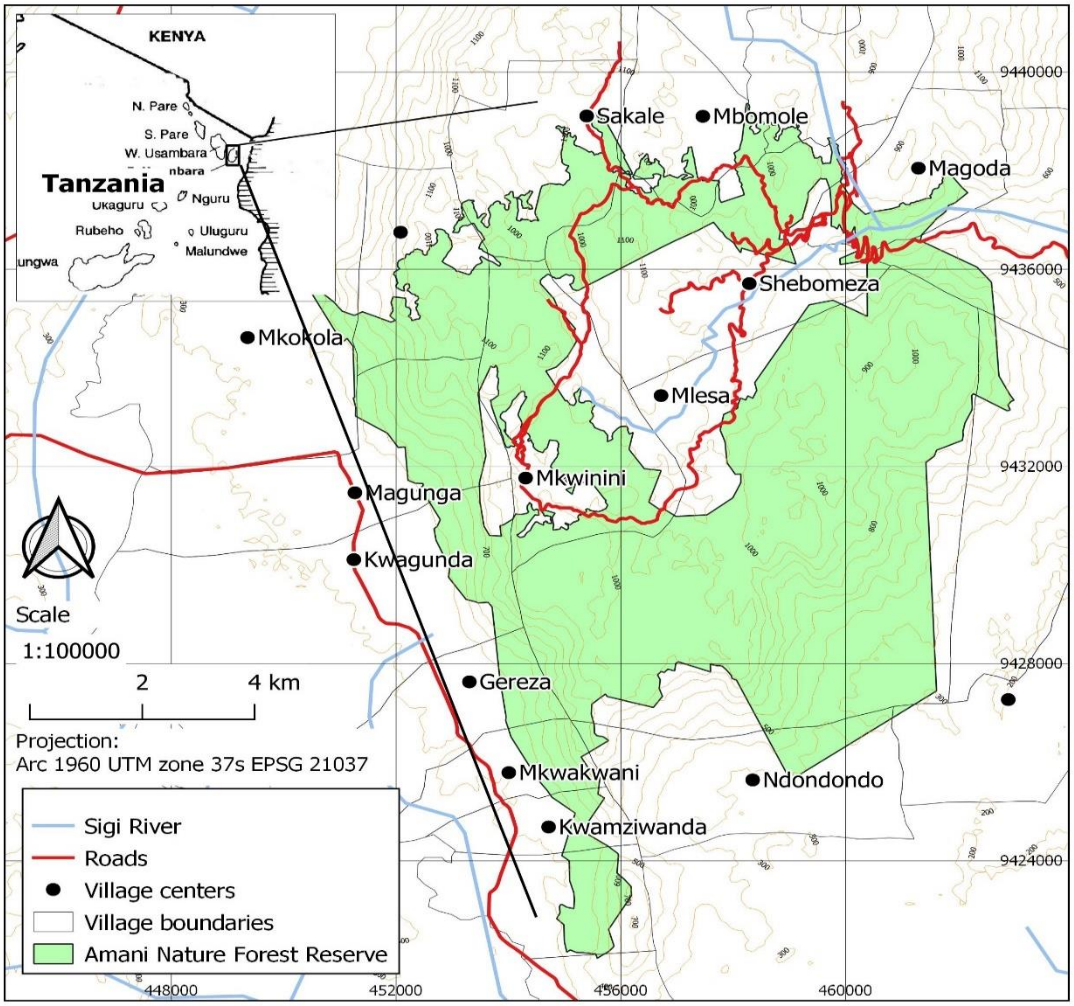


Figure 7: Map of East Usambara mountains showing the location of Amani Nature Forest Reserve (Frontier Tanzania, 2001)

3.2 Study Design and Methodology

3.2.1 Forest Vegetation Survey

Forest survey adopted a study design by Frontier Tanzania (2001) and was resurveyed the same transects and plots that had been established in 1998. Then, the current distribution of *M. eminii* was surveyed relative to other native tree species along fourteen straight line grid, 900 m apart from each other and of various lengths, ranging from 0.6 km to 11 km (Frontier Tanzania, 2001). The grid lines were orientated from West to East to facilitate maximum sampling of the altitudinal variation. Vegetation sample plots were 20 m x 50 m, located at every 450 m along each grid. The 60 plots out of 181 that had been established in 1998 were surveyed. The 30 plots invaded already in 1998 by *M. eminii* and 30 plots that had not been invaded in 1998 (control) were investigated. Plots that were close to the border as it was expected that these might be the first ones to be invaded and plots located above 800 m.a.s.l where *M. eminii* is usually found were included. Other variability considered were population size of adjacent villages, accessibility and socio economic activities such as factories, tea plantations and settlements resurveyed invaded and control plots were randomly distributed within the entire forest reserve (Fig. 8).

In each sample plot, all tree species with diameter at breast height (DBH) for *M. eminii* trees were identified. Also 10 m x 10 m sub-quadrats (four in each plot) were laid to assess regeneration in each sample plot, in which all tree species and measured *M. eminii* trees with DBH below 10 cm (hereafter called saplings) were identified. Elevation and aspect of each sample plot were recorded together with woody species richness, abundance and relative density. Tree species diversity was calculated in each sample plot using Shannon-Wiener index. Shannon-Wiener index was preferred in this study because it gives information on both species richness and their relative abundances (Hitimana *et al.*, 2004; Kijazi *et al.*, 2014) and mapped the distribution of *M. eminii*.

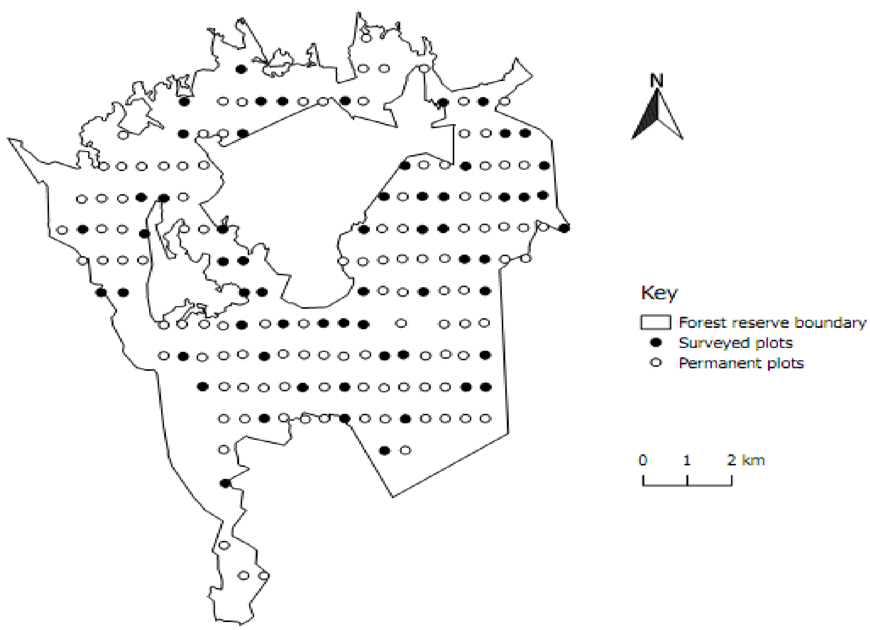


Figure 8: Amani Nature Forest Reserve map showing permanent plots established by Frontier. Of those plots, black circles were those selected for the study to monitor the spread of *Maesopsis eminii* (n = 60)

3.2.2 Satellite Imagery Analysis

Remote Sensing data of forest vegetation cover for the years 1998 and 2018 were obtained from United States Geological Survey (USGS) Earth Explorer satellite imagery archive. Landsat- 5-TM of October 1998 and Landsat-8-OLI of November 2018 were selected. Preference to Landsat imagery was due to their relatively high resolution (30 m × 30 m) and appropriate spectral designed suitability for vegetation cover analysis (Table 1).

Table 1: Landsat Imagery properties downloaded for forest vegetation cover classification

Type	Sensor	Path/Row	Acquisition date	Cloud cover (%)
Time 1	Landsat 5 TM	166/064	21/10/1998	0.00
Time 2	Landsat 8 OLI	166/064	15/11/2018	0.36

Prior to classification, the Landsat images were re-projected to Arc UTM 1960, Zone 37S. Images were pre-processed for more direct association between the biophysical phenomena on the ground and the acquired data (Coppin *et al.,* 2002). During image pre-processing, the Landsat layers were masked and stacked together to reduce the effect of cloud cover; clipped and radiometric calibration and image enhancement were applied. Radiometric calibration involved conversion of per pixel value to radiance and to convert radiance to reflectance, performed in Environment for Visualizing Images (ENVI) version 5.3 software (Key & Benson, 2006).

Pixel-based vegetation cover classification was performed in ENVI 5.3. I used multispectral bands; 1–5 and 7 of the Landsat- 5- TM and bands 2–7 of Landsat 8 OLI images. Spectral band combination of RGB (Red, Green, Blue) color composite and true colors composite used band 4, 3 and 2 for Landsat 5 TM and band 5, 4 and 3 for Landsat 8 OLI. This band combination were clearer and different vegetation types could be easily separated. Prior to image classification, two land cover classes were developed: a) forest, and b) non-forest. Forest was defined as a continuous stand of trees with no evidence of farming or settlement (Kilawe *et al.,* 2018b). All other cover types were defined as non-forest including but not limited to grassland, open land, agricultural fields, settlements, grassland, infrastructure and other area of land covered with trees less than 5 m.

Training samples for each land cover class were drawn from the images, a minimum of 50 samples for each class was considered adequate. Differentiation of classes was based on image color, tone and texture by using different spectral band combination such as; true colors composite, infrared and vegetation analysis using band 4:3:2 for Landsat 5 TM and band 5:4:3 for Landsat 8 OLI where forest appear as red and non-forest as green, gray, blue or black. Land cover classification was performed in ENVI using support vector machine classifier (SVM), which is considered to give high classification accuracy (Huang & Townshend, 2002; Pal & Mather, 2005). Error matrix was used to assess and measure the accuracy of vegetation cover map (Wulder *et al.,* 2008, Congalton, 1991). Every classified map was assessed by randomly collecting 254 ground truthing points for the year 2018 and 290 points for the year 1998 from respective unclassified images and assigning classes to each point based on visual interpretation.

A confusion matrix was run to compare classes to the classified images based on Wulder *et al.* (2008).

3.2.3 Germination Experimental Design

The experiment was conducted in shade houses at the central nursery, Kwamkoro Station, in Amani Nature Forest Reserve. Shade houses (Fig. 9) were constructed with shade net (Hessian nylon, Illuminum Company Ltd, Nairobi Kenya) to provide forest-like sun flecks. Shade nets (one meter squire each side) were calibrated with shade level-categories of 0% (L0), 50% (L50), 65% (L65) and 85% (L85), representing light regimes frequently found in tropical natural forests throughout the entire growing seasons (Flores *et al.*, 2016; Kyereh *et al.*, 1999; Svriz *et al.*, 2014). The methods for seed germination experiments in Pinus species by Zhang *et al.* (2012) was adopted with some modification, including use of 50% shade instead of 40% and conducting the experiment during wet and dry season unlike the author who repeated the experiment for several years. *Maesopsis eminii* seeds were obtained from Amani Central Nursery, collected in February 2018 and air dried for four weeks before sowing as recommended by in Binggeli (1989) and Mugasha (1981).

Figure 9: Shade houses for *Maesopsis eminii* seed germination experiments at Kwamkoro central nursery, Amani Forest, Tanzania. Shade house A = 50% shade level, B = 65% shade level C= 85% shade level

Based on *M. eminii* seed biology, it is known that seed viability lasts for 6 months and it was important to air dry seeds before sowing in order to reduce moisture content which hampers seed viability (Mugasha, 1981). Soils were collected from the forest, sieved to exclude residual roots or seeds and air dried prior to use. Ten seeds were sowed per each shade category and replicated four times, i.e., a total of 160 seeds were sowed. Seed beds at each shade level were kept moist by regular watering with 1 litre *ad libitum*. As the treatment of irrigation was equal for all, each seed was given the same chance for germination. In this experiment, germination was defined as the first needle or radicle sprout becoming visible (Flores *et al.,* 2016) and germination success was recorded at 7-day intervals and ceased when no further seeds germinated for seven days. The experiments were carried out in March and April, 2018, during the wet season, with an average monthly precipitation and temperature of 256 mm and 23°C and repeated during the dry season, in July and August, 2018, with average precipitation and temperature of 67 mm and 15°C respectively (URT, 2017). In this experiment, the following parameters were collected.

(i) Germination Parameters

Five different germination parameters namely Final Germination Percentage (FGP), Mean Germination Time (MGT), Germination Index (GI), Coefficient of Velocity of Germination (CVG) and Germination Rate Index (GRI) were assessed consistently to Ajmal and Ungar (1998), Al-Ansari and Ksiksi (2016), Aravind *et al.* (2018) and Kader (2005). Final Germination Percentage (FGP) attained under each shade level was calculated as:

$$FGP = \frac{Ng}{Nt} x100\% \quad 1$$

Whereby N_g = Total number of seeds germinated and N_t = Total number of seeds evaluated. The Mean Germination Time (MGT) of seeds under a given shade level was calculated as:

$$MGT = (\sum Ni * Ti)/(\sum Ni) \quad 2$$

Whereby N_i = Number of seeds germinated per day and T_i = Number of days from the starting the experiment. The FGP and MGT were combined and presented in the form of Germination Index (GI) calculated based on the formula:

$$GI = \sum Nx * Ti \quad 3$$

with N_x = Number of germinated seeds at the end of the experiment and T_i = Number of days from the beginning to the end of the experiment. Coefficient of Velocity of Germination (*CVG*) was calculated to find out the rapidity of germination through the following formula:

$$CVG = (\sum Ni * 100)/(\sum Ni * Ti) \quad 4$$

Ni = Number of seeds germinated in a given period of time, Ti = Number of days, Germination Rate Index (*GRI*) represented the percentage of germination per day and was calculated by the following formula:

$$GRI = \sum Ni/Ti \qquad 5$$

Where Ni = Number of seeds germinated in a given time, Ti = Number of days.

(ii) Growth Parameters

Shoot height (SH), stem diameter (SD), total fresh biomass (TFB), total dry biomass (TDB) and total leaf chlorophyll content (ChC) were measured as morphological and physiological indicators of seedling health and quality (Haase, 2008) across various shade level treatments during dry and wet seasons. The five *M. eminii* seedlings was selected from each replicated site and measured shoot height using a meter stick. This was measured as a vertical distance from the cotyledon scar to the end of the growing tip similar to (Mexal *et al.,* 1990). Stem diameter was measured with digital calipers perpendicular to the stem at the scar of first leaf as an average of five seedlings in each replicate. Total fresh and dry (dried at 65^{o}C for 48 hours in hot air Asian oven manufactured by IndiaMART, New Delhi) biomass was recorded using a digital weighing scale and represented shoot and root mass of *M. eminii* seedlings (Haase, 2008; Mašková & Herben, 2018). Leaf chlorophyll content (ChC) of *M. eminii* seedlings from each shade level were extracted based on procedures similar to Alpert (1984) and Ngondya *et al.* (2016). Leaves from five seedlings selected randomly from replicates were picked in each treatment. The 70 mg of young fresh leaves were immersed in 6 ml of Dimethyl Sulfoxide (DMSO) without grinding, and incubated at 65°C for 12 hours in Asian oven manufactured by IndiaMART, New Delhi. The extract was transferred to a test tube and made up to a total volume of 10 ml with more DMSO. A 3 ml chlorophyll extract of *M. eminii* leaves were transferred into glass cuvettes to determine optical density (OD) of the sample. The OD of blank liquid (DMSO) and that of *M. eminii* samples were determined under 2800 UV/VIS spectrophotometer (UNICO®) at 663 nm and 645 nm based on Hiscox and Israelstam (1979). The absorbance of the blank was deducted from the absorbance readings of every sample prior to calculations being made. *M. eminii* leaf chlorophyll contents were calculated based on the Equation that:

Leaf Chlorophyll Content = 0.0202$A663$ + 0.00802$A645$ (Hiscox & Israelstam, 1979) (6)

Whereas; A663 and A645 are absorbance readings at 663 nm and 645 nm respectively.

3.2.4 Socio Ecological Survey

In studying distribution of *M. eminii* in household farms and socio ecological interactions, the reconnaissance survey was conducted in the forest communities inside the forest reserve as well as in the forest boundary. The survey encompassed interviews, participant observations, and use of archive data to gain an overview of existing *M. eminii* management strategies, distribution and community perspectives in the study area. The reconnaissance survey results provided us historical information on the invasive species as well as guidance on the areas to focus and target for main field data collection.

Stratified random sampling approach was used to identify locations of household farms in each of the four forest zones, namely South zone, East, North and West. Sampling units were the household farms ranging 0.5 to 1 ha in size, which is the average household farms commonly owned by forest communities adjacent to the Amani Nature Forest Reserve (URT, 2017). The farms cultivating maize, cassava, bananas, beans, sugarcane, cinnamon, cloves and black pepper were purposively selected as these are the main food and cash crops cultivated in adjacent forest communities (Hall *et al.*, 2011). The primary data were collected through semi-structured interviews from household farm holders, forest reserve officers, village leaders and additionally counted all *M. eminii* trees in the interviewed farms. The 102 farmers were interviewed (representing 5.1% of the total households adjacent ANFR) from 20 villages (Table 2) as well as 33 key informants who were seven forest reserve officers, six Agricultural officers and 20 local village leaders. The questionnaire was administered to respondents aged 25 years and above, who had lived in the respective location for at least five years or more. The overall information on understanding of *M. eminii* species, introduction and distribution of *M. eminii* in the farms, their perceptions on threats of *M. eminii*, control and management of the invasive species in their communities was collected.

