

**THE EFFECT OF LOGGING AND INVASION OF *ACACIA MEARNSII* ON  
REGENERATION OF *OCOTEA USAMBARENSIS* IN CHOME NATURE  
RESERVE, TANZANIA**

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**A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR  
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## EXTENDED ABSTRACT

The East African Camphor (*Ocotea*), a canopy tree species and an important component of Chome Nature Reserve (CNR) which used to occupy more than 50% of the forest canopy is seriously declining in density. Although the species is illegally logged for timber, the main concern of ecologists is the declining regeneration and death of individuals in all age classes. Increasing selective logging and tree cutting for fuel wood are implicated to impair recovery of Camphor forests by changing suitable habitats for its growth and initiating severe heart wood decay through broken branches and injuries, thus creating entry points for the decay fungi. In addition, establishment of *Acacia mearnsii*, an invasive tree in forest edges and its subsequent expansion in disturbed areas pose additional threats to the recovery and restoration of the *Ocotea* forests. Paucity of quantitative evidence of the influence of selective logging on regeneration and advance growth of *Ocotea* and the spread of decay fungi from mature to young *Ocotea* individuals, poses significant gap in our understanding of the ecology of *Ocotea* and management of the problem. Similarly, lack of estimates of coverage and costs to control the invasive tree *A. mearnsii* retards conservation efforts that would have been taken to maintain and restore the forest with native tree species. Therefore, this study was carried out with the overall objective of assessing the effect of logging and invasion of *A. mearnsii* on regeneration of *Ocotea usambarensis* so as to generate knowledge that is needed for restoration and conservation of CNR. In this study, the influence of logging on regeneration and population structure of *Ocotea* was examined in 62 plots of 10 m wide by 100 m long. The spread of heart wood decay from mature individuals to root suckers were assessed from 31 pairs of parent - suckers of *Ocotea*. Also, the

area invaded by *A. mearnsii* in CNR was marked and tracked using the Global Positioning System device and estimated using the Quantum Global Information System. Control costs were estimated using established figures and rates from similar studies on management of *A. mearnsii* from South Africa. Results indicated that the effect of selective logging was crucial in determining the regeneration and population structure of *Ocotea*. It is also noteworthy that *Ocotea* is rarely regenerating in disturbed areas below 1500m above sea level due to changes in their suitable habitat after severe logging. The study also indicated that, heart wood decay does not spread from parent individuals to suckers through the adjoining roots. With regard to coverage and cost to control *A. mearnsii* invasion which threatens restoration of *Ocotea* forest, it was found that the equivalent condensed area occupied by *A. mearnsii* is about 210 ha (i.e. 1.5% of the reserve area) and the total costs for mechanical clearing of the invaded area was estimated at TZS 164.64 million. It is recommended that, before embarking into mechanical control operations, experimental plots on clearing should be set to assess other externalities that may need management consideration during scaling up. To promote regeneration, advance growth and hence recovery of *Ocotea* forest, ongoing conservation activities in CNR need to be supplemented with enrichment planting and slashing of brambles to free few regenerating sapling of *Ocotea*.

## DECLARATION

I, JOHN RICHARD, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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John Richard

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Date

The above declaration confirmed by

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## **DEDICATION**

To the Almighty God, who created such a wonderful world for us to study and enjoy



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## LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CBD	Convention of Biological Diversity
CNR	Chome Nature Reserve
COSTECH	Commission of Science and Technology
DBH	Diameter at Breast Height
EAMs	Eastern Arc Mountains
GLM	General Linear Model
GPS	Global Positioning System
IAPs	Invasive Alien Plants
IUCN	International Union for Conservation of Nature
LSD	Least Significance Difference
MEA	Millennium Ecosystem Assessment
MNRT	Ministry of Natural Resources and Tourism
OR	Odds Ratios
PWBO	Pangani Water Basin Organisation
SUA	Sokoine University of Agriculture
TZS	Tanzanian Shillings
URT	United Republic of Tanzania
ZAR	South African Rands



## CHAPTER ONE

### 1.0 INTRODUCTION

#### 1.1 Background Information

Anthropogenic disturbances including extraction of timber, uncontrolled fires, clearance for subsistence agriculture and charcoal making have been cited as major causes of habitat change resulting in loss of biodiversity in most tropical forests (MEA, 2005; FAO, 2010). These forests and in particular tropical montane forests, include the most species-rich and diverse terrestrial ecosystems on Earth (Newmark, 2002, Hall *et al.*, 2009). However, despite their high and exceptional biological importance, current scenarios show that exploitation through illegal logging and tree cutting for fuel wood is more extensive in tropical forests than in the rest of the world (MEA, 2005). Such disturbances have led to regeneration failure of several commercial timber species due to changes in local environmental conditions necessary for their regeneration and establishment (Hall *et al.*, 2003; Makana and Thomas, 2005). Also, forest exploitation is recognised as one of the factors amplifying alien plants invasion in most tropical countries (Hulme *et al.*, 2013).

Tropical montane forests form very important ecosystems in Tanzania and occupy about 5% (i.e. ca 1.7 million ha) of the total forest area (URT, 1998). About half of this is found within the Eastern Arc Mountains (EAMs) of Tanzania (URT, 2010), one of the biodiversity “hot spot” areas in the world, which by the year 2000 had lost nearly 80% of its paleoecological forest area (Hall *et al.*, 2009). These forest-capped mountains which include the Pare, Usambara, Uluguru, Udzungwa and Nguru

blocks serve as the largest “water tower” in the country. Dar es Salaam city, Morogoro, Tanga, Iringa and nearby small towns depend entirely on water flowing from these mountains. Although forest exploitation is not allowed and the forests are strictly managed for water catchment and biodiversity conservation, illegal logging and encroachment for agriculture are still going on (Richard *et al.*, 2014). Chome Nature Reserve (CNR), which is the largest forest block in the Pare Mountains, is one of the areas in the EAMs where illegal logging and forest fires are considered the main conservation challenges (Malimbwi *et al.*, 2001, MNRT, 2008). Logged tree species are mainly *Ocotea usambarensis*, *Ficalhoa laurifolia*, *Podocarpus latifolius* and *Newtonia buchananii* (Bakari, 2002). The other challenge, which is also common in most of the EAMs, is the invasion from exotic plants introduced more than half a century ago for provision of various goods and services (Dawson *et al.*, 2008). Recent surveys in CNR have indicated that *Acacia mearnsii* which was planted in adjacent farmlands for provision of tannins and fuel wood has seriously invaded disturbed and riparian areas, thus posing a growing threat to conservation of this reserve (MNRT, 2008).

Although there could be significant reductions of anthropogenic activities in EAMs due to upgrading of high biodiversity rich forests to nature reserves, which means higher protection status, post-disturbance recovery of many tree species still remains a matter of concern (Richard *et al.*, 2014). For example, several valuable timber tree species such as *Ocotea usambarensis*, *Ficalhoa laurifolia*, *Podocarpus latifolius* which used to be abundant, now experience insufficient regeneration (Hamilton, 1989; Bakari, 2002). The failure to regenerate adequately is attributed to factors such

assignificant changes in habitat quality (Iversen, 1991),increased seedpredation (Bussmann, 2004) and competition with invasive alien plants (Richard *et al.*, in press). For the case of *O. usambarensis* which regenerates mainly through root suckers, declining regeneration and mortality have also been attributed to heart rot (decay of heart wood) which is thought to spread from parent trees to regenerants through roots and cause death (Nsolomo and Venn, 1994; 1998).

## **1.2 Logging and Regeneration of *Ocotea usambarensis***

*Ocotea usambarensis* Engl. (hereafter referred to as *Ocotea*) is a tree of moist mountainous forests of tropical Africa occurring mainly between 1500 to 2300 m above sea level (Mbuya *et al.*, 1994). Therefore,it is a common tree species in mountainous area of Kenya, Uganda,Tanzania, Malawi and Zambia but it is neither found in mountain ranges of Cameroon nor in Ethiopia (Renvall and Niemelä, 1993). In Tanzania, the species is mainly found in the Eastern Arc Mountains and Mount Kilimanjaro and few populations also exist in mountain areas of Mbulu (URT, 2015).*Ocotea* is a valuable utility hardwood which was exploited extensively for export after the 1940s, and used for furniture, panelling, vehicle building, boat ribs, flooring, acid vats, fittings in shops and laboratories, and for veneers (Nsolomo and Venn, 2000).Fromearly 1930s to mid 1980sbefore logging was banned in all catchment areas, the main timber harvested in west Usambara and southern Kilimanjaro was from huge *Ocotea* trees (Lovett and Poés, 1993) which probably had not been harvested for a longtime. Consequently, the selective mechanized logging using tractors and caterpillars impacted and destroyed an alarmingly high proportion of *Ocotea* forests which in some areas occupied more than 50% of the forest canopy (Hemp, 2006; Persha and Blomley, 2009). Although CNR was also

exploited during this time, the intensity was not as high as in the two mentioned forests, because logging was mainly by pitsawing (MNRT, 2008).

*Ocotea* regenerates mainly from suckers and coppices (Mbuya *et al.*, 1994). Coppicing from stumps and suckering from parent roots is often prolific following disturbance particularly felling of mature *Ocotea* or poisoning of defective trees (Mugasha, 1996; Bussmann, 2004). *Ocotea* regeneration occurs typically in groups around the stumps of felled trees. Although such groups vary in extent, in its favourite habitat, regenerants from a single *Ocotea* stump may cover an area of 12 m radius or more. Early studies on regeneration of montane forests in southern slopes of Kilimanjaro and in the West Usambara Mountains (Willan, 1965; Kimariyo, 1972) reported that *Macaranga kilimandscharica* was a dominant species in gaps where *Ocotea* is absent following natural death or logging. Consequently, saplings of *Ocotea* were successfully competed by *M. kilimandscharica*, a pioneer species with almost 50% higher growth rate than that of the *Ocotea* (Bussmann, 1999). In this case, *M. kilimandscharica* plays an important role as shade tree, as *Ocotea* saplings apparently do not tolerate full sun. After the breakdown of the relatively short-lived *M. kilimandscharica* trees, the meanwhile well-established young *Ocotea* trees close and shade the gaps, and effectively prevent further germination or establishment of *M. kilimandscharica*, consequently forming *Ocotea* stands of a more or less uniform age structure (Bussmann, 2001).

Similar to other tropical timber species, *Ocotea* is known to experience low sexual regeneration through seedlings (Newmark, 2002). Although germination of sown

seeds is fairly good (Msanga, 1998), seed viability is very short and therefore precludes the formation of a seed bank and/or dries out before reaching potential regeneration sites (Bussmann, 1999; Baskin and Baskin, 2005). A study in Mount Kenya found that vegetative regeneration through suckers was more important than sexual regeneration, because the density of root suckers was found to be 6 times higher than that of seedlings (Kleinschroth *et al.*, 2013). In Tanzania, the characteristic of *Ocotea* to produce many suckers after disturbance has been used to devise a management scheme for timber production (Willan, 1965).

### **1.3 Post-disturbance Recovery in Montane Forests**

The forests of Eastern Arc Mountains, particularly the submontane and montane (i.e. between 800 and 1800 m above sea level) have been subjected to heavy logging for decades (Hamilton, 1989). Other anthropogenic disturbances such as clearance for farmlands, forest fires, harvesting of building materials and fuel wood have also contributed significantly to the destruction of the natural forests (Burgess *et al.*, 2002), but timber harvesting is still considered widespread and pervasive. Although tropical forests have been considered more resilient to disturbance (Chazdon, 2003) and also resistant to plant invasion than many other ecosystems (Rejmánek, 1996), discerning which level of disturbance does not interfere with recovery of forest structure and composition has always been very difficult (Waser *et al.*, 2013). Tree removals, especially emergent trees with large canopies like *Ocotea*, modify the ecological conditions under the canopy. These changes affect the regimes of light, moisture, wind speed, temperature and composition of the micro-organisms. As a

result, floral species composition also changes, adapting to the modified conditions (Myers *et al.*, 2000).

According to the concept of ecological succession (Connell and Slatyer, 1977), what would normally happen after disturbance is the recruitment and establishment of early-successional tree species which benefit from the conditions associated with tree removals. Then, the density of early-successional tree species would decline gradually and after a long period of time replaced by mid and late-successional tree species. However, the establishment of forest with late-successional tree species similar to the ones that existed before disturbance depends strongly upon the presence of remnant forests in the immediate area for provision of propagules (Chazdon, 2003). The failure of some late- successional tree species to regenerate after disturbance has received additional explanations. For example the failure of *Ocotea* to regenerate in Amani Nature Reserve, a part of the EAMs, has been linked with the “little ice age” which was experienced in Eastern Africa between AD 1500 and AD 1800 (Hamilton, 1989). It was suggested that this cooler period might have pushed down the vegetation belts some 200m, explaining the existence of montane tree species found as relicts at anomalously low altitude where they are now unable to produce or regenerate (Iversen, 1991).

It is widely recognized that, disturbances that impact soils as well as aboveground vegetation, such as bulldozers, skidders, heavy grazing, and fires significantly slow down the rate of forest structural recovery and can have long-lasting effects on species composition (Newmark, 2002; Chazdon, 2003). Nevertheless, most of Eastern Arc Mountain ranges are associated with rainfall regimes which offer better

forest-growing conditions than most of the nearby lowlands. Therefore, the high rainfall (Iversen, 1991), long-term climatic stability (Hamilton, 1989), soil characteristics, proximity of disturbed areas to forest reserves (Hall *et al.*, 2009), together with the increasing conservation emphasis (URT, 2010) still offer great opportunities and it is expected to promote a relatively rapid recovery and restoration of this ecosystem.

#### **1.4 Heart wood Decay in *Ocotea usambarensis***

Heart rot (decay of heart wood) is considered the main problem in many mature *Ocotea* trees of 50 years or older (Dick, 1969; Nsolomo and Venn, 2000), such that several of these trees have developed hollow stems. A survey of *Ocotea* trees in the Kilimanjaro forest indicated that the decay spread to an average of 12% of the total volume of an infected tree, and hence such trees were useless as peeler logs (Nsolomo and Venn, 2000). Heart rot is a fungal disease that causes decay of wood at the centre of tree trunks and branches. Heart rot fungi enter trees through branch stubs and injuries resulting from stem or branch breakage, fire and insect damages (Rimbawanto, 2006). Although heart rot facilitates breakdown of wood to release carbon and minerals that have been fixed by trees, thus important in nutrients cycling, it is undesirable in commercial forestry (Schwarze, 2007). The decay is caused by white-rot fungi which preferentially digest the lignin resulting to changes in colour, texture, strength and hence the quality of the wood (Rimbawanto, 2006).

Normally, in active growing trees there is a natural mechanism that limits the spread of wood-decaying fungi into live healthy sapwood. The spread of fungi from discolored wood is limited by the formation of reaction zone in response to activity

of the wood pathogen (Schwarze, 2007). The production of this marginal zone resulting from the interaction of the wood-decay pathogen and live cells of sapwood is called compartmentalization (Shortle and Dudzik, 2012). Therefore, the formation of a hollow tree is the result of the protective response of living cells of sapwood to wall-off (compartmentalize) fungal infection initiated by wounding and the continued formation of wood by the vascular cambium (Smith, 2006). In most cases, unlike root rot, heart rot does not cause death to trees as it is mainly restricted to the non-living part of the tree (Schwarze, 2004), but significantly deteriorate the quality and reduce production of solid wood. The decay usually develops slowly over a period of many years, thus it is much more common and serious in overmature trees than in young ones.

The problem of heart rot as the main defect in mature *Ocotea* trees was reported since 1960s by Dick (1969). Later, Renvall and Niemelä (1993) and Nsolomo *et al* (2000) carefully collected and studied fungi decaying *Ocotea* logs, stumps and standing trees. The former scientists found 10 polypore (Basidiomycetes) species that decay *Ocotea*, including *Phellinus senex* which had long been implicated as a cause of heart rot of the species, because of the occurrence of its basidiocarps on stems and butts of standing trees. Nsolomo *et al* (2000) isolated 72 species including 12 basidiomycetes from decay of standing *Ocotea* trees and found that although *P. senex* cause significant weight loss but it does not pioneer decay in *Ocotea* (Nsolomo and Venn, 2000). The study by Nsolomo *et al* (2000) contributed significantly in this aspect, because from the many fungi that were isolated, the study clearly separated between primary colonizers which can invade sapwood of living trees through wounds and secondary colonizers which cannot do so.



### 1.5 Invasive Alien Species in Protected Areas

Degradation of forest ecosystems and their invasion by alien plants are inextricably linked. The threat posed to biodiversity by alien invasive species is considered second only to that of habitat loss (MEA, 2005). Plants are among the most important alien invasive species worldwide (Binggeli, 1998). Normally, when they establish in new environments, subsequent expansion is often exponential until all the potential habitats becomes fully occupied (Marais *et al.*, 2004). Expanding populations of alien invasive plants even to areas regarded as strictly conserved, for example in the EAM blocks, are a warning signal that if concerted efforts are not taken now, then the costs of controlling or eradicating the species in future will be prohibitively expensive. Despite the growing threat from species like *Lantana camara*, *Maesopsis eminii* and *A. mearnsii*, little has been done to manage the species in most of the nature reserves, including the CNR (URT, 2010).

Majority of the species invading EAM forests were introduced for potential commercial gain, with economic development of the area being the central goal (Cronk and Fuller, 1995) and a few others were accidentally introduced (Dawson *et al.*, 2008). But anthropogenic disturbance of forests adjacent to where these species were introduced, promoted their invasion and displacement of native species (URT, 2010). For example, *Acacia mearnsii* was introduced adjacent to CNR in mid 1950s to provide fuel wood and for production of barks which were being sold to Giraffe Tannin Industry in Lushoto, thus contributed income generation to the local communities (MNRT, 2008). However, the species has turned to be a conservation challenge for CNR due to its rapid expansion particularly along riparian areas on the

plateau. In spite of the fact that *A. mearnsii* has been widely cultivated for soil improvement and erosion control, it is well recognized for threatening native habitats by competing with indigenous vegetation and increasing water loss from riparian zones (Nyoka, 2003). Like in many other nature reserves in the EAMs, conservation and restoration of forest in CNR can hardly be achieved if not integrated with management of the alien invasive species (Richard *et al.*, in press).