Table 2: Sampling units and samples for household interviews in Amani Nature Forest Reserve (See also Fig. 18)

Forest reserve area	Village name	No of households
North	Mbomole	5
	Derema	4
	Manga	6
	Shebomeza	6
	Ndola	5
East	Kwamdimu	5
	Kisiwani	5
	Mashewa	5
	Mlesa	6
	Kimbo	5
West	Gereza	5
	Mkwakwani	5
	Kwagunda	4
	Mikwinini	5
	Muhemi	5
	Sarawe	5
South	Kwamzindawa	5
	Mnyuzi	5
	Potwe mpirani	6
	Potwe ndondondo	5

3.3 Data Analysis

Vegetation cover changes between 1998 and 2018 were captured through change detection analysis of Satellite images. The Change Workflow post classification change detection was performed in ENVI 5.3 software and produced maps and statistics indicating the area that had been converted from forested to non-forested vegetation and vice versa. Ground forest inventory and survey data were summarized, categorized and analyzed using both inferential and descriptive statistics. Individual tree species were identified at plot, species and family levels. Individual tree species were characterized in terms of species richness, abundance, density (no of trees/hectare) and diameter at breast height (DBH) classes. Species diversity in the surveyed area was presented using Shanon Wiener index while differences in species richness and DBH classes were compared using Mann-Whitney U test. Shannon-Wiener index was preferred because it combines both species richness and their relative abundances consistent to Kijazi *et al*. (2014). The relationship between *M. eminii* density and elevation gradient, distance from forest edge, village centers and species richness were determined using Spearman's Rank order correlations. For germination experimental design, effects of different shade levels, seasonality and their interaction on seed germination rates were compared using one-way ANOVA in a factorial design using Tukey HSD post hoc test.

The thematic analysis method (Cumming & Allen, 2017) was used to analyze socio-ecological data gathered from interviews. The ideas, patterns and knowledge from respondents and presented in form of common themes and percentages were identified. The number of *M. eminii* individuals in each household farm were counted, grouped and presented as percentage and density per hectare in relation to all farms surveyed. The size of each *M. eminii* tree was measured, summarized and grouped the results in according DBH classes against their frequencies in percentages. Relationship between respondents' knowledge about *M. eminii* invasion, potential management options, use of *M. eminii* versus age of respondents and distance from forest reserve boundary were compared using Spearman Rank Order Correlation. Level of significance was set at $\alpha = 0.05$. Prior to analysis, all data were tested for normality using Shapiro Wilks test, where results greater than 0.05 were regarded as being normally distributed. Statistical analyses were carried out in IBM SPSS version 20 and OriginPro 2015 software.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Forest Vegetation Survey

(i) Change in *Maesopsis eminii* Distribution

Out of 30 control sample plots that had not contained *M. eminii* in 1998, seven plots (23%) were observed to have been invaded by *M. eminii*, while all plots that had been invaded in 1998 still contained same *M. eminii* in the year 2018. Three of the seven newly infested vegetation sample plots were located in the southwestern region of the nature forest reserve, adjacent to highly populated villages namely Kwagunda, Gereza, Mkwakwani, Kwamzindawa and Mnyuzi (Fig. 3). Half of the entire local human population adjacent to Amani Nature Forest Reserve is located in these villages, south and south west of the forest reserve (URT, 2017). It was found that *M. eminii* currently occupies 86 plots (48%) as compared to 79 plots (44%) in 1998 and out of 181 permanent sample plots in the entire forest reserve (Fig. 3). The field survey data of this study concurred with remote sensing data as three plots out of seven newly invaded sample plots were recorded within the areas that were classified as "converted into forest". Based on these findings, there was an increase of *M. eminii* individual trees by 4 % (86 plots out of 181 permanent plots) in the surveyed plots from 1998 to 2018.

(ii) Tree Species Richness and Abundance

A total of 721 and 642 individual trees was recorded in invaded and control sample plots, respectively. In invaded plots, *M. eminii* species was the most dominant species with 206 individuals (29%), followed by *Cephalosphahela usambarensis* and *Allablankia stuhlmanii* with 87 (12%) and 65 (9%) individual trees respectively. In control plots, the most abundant species were *C. usambarensis, A. stuhlmanii* and *N. buchananii*, covering 74 (11.5%), 69 (11%) and 62 (10%) individual trees, respectively (Fig. 10). Despite the variation in species abundance, the mean number (±SD) of individuals per plot between invaded (40 ± 0.99) and control sample plots (36 ± 0.47) did not differ statistically ($t_{(118)} = 0.31$, $p = 0.761$). Control plots hosted 60 different tree species while it was found that only 46 tree species in invaded plots (Appendix 1). A significant difference ($U = 1490$, $z = 2.9$, $p = 0.04$) was recorded in tree species richness between invaded and control sample plots. Control plots contained more native species such *C. usambarensis, A. stuhlmanii, N. buchananii, C. odorata* than invaded plots (Appendix I). The

Shannon-Wiener diversity index differed significantly between invaded (1.63 ± 0.49) and control plots (1.87 ± 0.35; $t_{(58)} = -2.19$, $p = 0.033$).

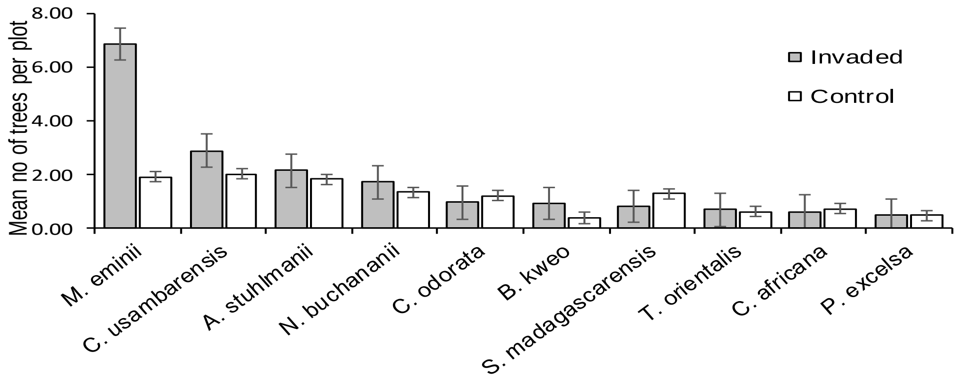


Figure 10: Mean (± SD) number per plot of 10 trees species in *Maesopsis eminii* invaded plots and control plots in the Amani Nature Forest Reserve. Also see appendix I for complete list of tree species in invaded and control plots. Control plots are those plots which had no *Maesopsis eminii* during 1998 survey by Frontier Tanzania (2001)

The study recorded no significant difference between mean number of *M. eminii* in 2018 (0.41 ± 0.56) and in 1998 (0.35 ± 0.52; $t_{(118)} = 0.51$, $p = 0.611$). However, the cumulative mean number of *M. eminii* was slightly higher in 2018 as compared to 1998 (Fig. 11).

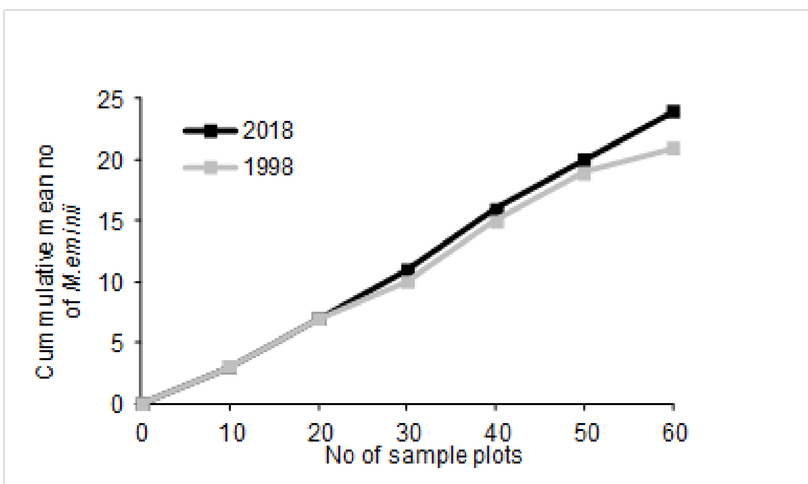


Figure 11: Changes in the mean number of *Maesopsis eminii* stems between 1998 and 2018 in 60 (invaded and control plots) vegetation sample plots

(iii) Population Structure of *Maesopsis eminii*

In invaded plots, mean DBH of *M. eminii* revealed few saplings (2%), while large trees (DBH = 31-50) contributed 62% and very large trees (DBH > 50 cm) occupied about 5% (Fig. 12). In control plots, *Maesopsis eminii* had 26% saplings and 51% pole-sized (DBH 11-20) trees while mature (DBH > 30) trees contributed 23% (Fig. 6). Despite this variation, there was no significant difference in mean DBH size between invaded plots (16.6 ± 13) and control sample plots (9.5 ± = 11; $t_{(10)}$ = 1.02, p= 0.34).

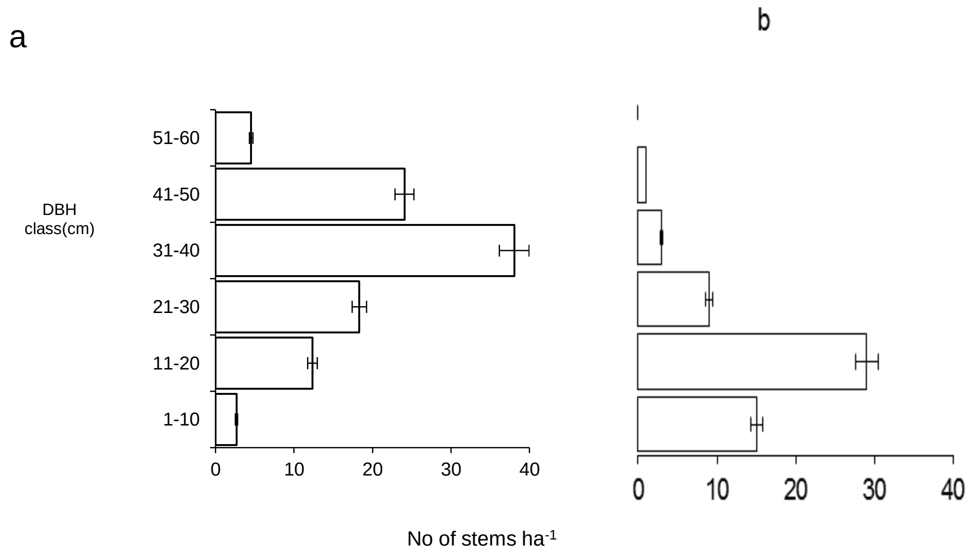


Figure 12: Mean (± SE) Diameter at Breast Height (DBH) distribution indicating population structure of *Maesopsis eminii* in (a) invaded plots and (b) control plots

The number of *M. eminii* individuals per hectare (ha^{-1}) was positively associated with higher altitudes ranging above 800 masl (ρ = 0.33, P = 0.011) but there was no correlation with distance away from the forest reserve boundary (ρ = 0.11, P = 0. 394) nor with distance away from. village centers (ρ = - 0.08, P = 0.502). However, tree species richness in general dropped slightly with increasing distance away from village centers (ρ = -0.26, P = 0.047; Fig. 13).

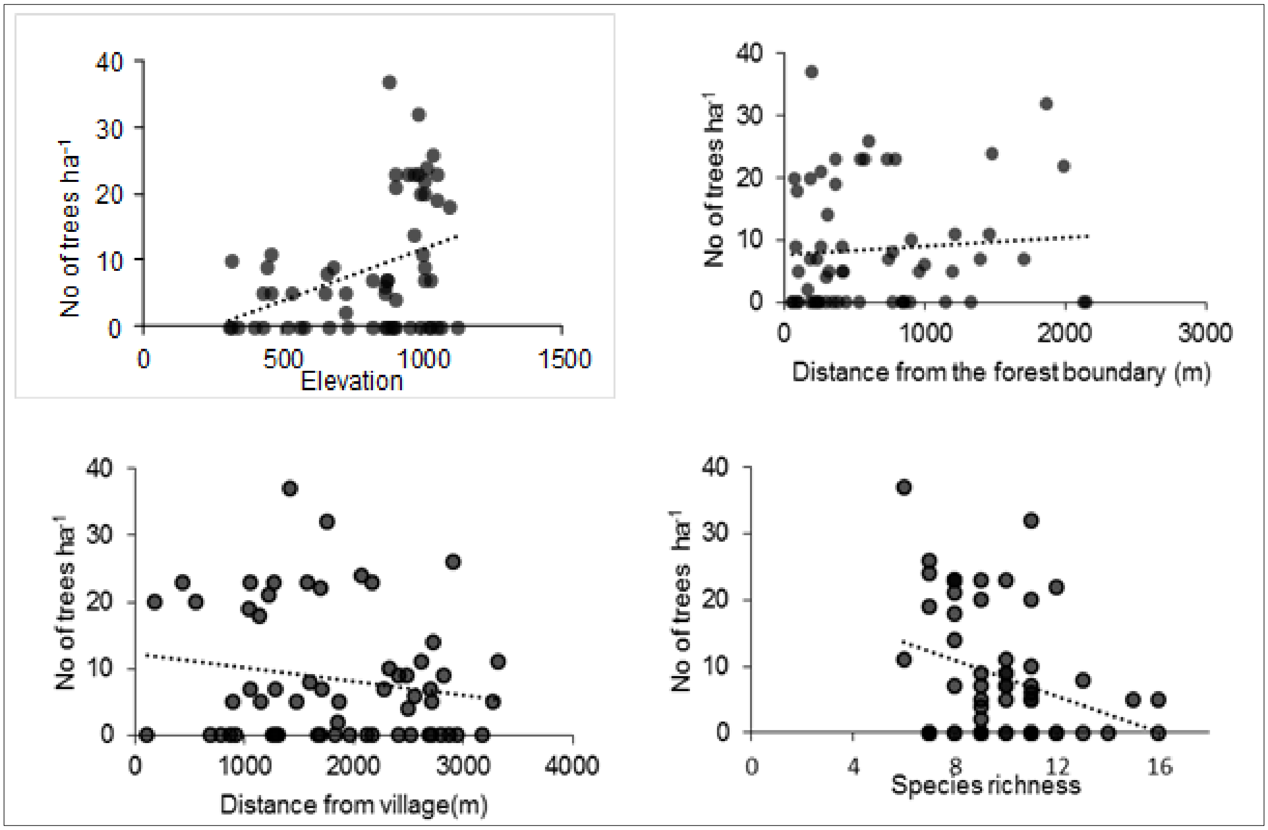


Figure 13: Spearman's Rank Order Correlation between the number of *Maesopsis eminii* trees ha-1 and elevation gradient, distance from the forest boundary, distance from village centers and species richness variation in each sample plot (n = 60) in ANFR in 2018

4.1.2 Satellite Imagery Analysis

(i) Vegetation Cover Classification in 1998 and 2018

Landsat vegetation cover classification revealed that in 1998, the reserve had 5701 ha (68%) of covered with forest and 2667 ha of non-forest area. While in 2018 the study found that, the area covered with forest had increased to 6778 ha (81%), while non-forested area decreased to 1590 ha (19%) (Fig. 14).

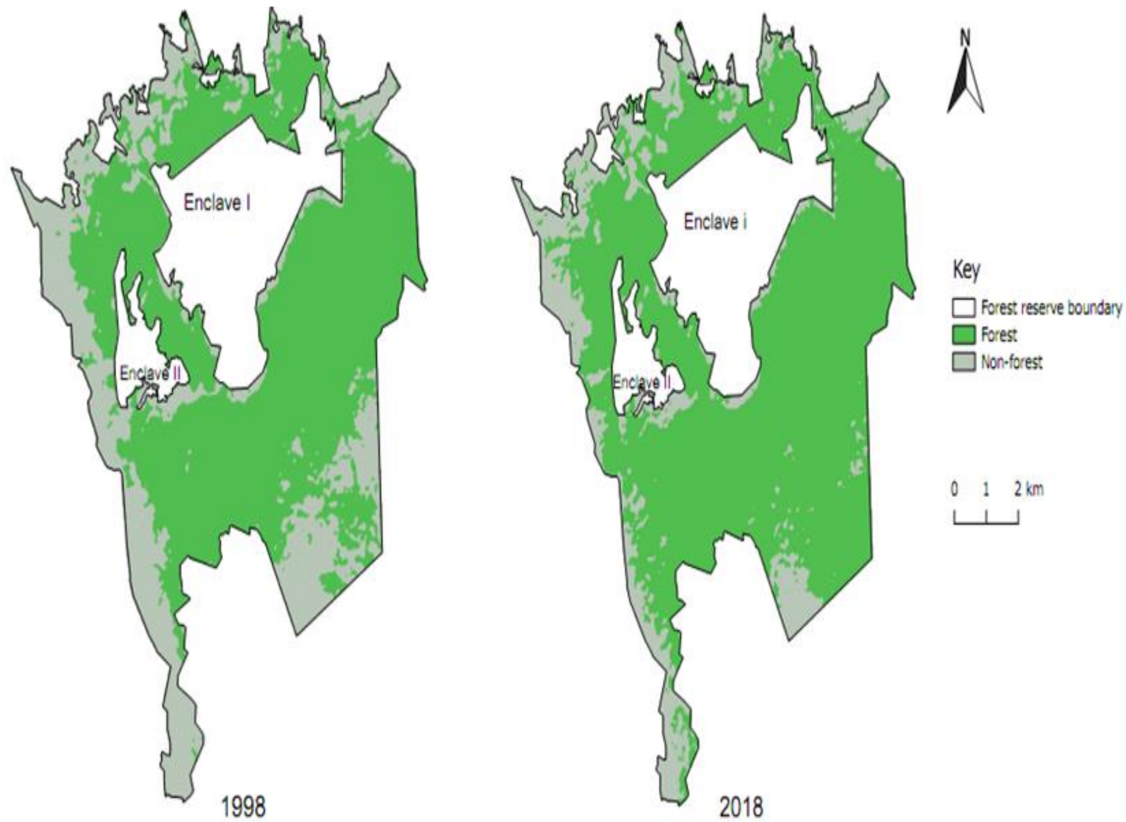


Figure 14: Amani Nature Forest Reserve cover maps for 1998 and 2018 indicating forest and non-forest coverage

(ii) Vegetation Cover Changes Between 1998 and 2018

Change detection analysis indicated that 1077 ha (13%) of non-forested vegetation cover, mostly in the southwestern part and in the boundary area of the reserve, had been converted to forest while only 55 ha (1%) had been converted to non-forested vegetation over the past 20 years (Fig. 15). Overall, Producer and User accuracy assessment results for 1998 and 2018 classified vegetation cover maps reached between 95% and 100%.

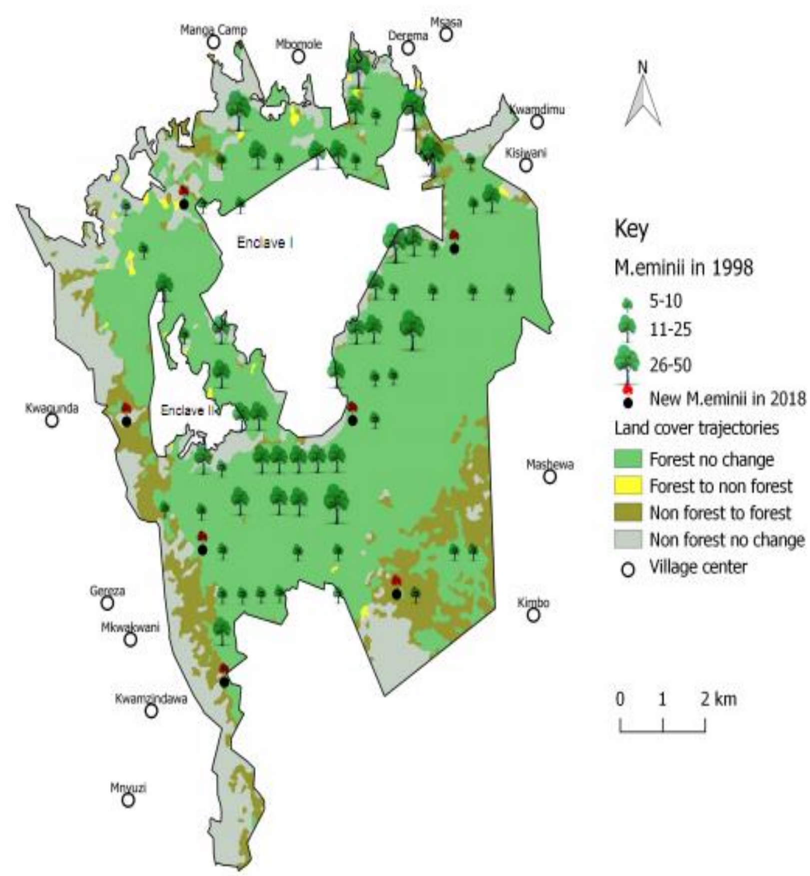


Figure 15: The map of Amani Nature Forest Reserve indicating vegetation class changes (forest versus non-forest) between 1998 and 2018, villages surrounding forest reserve and current (2018) distribution of the invasive species *Maesopsis eminii*. Size of tree symbols represents different numbers of *Maesopsis eminii* trees within the sampling plot, tree symbols with red color and black dot indicates newly invaded plots

4.1.3 Germination Experiment for *Maesopsis eminii* seeds

(i) Germination Response Across Different Light Levels

During the wet season, the mean number of germinated *M. eminii* seeds did not differ significantly across shade levels ($F_{3, 12} = 3.49$, P = 0.051; Table 1). However, there was a significant trend of the Final Germination Percentage (FGP) being 1.5 times higher at 0% shade level (L0) than that of 85% shade level (L85) and the Germination Index (GI) of L0 was twice as high compared to L85 (Table 1). Cumulative mean germination rate (Fig. 4) was highest at L0 and lowest at L85. In general, all germination parameters declined slightly as shade levels increased (Table 1).

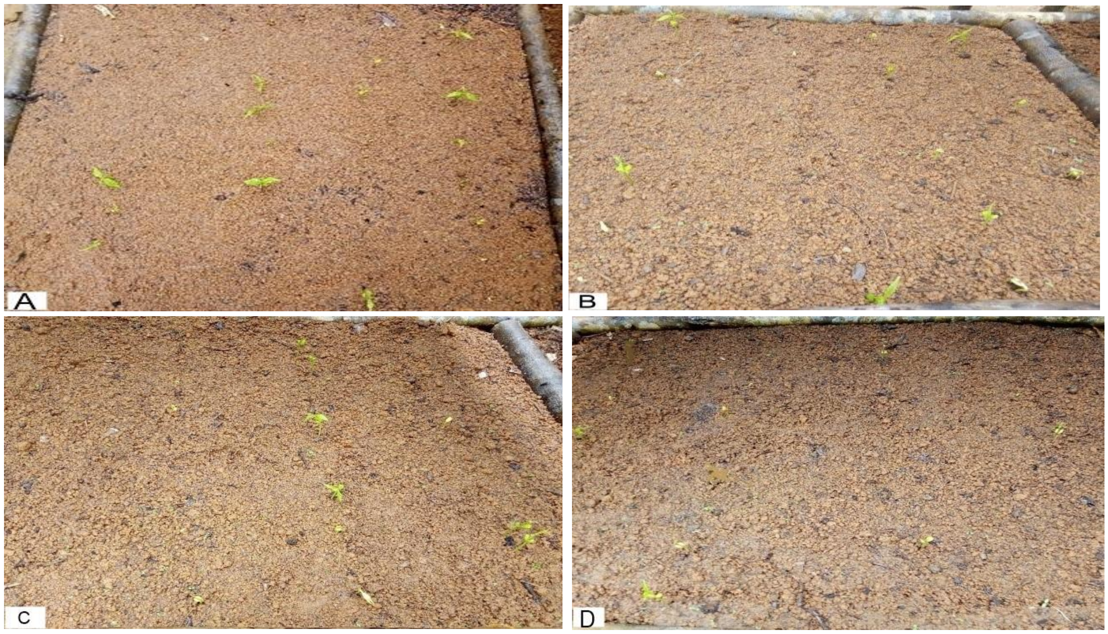


Figure 16: Germination for *Maesopsis eminii* seeds in Amani central nursery, Tanzania, in the seventh week of the experiment in 2019. Image A = 0% shade level, B= 50% shade level, C = 65% and D = 85% shade level

Table 3: One-way ANOVA test for germination parameters (± SE) during the wet and dry season after 12 weeks of germination experiment

Germination parameters	**Season**	**L0**	**L50**	**L65**	**L85**	$F_{(3,12)}$	***P***
Mean Germination Rate	Wet	9±0.3[a]	8±0.4[a]	9±1.0[a]	7±0.5[a]	3.49	0.051
	Dry	9.5± 0.6[a]	7.5± 1.3[a]	3.7± 1.3[b]	1.3± 1.0[c]	48.74	<0.001
Final Germination Percentage	Wet	93±1.7[a]	88±1.8[b]	78±1.8[c]	55±1.6[d]	146.05	<0.001
	Dry	95± 2.0[a]	75± 2.0[b]	38± 2.0[c]	13± 1.0[d]	589.68	<0.001
Mean Germination Time	Wet	38±1.5[b]	43±1.5[a,]	41±1.5[a,b]	42±2.1[a,c]	7.07	0.005
	Dry	39± 2.1[a]	41± 2.1[a,b]	44± 0.6[b,c]	45± 1.0[c]	14.46	<0.001
Germination Index	Dry	494±1.5[d]	387±2.1[b]	430±2.0[c]	270±21[d]	335.93	<0.001
	Wet	495± 1.0[a]	313± 1.0[b]	176± 1.5[c]	58± 3.0[d]	921.56	<0.001
Coefficient of Velocity of Germination	Dry	2.7±0.2[a]	2.3±0.2[b,d]	2.4±0.1[b,c]	2.4±0.1[c,d]	6.06	0.009
	Wet	2.6± 0.3[a]	2.0± 0.4[a]	2.3± 0.2[a]	2.2± 0.4[a]	2.69	0.093
Germination Rate Index	Dry	0.3±0.1[a]	0.2±0.1[a]	0.2±0.1[a]	0.2±0.1[a]	1.24	0.337
	Wet	0.3± 0.2[a]	0.2± 0.1[a]	0.1± 0.1[a]	0.1± 0.1[a]	2.44	0.115

Data in the same row with different letters represent significant differences between shade levels ($P < 0.05$) according to Tukey's Post Hoc test. Shade levels: L0 = 0%, L50 = 50%, L65 = 65% and L85 = 85%

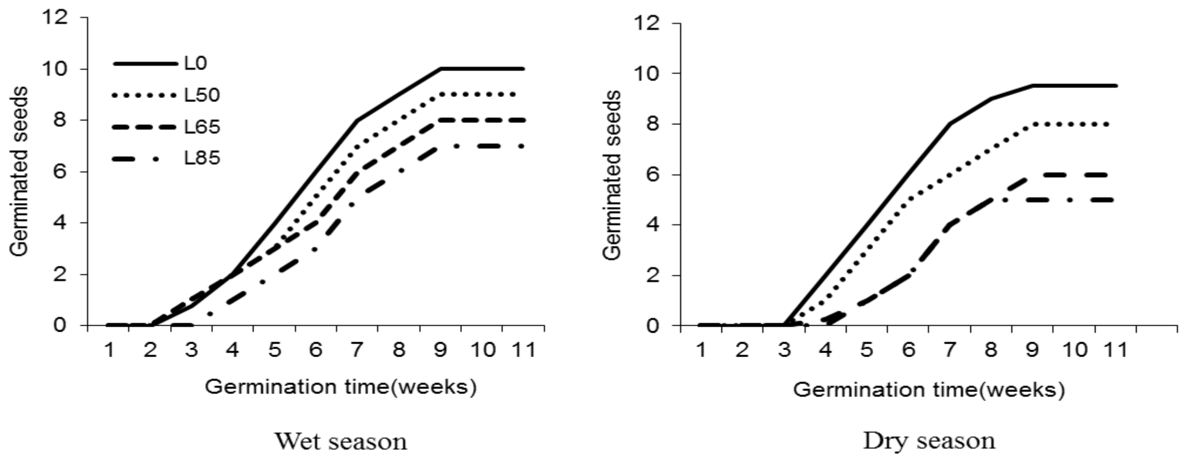


Figure 17: Germination time and cumulative mean number of *Maesopsis eminii* seeds that germinated during the wet and dry season over the period of 12 weeks. Line types reflect different levels of shade treatment: L0 = 0% shade level, L50 = 50% shade, L65 = 65% shade, and L85 = 85% shade

Growth parameters of *Maesopsis eminii* seedlings during the wet season indicated significant differences, particularly in stem diameter, shoot height, total fresh biomass and chlorophyll content but not in total dry biomass across different shade levels (Table 2).

Table 4: Mean growth parameters of *Maesopsis eminii* seedlings growing at different shade levels during the wet and dry season. Measurements were taken on the twelfth week of the experiment. L0 = 0% shade level, L50 = 50% shade, L65 = 65% shade, and L85 = 85% shade

Growth parameters	**Season**	**L0**	**L50**	**L65**	**L85**	$F_{(3,12)}$	**P**
Stem Diameter	Wet	2.57±0.1^{a}	2.68±0.1^{a}	1.98±0.1^{b}	2.48±0.1^{b}	9.91	<0.001
	Dry	2.3± 0.1^{a}	2.5 ± 0.1^{a}	1.9 ± 0.1^{b,c}	1.92 ± 0.1^{c}	24.40	<0.001
Shoot Height	Wet	13.2±0.2^{a}	19.1±0.5^{b,d}	20.4±0.9^{c}	17.7±0.7^{d}	25.72	0.002
	Dry	13.0 ±0.2^{a}	18.6 ± 0.6^{b,d,e}	19.3 ± 1.0^{c}	16.1 ± 0.5^{e}	19.90	<0.001
Total Fresh Biomass	Wet	4.9±0.1^{a}	8.4±0.5^{b}	9.0±0.2^{b}	5.9±0.5^{c}	88.23	<0.001
	Dry	3.9± 0.3^{a}	7.6 ± 0.4^{b,c}	8.6 ± 0.2^{c}	5.1 ± 0.3^{a}	32.00	<0.001
Total Dry Biomass	Wet	1.5±0.3^{a}	1.9±0.1^{a}	1.9±0.1^{a}	1.5±0.2^{a}	3.42	0.054
	Dry	0.9 ± 0.1^{a}	1.4 ± 0.1^{b,c}	1.4 ± 0.1^{c}	1.0 ± 0.1^{a}	18.10	<0.001
Chlorophyll Content	Wet	0.02±0.002^{a}	0.03±0.001^{b}	0.03±0.001^{b}	0.03±0.001^{b}	15.9	0.002
	Dry	0.01±0.001^{a}	0.02±0.001^{b}	0.03±0.001^{c}	0.03±0.001^{c}	35.30	<0.001

Different letters across rows represent significant differences according to Tukey's Post Hoc ($p < 0.05$).

During the dry season, the mean number of germinated *M. eminii* seeds differed significantly across all shade levels. Tukey HSD test indicated that particularly at higher shade levels (65% and 80%), the germination rates were less than 30% of that 0%. Final Germination Percentage and Germination Index at 0% were both eight times higher than at 85% and GRI was three times higher as compared to that at 85% (Table 1). Furthermore, it took six days more (MGT) for *M. eminii* seeds to germinate in 85% shade as compared to germination time in 0% shade. In the dry season, all measured growth parameters (stem diameter, shoot height, total fresh and dry biomass as well as chlorophyll content) differed significantly with shade levels (Table 2). Stem diameter decreased with increase in the shade level, while ChC increased with increase in shade. At L85, ChC of *M. eminii* seedlings was three times higher than ChC in L0 shade level. The SH, TFB and TDB increased with increase in shade levels at 50% and 65% but they were reduced at 85% shade level.

(ii) Effect of Seasonality on Germination of *Maesopsis eminii* seeds

The influence of both seasonality and shade level on germination and growth parameters of *M. eminii* seeds were assessed. All germination parameters were significantly reduced during the dry season except for GRI and CVG. The MGR and FGP were twice as high in wet season as compared to the dry season while FGP was three times as high in the wet than in the dry season. The main effect for shade level was significant at all germination parameters except for GRI. Similarly, the interaction effect was significant to all germination parameters except CVG and GRI (Table 5).

Table 5: Factorial ANOVA to compare main effects of seasonality (dry and wet), shade levels (0%, 50%, 65% and 85%) and the interaction between seasonality and shade level on the mean germination parameters of *Maesopsis eminii* seeds after 12 weeks

Germination parameters	Seasonality		Shade level		Interaction	
	$F_{(1, 24)}$	*P*	$F_{(3, 24)}$	*P*	$F_{(3, 24)}$	*P*
Mean Germination Rate	48.96	<0.001	35.91	<0.001	18.52	<0.001
Final Germination Percentage	536.64	<0.001	610.62	<0.001	161.34	<0.001
Mean Germination Time	5.36	0.029	15.51	<0.001	5.52	0.005
Germination Index	4913.61	<0.001	5044.37	<0.001	959.42	<0.001
Coefficient of Velocity of Germination	3.56	0.072	5.99	0.004	0.49	0.692
Germination Rate Index	1.11	0.304	3.43	0.033	0.45	0.720

It was found that all growth parameters i.e., stem diameter, shoot height, total fresh biomass, total dry biomass as well as total chlorophyll content were significantly reduced during the dry season as compared to the wet season. For example, total chlorophyll content and dry biomass were twice as high during the wet season as compared to during the dry season and decreased with an increase in shade levels. The main effect of shade was significant for all growth parameters while there was no significant interaction effect of the two variables except for stem diameter (Table 6).