## 1.6 Problem Statement and Justification

Despite some improvements in forest condition due to reduction of anthropogenic activities as a result of upgrading the conservation status of some EAM forests, declining regeneration and death of some species which used to be dominant in these forests still remain a matter of concern to ecologists (Richard *et al.*, 2014). Of particular interest in this study, is the East African camphor, *Ocotea usambarensis* which used to be the dominant canopy tree species of humid East African montane forests (Renvall and Niemelä, 1993). In CNR before mid 1980s, *O. usambarensis* occupied more than 50% of the canopy density above 1600 m above sea level. Thereafter, many studies in EAM forests including the CNR (Iversen, 1991; Lovett and Poós, 1993; Maliondo *et al.*, 1998; Hemp, 2006) have reported that the population structure of *Ocotea* is dominated by mature trees, thus very unstable and in heavily logged areas, individuals with DBH < 50 cm are completely absent (Hamilton, 1989; Kleinschroth *et al.*, 2013). Factors attributed to the decline of *Ocotea* could be multiple, but stem mainly from habitat deterioration (Richard *et al.*, 2014). Although several studies (Willan, 1965; Bussmann, 2001; Bitahiro *et al.*, 2006) suggest that regeneration of *Ocotea* which is mainly through root suckers could

benefit from gap opening, local condition requirements for advance growth of the young regenerants remain largely unknown. Furthermore, the invasion of *A. mearnsii* which is wildly occupying disturbed areas of CNR poses an additional problem for establishment and recovery of relatively slow growing tree species like *Ocotea*.

*Ocotea ambarensis* forms a very important component of the water catchment forests of CNR, which apart from being a dependable source of water to more than 260,000 people (NBS, 2012), it also contributes significantly to climate amelioration of the area and nearby small settlements (PWBO/IUCN, 2006). However, the effects of disturbances (e.g. illegal logging and tree cutting for fuel wood) on regeneration and recovery of *Ocotea*, hence the ecosystem of CNR are poorly understood. Also, the increasing threat to this ecosystem that is created by the invasion of *A. mearnsii* further complicates conservation and restoration strategies of CNR. Consequently, decisions to control invasions in CNR to pave way for restoration of native species will always face difficulties if concrete evidence of impacts and cost estimates needed to control the species are lacking. Although, a lot of quantitative information has been generated on invasion characteristics, abundance and distribution of alien invasive plants in the EAMs (Bingelli, 1998; Cordeiro *et al.*, 2004; Dawson *et al.*, 2008), studies estimating costs needed to manage the species thus controlling their invasion are not available. Therefore knowledge generated from this study on the demography, current regeneration patterns of the *Ocotea* population, coverage of *A. mearnsii* and resources needed to manage it will be very vital for the management and conservation of CNR.

## 1.7 Research Objectives

### 1.7.1 Overall objective

The overall objective was to study the effect of logging and invasion of *Acacia mearnsii* on regeneration of *Ocotea usambarensis* as to generate knowledge that is needed for restoration and conservation of Chome Nature Reserve

### 1.7.2 Specific objectives

- i. To assess factors that are responsible for declining regeneration and death of *Ocotea usambarensis* in Chome Nature Reserve;
- ii. To examine the effect of logging on recovery and population structure of *Ocotea usambarensis* in Chome Nature Reserve;
- iii. To assess the spread of heart rot and decay fungi from parent trees to root suckers in *Ocotea usambarensis* in Chome Nature Reserve;
- iv. To estimate coverage and costs required to control *Acacia mearnsii* invading disturbed and riparian areas of Chome Nature Reserve.

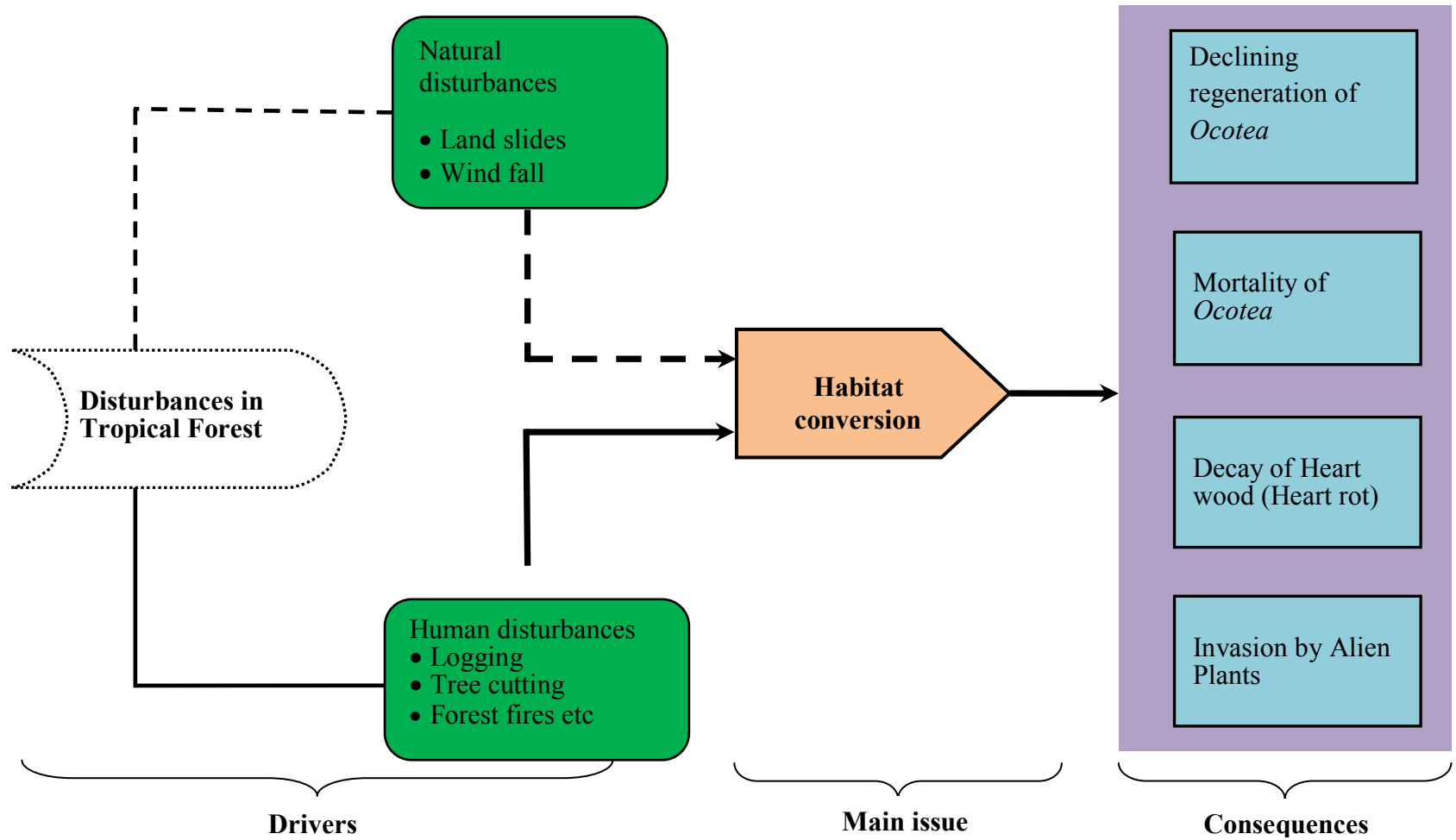
## 1.8 Conceptual framework

The association between drivers of habitat conversion and its hypothesised consequences are elaborated in the conceptual framework of this study (Fig.1). The declining regeneration of *Ocotea*, death of individuals in all age classes, decay of heart wood and invasion of disturbed areas of the reserve by *Acacia mearnsii* could be invoked by habitat conversion which has resulted from forest disturbances (Hamilton, 1989; Iversen, 1991; Nsolomo and Venn, 2000; Kleinschroth *et al.*, 2013; Richard *et al.*, 2014). However, forest disturbances can be either natural such as landslides and wind fall or human-caused (anthropogenic) such as logging, tree

cutting for fuel wood and poles, forest fires and encroachment for agriculture. As indicated by full lines in the conceptual framework, contrary to dotted lines representing natural disturbance, this study concentrated on few anthropogenic disturbances mainly logging and tree cutting and their consequences.

## **1.9 Thesis outline**

The thesis is structured into six chapters. The first chapter (Chapter 1) provides the general introduction including the background information, description of concepts that appear throughout the thesis, problem statement, justification, and the objectives of the study. It is then followed by four detailed studies which are presented as articles or manuscripts. Each of these manuscripts is a separate chapter of the thesis. Chapter 2 addresses the declining regeneration and death of *Ocotea usambarensis*; Chapter 3 addresses the effect of logging on recovery and population structure of *Ocotea usambarensis*; Chapter 4 assess the likelihood of decay fungi to spread from parent trees root suckers and cause death; Chapter 5 estimates the coverage and costs required to control *Acacia mearnsii* invasion resulting from anthropogenic disturbance particularly logging. Lastly, Chapter 6 provides conclusion and major recommendations from this study. A summary of methods and techniques to address the specific objectives I –IV which form chapters 2 – 5 respectively is provided hereunder:



**Figure 1:** Conceptual framework of the study

**Chapter 2:** In this chapter, it was hypothesized that the declining regeneration and death of *Ocotea* is a result of heart rot in mature trees and extensive selective logging. Field surveys to determine the intensity of logging were carried out in 62 plots of 10m wide and 100 m long that were established evenly to represent the whole forest reserve. All trees within a plot were enumerated and recorded as live, cut or naturally dead. Assessment of heart rot intensity on both live and dead *O. usambarensis* was done in order to determine the cause of their health status and its influence on density of young individuals. The condition of each plot was assessed in terms of disturbance level, as this was then used to determine the influence of disturbance on regeneration and death of *O. usambarensis*.

**Chapter 3:** In this chapter, the interest was to understand the effect of logging on recovery and population structure of *Ocotea* in CNR. Therefore, following a detailed survey in Chapter 1, areas of sampling plots for this study were classified into one of the three logging intensities based on density of stumps; as heavily logged, intermediate logged and unlogged areas. Proportional representation of *Ocotea* individuals of various growth stages was compared across the three logging intensities. Also the association between density of stumps and number of young *Ocotea* individuals is evaluated to determine future tree composition of the forest canopy across the disturbance levels.

**Chapter 4:** From the results of Chapter 1, it was hypothesized that the decay fungi causing heart rot spread via roots from parent trees to root suckers. The hypothesis was tested by determining presence-absence of decay fungi in the roots connecting

parent trees and their suckers. Increment borer was used to collect cores from inner wood which were cultured, incubated and observed for any fungal growth. The influence of tree size (diameter) and distance between parent trees and their suckers on spread of decay fungi was also assessed in this chapter.

**Chapter 5:** Since the alien tree *Acacia mearnsii* was found to invade disturbed forest edges, logging routes and riparian areas, its management was considered necessary if conservation and restoration of the reserve by native plant species is to be achieved. Therefore, estimate of coverage and density of *A. mearnsii* was determined using field surveys and Quantum Global Information System techniques. Also, by adopting control costs and incremental water use by *A. mearnsii* established under the South African Programme “Working for Water” the impact and total costs for controlling *A. mearnsii* in CNR are estimated.



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## **CHAPTER TWO**

**Manuscript One: Assessment of factors for declining regeneration and death of  
East African Camphor in a moist montane forest of Tanzania**

Richard, J., Madoffe, S. S. and Maliondo, S.M.S.

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## ASSESSMENT OF FACTORS FOR DECLINING REGENERATION AND DEATH OF EAST AFRICAN CAMPHOR IN MOIST MOUNTANOUS FOREST OF TANZANIA

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**RICHARD J, MADOFFE SS & MALIONDO SMS. 2014. Assessment of factors for declining regeneration and death of East African camphor in moist mountainous forest of Tanzania.** The East African camphor (*Ocotea*), a canopy tree species and an important component of Chome Nature Reserve is seriously declining in density. Although the species is still illegally logged for timber, the main concern of ecologists is the declining regeneration and death of individuals in all age classes. In this study, we examined the influence of disturbance and heart rot on the regeneration and death of *Ocotea*. Forest disturbance and the status of *Ocotea* were assessed in 62 strips of 10 m wide and 100 m long. The results of this study indicate that disturbance was a more important determinant of *Ocotea* death than heart rot, and regeneration of *Ocotea* was much influenced by elevation. There was no evidence for the influence of disturbance on regeneration. These results suggest that the distribution of *Ocotea* in Chome Nature Reserve was shifting towards higher elevation. This was due to degradation of habitats suitable for growth of *Ocotea* in lower accessible areas. Therefore, protection by restricting anthropogenic activities in the nature reserve is important for restoring and maintaining camphor forests.

Keywords: *Ocotea*, Chome, elevation, illegal logging, habitat

### INTRODUCTION

Anthropogenic disturbances including extraction of timber, uncontrolled fires, clearance for subsistence agriculture and charcoal making have been cited as major causes of habitat change resulting in reduction of plant species diversity in most tropical forests (MEA 2005). One example of such habitats is the Eastern Arc Mountains of Tanzania, one of the hot spot biodiversity areas in the world, which by the year 2000, had lost nearly 80% of its paleoecological forest habitat (Hall et al. 2009). Several studies in the Eastern Arc Mountains have reported decline in regeneration and density of important tree species which is associated with disturbance and overexploitation (Hamilton 1989, Mrema & Nummelin 1998, Frontier Tanzania 2001, 2005, Mwang'ingo et al. 2004). One of the species declining seriously in the Eastern Arc Mountains is the East African camphorwood, *Ocotea usambarensis* (referred to as *Ocotea* from here on). Although *Ocotea* is still illegally logged for timber, the declining regeneration and death of the species have been attributed to heart rot (Nsolomo & Venn 1994).

*Ocotea* whose native range in Tanzania is confined to the Eastern Arc Mountains and Mount Kilimanjaro (Mbuya et al. 1994), is also known to occur in mountain rain forests of Kenya, Uganda, Malawi and Zambia (Renvall & Niemela 1993). *Ocotea* used to be the dominant tree species in Chome and Magamba Nature Reserves (both in the Eastern Arc Mountains, Table 1) and on the southern slopes of Kilimanjaro, but its stands have been logged extensively, a practice started before the 1930s (Kimariyo 1972, Hamilton & Mwashia 1989). *Ocotea* regenerates mainly from suckers and coppices and in its favourite habitats can grow to a height of 40 m and diameter up to 3 m (Mbuya et al. 1994). Although germination of sown seeds of *Ocotea* is fairly good (Msanga 1998), natural regeneration from seed is uncommon due to predation by squirrels or damage by larvae before ripening (Bussmann 2004). It is for this reason that early research on *Ocotea* concentrated on finding alternative ways to regenerate the species and regeneration from root suckers proved to be the best (Kimariyo 1971, Mugasha 1996).

**Table 1** Stand characteristics and density of *Ocotea usambarensis* (dbh > 10 cm) in the Eastern Arc Mountain forests as recorded from each of the four nature reserves, namely, Chome (CNR), Magamba (MNR), Uluguru (UNR) and Amani (ANR) Nature Reserves

Nature reserve	Elevation (m asl)	Average tree density (stems ha <sup>-1</sup> )	<i>Ocotea</i> density (stems ha <sup>-1</sup> )	% of canopy occupied by <i>Ocotea</i>	Current regeneration status	References
CNR	1250–2463	342	36	Dominant tree with over 42% of the canopy	Regenerating above 1500 m asl	Malimbwi & Mugasha (2001)
MNR	1650–2300	405	113	Dominant tree with over 57% of the canopy in some areas	Regenerating above 1500 m asl	Maliondo et al. (1998)
UNR	600–2638	364	17	Occupy over 3.7% of the canopy	Regenerating above 1700 m asl	Frontier Tanzania (2005)
ANR	300–1128	472	0.12	Occupy only 0.03% of the canopy	No regeneration	Hamilton (1989), Frontier Tanzania (2001)

For several years, declining regeneration and death of *Ocotea* stands, which account for almost 50% of some forests in the Eastern Arc Mountains, have drawn attention of many scientists. Occurrences of *Ocotea* stand mortality for example in Chome Nature Reserve has increased since it was first noticed (L.Nshubemuki, personal communication). Usually deaths of *Ocotea* take the form of dieback of branches which finally leave the dead trees branchless. The declining regeneration and mortality have been attributed to heart rot which is thought to be transmitted from mother trees to regenerants through roots and causes death (Nsolomo & Venn 1994, 1998). Recently, however, we observed that deaths of *Ocotea* are more frequent in highly disturbed areas. In less disturbed areas, several *Ocotea* trees which had hollow trunks due to heart rot were still having green crowns and had recruited several surviving regenerants in their vicinity. In the 1930s, heart rot was already a common problem in mature *Ocotea* trees. The decay limited the use of the species for peeler logs. However, at that time, deaths in all age classes which are seen nowadays were not observed (Willan 1965). The performance of *Ocotea* which is a climax tree species but also has characteristics of pioneer species may be altered by disturbance (Bussmann 2001). Paucity of quantitative evidence of the influence of disturbances and heart rot poses significant gap in our understanding of the ecology of *Ocotea* and management of the problem. Therefore, in

this study we surveyed Chome Nature Reserve which is a moist forest of differentially disturbed areas (based on past licensed logging activities) to determine the importance of disturbance on dieback and regeneration of *Ocotea*.

## MATERIALS AND METHODS

### Study area

Chome Nature Reserve, which covers 14,283 ha of land is located between 4° 10'–4° 24' S and 37° 53'–38° 00' E. The altitude of Chome Nature Reserve ranges between 1250 and 2463 m above sea level. Rainfall is estimated at 3000 mm on the wetter eastern side of the reserve, while the dryer western slopes receive an estimated 1500–2000 mm. Temperature ranges between a minimum of 15 °C in July and a maximum of 20 °C in February (Lovett 1993). Main vegetation types are submontane, montane and upper montane forests. The montane forest occurs between 1500 and 2300 m above sea level which, before extensive logging, was dominated by *Ocotea*. Unlike many other forests in the Eastern Arc Mountains, huge *Ocotea* trees reaching 45 m in height and 2 m diameter are common in the Chome Nature Reserve (URT 2010). Much of the disturbances after the logging ban in 1986 are due to illegal logging of *Ocotea*, *Podocarpus* spp. and *Newtonia buchananii*. In addition, *Parinari excelsa*, a common tree species in the submontane forest, is cut for fuelwood, whereby big trees are

**Table 1:** Stand characteristics and density of *Ocoteausambarensi* (dbh > 10cm) in the Eastern Arc Mountain forest as recorded from each of the four nature reserves, namely Chome (CNR), Magamba (MNR), Uluguru (UNR) and Amani (ANR) Nature Reserve.

debarked to hasten their death and later felled for fuelwood.

### Data collection

In determining the intensity of tree cutting and other past human disturbances in the forest, the study adopted techniques that were used by Frontier Tanzania (2005). Eight transects ranging from 2 to 3 km in length were established from the boundary to the interior of the forest towards Shengena peak. The forest was accessed from eight villages (Vushanje, Mtii, Mvaa, Changuluwe, Gonjanza, Suji, Tae and Chome) which border the forest. The villagers practise illegal pit-sawing in the reserve. Data were collected along each transect in a 10 m wide (i.e. 5 m on either side of the transect line) and 100 m long strip with an interval of 200 m between strips. This gave a total of 62 strips in all the eight transects, equivalent to 0.05% of the sampled area of Chome Nature Reserve. Heath land (1458 ha) which is dominated by *Philipia* spp. was not sampled in this study.

Along the strip, each woody plant (i.e. not lianas or creepers) with diameter at breast height (dbh) > 5 cm was measured, identified and recorded as live, cut or naturally dead. All young *Ocotea* trees with dbh ≤ 5 cm within the strips were counted and those with dbh > 5 cm were assessed in terms of their health status (live, dying back or dead) and their site elevation recorded. Assessment of heart rot intensity on both live and dead *Ocotea* was done in order to predict the cause of their health status. The heart rot intensity indices were scored on a scale of 1 to 3, where 1 = trees with severe heart rot signified by holes in the trunks, 2 = trees with clear symptoms of decay (i.e. fungal fructification and epicormic branches) and 3 = trees which had none of the above defects (Nsolomo & Venn 2000). In assessing the influence of heart rot on the regeneration, only mature *Ocotea* trees with dbh > 30 cm within the strip were considered. The index with highest frequency (mode) in the strip was regarded as the score for heart rot intensity of the strip.

The condition of each strip was assessed in terms of disturbance intensities due to past human activities. The intensities were ranked as mild, moderate or high disturbance. The criteria that were used by the survey team as a measure of disturbance intensities were presence of foot

paths, presence of sawing pits, number of logs and tree stumps, absence of climbers and the general forest physiognomy. Canopy density, mostly used to determine regeneration in tropical forests, was assessed in each strip and this also assisted as additional measure of disturbance. Percentage of the canopy density was measured using concave spherical densitometer (Lemmon 1957). Three readings of the canopy density were taken over each strip (one at the middle and one each at both ends) and the average calculated.

### Data analysis

Data were analysed using SAS 9.1.3 (2009). One-way ANOVA was used to explain basic trends in forest and *Ocotea* status in relation to the three disturbance categories. Before running the ANOVA, all variables that did not pass normality test were log (x + 1) transformed with the exception of canopy cover (arcsine transformed) as well as elevation and density of live trees (both were normally distributed). Multiple regression analysis (using backward elimination) was used to determine the influence of elevation, disturbance, canopy cover and heart rot intensity on regeneration and health status of *Ocotea* trees. Models were re-run excluding the elevation in the explanatory variables to determine effects of disturbance, heart rot intensity and canopy cover on regeneration and health status of *Ocotea*. Before running the regression analysis, correlation between explanatory variables were computed and co-linearity was diagnosed using variance inflation factor.

## RESULTS

### Density of stumps and live trees

Generally, the entire nature reserve was disturbed with the exception of small patches at high altitude (> 2200 m above sea level) which were covered with tree species such as *Myrica salisfolia*, *Memecylon deminutum*, *Myrsine pulchura* and *Schefflera myriantha*. These species were less preferred by the surrounding communities. The most common and frequently registered form of existing disturbance in the nature reserve was tree cutting. Of the 62 strips surveyed, 16 were highly disturbed, 22 moderately and 24 were in semi natural forest where disturbance was mild (Table 2). There was no evidence

**Table 2** Stand characteristics, elevation and canopy cover recorded (mean  $\pm$  SE) in strips with different disturbance intensities in Chome Nature Reserve, Tanzania

Variable	Disturbance intensity		
	High	Moderate	Mild
Number of strips	16	22	24
Average dbh of <i>Ocotea</i> (cm)	37.6 $\pm$ 5.7	54.9 $\pm$ 24.3	94 $\pm$ 47.1
Density of <i>Ocotea</i> (stumps ha <sup>-1</sup> )	57 $\pm$ 19	29 $\pm$ 11	7 $\pm$ 3
Density of <i>P. excelsa</i> (stumps ha <sup>-1</sup> )	126 $\pm$ 44	34 $\pm$ 32	0
Density of live trees ha <sup>-1</sup>	354 $\pm$ 42	531 $\pm$ 34	504 $\pm$ 41
Density of stumps ha <sup>-1</sup>	399 $\pm$ 44	189 $\pm$ 21	73 $\pm$ 10
Elevation (m)	1450 $\pm$ 34	1712 $\pm$ 65	1953 $\pm$ 56
Canopy cover (%)	74.6 $\pm$ 4.5	82.4 $\pm$ 1	89.9 $\pm$ 0.7

dbh = diameter at breast height

of past illegal logging (such as saw pits or old stumps of *Ocotea*) at high altitude as more than 60% of the stumps were from recent cuts. Density of stumps varied significantly in the three disturbance categories ( $F_{2,59} = 42.7$ ,  $p < 0.0001$ , Table 2). In highly disturbed areas, an average of 399 trees ha<sup>-1</sup> were cut. In this case, the density of stumps in highly disturbed areas was almost six times higher than in mildly disturbed areas. *Ocotea* and *P. excelsa* were the most cut tree species with average of 57 and 126 stumps ha<sup>-1</sup> respectively (Table 2). Almost all cut *Ocotea* were big trees with dbh > 30 cm while cut *P. excelsa* were both small and big trees. Unlike in other Eastern Arc Mountain forests, big *Ocotea* trees with dbh > 100 cm still exist in mildly disturbed areas.

On average, density of live trees was significantly higher in intermediate disturbance ( $F_{2,59} = 4.9$ ,  $p < 0.01$ , Table 2) than highly disturbed areas. Elevation varied significantly across disturbance categories ( $F_{2,59} = 17.8$ ,  $p < 0.001$ , Table 2), with areas in low altitude being more disturbed than in high altitude. Canopy cover also exhibited significant difference ( $F_{2,59} = 12.3$ ,  $p < 0.001$ , Table 2) between disturbance categories.

#### Disturbance, elevation and canopy cover

In all regression models, elevation was the only consistent variable explaining the variation in density of *Ocotea* regenerants, dead and live trees (Table 3). Density of regenerants and live trees increased with increasing elevation while that of dead trees decreased. Although disturbance could not explain the variation in density of regenerants, it significantly explained the

variation in density of dead *Ocotea*. As expected, density of live trees decreased with increasing disturbance. In the best-fit models, canopy cover also significantly ( $p < 0.001$ ) determined variation in density of regenerants and dead trees. Heart rot did not account for any variation as it was not significant ( $p > 0.05$ ) in all models. Co-linearity was not particularly a problem as all the variance inflation factors were lower than 2.5, thus, all the explanatory variables were used in explaining regeneration and health status of *Ocotea*. Elevation was significant correlated with disturbance ( $r = -0.61$ ,  $p < 0.01$ ,  $df = 62$ ) and, as expected, canopy cover significantly correlated with disturbance ( $r = -0.54$ ,  $p < 0.01$ ,  $df = 62$ , Table 4).

In examining the influence of elevation on other explanatory variables, models were re-run excluding the elevation. All models for disturbance index were not affected by excluding elevation (Table 5). However, for canopy cover, significant positive value ( $p < 0.0001$ ) was included for both regenerants and live tree densities and non-significant value, for dead trees model. Again, heart rot index is not significant in all models ( $p > 0.05$ ). Therefore, without explicit information on elevation, results suggest that disturbance was more important in determining the health of *Ocotea* trees. *Ocotea* still regenerated in high altitude, particularly between 1600 and 2200 m above sea level. Most of the regenerants encountered were from root suckers, few were from recent cut stumps as coppices and very few as seedlings. Generally, it was observed that coppices and suckers emanating from the same parent tree differed in

**Table 2:** Stand characteristics, elevation, and canopy cover recorded (mean  $\pm$  SE) in strips with different disturbance intensities in Chome Nature Reserve, Tanzania

**Table 3** Results of multiple regressions showing the influence of elevation, disturbance, canopy density (arcsine transformed) and heart rot on regeneration and health status of *Ocotea* in Chome Nature Reserve, Tanzania

Variable	Regenerants	Health status	
		Dead/dying back	Live
Adjusted r <sup>2</sup>	0.61	0.62	0.35
F	48.84	31.95	16.26
Elevation	0.0072****	-0.0015**	0.0016****
Disturbance index	-	0.7512****	-0.8256**
Canopy cover	-0.10236***	-0.0281**	-
Heart rot index	-	-	-

\* =  $p < 0.05$ , \*\* =  $p < 0.01$ , \*\*\* =  $p < 0.001$  and \*\*\*\* =  $p < 0.0001$  '-' indicates values that were dropped out as they were non significant

**Table 4** Results of Pearson's correlation coefficient between explanatory variables

Variables	Elevation	Disturbance index	Canopy cover	Heart rot index
Elevation	1.00	-0.613****	0.225	0.037
Disturbance index		1.00	-0.543****	-0.003
Canopy cover			1.00	0.073
Heart rot index				1.00

\* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$  and \*\*\*\* $p < 0.0001$

**Table 5** Results of multiple regressions showing the influence of disturbance, canopy density (arcsine transformed) and heart rot after eliminating the effect of elevation on regeneration and health status of *Ocotea* in Chome Nature Reserve, Tanzania

Variable	Regenerant	Health status	
		Dead/dying back	Live
Adjusted r <sup>2</sup>	0.43	0.54	0.34
F	45.8	72.4	15.4
Disturbance index	-	0.68****	-0.934**
Canopy cover	0.045****	-	0.0359****
Heart rot index	-	-	-

\* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$  and \*\*\*\* $p < 0.0001$ ; '-' indicates values that were dropped out as they were non significant

their vitality, whereby coppices were weaker and drying out while suckers were healthy and had thicker root collar diameter.

#### DISCUSSION

Despite the official logging ban in 1984 and the many steps that were taken to improve the forest

condition by reducing anthropogenic activities in all the Eastern Arc Mountains, logging for timber and tree cutting for fuelwood are still a problem in Chome Nature Reserve. Control of illegal harvesting, in particular *Ocotea*, is virtually impossible unless surrounding communities are practically involved in forest management (Malimbwi & Mugasha 2001). The fact that at

**Table 3** Results of multiple regressions showing the influence of elevation, disturbance, canopy density (arcsine transformed) and heart rot on regeneration and health status of *Ocotea* in Chome Nature Reserve, Tanzania.

**Table 4** Results of Pearson's correlation coefficient between explanatory variables

**Table 5** Results of multiple regressions showing the influence of disturbance, canopy density (arcsine transformed) and heart rot after eliminating the effect of elevation on regeneration and health status of *Ocotea* in Chome Nature Reserve, Tanzania.



least 10 stumps of *Ocotea* per ha was from recent cuts still posed significant threat to *Ocotea*, which is already in decline due to dieback (URT 2010). The objective to conserve biodiversity and water catchments by upgrading most of the Eastern Arc Mountain forests to nature reserves may not be realised if conservation plans are not supplemented with identification and promotion of other alternative income-generating activities. Currently, illegal logging is still one of the primary income-generating activities for the communities around Chome Nature Reserve. Most of the efforts undertaken by forest guards to stop logging received risky and stiff objection from surrounding communities especially from the youths. Negative correlation between elevation and disturbance suggests that areas in low altitudes were more disturbed than in the high altitudes where access was difficult. This situation, which is very common to almost all the Eastern Arc Mountain forests, is threatening the existence of species with restricted range in low altitudes (Hall et al. 2009).

Although results from this study show that density of regenerants was primarily influenced by elevation, the role of heart rot on *Ocotea* regeneration cannot be underestimated. This is based on the fact that by assuming all encountered regenerants emanated only from mature trees within the strip we might have inadequately determined the influence of heart rot on the regeneration of *Ocotea*. Survey in the Uluguru show that sucker production is inversely related to the degree of heart rot in *Ocotea* stumps (Mwamba 1986). Nevertheless, such results cannot be used to conclusively infer the relationship between degree of heart rot in standing *Ocotea* trees and regeneration as it is obviously expected that severely rotted stump cannot support regenerants. Notwithstanding these limitations, the study has found no evidence of a relationship between disturbance and regeneration of *Ocotea*. Hence, regeneration of *Ocotea* was only influenced by elevation. *Ocotea* is light demanding at the early stage of its growth and this is one of the reasons why is considered as both a pioneer and a climax tree species (Kimariyo 1971, Mugasha 1978). Results from this study do not contradict with these findings as, in this study, most of the regenerants of *Ocotea* were also found in localised gaps at high altitudes but not in severely disturbed low altitudes where canopies were more open. In contrast, succession

and regeneration studies in montane forest of Kenya reported failure of regeneration of *Ocotea* in open canopy after large-scale logging (Bussmann 2001, 2004).

The influence of altitude on regeneration of *Ocotea* in Chome Nature Reserve provides reasons for declining regeneration in lower parts of the Eastern Arc Mountains which used to have *Ocotea* as one of the dominant tree species. In Amani Nature Reserve *Ocotea* was abundant but restricted within 900 to 1100 m above sea level (Hamilton 1989). Although direct comparison between the four nature reserves is difficult, *Ocotea* would currently be considered a rare tree species in Amani Nature Reserve based on its proportion to other tree species (Table 1). Amani Nature Reserve is considered more restored in terms of tree density than the other four nature reserves, yet it is the only reserve in the Eastern Arc where *Ocotea* is no longer regenerating. The highest point in Amani Nature Reserve (1130 m) is lower than the lowest point in Chome Nature Reserve (1250 m). Amani Nature Reserve is unusually wetter, moist and cold due to the influence of the Indian Ocean and this allows growth of tree species which are found in relatively higher altitudes in other Eastern Arc Mountain forests (Hamilton 1989, Iversen 1991). Altitude is directly linked to a variety of ecological factors with significant impact on plant regeneration, e.g. temperature, humidity and soil (Iversen 1991), which were not considered in this survey. Changes in such climatic variables are considered as one of the possible causes hampering regeneration of *Ocotea* in Eastern Arc Mountains (Iversen 1991, Schulman et al. 1998).

As with regeneration, densities of dead and live *Ocotea* were also influenced by altitude. However, disturbance had stronger influence than elevation on the death of *Ocotea*. Severe illegal cutting of upper canopy and climax species in Chome Nature Reserve such as *P. excelsa*, *Ficalhoa laurifolia* and *Podocarpus* spp. may have contributed to the death of *Ocotea* as the species is not known to be an open canopy species (Bussmann 2004). The role of disturbance, particularly logging on forest condition has been widely studied. In most cases, disturbance is implicated as the factor that predisposes trees to insects and diseases which finally cause death of the trees (Hennon & DeMars 1997). This study represents a very different scenario, in which disturbance is implicated as the cause

of tree death. When studying fungal decay in *Colophospermum mopane*, Smith and Shah-Smith (1999) found that the decay (heart rot) is not capable of causing death of the species. This was due to the fact that majority of the fungi isolated from *C. mopane* were saprophytes which attacked only dead heartwood and bark of the tree, without affecting the living cambium.

This study suggests that distribution of *Ocotea* in Chome Nature Reserve is shifting towards higher elevation due to changes in habitat quality. The previous moist and wetter habitats in Chome Nature Reserve might have shifted to high elevation due to persistent disturbance in the low elevation, resulting in adulterated plant distribution. Prevailing dieback of *Ocotea* stand and declining regeneration were possibly due to degradation of habitat suitable for the growth of *Ocotea*. However, the role of warmer microclimate than during previous period as reported by Hamilton (1989) and Hemp (2009) cannot be ruled out.

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### CHAPTER THREE

**Manuscript Two: Effect of logging on recovery and structure of *Ocotea usambarensis* Engl. In a montane forest of Tanzania**

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**Effect of logging on recovery and structure of *Ocotea usambarensis*(*Lauraceae*)  
in a montane forest of Tanzania**

**Abstract**

Despite significant reduction of logging activities in biodiversity-rich tropical montane forests, post-disturbance recovery of many timber tree species still remains a matter of concern. Examining population structure of tree species which used to be abundant before logging started is very important in understanding their potential for recovery. Chome Nature Reserve which was heavily logged for its valuable timber species *Ocotea usambarensis* before the mid 1980s provided the opportunity to study the recovery of this species. In this study, 39 plots each measuring  $20 \times 50$  m that experienced different levels of logging (unlogged, intermediate logged  $< 30$  stumps/ha and heavily logged  $\geq 30$  stumps/ha) were surveyed for density of *O. usambarensis* of all age classes. Also canopy cover and altitude were recorded from each plot as additional explanatory variables of population structure. Results indicated that in lower accessible areas, the number of stumps of recently cut trees was almost equal to the number of old stumps indicating that logging is still going on. The population structure of *O. usambarensis* in the unlogged areas is characterized by high proportion of mature individual with DBH  $> 60$  cm and few regenerants with height  $< 1.5$  m, thus unstable. On the contrary, in the intermediate logged areas, the population structure is characterized by a good proportion of individuals in the lower age classes, hence stable and show potential for recovery. Although the proportion of regenerants is relatively higher in the heavily logged areas due to reduced canopy cover, development into large size classes still

need shade environment, hence the need for nurse tree species such as *Macaranga kilimandscharica*. It is therefore suggested that slashing of brambles but not *M. kilimandscharica* in heavily logged areas be considered to free saplings of *O. usambarensis* which die out due to competition.