Table 6: Factorial ANOVA comparing main effects of seasonality (dry and wet) and shading levels (0%, 50%, 65% and 85%) and the interaction effect between seasonality and shading level on mean growth parameters of *Maesopsis eminii* seeds after 12 weeks

Germination parameters	**Seasonality**		**Shade level**		**Interaction**	
	$F_{(1, 24)}$	*P*	$F_{(3, 24)}$	*P*	$F_{(3, 24)}$	*P*
Stem Diameter	26.09	<0.001	23.76	<0.001	3.31	<0.001
Shoot Height	7.33	0.012	32.39	<0.001	0.98	0.419
Total Fresh Biomass	7.98	0.009	103.53	<0.001	0.48	0.694
Total Dry Biomass	60.63	<0.001	12.61	<0.001	0.09	0.963
Total Chlorophyll content	43.77	<0.001	47.72	<0.001	1.94	0.150

4.1.4 Socio Ecological Survey

(i) Socio-Economic Profile of Respondents

The majority of the respondents were peasants (91%) while a small number were employees in both government and private sectors (Table 7). Most of the respondents had primary school education, and 5% had above secondary education such as professional certificates, diploma and a BSc degree. According to Katani (1999) education creates awareness, positive attitudes, values and motivation for better natural resources management among the people.

Table 7: Socio–economic profile of respondents in surveyed villages adjacent Amani Nature Forest Reserve, showing the number of respondents (n) in each category and the respective proportion (%) of all households interviewed (N = 102)

Profile parameter	n	% response
Age		
18 – 28	23	23
29 – 38	37	36
39 – 48	28	27
> 49	14	14
Gender		
Male	45	45
Female	55	55
Education Level		
No formal education	22	22
Primary education	59	58
Secondary education	15	15
Above secondary education	5	5
Main Occupation		
Peasants	93	91
Employee	9	9

(ii) General Understanding of the Invasive Species *Maesopsis eminii*

The overall understanding of the invasive species *M. eminii* among respondents, particularly its invasiveness, establishment and agricultural impacts to their households' farms was assessed. Overall, It was found a positive correlation between people's knowledge on *M. eminii* invasion with age of respondents (ρ = 0.49, P = <0.001). Ninety eight percent of the respondents admitted that *M. eminii* is a notorious tree species, which establishes, grows and invades quickly in their farms. However, only 68% of all respondents claimed that *M. eminii* might reduce crop yields compared to farms without *M. eminii* trees. Of all respondents, 27% reported to have not noticed any reduction in crop yields in fields strongly invaded with *M. eminii*. During follow up discussions, respondents narrated that while the invasive tree species is used in most agroforestry fields that are used for cash crops such as cardamom (*Elettaria cardamomum*), cinnamon *(Cinnamomum zeylanicum)* and cloves *(Syzygium aromaticum)* it is usually removed from maize, banana, sugar and cassava farms.

(iii) Population Distribution and Structure of *Maesopsis eminii*

Out of 102 household farms visited, 59 household farms (58%) contained *M. eminii* trees while 43 farms (42%) had no *M. eminii*. The study found that 61% of farms with *M. eminii* trees were distributed inside enclave I and II compared to distribution outside the forest boundary. The number of individual trees in a farm ranged from 0 to above 16 trees, with 6 – 10 trees being most common (in 49% of the households). Farms in the western region of the forest reserve had higher tree population sizes than in the east and north (Fig. 19a). Many *M. eminii* individuals recorded were saplings (33%) and pole sized (45%), and very few (6%) mature *M. eminii* trees (Fig. 19b). There was found a significantly negative association ($\rho = -0.49$, $P = <0.001$) between population size and distance from the forest reserve boundary. That is, farms close to the forest reserve had higher numbers of *M. eminii* trees compared to those far away.

Majority of respondents (93%) reported that growth and distribution of *M. eminii* in their household farms were spontaneously and naturally occurring in their sites after being dispersed by bats, monkeys and hornbills. They stated further that *M. eminii* grows very fast and survives well even in very poor soils. Hence, they often retain the species in household farms for timber, poles and fuel wood harvest. Together with Eucalyptus species, *M. eminii* are also widely used as fuel wood for drying tealeaves cultivated in the forest enclaves. However, key informants reported that most household farmers practice poor farming methods where soil conservation activities such as terracing as well as maturing and other soil improvement practices are not commonly used, which might render the areas prone to invasive species colonization.

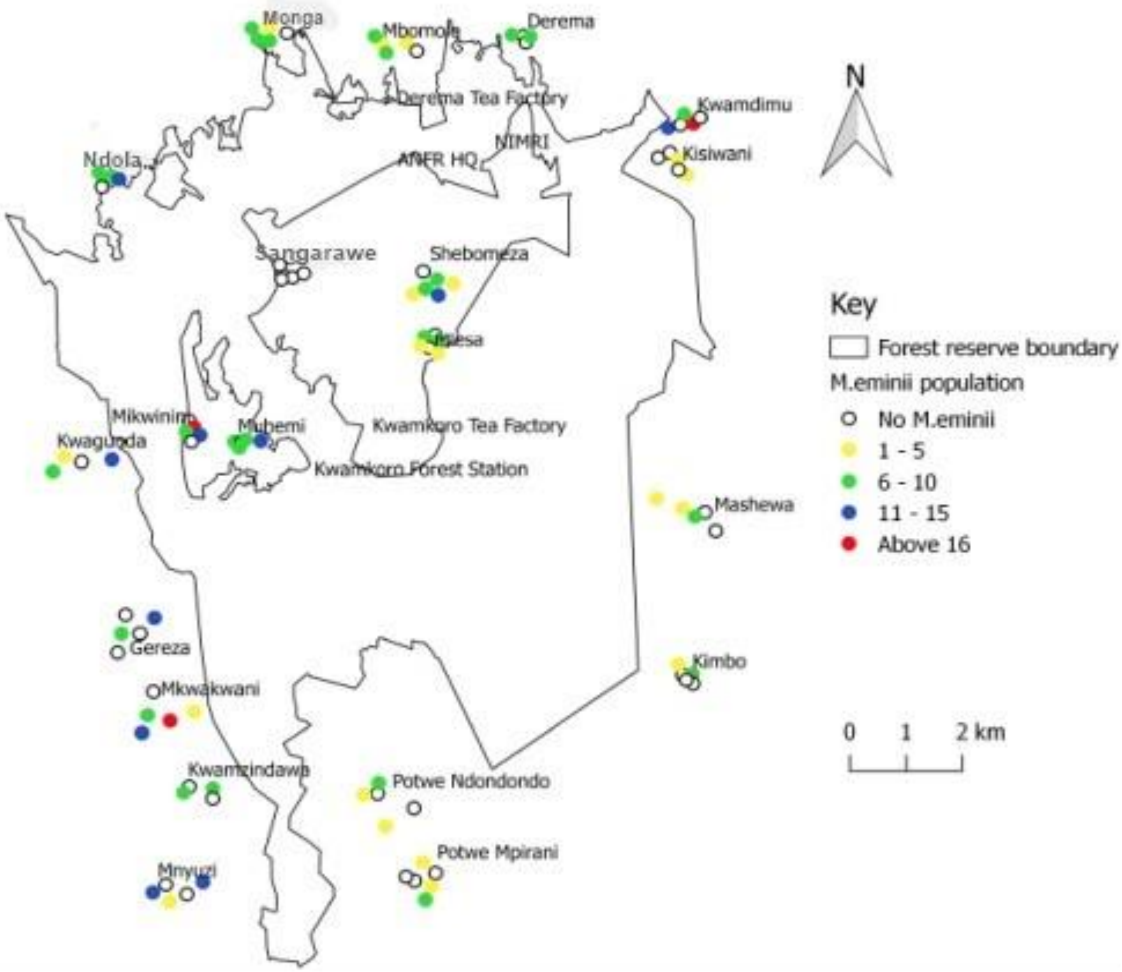


Figure 18: Location of household farms, distribution and population size of *M. eminii* species in surveyed villages adjacent Amani Nature Forest Reserve

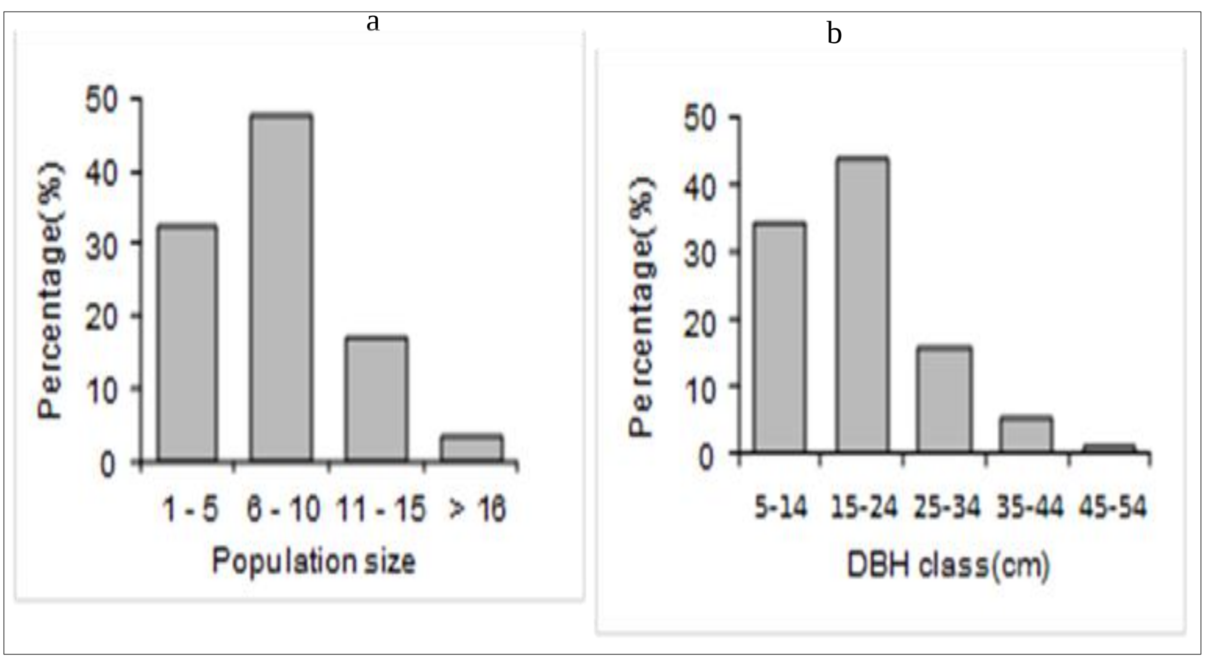


Figure 19: Population size and structure of *M. eminii* in 20 villages adjacent Amani Nature Forest Reserve

(iv) Prevention and Detection of *Maesopsis eminii*

The majority (78%) of respondents were not aware about the threats caused by *M. eminii* in both the farms and protected areas. The ANFR forest officers acknowledged that *M. eminii* is one of the exotic species that are posing threats and management challenges, while other key informants such as forest officers reported that the invasive species does not have any potential threats but rather nurses other native species due to its fast growth rate. However, 83% of farmers and key informants were able to detect and identify the pathways of movement and introduction of *M. eminii*. Abandoned farms, boundaries, forest edges and disturbed forest patches were mentioned by most respondents (81%) as the most vulnerable places, where *M. eminii* is introduced and manifests easily. With regard to detection, rapid response and reporting of the invasive species *M. eminii*, 89% of the respondents were able to detect and describe to the new infestation of *M. eminii*. Most respondents (93%) were able to describe morphological features of *M. eminii* seedlings and saplings at its early stages of introduction and establishments. Conservator of Amani Nature Forest Reserve reported to have good invasive species prevention plan which focuses to combat invasive species and keep them from becoming introduced and established in the first place. However, due to lack of funds and policy framework, it was reported that implementation of invasive species prevention plan has not been done in both protected area as well as adjacent sites and household farms.

(v) Control and Management of *Maesopsis eminii*

The study evaluated whether there are any eradication, containment and control measures in place to restrict an invading species to a particular area, reduce the abundance and density of infestation and keep harmful impacts of *M. eminii* to minimal within manageable limit. Sixty nine percent of respondents reported to engage in eradication and control of *M. eminii* in their farms. The majority of respondents (96%) mentioned physical felling and uprooting of *M. eminii* using hand held instruments such as machetes, slashes and axes as main method used to eradicate and control emerging *M. eminii* seedlings and saplings. The rest (4%) reported to use powered equipment such as brush-cutters and chain saw particularly for large *M. eminii* trees. However, 31% of farmers said they were not eradicating and controlling *M. eminii* trees from their farms. The reason provided were the fact that they make quick money out of *M. eminii* trees because it grows fast, straight, drought-tolerant species and unbuttressed trunk which can be quickly harvested within a rotation of 3-8 years and used for fuel, poles and timber. Others retain *M. eminii* trees in their households' farms and home gardens as a shade tree in their perennial crops such as cardamom, cinnamon, banana and coffee farms. On the other hand, the management of Amani Nature Reserve have not implemented any eradication and control measures despite presence of control plans in the 2017-2021 forest reserve management plan.

(vi) Rehabilitation and Restoration

Many farmers (96%) reported to have no rehabilitative or restorative measures in their sites once *M. eminii* trees have been eradicated or removed. They usually remove *M. eminii* in order to create space for their agricultural crops. However, few household farmers (5%) indicated evidence for rehabilitative measures where after removing *M. eminii* they tend to replace sites with other native species mainly *Tectona glandis, Melia azederach, Allabankia stuhlmanii* and *Syzygium aromaticum.*

4.2 Discussion

4.2.1 Forest Vegetation Survey

(i) Change in *Maesopsis eminii* Distribution

In the hypothesis, it was anticipated that *M. eminii* spread and recruitment would have declined between 1998 and 2018 in the conservation area and expected to observe negative spatial differences in its expansion. However, unlike the predictions under this study, it was found that that there was an increase in spatial distribution of *M. eminii* individuals between the year 1998 and 2018. Like other invasive tree species, the increase in *M. eminii* individuals was associated with changes in vegetation cover from non-forested to forested patches. This is in line with Hernández *et al.* (2014) who reported that invasive forest trees tend to increase their spatial range particularly along disturbed forest edges, boundaries and gaps. It was found a 13% increase in forested land since 1998 which mainly occurred in the western and northern areas at elevations below 600 m.a.s.l. These areas had large proportions of non-forested land, which might be attributed to a locally large human population in villages bordering the forest reserve, intensive tree harvesting and ineffective forest management before gazettment in 1997 (URT, 2017). This increase in forested land concurred with the increase in occurrence of *M. eminii.* Unlike to expectation that *M. eminii* spread and recruitment would decrease, it was recorded a 4% increase in occurrence of *M. eminii* in 2018 compared to the year 1998. The increase in occurrence was recorded away from the point of introduction of *M. eminii,* which had been in the North, below the Amani rest house and as part of collection of the Amani Botanic Garden (Mugasha, 1981). This wide spread of the invasive in the 1970s probably followed industrial logging and subsequent planting of *M. eminii* to restock the logged sites (Viisteensaari *et al.*, 2000). These plantations provided a massive seed source of *M. eminii*, particularly in the established forest gaps. *Maesopsis eminii* has now also been reported to the nearby forests such as Nilo nature forest reserve (Frontier Tanzania, 2002) Mtai forest reserve and Bombo East Forest reserve (Kijazi *et al.*, 2014), where it might be threatening the native plants and animals. *Maesopsis eminii* spread escalated in the 1990s, when a high industrial activity and an increasing human population were observed in communities surrounding Amani Nature Forest Reserve (Frontier Tanzania, 2001; Hamilton & Bensted, 1989). As a result, forested land and boundaries had been destroyed on a large scale to create plantations of sisal (*Agava sisalana*), exotic trees such as teak (*Tectona grandis*), *Grevillea robusta*, *Eucalyptus* species, *Cedrela odorata* and other agricultural crops (Hamilton & Bensted, 1989). These activities created forest gaps, which facilitated progressive invasion and spread of *M. eminii*, particularly in Amani Nature Forest reserve (Binggeli, 1989).

In other areas, where *M. eminii* has been taken beyond its natural range, similar patterns of invasion have been noted. While studying spontaneous regeneration associated to invasiveness, Bongers and Tennigkeit (2010) reported that *M. eminii* had been introduced in at least twelve countries outside its natural range. Out of these twelve countries, beside Tanzania mainland, spontaneous regeneration associated with invasiveness of *M eminii* was viewed with major concern in Puerto Rico and Pemba island (Bongers & Tennigkeit, 2010). Hulme *et al.* (2013) reported a rapid spread and abundant reproduction after seeds had dropped from the planted source of initially less than 100 ha of *M. eminii* stand on Pemba Island, and they predicted that this species will continue to spread on the island. Beentje (1992) reported the success in *M. eminii* colonization of gaps and open areas in Ngezi forest in Pemba island, where seeds had been dispersed from stands planted in the 1980s. In these areas, a dramatic land-use change, fragmented nature of the forest, and the dependence of invasive species for both commercial and local agriculture likely contributed to the spread and naturalization of this invasive plant species (Hulme *et al.*, 2013). Similar pattern is reported with invasive species *Prospos juliflora* and *Cedrera odorata* in Sudan and eastern Africa where it has exhibited vigorous growth and very wide ecological adaptability in poor soils, deforested and decertified areas (Abdulahi *et al.*, 2017; Chornesky & Randall, 2003). Therefore, *Maesopsis eminii* like other invasive species follow generalized pattern in terms of ability and adaptation to colonize gaps and disturbed areas.