**Keywords:** *Camphor, Chome nature reserve, population, regeneration, disturbance, Eastern Arc Mountains.*

## 1.0 INTRODUCTION

Over exploitation of forest products is currently recognized as one of the main drivers of habitat and biodiversity loss in tropical forests (Kleinschroth *et al.*, 2013). Despite their high and exceptional biological importance, current scenarios show that exploitation of particularly wood products is more extensive in tropical forests than in the rest of the world (MEA, 2005). Tropical montane forests form very important ecosystems in Tanzania and occupy about 5% of the total forest area (MNRT, 1998). About half of this is found within the Eastern Arc Mountains (EAMs) of Tanzania (URT, 2010). The mountains are recognized as a biodiversity “hot spot” area, because apart from harbouring vast biodiversity they have suffered markedly from anthropogenic disturbances particularly logging, which threatened existence of species (Myers *et al.*, 2000). These forest capped mountains also serve as the largest “water tower” in the country. To protect the biodiversity and catchment values, all forms of logging on the mountains were banned through a Presidential decree in 1984 (Hamilton, 1989). Although illegal pitsawing has not stopped completely, trends show that increased participation of communities in forest management has improved the situation (Mbwambo *et al.*, 2012).

Despite some improvements in forest condition due to reduction of anthropogenic activities, post-disturbance recovery of many tree species still remains a matter of concern (Richard *et al.*, 2014). For example, in Chome Nature Reserve (CNR) a part of EAMs, several valuable timber tree species such as *Ocotea usambarensis* (hereafter referred to as *Ocotea*), *Ficalhoa laurifolia* and *Podocarpus latifolius* which used to be abundant, now experience insufficient regeneration (Hamilton, 1989; Bakari, 2002; Richard *et al.*, 2014). The failure to recruit adequately is attributed to increased seed and seedling predation (Nsolomo and Venn, 2000), thick litter which preclude seed from reaching potential regeneration sites (Makana and Thomas, 2005) and competition with invasive alien plants (Richard *et al.*, in press). Manipulations of forest floor to improve regeneration and recruitment have been carried out on experimental plots, but results have not been scaled up to project the situation in a large area of forest (Lovett and Poós, 1993, Holmes, 1995). Other studies (Hallet *et al.*, 2003) have suggested that given enough time, normal forest succession which usually starts with pioneer species and then later dominated by climax species, will take place even without human assistance. However, this suggestion has ignored the fact that other drivers such as invasive alien plants and climate change can influence forest dynamics and completely change ecosystem structures (Chazdon, 2003; Chitiki, 2014). Also, practically, many tropical forests still experience different forms of anthropogenic disturbance, ranging from selective logging to root extractions for medicinal purposes (Zschocke *et al.*, 2000; Bitariho *et al.*, 2006), which altogether hinder the expected normal forest succession.

Chome is a nature reserve in the EAMs, where illegal logging is still one of the main conservation challenges (Malimbwi and Mugasha., 2001; MNRT, 2008; Richard *et al.*, 2014). Illegal exploitation of timber by pitsawing is relatively higher in CNR, than in other reserves in the EAMs (URT, 2010). Logged tree species are mainly *Ocotea*, *F. laurifolia*, *P. latifolius* and *Newtonia buchananii*, with the later two regenerating fairly well in previously logged areas (Bakari, 2002). Discussions with the communities surrounding CNR and presence of many new cut stumps of *O. usambarensis* (> 10 stumps/ha) and *P. latifolius* in the forest interior, indicate that many people still rely on pitsawing as their primary income generating activity (Richard *et al.*, 2014). In such situations, the effect of pitsawing which in most cases leads to formation of gaps, are certainly great and have a direct influence to forest structure and recovery. The tree species which is impacted the most is *Ocotea* which in mid 1980s occupied more than 50% of the canopy density above 1600 m above sea level (asl) (Lovett and Poós, 1993).

Many studies in East African montane forests (Hamilton, 1989; Iversen, 1991; Maliondo *et al.*, 1998; Hemp 2006) show that the population structure of *Ocotea* is dominated by mature trees, thus very unstable and in heavily logged areas, individuals with diameter classes < 50 cm are completely absent (Kleinschroth *et al.*, 2013). Although several studies (Willan, 1965; Kimaryo, 1971; Bussmann, 2001; Bitahiro *et al.*, 2006) suggest that regeneration of *Ocotea* which is mainly through root suckers could benefit from gap opening, advance growth of recruited individuals remains largely unknown. When studying factors affecting regeneration of *Ocotea* in CNR, Richard *et al* (2014) noted that, the species is still regenerating fairly well in

gaps at high altitude (above 1800 m asl). However, it was also not clear whether a reasonable proportion of the observed regenerants develops to mature trees and restores the forest. Therefore it is with this background that, a study was carried out in CNR to examine the demography of *Ocotea* in relation to previous and existing illegal logging to see whether the species exhibits different population structure across different disturbance scenarios. Also, examination of the population structure of *Ocotea* will provide insight into survival and development of young individuals into bigger size classes.

## **2.0 MATERIALS AND METHODS**

### **2.1 Study Area**

Chome Nature Reserve is a 14,283-hectare continuous forest block situated between  $4^{\circ} 10' - 4^{\circ} 24' \text{ S}$  and  $37^{\circ} 53' - 38^{\circ} 00' \text{ E}$ , and within an altitudinal range of 1250 to 2463 m above sea level. Rainfall is estimated at 3000mm on the wetter, eastern side of the reserve, while the dryer western slopes receive an estimated 1500 – 2000mm, with mist effect at higher altitudes. The dry season is between June and September and temperature ranges between a minimum of  $15^{\circ}\text{C}$  in July and a maximum of  $20^{\circ}\text{C}$  in February (Lovett and Pócs, 1993). This study was conducted within 1800 to 2300 m above sea level, in the eastern and south western side of the reserve.

Chome Nature Reserve is surrounded by 27 villages with a population of more than 70,000 people (NBS, 2012). This population density is relatively higher than in many other rural areas in Tanzania, consequently the reserve faces persistent pressure particularly from illegal timber harvesting, encroachment for agricultural activities

and animal husbandry. Although the reserve is the most species rich forest on Pare Mountains, its critical importance to upland and lowland communities lies on its high catchment values. All the major rivers of Same District where the reserve is administratively located, originate from the forested mountain peaks of CNR. Water from these rivers is extensively used for both traditional and modern paddy irrigation in the lowland (PWBO/IUCN, 2006). The excess water drains into the Pangani River for hydroelectric power generation which contributes to the national power grid of Tanzania.

## 2.2 Vegetation of the Study Area

Main vegetation types as explained by Lovett and Pócs (1993) are submontane, montane and upper montane forests. The montane forest occurs between 1500 and 2300 m above sea level which, before extensive logging, was dominated by *Ocotea* with the canopy density of more than 50%. Other important timber species in the montane forest include *Podocarpus spp.*, *Newtonia buchananii*, *Ficalhoa laurifolia* and *Xymalos monospora*. Under canopy tree species include *Aphloia theiformis*, *Balthasaria schliebenii*, *Cornus volkensii*, *Ekebergia capensis*, *Halleria lucida*, *Memecylon deminutum*, *Maesa lanceolata* and *Rapanea melanophloeos*. In exploited areas secondary stands include species such as *Macaranga kilimandscharica* and *Polyscias fulva*. Heath occurs along rocky ridges in shallow, acidic soil as natural vegetation. Secondary heaths, ferns and grassland occur in burnt areas in drier montane forest and now occupy large areas between 1600 to 2000 m with scattered stands in the east and north, and a continuous belt between the forest edge and cultivation in the drier west.



### 2.3 Description of the Study Species

*Ocotea usambarensis* Engl. (Lauracea) commonly known as East African camphor at maturity it may reach up to 45 m high with a massive trunk up to 3 m diameter at breast height (DBH). It is a common tree species in montane rain forests of East Africa at altitude between 1220 and 2440 m asl and precipitation levels between 1150 and 3100 mm year per year (Lovett and Pócs, 1993). It occurs on slopes and ridge tops and absent from the heavier, slower-draining soils of the valley bottoms. *Ocotea* produces smooth small fruits, green when mature enclosing very small seeds (about 6,600 seeds per kilogram). Although it is known that seed production in natural forests is rare, observations made in Lushoto and Kilimanjaro show that, the species seeds heavily in trial plots whose age ranged between 15 and 30 years. Leaves and wood are camphor scented but not the bark (Mugasha, 1996).

In Tanzania, *Ocotea* is common in the mountains of Usambaras, Kilimanjaro, Pares, Ulugurus, Ngurus, Tukuyu and Iringa (Mbuya *et al.*, 1994). Camphor wood is used for furniture, internal and external joinery, vehicle building, boat ribs, flooring, acid vats, fittings in shops and laboratories, and for veneers (Nsolomo and Venn, 2000). A decoction of the bark is used for relief of stomachache and gastric conditions as well as remedy for coughs and malaria (Msanga, 1998). *Ocotea* regenerates from suckers, coppices and rarely from seed. Although *Ocotea* is considered to be a climax species, it also exhibits characteristics of pioneer species. At some stages of its growth it behaves as a light demander than a shade tolerant, Also, at any stage when camphor is felled, root suckers are produced which, although able to persist under shade, grow rapidly in half or full light (Mugasha, 1996).

## 2.4 Designation Disturbance Intensities

Following detailed field surveys in CNR (Richard *et al.*, 2014) and guidance from old people who did logging in the forest before 1984; areas for sampling plots were classified into one of the three previous logging intensities:

- (i) *Heavily logged*. Previous heavily exploited areas through logging of particularly *Ocotea*. Although timber logging was regulated through license but harvesting plans were not properly followed, thus resulted to overexploitation. In this logging intensity category almost every mature *Ocotea* tree of good form was logged and the forest is therefore characterized by defective trees and many old stumps of *Ocotea*.
- (ii) *Intermediate logged*. Areas where although harvesting had not been allowed, pitsawing was carried out by local people. The areas were not heavily exploited as the freedom to logging was limited.
- (iii) *Unlogged*. Areas where no signs of previous logging activities were seen, however like in the other two categories several stumps of recently cut *Ocotea* were observed. In most cases, the plots under this category fell on areas with steep slopes and difficult to access.

These three categories represent different past logging intensities and are mutually exclusive. The assigned logging intensities correspond well with the number of old stumps recorded during the actual data collection in each plot.

## 2.5 Data Collection

To generate an objective measure of logging intensity, a thorough inventory of *Ocotea* stumps (of both old and recent cuts) in the selected study plots was conducted

in 2012. The study adopted plot size of 20m x 50m which was used by Frontier (2005) during biodiversity surveys in the EAM forests. As the decay of *Ocotea* stumps is slow, it is estimated that the number of old stumps indicates historical logging before and soon after logging ban, as heavy logging did not stop immediately after the ban in 1984. Therefore, three logging intensities (unlogged, intermediate logged  $< 30$  stumps/ha and heavily logged  $\geq 30$  stumps/ha) were identified based on number of old stumps, because stumps of recently harvested trees indicated by intact and creamy colour stumps do not represent previous disturbances. Thirty nine plots meeting these criteria (13 for each category) were identified for the study. All the plots were laid parallel to the slope to cover as much of the disturbed areas as possible, because in most cases loggers would prefer felling trees downward toward the slope to avoid hang ups. To ensure independence, a minimum distance of 200 m between the plots was kept.

Within each plot, measurements of diameter at breast (DBH) of all *Ocotea* trees  $> 1.5$  m in height were taken. At the centre of each plot, a smaller plot 6m x 6m was laid out to assess the density of all other tree species which are not *Ocotea* with DBH  $> 5$  cm. For consistence in measuring DBH of buttressed trees, measurements were taken just above the buttress if it was higher than 1.3 m. Therefore *Ocotea* individuals  $< 1.5$  m high were scored as young regenerants, between 1.5 m high and DBH  $< 5$  cm as saplings, between 5 cm and  $< 25$  cm DBH as juveniles, between 25 cm and  $< 60$  cm DBH as sub mature and  $\geq 60$  cm DBH as mature trees. Furthermore, all encountered *Ocotea* with DBH  $> 5$  cm were identified as either live or dead for subsequent demographic analysis. These censuses yielded information on the present

stage and size structure of populations. The elevation was recorded at the centre of each plot using a Global Positioning System (GPS) device (GPS Map 76CSx, Garmin Ltd., Kansas, USA). Canopy density, which is known to influence regeneration in tropical forests, was also assessed in each strip. Percentage of the canopy density was measured using concave spherical densitometer (Lemmon 1957). Three readings of the canopy density were taken over each plot (one at the middle and one each at both ends) and the average calculated.

## 2.6 Data Analysis

One-Way ANOVA was performed to describe the differences in total number of stumps of *Ocotea* per ha, elevation and canopy cover across the three logging intensities. Before running the ANOVA, canopy cover was arcsine transformed to meet the normality assumptions but the other variables were normally distributed. Mean separation was done using the Least Significant Difference (LSD). Chi-square test was used to compare proportional representation of *Ocotea* individuals of various growth stages across the three logging intensities. We used Generalized linear models (GMLs) with logging intensity (expressed as number of old *Ocotea* stump and number of recently cut *Ocotea* per ha) as a predictor to model the following dependent variables; number of young *Ocotea* regenerants, saplings, juvenile trees, sub mature trees, mature trees and number of other trees in the central subplots. We also used canopy cover and elevation as co-factors to get additional insight of their influences on the density of regenerants and development into bigger size classes. Finally, the statistical associations between density of stumps, number

of young regenerants and canopy cover were explored using pairwise correlation analyses. All analyses were done using SAS 9.1.3 (2009).

### 3.0 RESULTS

#### 3.1 Logging Intensities

The three logging intensities are significantly different in total number of stumps (Table 1;  $F_{2,36} = 21.7$ ,  $p < 0.0001$ ) and number of standing *Ocotea* trees ( $F_{2,36} = 16.9$ ,  $p < 0.001$ ). Canopy cover decreased with increase in disturbance and was significantly more open in heavily logged than in intermediate and unlogged areas ( $F_{2,36} = 24.3$ ,  $p < 0.001$ ). Although a gradient existed in average elevation across logging intensities, with heavily logged plots located in relatively lower elevations, overall there was no significant difference across the three intensities ( $F_{2,36} = 2.4$ ,  $p > 0.11$ ).

**Table 1:** Elevation, canopy cover, density of stumps and standing *Ocotea* trees recorded (mean  $\pm$  SE) in plots under three logging intensities in Chome Nature Reserve, Tanzania

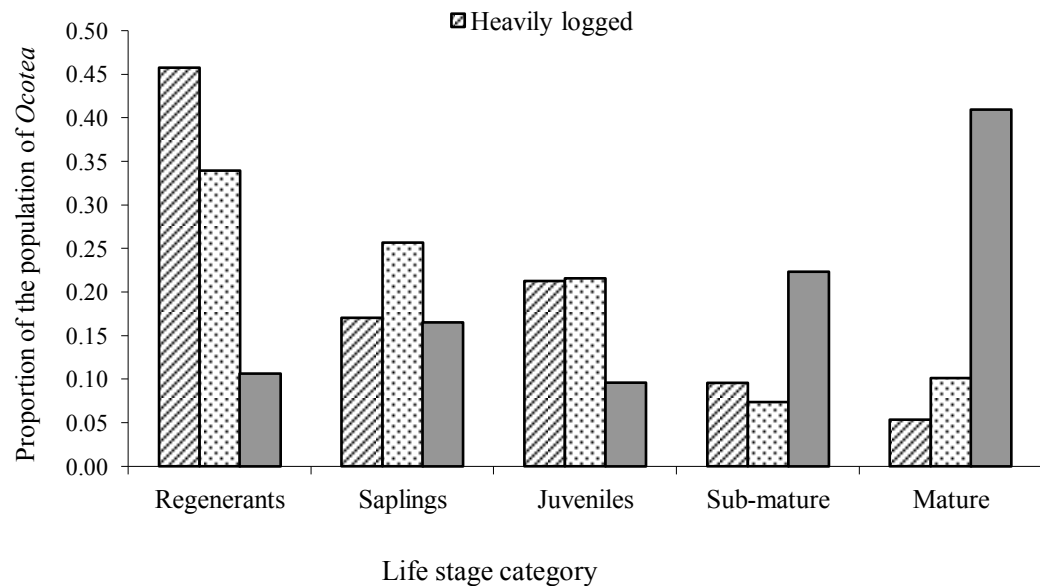
	Unlogged	Intermediate logged	Heavily logged
Elevation (m.a.s.l)	2034.2 $\pm$ 22.5	1977.8 $\pm$ 32.9	1951 $\pm$ 25.4
Canopy cover (%)	89.4 $\pm$ 1.2	86.4 $\pm$ 3.4	77.3 $\pm$ 4.5
Density of recent and old <i>Ocotea</i> stumps (per ha)	14.6 $\pm$ 3.1	46.9 $\pm$ 7.4	75.4 $\pm$ 9.1
Standing live and dead <i>Ocotea</i> trees (per ha)	106.9 $\pm$ 11.5	69.2 $\pm$ 7.9	35.4 $\pm$ 5.5

#### 3.2 Proportion of Individuals According to Life Stages

The density of *Ocotea* in the three logging intensities differed significantly in proportion representation of individuals of different life stages (Fig 1;  $\chi^2 = 126.26$ ,  $df = 8$ ,  $p < 0.001$ ). More than half of the overall heterogeneity was contributed by the

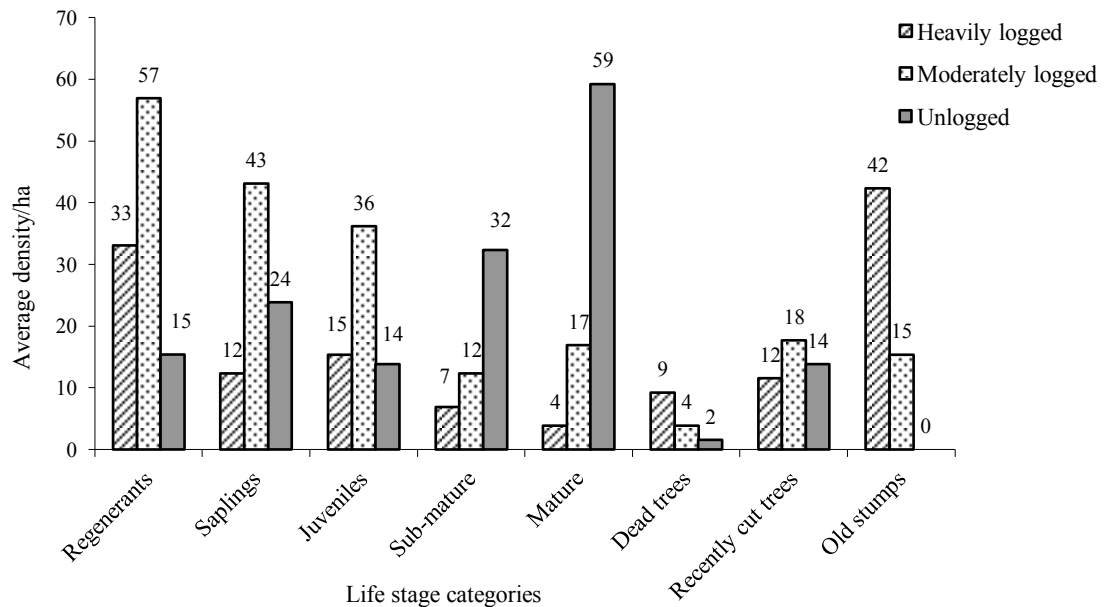
unlogged category (59% of total  $\chi^2$ ), which contained proportionally more sub mature and mature trees (i.e. tree of  $\text{DBH} \geq 25$  cm), and proportionally fewer young individuals with height  $< 1.5$  m. Intermediate logged and heavily logged categories contribute 21 and 20 percent of the overall heterogeneity.