In this study, there was not observed newly invaded sample plots in the closed, natural and undisturbed forests, except in sample plot P17, where it was observed *M. eminii* saplings thriving in a wide human-made gap. This shows that the invasive species takes advantage of disturbed sites and endanger disturbed forest than in natural undisturbed forests. Further, in mature, dense stands of *M. eminii* there was no record of any new *M. eminii* seedlings in Amani Nature Forest Reserve. Poor recruitment of *M. eminii* in old stands is probably due to the absence of adequate, large-scale disturbance that can create required gap size and probably enough light for germination of *M. eminii* seeds and seedling survival, leading to self-thinning (Mwendwa *et al.*, 2019). In addition to anthropogenic effect in creating gaps, natural phenomenon also contributed to dynamics of *M. eminii* in the study area. A recent study by Kilawe *et al.* (2018a) in Amani Nature Forest reserve reported that natural tree falls, not human disturbances, that created small gaps were only colonized by indigenous tree species and there was a substantial mortality and retrogressive recruitment of *M. eminii* in its original area of introduction.

A similar ecological strategy on its spread and colonization ability was noted in other areas, where *M. eminii* is not invasive and occurs naturally, i.e., in West Africa, Togo, Nigeria, Congo and southern Sudan, southern Uganda, north-western regions of Tanzania and western Kenya (Hall, 1993). In these regions, *M. eminii* has been reported to be unable to directly invade forests, possibly due to a combination of fire-sensitivity and sensitivity to competition, particularly for light (Ani & Aminah, 2006). Naturally, *M. eminii* is fire-sensitive and cannot establish in dense grass communities but its vigorous early growth ensures it escapes suppression by other trees and shrubs which germinate at the same time (Binggeli, 1989). Similar to many other trees, *M. eminii* exhibit the "Gulliver effect" where juveniles are suppressed by repeated topkill results in a demographic bottleneck where many juveniles being trapped in the grass flame zone for many years (Oliveras & Malhi, 2016).

Furthermore, the analysis of the diameter size distribution in invaded vegetation sample plots indicated a low proportion of saplings and young trees. As described by Saxena and Singh (1984) a population structure characterized by a high number of seedlings, saplings, and young trees compared to older trees indicates that this forest species has a high regeneration potential, whereas forest species with few or without any seedlings and saplings, suggest no regeneration at all. As denoted by Paul *et al.* (2018), plotting two population trends of different species in the same population graphs enables one to forecast which one can be replaced by the other species. The study found that in closed, undisturbed forest tracts, there is some evidence for low regeneration potential of *M. eminii* and its natality is decreasing, similar to conclusions by Kilawe *et al.* (2018) and Viisteensaari *et al.* (2000) who reported the numbers of native tree species such as *C. usambarensis* and *A. stulhmannii* are increasing in matured *M. eminii* stands.

However, if the source is still present in farmland and disturbed areas, the invasive potential of this species persists, as shown by the results presented in this study.

(ii) Tree Species Richness and Abundance

In line with my hypothesis, the study found higher species richness in control plots than in invaded sample plots. This might be contributed by high density of invasive species *M. eminii* in the invaded plots. This is supported by Binggeli (1998) who linked presence of *M. eminii* in East usambara with displacement of native species such as *A. stuhlmanii, A. obtusifolia, E. usambarensis and G. suaveolens* in East Usambara hence reduced floristic diversity. Similarly, Binggeli and Hamiltonn (1993) found a reduced representation in *M. eminii* rich forest of many endemic tree taxa. Suppression and displacement of native and endemic species is a typical manifestation of invasive tree species. Invasive plants possess various mechanism to facilitate suppression and displacement of native species. Liebhold *et al.* (2017) stated that invasive plants have the capacity to alter the stability and productivity of forest biodiversity globally. This mechanism facilitates exclusion of native plant species via either direct or indirect competition for resources such as water, nutrients and light (Epila *et al.*, 2017). This may result into total extinction of native plant species or degradation of the composition of native forests to degrade. Displacement and suppression of native plants can result in a plethora of cascading influences on many endemic species of the forest ecosystem.

4.2.2 *Maesopsis eminii* seed Germination

(i) Germination Across Different Light Levels

Seed germination and seedling establishment of invasive species in natural forest ecosystems are affected by environmental factors such as light, temperature, seasons and water availability (Leal *et al.*, 2013). In this study, shade levels significantly influenced seed germination during the dry but not during the wet season. Similar other studies such as Binggeli *et al.* (1993), Ioana *et al.* (2015) and Vieira *et al.* (2010) have found that invasive plants perform poorly in low light environments while displaying high survivorship and growth rate under high light conditions. The findings of reduced germination due to increase of shading level indicated that *M. eminii* seeds exhibit positive photoblastism, i.e. photoblastic seeds are capable of detecting light quality and quantity, a physiological process mediated by protein molecules referred to as phytochromes (Fenner & Thompson, 2005).

Photoreceptors have multiplicity of roles in plant physiology and have been the subject of plant invasion success and colonization abilities particularly during germination stage (Gioria & Pyšek, 2017). The study found that optimal *M. eminii* seed germination occurs when exposed to 0% shade level during the dry season. In the experiment, most (95% Final Germination Percentage) *M. eminii* seeds germinated after 38 days while seeds at greater than 50% shade level took longer to germinate as compared to 0%. These average times taken for breaking *M. eminii* seed dormancy and activating germination process is similar to Binggeli (1989) who reported same germination period for freely fallen fleshy *M. eminii* fruits. Dawson *et al.* (2009) and Epila *et al.* (2017) also found that *M. eminii* seed populations showed high germination rates particularly in large forest canopy gaps and forest edges as long as soil moisture is sufficient and arboreal seed dispersers are present.

(ii) Seasonality and Germination Response of *Maesopsis eminii* seeds

The Germination Index (GI) calculated combined both percentage and speed of germination and it magnified the variation among seed lots with an easily compared numerical measurement (Kader, 2005). The high GI recorded in 0% shade indicated a high germination arithmetic weight, which emphasizes the difference more clearly between germination percentage and speed along different shade levels. During the dry season it was recorded a GI at 0% that was 737 units larger than at L50. Similarly, Leal *et al.* (2013) observed that many alien plants show an increase in their germination rates when exposed to high light conditions, which favors their performance in disturbed areas. Vieira *et al.* (2010) observed that seeds of an invasive weed, *Cortaderia jubata,* had three times higher germination success at high light conditions than in the dark in coastal California.

Further, it was found that morphological growth characteristics and total chlorophyll contents were similarly influenced by shading level in both dry and wet seasons. For example, during the dry season, leaf chlorophyll contents were three times higher at 85% and 65% shade than at 0% shade level. According to Haase (2008) and Qi *et al*. (2019) seedling morphology such as stem diameter, shoot height and total biomass allocation are characteristics most commonly examined in forest seedling stock to evaluate seedling quality. In this study, it was found that most morphological characteristics of *M. eminii* seedlings were influenced by shade particularly during wet season. A large stem diameter predicted the best growth and survivorship of *M. eminii* seedlings in the 0 – 50% shade range. This large stem diameter is correlated with larger root systems and larger stem volume (Haase, 2008).

Similarly, shoots were taller in 0%-65% shade levels than under high shade, often associated with generally higher number of leaves and more access to sunlight enhancing photosynthetic capacity and transpiration, which is a competitive advantage over other species (Haase, 2008; Ranal & Santana, 2006; Udo *et al.*, 2016). There seemed to be an optimal shade level range for *M. eminii* seedling growth between 0-65% shade, which is supported by findings of Binggeli (1989) who reported higher seedling survivorship and lower mortality rate of *M. eminii* seedlings in open environments as compared to shaded in southern Uganda. Total chlorophyll content followed a similar trend with a maximum value recorded at 65% shade, agreeing with Galicia-Jiménez *et al.* (2001) who found higher chlorophyll content in *Hopea helfery* and *Hopea odorata* under conditions of low light intensities at 58%, 78% and 92% shade level. This mechanism is explained by Dibenedetto (1991) and Niinemets *et al.* (1998) as a response used by the plants to optimize quantum harvesting when shading level increases.

This study highlights the importance of adequate light levels in germination processes and hence, recruitment, establishment and distribution of *M. eminii* in the Amani Nature Forest Reserve. During the dry season particularly in the study area tall trees grow only little and lose a large number of their leaves, thereby increasing the amount of light reaching the ground, which then promote the growth of young seedling (Kilawe *et al.*, 2018; Epila *et al.*, 2017). Therefore, seasonality affected germination and development of *M. eminii* seeds in this study. In the dry season, unlike in the wet, seed germination was inhibited more strongly by shade. Sufficient availability of moisture during the wet season also triggered higher germination of *M. eminii* seeds to the extent of overcoming the impact of shading as was shown in this study. With advent of the rainy season and of the new flush of leaves, light levels drop and seedlings may die in the shade unless they are subjected to a gap size of minimum 300 m^2 (Kilawe *et al.*, 2018). Epila *et al.* (2017) stated similarly that water availability is a limiting factor for the occurrence of *M. eminii* and they found that 97% of the mapped *M. eminii* occurred in sites receiving an annual mean rainfall of more than 1000 mm. As reported by Boy and Witt (2005) and Ye and Wen (2017) in seedling establishment and overall environmental adaptation, seed germination represents an important development phase playing a critical role in invasion ecology.

4.2.3 Socio Ecological survey

(i) Distribution and Population Structure of *Maesopsis eminii*

This study highlights that *M. eminii* individuals were frequently found in farms located adjacent to Amani Nature Forest Reserve. In the study, high numbers of *M. eminii* were recorded in communities in the west and southwest regions of the forest reserve. This might be due to the large human population along this area (URT, 2017) which increases livelihood activities such as agriculture and harvesting of wood resources, which create gaps and favorable conditions for *M. eminii* colonization in unprotected forest areas. The findings compliment results by Hall *et al.* (2011) who reported that *M. eminii* was the dominant species in agroforestry, accounted for 50% of all stems measured in active agroforests, abandoned agroforests, and mature secondary forests, and was the most common species in their study.

The study observed and recorded higher numbers of saplings and younger trees than matured and adult trees. These findings suggest that the *M. eminii* population in unprotected areas and farms is viable with good regeneration potential. Based on Saxena and Singh (1984) a population structure characterized by a high number of seedlings, saplings, and young trees compared to older trees indicates that this forest species has a high regeneration potential, whereas forest species with few or without any seedlings and saplings, suggest no regeneration at all. Based on the findings, drivers towards successful distribution of the invasive species in household farms are twofold, distribution by natural dispersal agents namely bats, monkeys and hornbills (Dawson *et al.,* 2009) and intentional planting by farmers for domestic uses such as intercropping, agroforestry, fodder, poles and timber production.

Figure 20: Apeasant struggling with sprouting *Maesopsis eminii* in her mixed household farm in Mkwakwani village near Amani Nature Forest Reserve

(ii) Community Understanding of the Invasive Species *Maesopsis eminii*

Human being are integral part of the forest ecosystem and are involved to some degree in the entire process of the invasive plant species (García-Llorente *et al.,* 2008). The study found communities adjacent forest reserve had adequate understanding of the spontaneous spread of the invasive species *M. eminii.* However, they had limited understanding and knowledge on the impacts of *M. eminii* such as loss of soil fertility, elevation of soil PH, impoverished understory vegetation, little regeneration of primary forest trees and poor animal and plant diversity including that of the soil fauna. As reported by Sweddy (2015) local communities play major role in control and/or prevention of the introduction of invasive species, however majority of the population is not yet aware of this problem. Lack of knowledge on invasive species and its impacts exists among community members and may have contributed in the spread of *M. eminii* and unsustainable harvesting of forest in the study area. As reported by Binggeli and Hamiltonn

(1993) one of the main drivers for the spread and colonization of *M. eminii* was anthropogenic activities including large scale logging which took place in 60-70s.

Figure 21: Peasant in cardamom household farm invaded with *Maesopsis eminii* in Mikwinini village, adjacent Amani Nature Forest Reserve

The main economic activity for the majority of people is agriculture, both subsistence peasant farming and commercial estate farming, dominated by tea and sisal estates, which were introduced in the area by British and Germans colonisers respectively. Introduction of these commercial activities in the area attracted more outsiders such as laborers in the tea estates, and workers in commercial logging and pit sawing, who in turn are reported to clear more forests for subsistence farming and settlement. Considerable levels of encroachment by farmers onto these forests suggested that high levels of biodiversity erosion might be taking place unnoticed while creating favourable gaps and pitches for biological invasion for invasive species such as *M. eminii*. This underlines the importance of creating more understanding and awareness among community members adjacent forest reserve As ascertained by Hamilton and Bensted (1989) and Hokkanen (2002), problems associated with forest conservation can safely be based on the way people's values and perceptions determine their actions towards biological resources. It is actually people's actions, which contribute either to biodiversity conservation or to erosion.

(iii) Current Management Practices of *Maesopsis eminii*

Based on the study, the fact that invasive species management plan is not implemented in ANFR has contributed to unawareness of *M. eminii* problem among forest workers. During focus group discussion for example, some forest officers had views that *M. eminii* do not have any impacts to the forest ecosystem, and since the species has fast growth rate and taller borehole, it nurses and protect understory species. Furthermore, not implementing invasive species management plans and strategies may have facilitated spread of *M. eminii* in the edge of protected areas and along household farms and agroforestry in the villages surrounding ANFR. This is because invasive species management plans should have involved communities in detecting and preventing further spread of *M. eminii*. In doing so, community awareness on the impacts and ecology of invasives species, early detection and prevention measures would have been observed by community members. Lyimo *et al.* (2009) had similar observation on the contribution of anthropogenic changes which make many receiving environments more ‘invader friendly.

The second context of management of invasive species is the community participation in the prevention of the introduction and spread of invasive species *M. eminii*. The study observed inadequate community participation and awareness coupled with poor awareness on the threats paused by *M. eminii* in ANFR. The observed poor community participation and awareness on the threats and impacts of *M. eminii* implies continuing of anthropogenic activities, which promote the spread of the invasive species. This implies inadequate community awareness and understanding amongst key stakeholders in management of invasive species *M. eminii*. As ascertained by Heger and Van Andel (2019), although public awareness on the negative impacts of invasive species might be increasing amongst community members, education on invasive species is crucial for the long-term success of invasive plants prevention and management efforts. Boy and Witt (2005) noted similar weakness in Ethiopia, Ghana, Uganda, Zambia where many decision-makers were unaware of, or had little or no access to, data on invasive plant species, including species that were already wreaking havoc in their countries.

Unfortunately several studies (Gereau *et al.*, 2016; Kessy, 1998; Van Rensburg *et al.*, 2017; Sweddy, 2015) have reported on lack of communication in management of invasive species, not only between different arms of government, both national and local, but also between government and the private sector, and between decision-makers and affected communities and members of the public. For effective *M. eminii* management strategies in Amani Nature Forest Reserve, management options should seek and must communicate the role of forest community members in facilitating *M. eminii* establishment and spread, their detrimental impacts on native biota, and the forest ecosystem at large. Amani Nature Forest Reserve management must ensure communities are aware by providing opportunities for their involvement in early detection and control programmes as well as ensuring they are well informed. Moreover the management should consider providing information to the public on the ecology and impacts of *M. eminii.*

(iv) Potential Management Options for the Control of *M. eminii*

The present study synthesizes potential management options and strategies (Fig. 22) for the invasive species *M. eminii* in ANFR based on the study findings and reference from the National Invasive Species Strategy (2019). The proposed *M. eminii* management model aims at the observed newly invaded areas, and takes into account the current population structure of *M. eminii*, optimal light levels for growth and season when germination of *M. eminii* occurs at high rates *as* well as community participation practices.

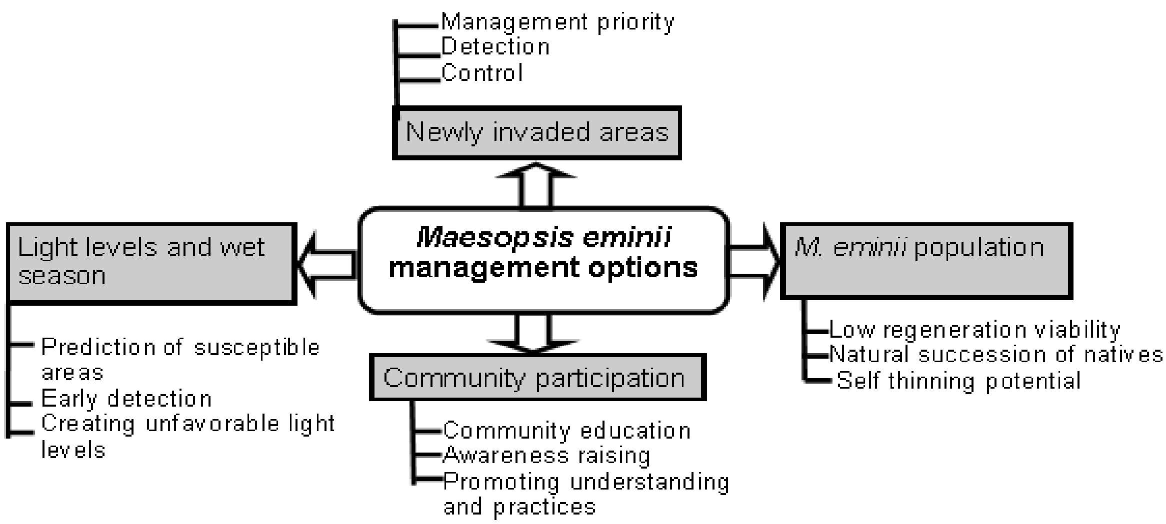


Figure 22: Potential management options model for *Maesopsis eminii* in Amani Nature forest reserve based on my different study components

Newly Invaded Areas

In this study, forest vegetation survey and satellite imagery analysis revealed that newly invaded areas are open sections in the western and southern regions of the ANFR, towards the forest boundaries, buffer zones, household farms as well as along agroforestry systems, away from seed sources. The observed newly invaded areas suggest regions for effective introduction, establishment and spread of *M. eminii* in both protected and unprotected areas. That is, the newly invaded areas potentially provide favorable conditions such as optimum sunlight, space and moisture contents for germination and hence early growth of *M. eminii* seeds. Similar to Hall

(1995) *M. eminii* has the ability to become established in a range of gap and soil surface conditions such as crown debris, the bole itself (once decay is advanced), bare mineral and humus soil. For the species to persist an area of soil must be well illuminated and remain unshaded until the Maesopsis which becomes established reaches canopy height. The gap therefore, must be too large for closure simply from lateral crown extension and from adjacent large trees and should not contain resilient trees able to regenerate shoots growing faster than the *M. eminii* seedlings.

The knowledge and information on the newly invaded areas provides useful insights for ANFR in controlling and management further spread of the invasive tree species *M. eminii.* The newly invaded areas indicate regions where introduction and establishment of invasive tree species *M. eminii* occurs. Further, more newly invaded areas helps the management of ANFR to predict other similar susceptible areas and hotspot regions for invasion. Based on this study findings then the management of ANFR will be able to identify appropriate areas of focus and *M. eminii* management priority. This information should further be used by the ANFR management to devise effective prevention and early detection mechanisms along these areas in order to stop further introduction and establishment of *M. eminii.* Tobin (2018) suggested that prevention is an effective management strategy that stops invasive plants from arriving in an area in the first place. In the event new invasive species are detected in these regions, measures to control the invasive species, eradication and containment are required in order to mitigate further spread and impacts of the invasive species (National Invasive Species Strategy and Action Plan, 2019).

Light Levels and Seasonality

The study reported that germination and early growth of *M. eminii* seeds are inhibited by an increase in shade level and are higher in wet season compared to dry season. This finding provides important insight on prevention of further spread of *M. eminii* through taking into account light and water availability regimes. It is evident that spread of *M. eminii* is fostered by light availability and different light levels acts as a barrier to the invasive capacity of *M. eminii*, particularly at germination and earlier growth stage. These findings have important management implication to ANFR in preventing and controlling further spread of *M. eminii.* To take advantage of this result, the ANFR management is advised to implement prevention and earlier detection strategies during the wet season such as reduced thinning when the species germinates at its highest rate. That is, searching and surveying of germinating and earlier growing *M. eminii* and preventing the species from becoming established through uprooting and enrichment planting with native species will be effective during wet season as compared to dry season.

Furthermore, increasing shade levels (50% - 80%) through nurturing the forest is likely to reduce *M. eminii*. Managing gaps, disturbances and soil surface conditions in order to lessen amount of light level reaching the forest floor will contribute in inhibiting germination and earlier growth of *M. eminii.* As reported by Binggeli (1989) for *M. eminii* species to persist an area of soil must be well illuminated and remain unshaded until the species become well established and reaches canopy height therefore, enrichment planting to fill natural gaps and controlling disturbances is likely to reduce spread of *M. eminii*. Viisteensaari *et al.* (2000) had similar view that the invasion of *M. eminii* in the ANFR has been facilitated by logging and other disturbance, controlled logging and managing disturbance are likely to reduce invasion of *M. eminii* in ANFR.

Maesopsis eminii Population Structure

The observed low proportion of saplings and young *M. eminii* in protected forest, particularly in dense stands implies that *M. eminii* has low regeneration potential and that it is unable to colonize already occupied stands. This information provides important insights to the ANFR management as it highlights that *M. eminii* control efforts should not be focused in these regions. Low regeneration potential of *M. eminii* in dense stands indicates that the species is in late stage of invasion and it exhibit self-thinning. As highlighted by Singh *et al.* (1996) successful regeneration of tree species is a function of the ability to initiate new seedlings, ability of seedlings and saplings to survive and grow.

For potential management of *M eminii,* management options for the invasive species should focus on to the areas recorded with high regeneration potential. These are the newly invaded areas in the forest edges, gaps, boundaries and buffer zones particularly adjacent communities with higher population in the west and southwest regions of the forest reserve. Moreover, the study anticipates a natural replacement of *M. eminii* in mature stand by indigenous species, this is similar to observation by Kilawe *et al.* (2018) and Viisteensaari *et al.* (2000) who reported the number of native tree species such as *C. usambarensis* and *A. stulhmannii* to have increased in mature *M. eminii* stands.

Community Participation

The observed lack of knowledge and understanding on the invasive species and its impacts among community members, might have contributed to unsustainable harvesting of native forest tree species and agricultural practices that lead to higher spread of *M. eminii* in household farms adjacent the forest reserve. This is apparent from the high proportion of saplings and young *M. eminii* recorded in household farms and forest boundaries. It is therefore, imperative that effective management of *M. eminii*, should focus on strengthening community participation and raising awareness among village members particularly small holder farmers. This is because human beings are an integral part of the forest ecosystem and local communities may play major role in helping to control and prevent introduction and establishment of invasive species (García-Llorente *et al.* 2008).

For effective control of *M. eminii* species, the management of ANFR should work hard to promote community understanding and raise awareness on the impacts of *M. eminii* such as loss of soil fertility, elevation of soil pH and impoverished understory vegetation (Binggeli, 1989). Educating villagers in these areas to find good native alternative trees for timber, poles and fuel wood would contribute in mitigating further spread of *M. eminii.* According to Lovert (1998), lack of public awareness is recognized as contributing to the ineffective control, fast spread and establishment of invasive species in rural areas. Similary, Hulme *et al.* (2013) recommended customized training programs for different stakeholders such as policy-makers, scientists, extension workers and affected communities in order to increase capability in control and eradication of invasive species. This should focus in topics such as invasive plant awareness, ecology and impacts of invasive species, invasive species management, accessing using global invasive species information sources, communication and teaching of invasive species issues would facilitate the implementation of an effective invasive species management program.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on the findings of this study, it is concluded that in Amani Nature Forest Reserve, *M. eminii* still encroaches, particularly along forest edges, plantations, and farmlands. The distribution ranges of *M. eminii* suggest that the species follows environmental filters and propagule pressure exerted in seed source populations, complimenting a report by Hall (2010). Additionally, it was found that forest edges, agricultural fields, forest gaps and vegetation structure traits, played an important role in defining invasion dynamics of *M. eminii*. This study reported that *M. eminii* is at a later stage of invasion, with lower regeneration potential, particularly in high density *M. eminii* stands. Based on the findings, it clear that the *M. eminii* population cannot replace itself in their mature stands but can rather be replaced by other native understory species such as *Cephalosphaela usambarensis, Newtoni buchananii* and *Belschmedia kweo*, which highlights an easy management potential to reduce this invasive.

It was further found that *Maesopsis eminii* seed germination, particularly during the dry season, was higher under lower shade levels. The ability to germinate under a wide range of environmental conditions is one of the distinguishing features for most invasive plant species and allows exploitation of broad niches, during which competition for resources is low (Epila *et al.,* 2018). This knowledge has important implications for predicting susceptible ecological niches and, hence, can foster proactive management strategies in the Amani Nature Forest Reserve. However, the factors triggering invasive species success might vary at different stages of the invasion process according to Tobin (2018). Given rapid climatic changes, knowledge of the germination behavior of native and alien species under natural conditions is crucial for predicting future plant community dynamics.

In addition, this study has explored the distribution of the invasive species *M. eminii* in relation to socio-ecological conditions in the study area. Studies on the interaction between rural communities surrounding the forests and the forest itself provide important information that helps to establish more efficient systems of forest management and conservation. This study found a continual spread and distribution of *M. eminii* in farms and agroforestry systems and this species was found at 57% of all surveyed farms. A high density of *M. eminii* trees was found in the west and south west of the reserve, where populations of the local community are high. Further, *M. eminii* species adjacent to the forest reserve had a high regeneration viability as it contained more saplings and younger individuals than matured and older trees. Overall, it was that found there was inadequate awareness, practices and understanding among people living close to the forest and key informants on the ecology, spread, impacts and management strategies of the invasive species *M. eminii* in Amani Nature Forest Reserve.

5.2 Recommendations

Based on the present study and findings, the study recommend future comparative studies of the genetic differentiation as well as biophysical factors between Amani Nature Forest Reserve where *M. eminii* is invasive and other areas such as lake Victoria basin, Bukoba and southern Uganda where *M. eminii* is not invasive. This will help to ascertain whether the species has undergone rapid evolutionary change, loss of genetic variation (founder effects), hybridization or adaptation to novel environments (Hamrick & Godt, 1996). A comparative study on biophysical factors will relate biological and physical factors between native and introduction sites to assess any differences in environmental factors, presence or absence of natural enemies, competitors and destructive diseases. Overall, the findings highlight that the species should be managed in its early invasion stage and that future man-made gaps should be quickly replanted with native species.

This study suggests that light levels might act as a barrier to the invasive capacity of *M. eminii*, particularly at germination stage. Therefore, light availability might be limiting its colonization success and wide distribution range in forest ecosystems. Hence, management of *M. eminii* invasion needs to take into account light and water availability regimes in the future. This can be achieved through early detection during the wet season when the species germinates at its highest rate and through minimizing forest gaps and other disturbances that might create favorable light conditions for *M. eminii*. Community education is recommended from the present study in order to promote adjacent community participation and foster higher level of public awareness about invasive species and their likely impacts as well as provide an overview to correctly identify species that are harmful to their livelihoods and their consequences. This will apparently draw attention of the society to the problem and help in identification and detection of the species involved, with assumptions that an educated public is a central resource in prevention of the introduction of invasive control in their areas.

REFERENCES

Abdulahi, M. M., Ute, J. A., & Regasa, T. (2017). Prosopis Juliflora l: Distribution, impacts and available control methods in Ethiopia. *Tropical and Subtropical Agroecosystems*, 20, 75–89.

Khan, A. M., & Ungar, I. A. (1998). Germination of the salt tolerant shrub Suaeda fruticosa from Pakistan: Salinity and temperature responses. *Journal of Seed Seed Science and Technology*, 26, 657–667.

Al-Ansari, F., & Ksiksi, T. (2016). A Quantitative Assessment of Germination Parameters: The Case of Crotalaria Persica and Tephrosia Apollinea. *The Open Ecology Journal*, 9(1), 13–21. https: //doi.org/ 10.2174/ 1874213001609010013

Alpert, P. (1984). Analysis of Chlorophyll Content in Mosses through Extraction in DMSO. *The Bryologist*, 87(4), 363. https://doi.org/10.2307/3242964

Ani, S., & Aminah, H. (2006). Plantation Timber of *Maesopsis eminii*. *Journal of Tropical Forest Science*, 18(2), 87–90.

Aravind, J., Devi, S. V., Ramadhani, J., Jacob, S. R., & Srinivasan, K. (2018). *The germination Metrics Package: A brief Introduction*. International Centre for Research in Agroforestry-National Bureau of Plant Genetic Resources, New Delhi. https://www.google.com/search? client=firefox- bd&q=The+ germination +Metrics+ Package %3A+A+brief+Introduction

Beentje, H. J. (1992). *Botanical Assessment of Ngezi Forest, Pemba*. Zanzibar Foresty Development Project and Finnish National Board of Forestry. https:// scholar. google. com/ scholar? hl=en &as_sdt =0%2 C5& q=B eentje% 2C +H. +J. +%281992%29. + Botanical+ Assessment+ of+ Ngezi+ Forest%2C+ Pemba.+ Zanzibar+ Foresty+ Development +Project +and +Finnish +National +Board +of+ Forestry. &btnG=.

Binggeli, P. (1989). The ecology of Maesopsis invasion and dynamics of the evergreen forest of the East Usambaras and their implications for forest conservation and forestry practices. In Hamilton, A. C., & Bensted-Smith, R (edts), *Forest Conservation in the East Usambara Mountains, Tanzania.* International Union for Conservation of Nature, Gland, Switzerland and Cambridge. https:// books. google. co.tz/books? hl= en&l r=&id=mdjQRmdKl-oC&oi =fnd&pg =PA269&dq =The+ecology +of+ Maesopsis+ invasion+ and+ dynamics+ of+ the+ evergreen+ forest+ of+ the+ East+ Usambaras+ and+ their+ implications+ for+forest+ conservation+ and+forestry +practices.+ +In+ Hamilton, +A.+C.,+%26+ Bensted- Smith, +R +(edts), +Forest +Conservation +in +the +East+ Usambara+ Mou&ots =tEGR4 A04h-&sig= 0YjCWRz3 AlHRivn2 OGOf5jfD Tso&redir_ esc= y#v= onepage &q&f=false

Binggeli, P. (1998). *An Overview of Invasive Woody Plants in the Tropics.* School of Agricultural and Forest Sciences, University of Wales. file:/// C:/ Users/ user/ AppData/ Local/ Temp/ Anoverviewofinvasivewoodyplantsinthetropics.pdf

Binggeli, P., & Hamiltonn, A. (1993). Biological invasion by *Maesopsis eminii* in the East Usambara forests, Tanzania. *Opera Botanica*, 121, 229–235.

Bongers, F., & Tennigkeit, T. (2010). *Degraded Forests in Eastern Africa: Management and Restoration.* Earthscan Publishing for sustainable future. https:// www. google. com/search? client=firefox-b-d&q= Degraded+ Forests+ in+ Eastern+ Africa%3A +Management +and+Restoration.+Earthscan+Publishing+for+sustainable+future.

Borghesio, L. (2012). *Disturbance in Tropical Forest Ecosystems: Perspectives from East Africa* [*Thesis Submitted as Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Biological Sciences (Ecology) in the Graduate College of the*]. University of Illinois at Chicago. https:// umanitoba. ca/ institutes /natural_ resources/ pdf/theses/PhD%20Thesis%20Long%202007.pdf

Boy, G., & Witt, A. (2005). Invasive Alien Plants and their Management in Africa. *Invasive Species*, 6975, 184.

Brooks, T., Mittermeier, R., Mittermeier, C., Da Fonseca, G., Rylindas, A., & Konstant, W. (2000). Habitat loss and extinction in the hotspots of Biodiversity. *Conservation Biology*, 16(4), 909–923.

Broz, A. K., Broeckling, C. D., He, J., Dai, X., Zhao, P. X., & Vivanco, J. M. (2007). A first step in understanding an invasive weed through its genes: An EST analysis of invasive Centaurea maculosa. *BMC Plant Biology*, 7(1), 1-10. https://doi.org/10.1186/1471-2229-7-25

Burgess, N., Butynski, T., Gordon, I., Luke, Q., & Sumbi, P. (2005). *Eastern Arc Mountains and Coastal Forests of Tanzania and Kenya.* Conservation International International Centre of Insect Physiology and Ecology and Nature Kenya Wildlife Conservation Society of Tanzania. https:// www. cepf. net/ sites/ default/ files/ final. easternarc. ep.pdf

Burgess, N. D., Butynski, T. M., Cordeiro, N. J., Doggart, N. H., Fjeldså, J., Howell, K. M., Kilahama, F. B., Loader, S. P., Lovett, J. C., Mbilinyi, B., Menegon, M., Moyer, D. C., Nashanda, E., Perkin, A., Rovero, F., Stanley, W. T., & Stuart, S. N. (2007). The biological importance of the Eastern Arc Mountains of Tanzania and Kenya. *Biological Conservation*, 134(2), 209–231. https:// doi. org/ 10. 1016/ j.biocon. 2006. 08.015

CABI. (2019). *Maesopsis eminii* (umbrella tree). Invasive Species Compendium. *https://www.cabi.org/isc/datasheet/32199#to*

CBD. (1992). *Convetion on Biological Diversity*. United Nations. https:// scholar. google. com/ scholar?hl= en&as_sdt =0%2 C5&q= %281992%29. +Convetion +on+ Biological+ Diversity.+ United+Nations.&btnG=

Chamier, J., Schachtschneider, K., Le Maitre, D., Ashton, P., & Van Wilgen, B. (2012). Impacts of invasive alien plants on water quality, with particular emphasis on South Africa. *Water SA*, 38(2). https://doi.org/10.4314/wsa.v38i2.19

Chornesky, E. A., & Randall, J. M. (2003). The Threat of Invasive Alien Species to Biological Diversity: Setting a Future Course. *Annals of the Missouri Botanical Garden*, 90(1), 67-76. https://doi.org/10.2307/3298527

Conservation and Management of the Eastern Arc Mountain Forests. (2007). *Biodiversity Conservation Thematic Strategy, Conservation and Management of the Eastern Arc Mountain Forests*. Global Environmental Facility. https:// www. thegef. org/ project/ conservation -and-management-eastern-arc-mountain-forests

Colautti, R. I., & MacIsaac, H. J. (2004). A neutral terminology to define ‘invasive’ species: Defining invasive species. *Diversity and Distributions*, 10(2), 135–141. https://doi.org/10.1111/j.1366-9516.2004.00061.x

Coppin, P., Lambin, E., Jonckheere, I., & Muys, B. (2002). Digital Change Detection methods in natural ecosystem monitoring. In E. Chuvieco (Edt), *Analysis of Multi-Temporal Remote Sensing Images* (3–36). https://doi.org/10.1142/9789812777249_0001

Cumming, G. S., & Allen, C. R. (2017). Protected areas as social-ecological systems: Perspectives from resilience and social-ecological systems theory. *Ecological Applications*, 27(6), 1709–1717. https://doi.org/10.1002/eap.1584

Dawson, W., Burslem, D. F. R. P., & Hulme, P. E. (2009). Factors explaining alien plant invasion success in a tropical ecosystem differ at each stage of invasion. *Journal of Ecology*, 97(4), 657–665. https://doi.org/10.1111/j.1365-2745.2009.01519.x

Dibenedetto, A. H. (1991). Light environment effects on chlorophyll content in Aglaonema commutatum. *Journal of Horticultural Science,* 66(3), 283–289. https://doi.org/10.1080/00221589.1991.11516155

Dos Santos, A. S., & Kiwango, H. R. (2010). Management of invasive plants in tropical forest ecosystems: Trials of control methods of Azadirachta indica. *World Applied Sciences Journal*, 10(12), 1414–1424.