Generally, logged areas are characterized by many individuals of the smaller size classes (with height  $< 1.5$  m and  $\text{DBH} < 5$  cm) and few individuals of bigger size classes with  $\text{DBH} \geq 25$  cm, and unlogged areas characterized by many trees with  $\text{DBH} \geq 60$  cm (Fig. 2). The mean diameter for individuals with  $\text{DBH} \geq 25$  cm in all study plots was 81 cm and the largest *Ocotea* tree recorded measured 246 cm DBH.



**Figure 1:** Proportional representation of different life stages of *Ocotea usambarensis* in the three disturbance categories in Chome Nature Reserve, Tanzania.

Deaths of *Ocotea* were recorded mostly in the juveniles and mature growth stages with the mean density of 4.8 individuals  $\text{ha}^{-1}$ . Proportions of dead *Ocotea* trees with height  $> 1.5$  m in the unlogged, intermediate logged and heavily logged areas are 1%, 3.4% and 19.3%, respectively. The number of stumps of recently cut *Ocotea* with  $\text{DBH} \geq 60$  cm accounted for 18%, 45% and 47% in the similar order of disturbance gradient, respectively. Mean density of other tree species ( $\text{DBH} > 5$  cm) recorded in the center plot was 881 stems  $\text{ha}^{-1}$ . *Macaranga kilimandscharica* which is typical fastly growing pioneer species was the dominant tree species in logged areas with a mean density of 161 individuals  $\text{ha}^{-1}$  (Table 2).



**Figure 2:** Average density of *Ocotea usambarensis* and stumps in the three logging intensities in Chome Nature Reserve, Tanzania

**Table 2:** The mean density of five most dominant tree species in the study area of Chome Nature Reserve, Tanzania

Botanical name	Family	Density (stem/ha)
<i>Macaranga kilimandscharica</i> Pax	<i>Euphorbiaceae</i>	161
<i>Xymalos monospora</i> Harv.	<i>Monimiaceae</i>	87
<i>Cassipourea malosana</i> Alston	<i>Rhizophoraceae</i>	75
<i>Podocarpus latifolius</i> Thunb	<i>Podocarpaceae</i>	73
<i>Psychotria</i> spp	<i>Rubiaceae</i>	61

### 3.3 Influence of Logging on Population Structure

According to the Zero-inflated Poisson models (Table 3), the density of saplings, sub-mature and mature trees were significantly predicted ( $p < 0.05$ ) by previous tree removal (i.e. previous logging intensity). Therefore, as the number of previously removed stems increased, the number of saplings, sub-mature and mature trees decreased significantly by a factor of 0.021 ( $p = 0.033$ ), 0.017 ( $p < 0.0001$ ) and 0.049 ( $p < 0.0001$ ), respectively. In the recently removed stump models, it is only young regenerants and juveniles that were significantly influenced by logging intensity. In this case, an increase in density of recently cut trees, lead to a 2.7% increase in regenerants ( $p < 0.01$ ). Unlike young regenerants, juveniles decreased marginally significantly ( $p = 0.053$ ) by a factor of 0.006.



**Table 3:** Densities of the five size classes of *Ocotea usambarensis* (means  $\pm$  SE) in relation to past and recent logging intensities.  $p$ -value indicates significant correlation in regression using GLMs (Zero-inflated Poisson;  $n = 39$ ).

	Mean $\pm$ SE	Logging intensity			
		Density of previously removed stumps $\text{ha}^{-1}$		Density of recently removed stumps $\text{ha}^{-1}$	
		Coefficient	$p$ -value	Coefficient	$p$ -value
Number of regenerants (height $< 1.5$ m) $\text{ha}^{-1}$	35.13 $\pm$ 5.84	-0.008	0.34	0.027	0.011
Number of saplings (height $\geq 1.5$ m, DBH $< 5$ cm) $\text{ha}^{-1}$	26.41 $\pm$ 3.90	-0.021	0.033	0.010	0.377
Number of juvenile (DBH 5 and $< 25$ cm) $\text{ha}^{-1}$	21.79 $\pm$ 3.46	-0.002	0.21	-0.006	0.053
Number of sub mature (DBH 25 and $< 60$ cm) $\text{ha}^{-1}$	17.18 $\pm$ 3.16	-0.017	$< 0.0001$	0.011	0.51
Number of mature trees (DBH $\geq 60$ cm) $\text{ha}^{-1}$	26.67 $\pm$ 5.12	-0.049	$< 0.0001$	0.004	0.89

In the Zero-inflated regression models, only canopy cover was significant ( $p < 0.05$ ) as a predictor for young regenerants density, but elevation could not predict densities of lower classes ( $p = 0.75$ ). Stem removal correlated significantly with elevation ( $p < 0.05$ ) and marginally significant with canopy cover ( $p = 0.054$ ).

#### 4.0 DISCUSSION

Timber logging is implicated as a serious threat to conservation of native tropical mountainous forest ecosystems (Hemp, 2006). Discerning which logging intensity does not significantly disturb and interfere with species recovery and result to changes in forest structures is always difficult (Waser *et al.*, 2013). Several studies agree that single tree felling techniques like pitsawing have, but little impact to species recovery. Nevertheless, if unregulated, such techniques can result to forest disturbance with similar effects to species recovery as mechanized logging using heavy equipment (Hall *et al.*, 2003). Chome Nature Reserve provides a good example of moist mountainous forests for studying post-disturbance recovery after

heavy pitsawing of valuable timber species. In this study, the influence of both earlier and recently logging intensities on the demography and recovery of *Ocotea* whose growth requirements differ with life stages has been analyzed.

#### **4.1 Logging Intensity and Regeneration**

Canopy opening through both anthropogenic and natural disturbance plays an important role in determining population structure of *Ocotea*. In this study gap opening through pitsawing has a significant influence on initiating regeneration and development of *Ocotea* individuals into bigger size classes. The proportion of young regenerants with height  $< 1.5$  m is much higher in logged areas compared to unlogged areas. Also, the study has indicated that the density of young regenerants is markedly different along the gradient of recently logged areas but not along the previously logged areas. It was clear that a certain level of canopy opening significantly increases the density of young regenerants. In general, increased light availability subsequent to logging usually enhances seedling establishment of both early and late successional species (Mwavu and Witkowski, 2009).

Early studies in southern Kilimanjaro and Usambara mountains (Willan, 1965; Kimaryo, 1971) indicated profusely suckering and coppicing of young *Ocotea* soon after felling operation. Consequently, it was suggested that removing of mature and defective *Ocotea* could produce more suckers than poisoning which reduce the forest canopy slowly (Mugasha, 1978). However, suckers and coppices produced through this means could not withstand the competition from brambles and *Macarangakilimandscharica*, a common pioneer species in camphor forests

(Bussman, 2004). This technique, coupled with slashing to free young regenerants, has been used in Lushoto (West Usambara), to establish monoculture trial plots of *Ocotea* which survived and grew fairly well (Mugasha, 1996).

Kleinschroth *et al.* (2013) reported a high percentage of old individuals and very low recruitment of *O. usambarensis* mainly as root suckers and few seedlings in previously heavily logged areas at Mt. Kenya. The number of seedlings was low and independent of logging intensity, but increased with higher light incidence. In contrast, the number of root suckers and logging intensity were negatively correlated. It was concluded that regeneration of *O. usambarensis* at Mt. Kenya is generally low and negatively influenced by historical logging, and that natural regeneration was inadequate for the recovery of *O. usambarensis*, and recommended enrichment planting as additional conservation measures to promote the species.

Bussman (1999) proposed that several valuable and fast growing indigenous species including *Juniperus procera* and *Vitex keniensis* could be used for agroforestry/plantation purposes. It would be interesting to explore the possibility of planting these species in gaps left by *O. usambarensis* either in mixture or as nurse trees to promote the regeneration of *O. usambarensis*.

#### **4.2 Advance Regeneration and Population Structure**

The decrease in density of mature trees with logging is obviously a direct consequence of stem removal by heavy pitsawing, but the decrease in number of sub mature trees could also be a result of habitat alteration in the past which led to

inadequate recruitment into large size classes. Although canopy cover in previously logged areas seems to have recovered due to high density of *M. kilimandscharica* and other fast growing species, it is still less dense compared to undisturbed forest where *Ocotea* is dominant. Development into larger size classes is clearly favoured by more shaded environment. This could explain why *Ocotea* is considered a shade-tolerant and a late successional species (Babaasa *et al.*, 2004). Furthermore, this provides another explanation as to why in many cases *M. kilimandscharica* is considered a nurse tree to *Ocotea* (Bussmann, 2001). Although both of them regenerate soon after disturbance (Mugasha, 1978), the presence of *M. kilimandscharica*, a fast growing and broad leave tree ensures appropriate shady environments for development of *Ocotea* saplings into larger size classes. In the unlogged category, the population structure is characterized by many mature trees and few trees in lower diameter classes. In general terms, this agrees with the hypothesis that although *Ocotea* is considered shade-tolerant, it experiences low recruitment under dense canopy (Bussmann, 2001) due to inadequate initial regeneration. Although, the study indicates that the population structure of *Ocotea* is more stable in logged areas than in unlogged areas indicated by the inverted “J” type of distribution (see Fig. 2), this stability resulting from anthropogenic disturbance is absolutely unacceptable. This is due to the fact that, density of mature *Ocotea* in logged areas is much lower than density in camphor forest which ranges between 60-120 stems ha<sup>-1</sup> of DBH > 80 cm).

## 5.0 CONCLUSION

Forest regeneration and advance recruitment may vary locally as a result of disturbances, especially logging. While unlogged areas do not provide suitable habitats for *Ocotea* regeneration, any form of logging as a means of canopy opening cannot be recommended because if unregulated can results to death of juveniles and sub mature trees which are shade demanders. However, in areas where harvesting is still going on, regulated single tree felling by pitsawing mimicking natural disturbance can be considered as a means to manage *Ocotea*. The ongoing conservation activities in EAMs need to be supplemented with enrichment planting and slashing of brambles, to free saplings of *Ocotea* and attain the usual recovery of camphor forest.

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## CHAPTER FOUR

**Manuscript Three: Heart rot spread from parent to root suckers in *Ocotea usambarensis* (East African camphor) in Chome Nature Reserve, Tanzania.**

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**Assessing heart rot spread from parent to root suckers in *Ocotea usambarensis***  
**(East African camphor)**

**Abstract**

Heart rot is a fungal disease that causes decay of heart wood in trees. It is caused by white-rot fungi which preferentially digest the lignin resulting to changes in colour, texture, strength and hence the quality of the wood. Heart rot is the main defect in mature *Ocotea usambarensis* and the decay is implicated to impair regeneration, hence the restoration of *O. usambarensis* forests. The infection of heart wood has also been observed in young *O. usambarensis*. As the species regenerates mainly through root suckers, assessing the spread of fungi from parent trees to suckers is imperative in an effort to investigate causes for declining regeneration of *O. usambarensis*. In this study, a total of 31 pairs of heart rotted parent *O. usambarensis* individuals and their proximal adjoined suckers were selected for collection of wood cores, which were extracted using an increment borer screwed close to the root collars of both ends of the connecting root. The cores were then sterilized, cultured in V8 juice agar and incubated at 25<sup>0</sup> C for determination of presence-absence of decay fungi. Results indicated that decay fungi were present in 23.8% and 4.8% of the cores extracted from root collars of parent trees and their paired suckers, respectively. There was no significant association between presence of infection in root collar of parent individuals and occurrences of infection in root-collar of their paired suckers. It was also indicated that only diameter of suckers could significantly explain the occurrence of infection in their stems, but distance between paired individuals and presence of decay in the parent trees could not significantly explain presence of

infection in suckers. The implication of these findings are then discussed with regard to occurrence of heart rot in mature *O. usambarensis* and their paired suckers and it was concluded that the decay does not seem to spread along the connecting roots. Instead, the current high prevalence of decay in both mature and young individuals of *Ocotea* is possibly a consequence of increased anthropogenic disturbance creating entry points for decay fungi through tree injuries and wounds.

**Keywords:** *Decay, fungi, compartmentalization, Chome Nature Reserve, isolation.*

## INTRODUCTION

Heart rot is a fungal disease that causes decay of wood at the centre of tree trunks and branches. Although heart rot facilitates breakdown of wood to release carbon and minerals that have been fixed by trees, thus important in nutrients cycling, it is undesirable in commercial forestry (Schwarze, 2004). Heart rot is caused by white-rot fungi which preferentially digest the lignin resulting to changes in colour, texture, strength and hence the quality of the wood. In most cases, unlike root rot, heart rot does not cause death to trees as it is mainly restricted to the non-living part of the tree (Shortle and Dudzik, 2012), but significantly deteriorate the quality and reduce production of solid wood. Heart rot fungi enter trees through branch stubs and injuries resulting from stem or branch breakage, fire and insect damages. In tropical forests, where disturbance is high and conditions favour growth of fungi, heart rot is increasingly becoming a very common problem in virtually every hardwood tree species (Rimbawanto, 2006). The decay usually develops slowly over a period of many years, thus it is much more common and serious in overmature trees than in young trees.

Big and overmature trees are common features of many humid tropical montane forests such as those of Eastern Arc and the Kilimanjaro Mountains. Although the forests were logged for timber from late 1930s to mid 1980s, many overmature trees of desired species such as *Ocotea usambarensis*, *Ficalhoa laurifolia*, *Newtonia buchananii* and *Podocarpus latifolius* were not logged due to poor accessibility, stem decay (heart rot) and bad stem form (Iversen, 1991). Consequently, the current upper storey in these forests is largely composed of overmature trees with advance stem decay and other defects. Such trees might have been important sources of propagules but also a cause of natural disturbance through breakage of structurally weakened stems and branches (Lonsdale *et al.*, 2008).

This study focused on the East African Camphor (*Ocotea usambarensis* - hereafter referred to as *Ocotea*), which used to be the dominant canopy tree species of humid East African montane forests below 2500 m above sea level (Kleinschroth *et al.*, 2013). Although in such habitats, *Ocotea* was known to regenerate fairly well through root suckers and coppices, a number of studies within the past 25 years (Hamilton, 1989; Mrema and Nummelin, 1998; Nsolomo and Venn, 2000; Kleinschroth *et al.*, 2013; Richard *et al.*, 2014) have reported a serious decline in the density of the species. Looking at the current density of regenerants, it is rarely simple to imagine that young naturally regenerated *Ocotea* (DBH < 15 cm) ever exceeded 1000 stem per acre as reported by Wood (1963). In earlier times, due to high densities of young *Ocotea* following logging, thinning in naturally regenerate stands was an imperative silvicultural operation in the humid forests of Eastern Arc and Kilimanjaro Mountains (Willan, 1965; Kimariyo, 1972). Also, it is due to the

high density of *Ocotea* that some areas in these forests were referred to as camphor forests (Maliondo *et al.*, 1998). Although the vegetation of CNR particularly the camphor forests have not been adequately documented as compared to those in West Usambara Mountains, records show that CNR holds the highest density of *Ocotea* in EAMs similar to that of Southern Kilimanjaro (Nsolomo, 1996).

Factors attributed to the decline of *Ocotea* include; heart rot (Nsolomo and Venn, 1994; 1998), climate change (Hamilton, 1989; Iversen, 1991; Renvall and Niemela 1993), intensive logging (Kleinschroth *et al.*, 2013) and habitat deterioration (Richard *et al.*, 2014). The latter three, might be the same factors contributing to decline of other native timber species in the Eastern Arc Mountains, and are directly linked to increased anthropogenic activities. The increasing conservation emphasis by declaring most of the forests in Eastern Arc Mountain nature reserves, which means higher protection status, has greatly reduced human activities in the area (URT, 2010). Hence, significant reduction of anthropogenic activities is expected to reverse the situation and restore habitats suitable for growth of species. However, heart rot, which in most cases occurs naturally, and hence difficult to control, still need further investigation. This is due to the fact that, heart rot has been implicated to impair regeneration and therefore restoration of *Ocotea* forests (Nsolomo and Venn, 1994; 1998). The infection of heart wood has been observed in young *Ocotea* of about 10 cm diameter at breast height (DBH), thus knowing how the fungi enter young trees is imperative in investigating causes for declining regeneration of *Ocotea*. Fungi responsible for the heart rot which is the major defect in logs of *Ocotea* have been well studied by Nsolomo and Venn (2000).

Referring to a study by Willan (1965), Nsolomo and Venn (2000) hypothesised that decay (heart rot) enters young suckers through roots from parent trees. The fact is, however, that no study has documented with certitude the spread of heart rot through root from parent trees to root suckers. This is due to the fact that spread of fungi in the root system cannot be determined reliably based on symptom development above ground. In efforts to investigate the problem of declining regeneration and testing the hypothesis that heart rot spreads and enters suckers through roots, this study isolated wood cores from adjoining roots between parent trees and suckers and determined the presence-absence of decay fungi. The study also determined whether distance has any influence on the spread of decay fungi from mother trees to suckers.

## **MATERIALS AND METHODS**

### **Study Area**

The study was carried out in Chome Nature Reserve (CNR), one of the forests in EAMs where large specimens of *Ocotea* with DBH > 2m are common. Chome Nature Reserve is a 14,283-hectare continuous forest block situated between 4° 10'–4° 24' S and 37° 53'–38° 00' E, and within an altitudinal range of 1250 to 2463 m above sea level. The importance of this reserve lies on its high catchment values, climate amelioration and ongoing discoveries of its diversity and endemism of both fauna and flora (Baker, 2001; Richard *et al.*, 2014). The climate, soils and vegetation of the areas have been described by Lovett and Pócs (1993).

### **Heart rot Fungi in *Ocotea***

The problem of heart rot as the main defect in mature *Ocotea* trees was reported since 1960s (Dick, 1969). Some years later, Renvall and Niemela (1993) and Nsolomo (1996) carefully collected and studied fungi decaying *Ocotea* logs, stumps and standing trees. The former scientists found 10 polypore (Basidiomycetes) species that decay *Ocotea*, including *Phellinus senex* which had long been implicated as a cause of heart rot of the species, because of the occurrence of its basidiocarps on stems and butts of standing trees. Nsolomo (1996) isolated 72 species including 12 Basidiomycetes from decay of standing *Ocotea* trees and found that although *P. senex* cause significant weight loss but it does not pioneer decay in *Ocotea* (Nsolomo and Venn, 2000).

Although a number of fungi could not be identified to genus level, so far the series of studies done by Nsolomo and Venn (2000), Nsolomo *et al* (2000a and b) are considered the most intensive with regard to decay fungi of *Ocotea*. The studies found that some of the fungi isolated from standing trees were secondary wood colonizers involved in the decomposition of heartwood or sapwood while few were primary colonisers capable of infecting fresh wounds in the sapwood. It is unfortunate that all the pure cultures that were prepared during the studies have not been maintained in Tanzania, possibly due to inadequate human and financial resources and therefore currently it is almost impossible to get the reference cultures. Therefore, apart from determining the presence-absence of decay fungi in *Ocotea* trees, this study did not identify the fungi isolated and cultured.



## **Data Collection**

### *Selection of trees and collection of wood cores*

A total of thirty one pairs of *Ocotea* individuals (10 standing trees and 21 stumps) and their proximal adjoined suckers of DBH > 5 cm were selected for collection of wood cores. To guarantee explicit pairing, partial excavation of the soil to expose connecting roots was done, but often the direction of connecting root from parent individual would tell its paired suckers. All the selected mature trees had advanced heart wood decay indicated by either presence of holes in their boles or spongy and stringy wood confirmed through examination of extracted inner cores. The condition of selecting decayed trees and not just any symptomatic *Ocotea* was necessary because the aim was to determine the spread of decay fungi from heart rotted trees to their paired root suckers. Also selected suckers had to have DBH > 5 cm, because in active growing trees heart rot is confined in the heart wood, thus younger *Ocotea* than this size are unlikely to have developed heart wood. Out of the 21 stumps, 10 were control without any indication of decay (Plate 1a) and the rest were heart rotted stumps with clear indication of decay (Plate 1b). For this study, stumps from recent cuts clearly reflected the condition of the felled trees and therefore adequately represented standing trees.



**Plate 1:** First logs of *Ocotea usambarensis* indicating (a) individuals without any sign of decay and (b) heart rotted individuals in sampled areas of Chome Nature Reserve

Diameter at stump height (normally within 0.5 - 1m from the ground) of all selected individuals was measured using a calliper and the distance between the paired individuals was measured using a measuring tape. In each pair, the connecting root was partially excavated (to expose upper sides of both root initials) for extraction of wood cores at about 0.5 m from the root collars. Collection of cores from the inner wood was carried out using a two-thread increment borer of 45cm length and 5.15mm diameter. The borer was screwed perpendicular to the root until it was judged sufficient to extract the inner wood. Similarly, wood core from each bole of the paired sucker was extracted at approximately 1 m above the ground for determination of presence-absence of fungi. The increment borer was sterilised with 70% alcohol after each use to avoid transferring of infection to other trees. Also, holes created by extraction of wood cores were covered by sterile bee wax to minimise post infection and the excavated soil replaced. Collected cores were labelled, preserved in a cool box and transported to Plant Pathology Laboratory at Sokoine University of Agriculture where culturing was carried out.

### *Sterilization, culturing and incubation of wood cores*

From each wood core, four small pieces of about 0.5 cm long were cut using sterile surgical blades. The pieces were dipped into 70% ethanol for 60 seconds to sterilize and break the surface tension. For a thorough sterilization, the pieces were again dipped in 2% v/v sodium hypochlorite (NaOCl) for about 180 seconds. Thereafter, the sterilized pieces were rinsed three times using distilled water and then blot dried between sterile filter paper. The dried pieces were cultured by pushing to stick just under the surface of V8 juice agar in labeled Petri dishes. All the processes from sterilization to culturing were done under aseptic condition (in lamina flow). Petri dishes were finally wrapped in Aluminium foil and incubated at 25<sup>0</sup> C for one week. After this duration, each Petri dish was carefully inspected at the point of inoculation to observe any signs of growing fungi. Petri dishes with growth of fungi at the point of inoculation were recorded as “present” and those without any sign were returned to the incubator and monitored regularly for a maximum of 28 days. This was done to insure that all Petri dishes were unambiguously declared “presence” or “absence” of decay fungi (Schwarze, 2004).

### **Data Analysis**

Occurrence of decay fungi close to the root collars of both parent individuals and suckers were scored as either present (1) or absent (0) while other variables (diameter and distance between paired individuals) were treated as continuous variables. Differences in diameter between control and heart rotted individuals, and infected and uninfected suckers were analyzed using a two-sample *T*-test. Chi-square test was used to determine association between presence of infection in parent

individuals and occurrences of root-collar infected suckers. Then, Pearson's product moment correlation was used to analyze the relationship between presence-absence of decay fungi in sucker and explanatory variables (i.e distance between paired trees, diameter of suckers and infection at the root collar of parent individuals). Because the response variable was binary and the sample size was small, the Exact logistic regression (Derr, 2009) was used to model the likelihood of occurrence of decay fungi in suckers' stems through the adjoined roots. The importance of explanatory variables in the logistic regression was interpreted using the Odds ratios (OR) which can take values of 0 to infinity; values  $< 1$  representing a decrease in probability of presence of decay fungi and those  $> 1$  representing its opposite. Greater departure from 1 indicates a stronger relationship between the variable and the response (Milbau and Stout, 2008). All statistical analyses were done using the SAS program, version 9.1.3.

## **RESULTS**

### **Heart rot and Tree Size**

The mean diameter of heart rotted and control individuals were 91.8 cm and 89.7 cm respectively. Diameter did not differ significantly between the two groups ( $t = -0.25$ ,  $p > 0.05$ , Table 1). Observation of the incubated cultures indicated that decay fungi were completely absent in all wood cores taken from root collars of control individuals. However, 30% of cores from stem of their paired suckers indicated presence of fungi. With regard to heart rotted individuals, decay fungi were present in 23.8% ( $n = 21$ ) of the wood cores and in only one core (4.8%) from root collars of

their paired suckers. Out of the 23.8% (i.e. 5 individuals), 3 were stumps and the remaining two were standing trees.

**Table 1:** Diameter at stump height of control and heart rotted *Ocotea usambarensis* and their paired suckers as recorded in Chome Nature Reserve, Tanzania

Heart rotted (diameters in cm)		Control (diameters in cm)	
Parent	Suckers	Parent	Suckers
66.3	14.0	76.2	12.6
87.1	7.7	87.3	5.9
99.0	10.7	72.8	*16.2
83.3	6.2	67.0	9.3
98.8	5.9	76.0	19.7
¥ 96.1	*¥ 21.9	132.2	8
64.5	13.2	98.4	6.3
76.1	14.9	91.0	9.3
96.7	*14.5	106.3	*15.3
71.2	5.1	89.6	*17.1
65.1	10.2		
58.8	9.7		
92.0	*16.4		
78.1	12.4		
120.0	*16.8		
95.0	13.1		
¥ 121.6	*19.5		
¥ 146.4	7.4		
94.7	16.5		
¥ 128.0	*11.6		
¥ 88.4	*19.0		

**Note:** ¥ indicates presence of fungi from root collar samples and

\* indicates presence of fungi from suckers' stem samples.

Overall, about one third of suckers ( $n = 31$ ) indicated presence of fungi in their boles. Mean diameter of bole-infected suckers was significantly larger than uninfected suckers ( $t$ -test = -4.62,  $p < 0.05$ , Table 1). Similarly, root collar-infected parent individuals had significantly larger diameter than uninfected ( $t$ -test = -3.30,  $p < 0.05$ ). Decay of heartwood was observed largely in over mature individuals and in few instances, in individuals with diameters  $< 80$  cm.

### Association of Infection between Paired Individuals

Chi-square test revealed that there is no significant association between occurrences of root-collar infected suckers and presence of infection in root collar of paired parent individuals ( $\chi^2 = 3.36$   $df = 1$ ,  $p$ -value = 0.067). Therefore, the spread of fungi from heart rotted parent individuals to suckers was not substantiated. The power of chi-square analysis using a sample size of 21 paired trees at  $p=0.05$  was found to be 70%.

**Table 2:** Pearson's Product Moment correlation coefficients between bole-infected sucker and explanatory variables (n = 21)

Variables	Bole infected sucker	Distance between trees	Diameter of suckers	Occurrence of root- infected parents
Bole infected sucker	1	-0.162	0.675*	0.553*
Distance between trees		1	-0.139	-0.126
Diameter of suckers			1	0.386
Occurrence of root-infected parents				1

**Note:** \* denotes that the correlations were significant at  $p < 0.05$

Occurrence of infection in the stems of *Ocotea* suckers was significantly and positively correlated with diameter of suckers and also occurrence of infection at the root collar of parent individuals ( $R = 0.675$ ,  $p = 0.001$  and  $R = 0.553$ ,  $p = 0.009$  respectively) (Table 2). Although, occurrence of infection in the stems of *Ocotea* suckers increases as the distance between paired trees decreases, the correlation was not significant ( $R = -0.162$ ,  $p = 0.482$ ). The average distance between paired individuals was 4.2 m. There were no significant correlations between explanatory variables, thus all the three continuous variables were used for subsequent modeling.

**Table 3:** Results of Exact logistic regressions examining the influence of distance between paired trees (m) and diameter of suckers (cm) on presence-absence of decay fungi in regenerants of *Ocotea usambarensis* in Chome Nature Reserve, Tanzania. SE = Standard error and OR= odds ratio

Variables	Estimates	SE	<i>p</i>	OR
Intercept	-9.418	4.862	0.053	
Distance between trees	-0.213	0.496	0.998	0.808
Diameter of suckers	1.106	0.379	0.004	3.021
Occurrence of root infected parents	0.401	0.312	0.875	0.542

Table 3 shows results of exact logistic regression, which revealed that only diameter of suckers could significantly explain the occurrence of infection in their stems ( $p < 0.05$ ). Neither distance between paired trees nor presence of infection in the parent trees were able to explain the presence of infection in the suckers ( $p > 0.05$ ). The OR indicates that the probability of occurrence of infection in sucker's stems is 3.02 times greater with every unit increase in diameter. The negative sign in the coefficient of distance between trees indicates the negative influence of distance on the infection.

## DISCUSSION

Heart rot is a common and economically important problem of mature hardwood trees in both planted and natural montane forests of Tanzania. For example, many mature *Ocotea* are so defective from heart rot that it is not worth felling them for sawn logs. Decay fungi and wood discoloration has also been reported in young *Ocotea* and was hypothesised to enter young trees from parent roots (Nsolomo and Venn, 2000). Nevertheless, no research has been carried out since then to confirm this phenomenon, probably due to lack of/or very few local forest pathologists. This

problem is therefore of particular interest because *Ocotea* regenerates mainly through suckers and rarely from seedling (Bakari, 2002).

The primary biotic decomposers of wood were basidiomycete decay fungi, which attack and degrade both wood in the forest and wood in service. Identification of decay fungi can be accurately carried out only if reference cultures are available, however presence and absence of decay fungi which was the interest of this study could be determined without them.

### **Heart wood Decay and Tree Size**

Presence of several large *Ocotea* (diameter > 100 cm) without any sign of decay indicated existence of unexpectedly good number of individuals in CNR which still have clear heart wood. Local people carrying out illegal logging seem to be very experienced in identifying heart rotted trees. In most cases they would fell trees free from heart rot, or sometimes trees with only the first log decayed. This is due to the fact that, in many observed recent cuts the fallen logs were completely sawn with only few exceptions where first logs (about 2m) were left unattended due to severe heart rot (*Ref.* Plate 1b). Existence of large asymptomatic *Ocotea* has also been reported in Southern Kilimanjaro and it is usually an indicator of a forest that has experienced fewer anthropogenic disturbances (Hemp, 2006). Heart rot is very common in previously disturbed areas, because apart from logging damages, severe debarking for medicinal purposes also cause stem injuries which are entry points for decay fungi (Bitariho *et al.*, 2006). In the present study, only one third of suckers emanated from heart rotted parent individuals indicated infection in their stems and



only one individual indicated infection at the root collar. Early studies by Dick (1969) concluded that heart rot is a problem of over mature trees because incidences of decay were often not in active young growing trees. However, the fact that about one third of suckers regenerating from asymptomatic trees had their bole infected, suggests high prevalence of decay fungi even in young *Ocotea*. The recent increase in occurrence of decay even to young individuals is a consequence of anthropogenic disturbance particularly logging and forest fires which cause broken top and branches, wounds and scorches to the surviving trees (Hemp, 2006).

### **Spread of Decay from Parent Trees to Suckers**

The present study has found no association between infection in young stems and presence of fungi at the root collar of their parent trees, meaning that the likelihood of spread of decay from parent root to suckers was not quantified. Since decay-causing fungi do not thrive under anaerobic conditions (Shortle and Dudzik, 2012), the high moisture content in the root and base of active growing young *Ocotea* might have been restricting fungal spread from parent trees. Also, literature has suggested that, when decay fungi get in contact with living cells, compartmentalization is initiated, which limits the spread of fungi into other areas while the trees continue to grow (Rimbawanto, 2006; Schwarze, 2007). Usually compartmentalization works out very well in active growing trees, but it also depends on environmental and genetic factors (Smith, 2006).

Decay fungi require a pathway from the outside to the dead tissues of the heart wood. Dead roots could provide entry points, just as dead branch stubs provide pathways

for heart wood decay of the upper stem. Therefore, this can provide explanation for a small insignificant percent of *Ocotea* suckers that indicated infection at the root collar which was possibly through dead parent roots. Similar observations were also reported in poisoning experiments of mature defective *Ocotea* in Southern Kilimanjaro and West Usambara, where a large percentage of regenerated coppices from poisoned trees were infected with decay fungi (Kimariyo, 1972).

Wood decay fungi are separated into top rots and root or butt rots depending on which part of the tree is affected. Heart rot is categorized as a top (upper) rot disease of trees. Heart rot fungi, seldom progress very far into the roots and therefore rarely spread from one tree to another via roots. Root and butt rot fungi colonize the lower stem and roots of trees. Some parasitize the cambium of roots while others remain within the central xylem and can be classified as saprophytes (Schwarze, 2004). With exception of coppices which grow right on the stumps, distance between heart rotted parent trees to suckers did not seem to influence spread of decay fungi which further stress that the infection observed in stem suckers could be through wounds and injuries rather than through roots.

## CONCLUSION

Although heart rot has become very common in mature *Ocotea*, the decay does not seem to spread along parent roots to suckers. Instead, the current high prevalence of decay in both mature and young individuals of *Ocotea* is possibly exacerbated by anthropogenic disturbance which cause wounds and injuries on trees. This is because the starting point for wood decay in living trees is a wound, which exposes the inner

wood for infection. Therefore, the increasing emphasis on conservation in both the Eastern Arc and Kilimanjaro mountains where *Ocotea* is found can reduce the incidence of heart rot in *Ocotea* and also other impacted hard wood species.