Eastern Arc Mountain Conservation Endowment Fund. (1999). *Eastern Arc Mountain Conservation Endowment Fund - Mountain Blocks [Database]. What Is the Eastern Arc*. http://www.easternarc.or.tz/eastern-arc-mountains/index.html

Eastern Arc Mountain Conservation Endowment Fund. (2013). *Baseline Survey Report for 8 Nature Reserves and 1 National Park in the Eastern Arc Mountains of Tanzania*. https://www.tfcg.org/wp-content/uploads/2018/05/ArcJournal30.pdf

Eggeling, W. J. (1947). Observations on the Ecology of the Budongo Rain Forest, Uganda. *The Journal of Ecology*, 34(1), 20-87. https://doi.org/10.2307/2256760

Engh, V. (2011). *Intergrated Conservation and Development project and efforts around Amani Nature Reserve, Tanzania and their effects on the livelihood and forest conservation.* [*Masters thesis*]. Norwegian University of Life Science. https://

nmbu. brage. unit. no/ nmbu-xmlui/ bitstream/ handle/ 11250/ 187743/ Final%20Master% 20Thesis%20Vegard%20Engh.pdf?sequence=1&isAllowed=y

Epila, J., De Baerdemaeker, N. J. F., Vergeynst, L. L., Maes, W. H., Beeckman, H., & Steppe, K. (2017). Capacitive water release and internal leaf water relocation delay drought-induced cavitation in African *Maesopsis eminii*. *Tree Physiology*, 37(4), 481–490. https://doi.org/10.1093/treephys/tpw128

Epila, J., Hubeau, M., & Steppe, K. (2018). Drought Effects on Photosynthesis and Implications of Photoassimilate Distribution in ^{11}C-Labeled Leaves in the African Tropical Tree *Species Maesopsis eminii Engl. Forests*, 9(3), 1-15. https:// doi. org/ 10.3390/f9030109

Epila, J., Verbeeck, H., Otim-Epila, T., Okullo, P., Kearsley, E., & Steppe, K. (2017). The ecology of *Maesopsis eminii Engl*. in tropical Africa. *African Journal of Ecology*, 55(4), 679–692. https://doi.org/10.1111/aje.12408

Flores, J., González-Salvatierra, C., & Jurado, E. (2016). Effect of light on seed germination and seedling shape of succulent species from Mexico. *Journal of Plant Ecology*, 9(2), 174–179. https://doi.org/10.1093/jpe/rtv046

Frontier Tanzania. (2001). East Usambara Conservation Area Management Programme, Forestry and Beekeeping Division and Metsähallitus Consulting. In K. Z. Doody, K. M. Howell, & E. Fanning (eds.), *Amani Nature Reserve: A biodiversity survey (Technical Paper No. 52; p. 145).* https:// www. pohjonen. org/veli/ usambara/ tecpap52.pdf

Frontier Tanzania, N. K. (2002). Forestry and Beekeeping Divison and Metsahallitus Consulting, Dar es Salaam, Tanzania and Vantaa, Finland. Forestry and Beekeeping Divison and Metsahallitus ConsulDar es Salaam, Tanzania and Vantaa, Finland. In N. K. Beharrell, E. Fanning, & K. Howell (eds), *Nilo Forest Reserve: A biodiversity survey (East Usambara Conservation Area Managmenet Programme, Technical Paper No. 53). https:/ /scholar. google. com/scholar? hl=en&as_ sdt=0%2 C5&q= Nilo+ Forest+ Reserve%3A +A+ biodiversity+ survey +%28East +Usambara +Conservation +Area +Managmenet +Programme%2C +Technical+ Paper+ No.+ 53%29.+ &btnG=*

García-Llorente, M., Martín-López, B., González, J. A., Alcorlo, P., & Montes, C. (2008). Social perceptions of the impacts and benefits of invasive alien species: Implications for management. *Biological Conservation*, 141(12), 2969–2983. https:// doi. org/ 10. 1016/j.biocon.2008.09.003

Gereau, R. E., Cumberlidge, N., Hemp, C., Hochkirch, A., Jones, T., Kariuki, M., Lange, C. N., Loader, S. P., Malonza, P. K., Menegon, M. & Kariuki, N. P. (2016). Globally threatened biodiversity of the Eastern Arc Mountains and coastal forests of Kenya and Tanzania. *Journal of East African Natural History*, 105, 115-201.

Gioria, M., & Pyšek, P. (2017). Early bird catches the worm: Germination as a critical step in plant invasion. *Biological Invasions*, 19(4), 1055–1080. https:// doi. org/10.1007/s10530-016-1349-1

Haase, D. L. (2008). Understanding Forest Seedling Quality: Measurements and Interpretation. *Tree Planters' Notes,* 52(2), 24-30.

Hall, J. (1993). *Maesopsis eminii and its status in the East Usambara Mountains (Technical Report No. 13).* Ministry of Tourism, Natural Resources and Environment, Tanzania Forestry and Beekeeping Division. https:// scholar. google. com/scholar?hl= en&as_ sdt= 0%2 C5&q= Maesopsis +eminii+ and+ its+ status ++in +the +Eas t+ Usambara +Mountains +%28 Technical+ Report+ No.+ 13%29.+ Ministry+ of+T ourism%2C+ Natural+ Resources+ and+ Environmen t%2C+ Tanzania+ Forestry+ and+ Beekeeping+ Division.&btnG=

Hall, J. (2010). Future options for Maesopsis: Agroforestry asset or conservation catastrophe? In F. Bongers, T. Tennigkeit (eds), *Degraded forests in Eastern Africa: Management and restoration (pp. 221–246).* Earthscan. https:// scholar. google. com/ scholar? hl=en&as_ sdt=0%2C5&q =Hall%2C+J. +%282010%29. +Future+ options+ for+ Maesopsis%3A+ Agroforestry+ asset+or+ conservation+ catastrophe%3F+ In +F. +Bongers%2C+T. +Tennigkeit +%28 eds%29 %2C+ Degraded+ forests+ in+Eastern+ Africa %3A +Management +and+restoration+ %28pp. +221 %E2%80 %93246%29. +Earthscan.&btnG=

Hall, J. M., Gillespie, T. W., & Mwangoka, M. (2011). Comparison of Agroforests and Protected Forests in the East Usambara Mountains, Tanzania. *Environmental Management*, 48(2), 237–247. https://doi.org/10.1007/s00267-010-9579-y

Hamilton, A. C., & Bensted-Smith, R. (1989). Forest Conservation in the East Usambara Mountains, Tanzania. IUCN, Gland, Switzerland and Cambridge, UK 392 pp.

Hamrick, J. L., & Godt, M. J. W. (1996). Effects of Life History Traits on Genetic Diversity in Plant Species. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 351(1345), 1291–1298. https://doi.org/10.1098/rstb.1996.0112

Heger, W. T., & Van Andel, T. (2019). A social-ecological perspective on ecosystem vulnerability for the invasive creeper coralita (Antigonon leptopus) in the Caribbean. *Global Ecology and Conservation*, 18, e00605. https://doi.org/10.1016/j.gecco.2019.e00605

Hernández, L., Martínez- Fernández, J., Cañellas, I., & De la Cueva, A. V. (2014). Assessing spatio-temporal rates, patterns and determinants of biological invasions in forest ecosystems. The case of Acacia species in NW Spain. *Forest Ecology and Management*, 329, 206–213. https://doi.org/10.1016/j.foreco.2014.05.058

Hiscox, J. D., & Israelstam, G. F. (1979). A method for the extraction of chlorophyll from leaf tissue without maceration. *Canadian Journal of Botany*, 57(12), 1332–1334. https://doi.org/10.1139/b79-163

Hitimana, J., Legilisho, K. J., & Thairu, N. J. (2004). Forest structure characteristics in disturbed and undisturbed sites of Mt. Elgon Moist Lower Montane Forest, western Kenya. *Forest Ecology and Management*, 194(1–3), 269–291. https: // doi. org/ 10. 1016/j. foreco.2004.02.025

Hokkanen, T. J. (2002). *Adapting UNESCO MAB-Principles to East Usambara Area, Tanzania (Technical Report No. 62; p. 61). East Usambara Conservation Area Management Programme.* http:// taccire. suanet. ac. tz/ xmlui/ bitstream/ handle/ 123456789/ 348/UHURU%20L. pdf?sequence=1

Hrdina, A., & Romportl, D. (2017). Evaluating Global Biodiversity Hotspots – Very Rich and Even More Endangered. *Journal of Landscape Ecology*, 10(1), 108–115. https://doi.org/10.1515/jlecol-2017-0013

Hubeau, M., Mincke, J., Vanhove, C., Gorel, A. P., Fayolle, A., Epila, J., Leroux, O., Vandenberghe, S., & Steppe, K. (2019). ^{11}C-Autoradiographs to Image Phloem

Loading. Frontiers in Forests and Global Change, 2. https: //doi. org/ 10. 3389/ ffgc. 2019. 00020

Hulme, P. E., Burslem, D. F. R. P., Dawson, W., Edward, E., Richard, J., & Trevelyan, R. (2013). Aliens in the Arc: Are Invasive Trees a Threat to the Montane Forests of East Africa? In L. C. Foxcroft, P. Pyšek, D. M. Richardson, & P. Genovesi (Eds.*), Plant Invasions in Protected Areas (pp. 145–165).* Springer Netherlands. https://doi.org/10.1007/978-94-007-7750-7_8

International Centre for Research in Agroforestry. (1992). *A selection of useful trees and shrubs for Kenya: Notes on their identification, propagation and management for use by farming and pastoral communities*. https: // www. cabi. org/ ISC/ abstract/ 19920663107

International Union for Conservation of Nature. (2000). *International Union for Conservation of Nature-Guidelines for the prevention of Buiodiversity Loss Caused by Alien Invasive Species.* Invasive Species Specialist Group, Gland Switzerland. https:// portals. iucn. org/ library/efiles/documents/Rep-2000-052.pdf

Kader, M. A. (2005). A Comparison of Seed Germination Calculation Formulae and the Associated Interpretation of Resulting Data. *Journal and Proceedings of the Royal Society of New South Wales*, 138, 65–75, 2005ISSN 0035-9173/05/020065–11 $4

Katani, J. (1999). *Coping strategies against deforestation: Impact of socio economic factors with special attention to gender—Based indigenous knowledge: A case study of Mwanza District.* Sokoine University of Agriculture. https:// scholar. google. com/citations? user= NQd6 Q6g AA AAJ &hl =en#d =gs_md_cita- d&u=%2 Fcitations % 3 F view_ op%3 D view_ citation % 26 hl%3 Den% 26 user %3 DNQ d6Q6 gA AAAJ%26 citation_ for_ view %3D NQ d6Q 6gAA AAJ%3A vV6vV6tm YwMC%26 tzom%3 D-180

Kessy, J. F. (1998). *Conservation and utilization of natural resources in the East Usambara forest reserves: Conventional views and local perspectives.* Wageningen University. https://edepot.wur.nl/138697

Key, C. H., & Benson, N. C. (2006). *Landscape Assessment (LA) Sampling and Analysis Methods.* USDA Forest Service. https:// www. researchgate. net/ publication/ 241688462_ Landscape_ Assessment_LA_Sampling_and_Analysis_Methods

Kijazi, L. P., Lusambo, M. S., Matura, S. M., & Seki, H. (2014). *Biodiverity Survey in East Usambara Bioshere Reserve [Technical report]*. Ministry of Tourism, Natural Resources and Environment, Tanzania Forestry and Beekeeping Division. http://www.unesco.org/science/doc/mab/2014/sc_mab_tanzania_eastUsambaraTechnicalRep2014.pdf

Kilawe, C. J., Mtwaenzi, I. H., & Mwendwa, B. A. (2018). *Maesopsis eminii Engl*. Mortality in relation to tree size and the density of indigenous tree species at the Amani Nature Reserve, Tanzania. *African Journal of Ecology*. https://doi.org/10.1111/aje.12538

Kohli, R. K. (Ed.). (2009). *Invasive Plants and Forest Ecosystems*. CRC Press. https:// www. routledge. com/ Invasive – Plants – and – Forest - Ecosystems/ Kohli – Jose - Singh-Batish /p/book/9781420043372

Leal, L. C., Meiado, M. V., Lopes, A. V., & Leal, I. R. (2013). Germination responses of the invasive *Calotropis procera* (Ait.) R. Br. (Apocynaceae): Comparisons with seeds from two ecosystems in northeastern Brazil. *Anais Da Academia Brasileira de Ciências*, 85(3), 1025–1034. https://doi.org/10.1590/S0001-37652013000300013

Liebhold, A. M., Brockerhoff, E. G., Kalisz, S., Nuñez, M. A., Wardle, D. A., & Wingfield, M. J. (2017). Biological invasions in forest ecosystems. *Biological Invasions*, 19(11), 3437–3458. https://doi.org/10.1007/s10530-017-1458-5

Liebhold, A. M., Brockerhoff, E. G., & Nuñez, M. A. (2017). Biological invasions in forest ecosystems: A global problem requiring international and multidisciplinary integration. *Biological Invasions*, 19(11), 3073–3077. https:// doi. org/ 10. 1007/s10530-017-1547-5

Lovett, J. C. (1998). Importance of the Eastern Arc Mountains for Vascular Plants. *Journal of East African Natural History*, 87(1), 59–74. https://doi.org/10.2982/0012-8317(1998)87[59:IOTEAM]2.0.CO;2

Lyimo, J. G., Kangalawe, R. Y. M., & Liwenga, E. T. (2009). Status Impact and Management of Invasive Alien Species in Tanzania. *Tanzania Journal of Forestry and Nature Conservation*, 79(2), 1-15.

Mack, R. N., Simberloff, D., Lonsdale, W. M., Evans, H., Clout, M., & Bazzaz, F. A. (2000). Biotic Invasions: Causes, Epidemiology, Global Consequences, and Control. *Ecological Applications*, 10(3), 689-710. https://doi.org/10.2307/2641039

Mašková, T., & Herben, T. (2018). Root:shoot ratio in developing seedlings: How seedlings change their allocation in response to seed mass and ambient nutrient supply. *Ecology and Evolution*, 8(14), 7143–7150. https://doi.org/10.1002/ece3.4238

May, S. (2007). *Invasive terrestrial plants*. Infobase Publishing. https:// www. Infobase publishing. com/ Bookdetail.aspx?ISBN=0791091317

McDougall, K. L., Khuroo, A. A., Loope, L. L., Parks, C. G., Pauchard, A., Reshi, Z. A., Rushworth, I., & Kueffer, C. (2011). Plant Invasions in Mountains: Global Lessons for Better Management. *Mountain Research and Development*, 31(4), 380–387. https://doi.org/10.1659/MRD-JOURNAL-D-11-00082.1

Mehari, Z. H. (2015). The invasion of *Prosopis juliflora* and Afar pastoral livelihoods in the Middle Awash area of Ethiopia. *Ecological Processes*, 4(1).1-13 https://doi.org/10.1186/s13717-015-0039-8

Miller, K. J. (2013). *Establishing the Derema Corridor in the East Usambara Mountains, Tanzania: A Study of Intentions versus Realities [Norwegian University of Life Sciences, AAs]*. https://brage.bibsys.no/xmlui/handle/11250/187973

Mugasha, A. G. (1980). Growth of *Maesopsis eminii Engl*. In pure stands and under different forms of competition (Tanzania Silviculture Research Note, p. 48). Ministry of Natural Resources and Tourism. Mugasha. https:// www. cabdirect. org/ cabdirect/ abstract/ 19850600033

Mugasha, A. G. (1981). *The silviculture of Tanzanian indegenous tree species. II. Maesopsis eminii (pp. 1–14).* Ministry of Tourism, Natural Resources and Environment, Tanzania Forestry and Beekeeping Division. https:// www. google. com/search? client=firefox-b-d&q= Mugasha %2C +A. +G. +% 281 981 %29. +The +silviculture +of+ Tanzanian+ indegenous+ tree+species.+II. +Maesopsis +eminii

+%28pp. +1%E2% 80%9314 %29.+ Ministry +of+ Tourism%2C+ Natural +Resources +and+ Environment %2C+ Tanzania +Forestry +and +Beekeeping+Division.