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## CHAPTER FIVE

**Manuscript Four: Invasion of *Acacia mearnsii* (Black Wattle) in Chome Nature**

**Reserve: estimating its coverage and control costs**

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**Invasion of *Acacia mearnsii*(Black Wattle) in Chome Nature Reserve:  
estimating its coverage and control costs**

**Abstract**

Problems caused by invasive alien plants on biodiversity and ecosystem services are increasingly becoming real and evident. While national-level strategies are in place in other regions, there is very little effort toward management of the species in Eastern Africa, even in the so called ‘hotspot’ biodiversity areas. This is partly due to inadequacy of concrete evidences of their impacts and estimates of control cost to guide decision making. This study therefore highlights impacts and presents estimates of coverage and costs needed to control *A. mearnsii* invading and displacing native species in Chome Nature Reserve in the north-eastern Tanzania. We surveyed invaded areas of the reserve with rare, scattered and dense coverage of *A. mearnsii*. With the use of GPS and Google maps, the surveyed areas were digitised and coverage of *A. mearnsii* determined using QGIS. Control costs and water use by the species were estimated using established rates and figures from South African studies. The equivalent condensed area occupied by *A. mearnsii* is about 210 ha (i.e. 1.5% of the reserve area). The invasion of *A. mearnsii* is more serious in the western bog vegetation and along upper tributaries of Saseni River. The incremental water use by *A. mearnsii* (i.e. the additional water use compared with the natural vegetation) is estimated at  $9.2 \times 10^5 \text{ m}^3/\text{year}$ . Mechanical clearing of the entire invaded area and follow up to clear re-growths and remove seedlings of *A. mearnsii* are estimated to costs TZS 164.64 million. To safeguard the value of this catchment forest and its biodiversity, controlling invasion of *A. mearnsii* is

considered an absolute necessity conservation activity of the reserve. However, it is recommended that, before implementing the operation, experimental plots on clearing should be set to assess other externalities that may need management consideration during scaling up to the entire reserve.

**Keywords:** *Alien plants, clearing, water use, heathland, nature reserve, Eastern Arc.*

## 1.0 INTRODUCTION

Globally, impacts of invasive alien species on biodiversity and ecosystem services are increasingly becoming real and evident (Gordon and Witt, 2013). The threat posed to biodiversity by these species is considered second only to that of habitat loss (CBD, 2005). Plants are among the most important invasive alien species worldwide. In most tropical countries where people still directly depend on forest resources for their survival (Monela *et al.*, 2000; FAO, 2010) relentless pressure has resulted into degradation and loss of forest cover, which altogether facilitate establishment of alien invasive plants (AIPs). Although, compared to other biomes, tropical forest ecosystems were considered more resistant to invasion (Rejmánek, 1996), current trends show that vulnerability to invasion and impacts on biodiversity are rapidly increasing (MEA, 2005). These trends cannot be reversed unless each Contracting Party of the Convention of Biological Diversity honours her contractual obligations by preventing introduction of, and/or controlling or eradicating alien species which are known to threaten ecosystems, habitats, or species (CBD, 1992).

Expanding populations of AIPs even to areas regarded as strictly conserved, for example national parks and nature reserves are a warning signal that if concerted efforts are not taken now, then the costs of controlling or eradicating the species in future will be prohibitively expensive. This is primarily due to the fact that, once AIPs get established in new environments, subsequent expansion is often exponential until all the potential habitats (invadable areas) becomes fully occupied (Marais *et al.*, 2004). With regard to invadable areas, strictly protected areas are not exempted, for they are protected not only because of their rich biodiversity but also because they might have suffered markedly from anthropogenic disturbance which has threatened existence of species (Myers *et al.*, 2000).

While there is no country in the tropics, including the least developed, that can afford to ignore the socio-economic impacts of AIPs, there has often been a reluctance to manage the species despite existence of proven methods that have worked very well elsewhere (Marais and Wannenburgh, 2008). Also, it is unfortunate that in most of the so called biodiversity ‘hotspot’ areas, for example in Eastern Africa, there is very little or no activity on the ground implemented to manage the AIPs (Gordon and Witt, 2013). A number of reasons for this reluctance are given, including financial constraints, inadequate knowledge on the ecology and prospective benefits of the species. The latter reason is probably the most challenging, thus controlling what are so-called “conflict species” (invasive species, that is, which despite all the damage and suffering they are causing, are seen to possess some useful attributes as well) has often received public criticism (Gordon and Witt, 2013). Some of the “conflict species” in Eastern Africa include *Acacia mearnsii*, *Prosopis spp* and *Leucaena*

*leucocephala*. However, this does not justify that “conflict species” should not be controlled; because in most cases after sometimes their negative impacts on ecosystem services exceed the benefits communities can derive from them (van Wilgen and De lange, 2011). In cases where several alien plants threatening ecosystems exist, the reluctance has also been attributed to the lack of priority species lists for management. The fact is, however, that even in forest reserves where there is few or only one invasive plant, decisions to control them have rarely been made.

In the Eastern Arc Mountains (EAMs) of Tanzania, one of the world’s biodiversity “hotspots” areas, such delayed response coupled with persistent forest degradation has resulted into AIPs expanding their populations and displacing native flora (Hulme *et al.*, 2013). Currently, mobilisation of resources for upgrading forest reserves to the status of nature reserves (which means higher level of protection from human activities) seems to receive a lion share of attention from conservation managers. While the rush to upgrade forest reserves to nature reserves is worthwhile, strategies to halt anthropogenic disturbances could be complimented with management of AIPs which are gradually in some areas replacing native vegetation. In most cases blames are thrown to those we refer to as “decision makers” that they delay creating an enabling environmental policy that would allow management of AIPs. However, making decision to control particularly “conflict species” has often been difficult when concrete evidence of their impacts and cost estimates to control the species are lacking. This study which is probably the first of its kind in Tanzania will therefore evaluate the possibility of controlling one of the “conflict species”

namely *Acacia mearnsii*, which though still seen in patches, is expanding its population in Chome Nature Reserve, a part of EAMs. The study specifically estimates the coverage and impact of *Acacia mearnsii* invasion on regeneration of native species and estimate the costs that are needed to control the species in Chome Nature Reserve.

### ***Description of the study species***

*Acacia mearnsii*, commonly known as Black wattle, is a fast-growing leguminous tree native to south-east Australia which is widely cultivated as an exotic species in a number of countries throughout the world (Impson *et al.*, 2011). It is commonly used as a source of tannins, resins, timber, fuel wood, pulp wood, charcoal, poles and green manure. Also it is used for soil erosion control, soil improvement, shade, shelter, and as an ornamental. Extensive areas under *A. mearnsii* exist in Brazil (200,000 ha), South Africa (2.5 million ha), East Africa (30,000 ha) and India (20,000 ha). In South Africa, the species is probably the most studied and documented in the field of plant invasion as it is one of the major invasive species throughout the country (Moyo *et al.*, 2009).

*Acacia mearnsii* is an evergreen tree which can grow up to 20m high. Although it can start to flower when about 2 years old, appreciable quantities of viable seeds are produced after the fifth year. *Acacia mearnsii* seeds may accumulate to high densities up to 20 000 seeds/m<sup>2</sup> in the seed bank and can remain viable up to 50 years. The seeds may be triggered to germinate *en masse* by fire. In disturbed mesic habitat, the species forms very thick thickets and drops large quantities of litter; and

therefore outcompete and replace indigenous vegetation including grass communities. It also increases transpiration and rainfall interception causing a decrease in stream flow (ISC, 2014). *Acacia mearnsii* ranks first in water use among invasive species currently present in South Africa, accounting for 17.4% of the total water use (Le Maitre *et al.*, 2000).

*Acacia mearnsii* was introduced in Chome Nature Reserve (CNR) in mid 1950s as boundary trees and later planted as woodlots adjacent to the reserve for bark production which was being sold to Giraffe Tannin Industry in Lushoto, Tanga. Following anthropogenic disturbance in the forest, particularly due to forest fires and illegal logging of *Ocotea usambarensis*, *Podocarpus latifolius* and *Ficalhoa laurifolia*, the species started to invade the forest and in some areas completely replaced indigenous vegetation (MNRT, 2008).

## **2.0 METHODS**

### **2.1 Study Area**

#### **2.1.1 Location and size**

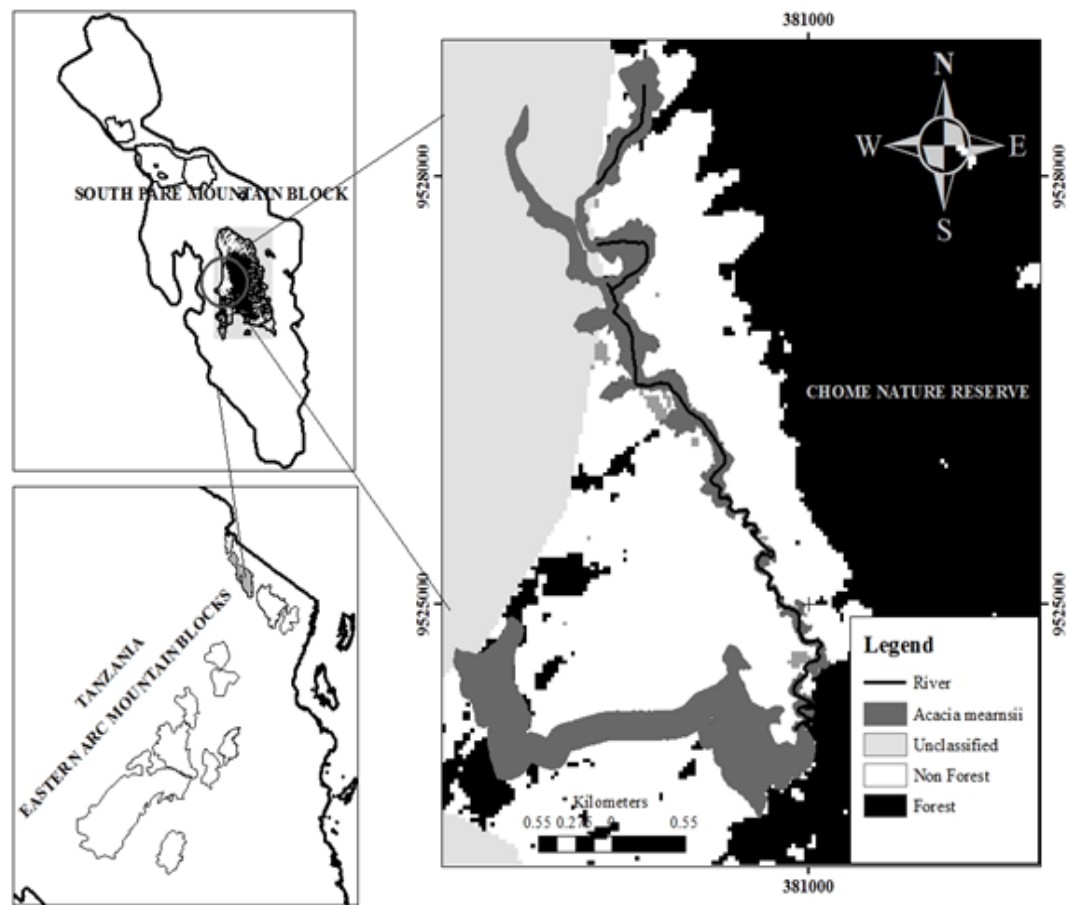
Chome Nature Reserve is situated in the north-eastern Tanzania between 4° 10' to 4° 24' S and 37° 53' to 38° 00' E. It is the largest forest block in the South Pare Mountains and covers an area of 14,213 hectares of various forest types and montane grassland. The entire reserve straddles an altitudinal range of 1,250 m to 2,462 m above sea level (Baker, 2001). This particular study concentrated on the western, northern and southern part of the reserve (Fig. 1 & 2) between 1,700 m and 2100 m above sea level, where *A. mearnsii* has invaded bog vegetation and disturbed forest.

### **2.1.2 Climate and soils**

Rainfall in CNR is bi-modal, with short rains occurring between October and December and long rains between March and June. The amount of rainfall ranges from 1500-2000 mm on the dryer western side to 3000 mm on the wetter eastern side of the reserve. The dry season is between June and September, with light rainfall occurring at higher altitudes. Temperatures vary with rainfall, from a minimum of 15°C in July to 20°C in February. Soil types vary with topography; acidic lithosols predominate on ridges with ferralitic latosols on the slopes. On the western grassland plateau, hitosols have developed in depressions under the heath and bog vegetation (Lovett, 1993).

### **2.1.3 Vegetation of the study area**

Although the vegetation of CNR varies considerably as a result of differences in altitude and rainfall, it can be classified into four main types/zones (i) sub-montane forest on the eastern ridge between 1250 – 1600 m; (ii) montane forest above 1500 m with a drier type on the lower slopes and rain-shadow areas, and a wetter type on the eastern slopes and mainly in valleys on the western slopes; (iii) elfin forest dominating areas above 2300m on the highest ridges; and (iv) heath and grassland which cover more than 10 percent of the forest, with secondary heath and thickets replacing another large portion of dry montane forest following fire and illegal logging (Barker, 2001). The proportion of vegetation classes which resulted from anthropogenic and natural disturbance is shown in Table 1.



**Figure 1:** Location of areas that are highly invaded by *Acacia mearnsii* in the Western part of Chome Nature Reserve as zoomed from among the Eastern Arc Mountain Blocks



**Table 1:** Vegetation classes of Chome Nature Reserve and their percent coverage reflecting proportion of disturbed and non-forest areas as adopted from Aerial survey of 2003 by UNDP/GEF East African Cross Border Project (Persha, 2003)

Vegetation type/zone	Extent		Plant forms and features
	Ha	(%)	
Closed canopy forest	2713.8	19	Usually with emergent, canopy, understory and forest floor layers of different plant species. Characterised by many emergent and canopy tree species and the dominant tree species used to be <i>Ocotea usambarensis</i>
Semi-degraded forest	5427.5	38	Closed canopy forest is limited to valleys. This type is also characterised by dead trees and bracken on ridge tops as a result of frequent forest fires.
Degraded forest	2713.8	19	Presence of isolated canopy species with many patches of secondary forest, pioneer shrubs and annual plants.
Heathland/grassland/thickets	3427.9	24	Species rich-shrubland dominated by <i>Erica spp</i> , and interrupted by grassland patches and thickets

#### 2.1.4 Socio-ecological importance of the reserve

Chome Nature Reserve is one of the Important Bird Areas in Tanzania and also a home to one threatened endemic bird species (*Zosterops winifredae*) which is recorded only from this area (Persha, 2003). Apart from the biodiversity value, the critical importance of CNR to adjacent communities lies on its high catchment values which is also threatened by the expanding population of *A. mearnsii*. All the four major rivers of the district (i.e. Yongoma, Saseni, Mhokevunta and Hingilili) originate from forested peaks in the reserve. More than 60% of the population

(269,803 people) in the district (NBS, 2012) depend on water from the reserve for domestic and agricultural activities. The water is extensively used for paddy irrigation in the lowland of South Pare Mountains (PWBO/IUCN, 2006). The excess water drains into the Pangani River for hydroelectric power generation which contributes to the national power grid of Tanzania. Also, water from the catchment supports wildlife and the ecosystem of Mkomazi National Park (MNRT, 2008). Therefore the reserve is a complex of mountain peaks, river networks and a habitat for various important flora and fauna.

## **2.2 Data Acquisition and Parameters Estimations**

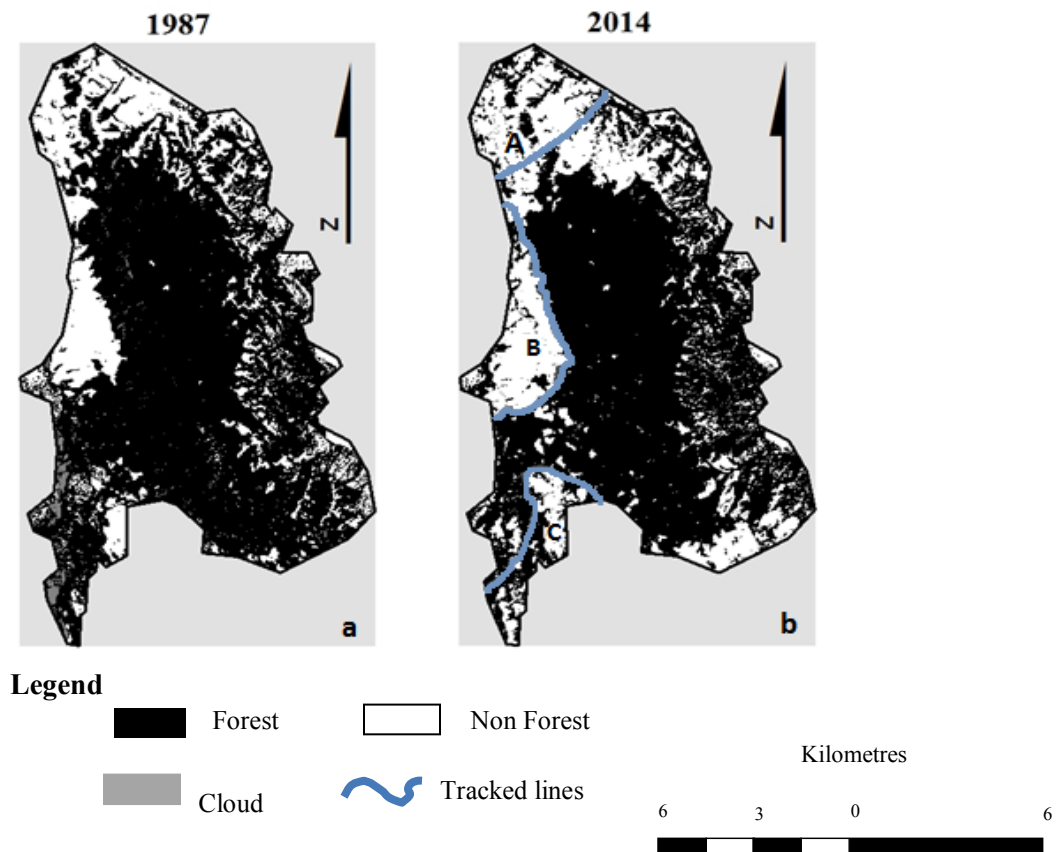
### **2.2.1 Estimating density and coverage of *Acacia mearnsii***

To determine the distribution and density of *A. mearnsii*, a reconnaissance survey was carried out in all potential areas with the guidance of a vegetation map (Persha *et al.*, 2003) and local forest guides. The map was used to locate areas of degraded forests and disturbed river banks which were of particular interest in the survey as the species prefers these areas. Therefore, based on the density of *A. mearnsii*, the surveyed areas were categorised into three classes; (i) rare (*A. mearnsii* known to be present but canopy cover less than 1%), (ii) scattered (with canopy cover greater than 1% but < 25 %) and (iii) dense (canopy cover > 25%, see Plate 1).