Mugasha, A. G., Mgangamundo, M. A., & Zahabu, E. (2000). *Is Maesopsis eminii a problem in East Usambara Forests?* Faculty of Forestry & Nature Conservation, Sokoine University of Agriculture. https:/ /www. google. com/ search? client=firefox-b-d&q= Mugasha %2C +A. +G.%2C + Mgangamundo %2C+ M.+ A. %2C +%26 +Zahabu%2C +E. +%282000%29. +Is+ Maesopsis+ Eminii +a+ problem+ in+ East+Usambara+Forests%3F+Faculty+of+Forestry+%26+Nature+Conservation% 2C+Sokoine+University+of+Agriculture.

Musila, S. N. (2006). *Fruit productivity and other life history traits of Maesopsis eminii at a forest edge and in a closed habitat of Amani, East Usambara Mts. University of Vienna*. https:// scholar.google.com/ scholar?hl=en&as_sdt= 0%2 C5&q= Musila %2C+S.+N.+% 2820 06%2 9.+Fruit +productivity +and +other +life+ history +traits +of+ Maesopsis +eminii +at +a+ forest+ edge+ and+ in+ a+ closed+ habitat+of+Amani%2C+East+Usambara+Mts.+University+of+Vienna.&btnG=

Mwendwa, B. A., Kilawe, C. J., & Treydte, A. C. (2019). Effect of seasonality and light levels on seed germination of the invasive *tree Maesopsis eminii* in Amani Nature Forest Reserve, Tanzania. *Global Ecology and Conservation, 24*, 1-11. https://doi.org/10.1016/j.gecco.2019.e00807

Ngondya, I. B., Munishi, L. K., Treydte, A. C., & Ndakidemi, P. A. (2016). A nature-based approach for managing the invasive weed species Gutenbergia cordifolia for sustainable rangeland management. *Springer Plus*, 5(1), 1-14. https://doi.org/10.1186/s40064-016-3480-y

Ngondya, I. B., Treydte, A. C., Ndakidemi, P. A., & Munishi, L. K. (2017). Invasive plants: Ecological effects, status, management challenges in Tanzania and the way forward. *International Network for Natural Sciences*, 10(3), 204–2017.

Niinemets, U., Kull, O., & Tenhunen, J. D. (1998). An analysis of light effects on foliar morphology, physiology, and light interception in temperate deciduous woody species of contrasting shade tolerance. *Tree Physiology*, 18(10), 681–696. https://doi.org/10.1093/treephys/18.10.681

Oliveras, I., & Malhi, Y. (2016). Many shades of green: The dynamic tropical forest–savannah transition zones. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 371(1703), 1-15. https://doi.org/10.1098/rstb.2015.0308

Orwa, C., Mutua, A., Kindt, A., Jamnadass, R., & Anthony, S. (2009). *Agroforestry Database*: *A tree reference and selection guide version 4.0.* http:// www. worldagroforestry. org/ sites/ treedbs/treedatabases.asp

Paul, A., Khan, M. L., & Das, A. K. (2018). Population structure and regeneration status of rhododendrons in temperate mixed broad-leaved forests of western Arunachal Pradesh, India. *Geology, Ecology, and Landscapes*, 1–19. https://doi. org/ 10. 1080/24749508.2018.1525671

Qi, Y., Wei, W., Chen, C., & Chen, L. (2019). Plant root-shoot biomass allocation over diverse biomes: A global synthesis. *Global Ecology and Conservation*, 18, 1-14. https://doi.org/10.1016/j.gecco.2019.e00606

Ranal, M. A., & Santana, D. G. (2006). How and why to measure the germination process? *Revista Brasileira de Botânica*, 29(1), 1–11. https://doi.org/10.1590/S0100-84042006000100002

Saxena, A. K., & Singh, J. S. (1984). Tree population structure of certain Himalayan forest associations and implications concerning their future composition. *Vegetatio*, 58(2), 61–69. https://doi.org/10.1007/BF00044928

Shackleton, R. T., Witt, A. B., Aool, W., & Pratt, C. F. (2017). Distribution of the invasive alien weed, *Lantana camara*, and its ecological and livelihood impacts in eastern Africa. *African Journal of Range & Forage Science*, 34(1), 1–11. https:// doi. org/ 10. 2989/ 10220119.2017.1301551

Sheil, D. (1994). Naturalized and invasive plant species in the evergreen forests of the East Usambara Mountains, Tanzania. *African Journal of Ecology*, 32(1), 66–71. https://doi.org/10.1111/j.1365-2028.1994.tb00556.x

Shoo, R. A., & Songorwa, A. N. (2013). Contribution of eco-tourism to nature conservation and improvement of livelihoods around Amani nature reserve, Tanzania. *Journal of Ecotourism*, 12(2), 75–89. https://doi.org/10.1080/14724049.2013.818679

Simberloff, D. (2013). *Invasive Species: What Everyone Needs to Know*. Oxford University Press. https:// global. oup. com/ academic/ product/ invasive - species-9780199922031? cc=tz&lang=en&

Stattersfield, A. J., Crosby, M. J., Long, A. J., & Wege, D. C. (1998). Endemic Bird Areas of the World: Priorities for Biodiversity Conservation. *Bird Life Internation*,7, 218–236.

Sweddy, H. (2015). *Assessment of community awareness and perception on spread of invasive plant species along roads in Northern Tanzania. The 5th Asian-Pacific Weed Science Society Conference on "Weed Science for Sustainable Agriculture, Environment and Biodiversity", Hyderabad, India during 13-16 October*. https:/ /www. imedpub. com/articles/ assessment – of – farmers – perceptions – on - the-status - of- astripomoea- hyscamoides -kongwa- weed- invasiveness- in-central-tanzania. php? aid= 21967

Thapa, S., Chitale, V., Rijal, S. J., Bisht, N., & Shrestha, B. B. (2018). Understanding the dynamics in distribution of invasive alien plant species under predicted climate change in Western Himalaya. *Plos One*, 13(4), 1-16. https:// doi. org/ 10. 1371/ journal. pone. 0195752

Tobin, P. C. (2018). Managing invasive species. *Research*, 7, 1-8. https:// doi. org/ 10. 12688/ f1000 research.15414.1

Turner, W. R., Brandon, K., Brooks, T. M., Costanza, R., Da Fonseca, G. A. B., & Portela, R. (2007). Global Conservation of Biodiversity and Ecosystem Services. *BioScience*, 57(10), 868-873. https://doi.org/10.1641/B571009

Udo, N., Tarayre, M., & Atlan, A. (2016). Evolution of germination strategy in the invasive species Ulex europaeus. *Journal of Plant Ecology*, 10(2), 375–385. https:/ /doi. org/ 10. 1093/ jpe/ rtw032

United Republic of Tanzania. (2017). *Fores Management Plan for Amani Nature Reserve*. Ministry of Natural Resources and Tourism-Tanzania Forest Services. https:// www. tfcg. org/ wp-content/ uploads/ 2018/05/ArcJournal30.pdf

United States Department of Agriculture. (2013). *National Strategic Framework for Invasive Species Management (FS-1017; p. 36).* United States Department of Agriculture

Forest Sevice. https:// digitalcommons. usu. edu/ cgi/ viewcontent. cgi? article=1537 &context= govdocs

Van Rensburg, J., Van Wilgen, B. W., & Richardson, D. M. (2017). The challenges of managing invasive alien plants on private land in the Cape Floristic Region: Insights from Vergelegen Wine Estate (2004–2015). *Transactions of the Royal Society of South Africa*, 72(3), 207–216. https://doi.org/10.1080/0035919X.2017.1288175

Vardien, W., Richardson, D. M., Foxcroft, L. C., Thompson, G. D., Wilson, J. R. U., & Le Roux, J. J. (2012). Invasion dynamics of *Lantana camara L*. (sensu lato) in South Africa. *South African Journal of Botany*, 81, 81–94. https:// doi. org/ 10. 1016/j.sajb.2012.06.002

Vieira, D., Socolowski, F., & Takaki, M. (2010). Seed germination and seedling emergence of the invasive exotic species, *Clausena excavata*. *Brazilian Journal of Biology*, 70(4), 1015–1020. https://doi.org/10.1590/S1519-69842010000500014

Viisteensaari, J., Johansson, S., Kaarakka, V., & Luukkanen, O. (2000). Is the alien tree species *Maesopsis eminii Engl.* (Rhamnaceae) a threat to tropical forest conservation in the East Usambaras, Tanzania? *Environmental Conservation*, 27(1), 76–81. https://doi.org/10.1017/S0376892900000096

Wilcove, D. S., Rothstein, D., Dubow, J., Phillips, A., & Losos, E. (1998). Quantifying Threats to Imperiled Species in the United States. *BioScience*, 48(8), 607–615. https://doi.org/10.2307/1313420

Ye, J., & Wen, B. (2017). Seed germination in relation to the invasiveness in spiny amaranth and edible amaranth in Xishuangbanna, SW China. *Plos One*, 12(4), 1-15. https://doi.org/10.1371/journal.pone.0175948

APPENDICES

Appendix 1: Species Abundance in Invaded and Control plots

Family	Species	Species abundance	
		Invaded plots	Control plots
Rhamnaceae	*Maeopsis eminii*	206	58
Myristicaceae	*Cephalosphaela usambarensis*	87	61
Clusiaceae	*Allablankia stuhlmanii*	65	55
Mimosaceaae	*Newtonia buchanani*	52	41
Cannabaceae	*Celtis Africana*	29	37
Lauraceae	*Beilschmiedia kweo*	28	12
Anacardiaceae	*Sorindea madagascarensis*	25	39
Cannabaceae	*Trema orientalis*	21	19
Boraginaceae	*Codia Africana*	19	22
Chrysobalanaceae	*Parinari excels*	15	15
Meliaceae	*Khaya anthotheca*	13	13
Rubiaceae.	*Sericanthe odoratissima*	12	12
Fabaceae	*Albizia gummifera*	11	9
Meliaceae	*Cedrela odorata*	10	11
Moraceae	*Mesogyne insignis*	9	9
Lauraceae	*Ocotea usambaransensis*	8	7
Sapindaceae	*Blighia unijugata*	7	15
Chrysobalanaceae	*Parinari curatellifolia*	7	6
Euphorbiaceae	*Ricinodendron heudelotii*	6	7
Rubiaceae.	*Rothmania manganjae*	5	7
Phyllanthaceae	*Bridelia micrantha*	4	6
Malvaceae	*Cola usambarensis*	4	12
Lauraceae	*Cryptocarya liebentiana*	4	6
Rubiaceae	*Leptactina benguelensis*	4	4
Urticaceae	*Myrianthus holstii*	4	28
Rosaceae	*Prunur African*	4	11
Anacardiaceae	*Rhus natalensis*	4	9
Combretaceae	*Terminalia sambesiaca*	4	4
Clusiaceae	*Garcinia volkensii*	3	7
Hypericaceae	*Harungana madagascariensis*	3	5
Euphorbiaceae	*Macaranga capensis*	3	7
Euphorbiaceae	*Sapium ellipticum*	3	7
Olacaceae	*Strombosia scheffleri*	3	6
Leguminosae	*Acacia polyacantha*	2	5
Apocynaceae	*Dictyophleba lucida*	2	5
Moraceae	*Ficus lutea*	2	4
Apocynaceae	*Landolphia lucida*	2	5
Anacardiaceae	*Lannea schimperi*	2	4
Bignoniaceae	*Markhamia lutea*	2	4
Fabaceae	*Millettia usambarensis*	2	4
Lauraceae	*Phyllanthus inflatus*	2	5
Myrtaceae	*Eucalyptus tereticornis*	1	3
Malvaceae	*Grewia platyclada*	1	3

Chrysobalanaceae	*Maranthes goetzeniana*	1	3
Celastraceae	*Maytenus acuminata*	1	3
Celastraceae	*Maytenus holstii*	1	4
Fabaceae	*Albizia petersiana*	0	1
Euphorbiaceae	*Alchornea hirtella*	0	1
Icacinaceae family	*Alsodeiopsis schumannii*	0	2
Gentianaceae	*Anthocleista grandiflora*	0	2
Moraceae	*Antiaris toxicaria*	0	2
Aphloiaceae	*Aphloia theiformis*	0	2
Moraceae	*Aulacocalyx diervilleoides*	0	2
Cannabaceae	*Celtis philippensis*	0	1
Agavaceae	*Dracaena steudneri*	0	1
Putranjivaceae	*Drypetes gerrardii*	0	1
Leguminosae	*Erythrophleum guineense*	0	1
Rubiaceae	*Oxyanthus speciosus*	0	2
Olacaceae	*Rytigynia schumannii*	0	2
Rutaceae	*Teclea amanuensis*	0	3

RESEARCH OUTPUTS

(i) Journal Papers:

Mwendwa, B., Kilawe, C. K., Treydte, C. T. (2019). Effect of seasonality and light levels on seed germination of the invasive tree *Maesopsis eminii* in Amani Nature Forest Reserve, Tanzania, *Global Ecology and Conservation*, 21. https:// dx. doi. org/ 10. 1016/j. gecco. 2019. e00807

Mwendwa, B., Kaaya, O., Kilawe, C. K., Treydte, C.T. (2019). Spatio-temporal invasion dynamics of *Maesopsis emini*i in Amani Nature Forest Reserve, Tanzania. *Forest Ecology and Management,* 465 (2020) 118102

Mwendwa, B., Kilawe, C. J., Treydte, A. C. (2020). *Socio-ecological Study and Potential Management Options for Invasive species Maesopsis eminii in Amani Nature Forest Reserve, Tanzania (Manuscript).*

(ii) Poster presentation

Poster presentation

Invasion Status and Potential Management Options of the Invasive Tree Species *Maesopsis eminii* in Amani Nature Forest Reserve, Tanzania

By BEATUS MWENDWA - PhD Life Sciences (Biodiversity and Ecosystem Management)
Nelson Mandela African Institution of Science and Technology

INTRODUCTION

- *Maesopsis eminii* invasion in Amani Nature Forest Reserve was considered an ecological disaster in the 1980s (Hamilton,& Bensted-Smith, 1989).
- After more that 50 years have elapsed since its invasion, there is little information available on its invasion progress and earlier growth behavior
- The study evaluates invasion progress and the effects of shade on germination and earlier growth of *M. eminii*

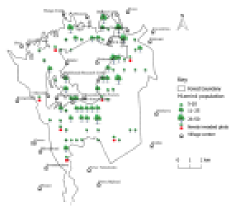
OBJECTIVES

- To quantify the current spatial distribution of invasive tree species *M. eminii*
- To evaluate changes in spatio-temporal distribution of *M. eminii* over the last 20 years
- To determine biophysical factors that promote the invasiveness of *M. eminii* in the study area
- To investigate potential options for management of the invasive tree species *M. eminii*

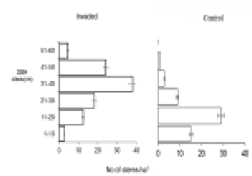
METHODOLOGY

- Forest vegetation survey
- Shade house experiment
- Forest vegetation (semi supervised) classification
- Socio-ecological survey
- Mapping
- Vegetation cover change detection analysis

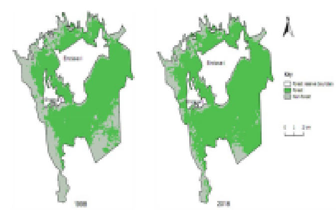
RESULTS



Current distribution of *M. eminii in Amani Nature forest reserve*



Population structure of *M. eminii* in invaded and uninvaded plots



Forest vegetation cover changes in Amani Nature Forest Reserve in 1998 and 2018

DISCUSSION

- *M. eminii* natality is decreasing and has shown low regeneration potential in dense stands
- *M. eminii* seed germination was higher in lower shade levels during wet season than dry season
- Management strategies of M. eminii should include the provision of unfavorable light regimes and take seasonality into account

CONCLUSION

In ANFR, M. eminii still encroaches particularly along forest edges, plantations, and farmland

RECOMMENDATIONS

The study recommend future comparative studies of the genetic differentiation as well as biophysical factors between Amani Nature Forest and other areas where *M. eminii* is not invasive

REFERENCES

Hamilton, A. C., & Bensted-Smith, R (edts). (1989). Forest Conservation in the East Usambara Mountains, Tanzania. IUCN, Gland, Switzerland and Cambridge, UK 392 pp