#### ***(a) Density and coverage of *Acacia mearnsii* in densely invaded areas of CNR***

Densely invaded areas can be easily drawn as polygons on land cover maps if their boundary points are known. In this case, a handheld Global Positioning Systems (GPS) receiver was used to record several waypoints around the areas. Waypoints

were then overlaid on a high resolution Google map to guide digitisation of the areas and connect the points to form polygons (refer Fig.1). The digitized vector layers in Keyhole Markup Language (.kml) format were converted to shapefiles in Quantum Global Information System (QGIS) for area determination of each drawn polygons. The invaded areas were converted to “condensed ha” (the equivalent areas in ha with canopy cover 100%) based on the estimated density of *A. mearnsii*. This conversion used the formula:  $C = d/100 \times A$ , where  $C$  is the area expressed as condensed ha,  $d$  is the density (% cover) of *A. mearnsii*, and  $A$  is the area in ha that is invaded by *A. mearnsii* (Le Maitre *et al.*, 2002; Marais *et al.*, 2004).



**Figure 2:** Land cover map of Chome Nature Reserve (a) for the year 1987 and (b) for the year 2014 showing study section A, B and C invaded with *Acacia mearnsii*

**(b) Density and coverage of *Acacia mearnsii* in rare and scattered areas of  
CNR**

A different procedure was used to estimate the percentage cover of *A. mearnsii* in the northern and southern landscapes which fit best in the rare and scattered classes. We explored the two areas using nine footpaths (5 in the northern and 4 in the southern part) that are frequently used by villagers to access the forest interiors. The footpaths pass on undulating landscapes characterised by heath land and forest patches on ridges and valleys, respectively. Therefore, along the paths each encountered forest patch, was surveyed and the proportion of *A. mearnsii* to other tree species was determined and recorded. Waypoints were taken at the end of each path (where no more *A. mearnsii* was encountered) and delineated as polygon A and C (Fig. 2b) for areas determination (refer 2.2.1a).

### **2.2.2 Estimating costs for controlling *Acacia mearnsii***

The total cost that would be needed to control *A. mearnsii* in CNR, were estimated by multiplying the area under invasion (condensed ha) by costs per hectare. Estimates of costs for controlling *A. mearnsii* were ascertained from various studies that were carried out in South Africa (Marais *et al.*, 2004; Marais and Wannenburgh, 2008; van Wilgen *et al.*, 2012, McConnachie *et al.*, 2012). The studies provide cost estimates for controlling AIPs, mainly *A. mearnsii* using data that had been collected from the year 1994 to 2012 (van Wilgen *et al.*, 1997). The average cost per condensed ha (for clearing and a minimum of two follow-ups) reported in these studies range from South African Rands (ZAR) 2634 to 3177. In this particular study we adopted the average costs from Marais *et al.* (2004) which was ZAR 3144

equivalent to TZS 470,185/= (adjusted using the current exchange rate 1ZAR  $\equiv$  TZS 149.55/= (BOT, 2015). We preferred using Marais *et al.* (2004) over the other studies because it has explicitly separated cost of initial clearing and follow-up from costs of herbicides. Information on health risks resulting from the use of herbicides in catchment areas is still inadequate (Moyo, 2009); thus their use were not considered in this study. All other costs apart from clearing and follow-up (e.g. office work, meetings, supervision and transport) were lumped together as overhead costs, which normally accounts for 40% of the total costs (Marais *et al.*, 2004; van Wilgen *et al.*, 2012). The total costs per condensed ha was therefore the sum of costs for clearing, follow-up and overheads.

### **2.2.3 Estimating water use by *Acacia mearnsii***

Again, to determine water use by *A. mearnsii*, estimates from South African studies conducted in catchment areas (Le Maitre *et al.*, 2000; van Wilgen *et al.* 2011; Meijninger and Jarman, 2014) with more or less similar climatical conditions as CNR were adopted. These studies provide information based on data that have been collected for over 20 years, thus can be used to provide reliable estimates on water use. In the current study, the estimates of water use by *A. mearnsii* were derived from information collected from highly invaded areas of South Africa including KwaZulu-Natal, Western Cape, Mpulanga and Eastern Cape provinces. The average temperature in these area ranges from 15°C to 30°C and 9°C to 18°C during summer and winter, respectively. The average tree age for water use estimations was 15 years. The congruence of the two variables to the situation in CNR justifies the use

of estimates from these studies as a first approximation as water use is largely influenced by temperature and tree age/biomass.

#### 2.2.4 Forest conversion and invasion rate in Chome Nature Reserve

To estimate these parameters under a scenario of no control, three important assumptions were made: (a) invasion of *A. mearnsii* from nearby woodlots started in the mid-1980s as reported in MNRT (2008) (b) the rate of invasion will remain constant throughout (c) *A. mearnsii* will be the only invader in CNR and that future spread will be confined only to current degraded areas until the canopy density reaches 100%. Therefore, to determine the size of deforested area (i.e. area susceptible to future invasion), forest cover change between 1987 and 2014 was estimated from the land cover classification of remotely sensed images. Images that were used in the analysis of land cover changes were from Landsat TM<sup>a</sup> and Landsat OLI<sup>b</sup> in the path/row 167/63 acquired on 02/02/1987 and 11/01/2014, respectively. The classes of interest in both images were forest and non-forest, and Post Classification Comparison (PCC) was used for change detection.



**Plate 1:** Invasion of *Acacia mearnsii* in Chome Nature Reserve, Tanzania (a) beneath *A. mearnsii* invaded areas (b) invasion of *A. mearnsii* along tributaries of Saseni River.

### 3.0 RESULTS

#### 3.1 Coverage and Canopy Density of *Acacia mearnsii*

The whole area that was surveyed in this study (i.e. 2997 ha, Table 2) is invaded to some degree by the exotic tree *A. mearnsii*. The density of *A. mearnsii* ranges from rare (less than 1% of the vegetation canopy) in the interior of northern part of the reserve to dense canopy (> 75% canopy cover) along the upper tributaries of Saseni River. The equivalent condensed area occupied by *A. mearnsii* is approximately 210 hectares (Table 2). Therefore, about 25% of what is classified as forest (877 ha) in the surveyed area is occupied by *A. mearnsii*. The western part (section B) is seriously invaded with more than 75% of its forest occupied by the species. Recollections from local forest guides indicated that *A. mearnsii* occurs in all disturbed areas in the periphery of CNR. However, invasion is more concentrated in riparian areas in the western and southern parts where *A. mearnsii* was introduced adjacent to the reserve (Plate 1). During the survey, it was observed that illegal mining for alluvial gold which is done by diverting river courses and excavating the river sand has also facilitated the invasion.

**Table 2:** Estimated area under invasion by *Acacia mearnsii* in three surveyed sections of Chome Nature Reserve, Tanzania

Sites	Area surveyed (Ha)	Forest area (Ha)	Non-forest area (Ha)	Cover % under invasion		Estimated condensed area (Ha)
				Forest	Non-forest	
Northern part (A)	1212	304	908	5	1	24.3
Western part (B)	1042	179	863	75	1	142.9
Southern part (C)	743	394	349	10	1	42.9
Total	2997	877	2120			210.1

\* Estimated condensed area = condensed area under forest + condensed area under non-forest

### 3.2 Status of Invasion of *Acacia mearnsii* in Rare and Heath Lands

The difference in the density of *A. mearnsii* between highly invaded western part and other areas of the reserve is marked. The average canopy cover in the northern and southern parts is only about 5% and 10% respectively (Table 2). In the northern part (section A), forest occupies about 25% of the area and about 50% in the southern (section C). As with other native tree species, distribution of *A. mearnsii* in the northern and southern parts is mostly limited along valleys where deep and wet soils can support luxuriant growth. In non-forest areas (i.e. heathland), *A. mearnsii* occupies about 1% of the vegetation cover. Therefore, the equivalent condensed area in the non-forest areas is estimated at 21.2 ha (Table 2). Also, it was observed that, the southern and northern parts of the reserve have also been invaded by *Eucalyptus* spp. Presence of mature boundary *Eucalyptus* trees provides reliable seed source which facilitate invasion along disturbed forest boundaries and some hundred meters to forest interiors.



### 3.3 Control cost of *Acacia mearnsii*

The total cost for controlling *A. mearnsii* in Chome Nature Reserve is estimated at TZS 164.64 million; including overheads TZS 65.82 million which were calculated as 40% of the total costs (Table 3). The average total cost per condensed ha is TZS 783,641/=. The mesic habitat in the Western part which is heavily invaded (section B) will require almost 70% of the estimated control costs. About 10 % of *Acacia* trees in this area are mature and some with fairly good stem forms suitable for selling.

**Table 3:** Estimated control costs for *Acacia mearnsii* as distributed in the three surveyed sections of Chome Nature Reserve, Tanzania.

Study sections	Invaded area (condensed ha)	Costs (TZS million)			% total costs
		Initial clearing and follow-up	Overhead costs	Total costs	
Northern part (A)	24.3	11.43	7.62	19.04	11.6
Western part (B)	142.9	67.19	44.79	111.98	68.0
Southern part (C)	42.9	20.17	13.45	33.62	20.4
Total	210.1	98.76	65.86	164.64	100

Note: Initial clearing and follow-ups cost TZS 470,185 per ha and overheads are calculated as 40% of the total costs.

### 3.4 Estimated Water Use by *Acacia mearnsii*

The average additional water use by *A. mearnsii* is estimated at 4390 m<sup>3</sup>/ha per annum. This constant which has been used to calculate water use by *A. mearnsii* in CNR, was simply ascertained by dividing the total area covered with *A. mearnsii* by the total incremental water use by the plants as recorded in Le Maitre *et al.*(2000).

This implies that the average additional water use due to invasion by *A. mearnsii* which has replaced 210 ha of native vegetation in CNR is estimated at  $9.21 \times 10^5 \text{ m}^3$  per annum (Table 4).

**Table 4:** Estimation of incremental water use by *Acacia mearnsii* in Chome Nature Reserve.

	Area covered with <i>A.mearnsii</i> (condensed ha)	Incremental Water use (millions of $\text{m}^3$ )	Average water use per ha ( $\text{m}^3/\text{ha}$ )
South African estimates	131341	576.58	4389.94
Estimated CNR values	210	0.9218	4389.94

\*The incremental water use per ha by *Acacia mearnsii* was estimated from Le Maitre *et al.*, 2000 which provides mean annual water use of major invasive species in South Africa.

### 3.5 Forest Conversion and Invasion Rate of *Acacia mearnsii*

For the period between 1987 and 2014, more than 7% (771 ha) of the moist mountainous forest cover has either been lost or converted to non-forest (i.e. either shrub land or open land dominated by fern/bracken). The annual rate of forest conversion to non-forest during this period is therefore estimated at 28.56 ha (Table 5).

On the other hand, the annual rate of invasion by *A. mearnsii* is about 8 condensed ha per annum (i.e. the annual increase of *A. mearnsii* coverage which has resulted to 210 ha cover since 1987). This implies that, for every 4 ha of natural forest converted, one ha has been replaced by *A. mearnsii*. Therefore, it will take about 100

years for *A. mearnsii* to cover all degraded areas (771 ha) to a density of 100%, assuming no additional loss of forest cover.

**Table 5:** Land cover change in Chome Nature Reserve between the year 1987 and 2014

Cover class	1987		2014		Change area (Ha)	Annual rate of change (ha/year)
	Cover area		Cover area	%		
	(Ha)	% cover	(Ha)	cover		
Forest	10458	74.12	9687	68.71	-771	-28.56
Non forest	3466	24.57	4411	31.29	945	35.00
Shadow	185	1.31	0	0.00		
Cloud	0	0.00	12	0.09		
Total	14109	100	14098	100		

#### 4.0 DISCUSSIONS

This is the first study in Tanzania to provide cost estimates for the control of *A. mearnsii* which is currently among the most aggressive woody plants of riparian areas in Eastern and Southern Africa. By estimating its coverage and impacts to native vegetation in Chome Nature Reserve, the study puts the magnitude of the problem very clear, thus alerts managers to mobilize resources needed to manage the species. However, the methods and accuracy in estimating the costs for controlling *A. mearnsii* which have relied much on research and information recorded from areas employing advanced technologies in managing invasions (in this case South Africa), inevitably suffer from a number of caveats due to inadequate baseline information. For example, amount of viable seeds and age structure of stands of *A. mearnsii* in invaded landscapes and actual operation costs for similar forest activities like clearance of fire lines. Despite the limitations, which if considered would have

possibly revealed some underestimations; the study has been able to provide a working figure for the control of *A. mearnsii*.

#### **4.1 Extent of Invasion**

Currently, *A. mearnsii* is estimated to occupy approximately 210 condensed ha which is about 1.5% of the area of CNR. Condensed area simply expresses the extent of invasion as the equivalent of 100% cover. For example, an area of 20 ha with 50% cover of *A. mearnsii* is equivalent mathematically to a condensed area of 10 ha with 100% cover of *A. mearnsii*. Put in perspective, the 210 ha is more than the total acreage of *A. mearnsii* (196 ha) under government forest plantation in Tanzania (Ngaga, 2011). Although it may appear ridiculous to compare area under invasion to area under commercial forest plantations, this suggests two important points; (i) the reserve undesirably holds bigger area under *A. mearnsii* than the formal acreage in government plantations (ii) if clearing of *A. mearnsii* is effected, part of the control costs could be obtained from sales of the mature trees.

The most seriously invaded part of the reserve is the western bog vegetation where river banks are completely covered by *A. mearnsii*. The invasion in this part accounts for 70% of the total condensed area. Riparian areas appear to be particularly prone to invasion, probably because water is freely available for growth and also facilitating dispersal of seeds (Le Maitre *et al.*, 2002). Also, illegal mining for alluvial gold along river banks has greatly contributed to invasion of *A. mearnsii*. Mining has diverted and widened river courses and consequently created extensive seed beds for the species.

Given the current distribution of *A. mearnsii*, heathlands could be considered as less vulnerable to invasion due to nutrient-poor soils. However, this leguminous species which is known to improve soil fertility by increasing nitrogen (van Wilgen *et al.*, 2011, ISC, 2014), may slowly improve the nutrient-poor heathlands to support its spread. In fact, during our survey, several seedlings of *A. mearnsii* were observed on heathlands as compared to any other tree species. The possibility for further invasion is also high; because heathlands are prone to frequent fires which trigger germination of *A. mearnsii* (Moyo *et al.*, 2009). Therefore, if decision to control is delayed further, the species has the potential to invade not only the riparian areas but also the heathlands which currently are considered infertile.

#### **4.2 Impact of Invasion and Reduction of Stream Flow**

Although *A. mearnsii* has been widely cultivated for soil improvement and erosion control, it is well recognized for threatening native habitats by competing with indigenous vegetation and increasing water loss from riparian zones (Nyoka, 2003). By changing the soil chemistry, forming dense stand and maintaining high green leaf area throughout the year, *A. mearnsii* has been successful in replacing native species such as *Ficalhoa laurifolia* in valley bottoms and *Ocotea usambarensis* in burnt areas. Apart from affecting native vegetation, the impact to water resources due to its high evapotranspiration rate has also been well researched and estimated in other countries (Dye and Jarman, 2004; Moyo *et al.*, 2009; Meijninger and Jarman, 2014). For example, in South Africa *A. mearnsii* is ranked number one in terms of water use. In the year 2000, the area occupied by *A. mearnsii* was 131,341 condensed

ha and the mean annual water use by the species was estimated at  $576.58 \times 10^6 \text{ m}^3$  (Le Maitre *et al.*, 2000).

Although not particularly on *A. mearnsii*, the Pangani Water Basin Office has generally identified alien plants as one of the main cause that impair the hydrology of the basin (PWBO/IUCN, 2007). The impact of *A. mearnsii* on water resources can be put into perspective by comparing the water use with mean annual runoff in Mkomazi basin where the Sasei River discharges its water. Mean annual runoff (MAR) in the basin recorded at Pangani Korogwe station (Code Station 1D14) from 1995 – 2012 is  $20.78 \text{ m}^3/\text{s}$  ( $6.55 \times 10^8 \text{ m}^3/\text{year}$ ) (PBWO, 2013). Therefore, the estimated mean water use of  $9.2 \times 10^5 \text{ m}^3/\text{year}$  implies that *A. mearnsii* reduces steam flow of Mkomazi basin by 0.14%. The incremental water use per ha by *A. mearnsii* (i.e.  $4390 \text{ m}^3/\text{ha}$ ) is more than twice the amount of water used in improved schemes (i.e.  $1995 \text{ m}^3/\text{ha}$ ) along the Pangani basin (Turpie *et al.*, 2003).

#### 4.3 Estimated Control Costs

The estimated amount of money (TZS 164.64 Million) needed to control *A. mearnsii* in CNR is still within the cost range of many forest operations. This amount is about 2.5% of the five-year proposed budget of CNR. Comparing with other operation costs in CNR, the estimate for controlling *A. mearnsii* is far less than the proposed five-year budget for protection against forest fires (TZS 265.3 million) and slight higher than the budget for extension services (TZS 148.4 million). The proposed five-year total budget for CNR, which would cover costs for all forest operations, infrastructures development and salaries, is about TZS 6.69 billion (MNRT, 2008).

Therefore, while TZS 164.64 million remains as an estimate, yet it provides a working figure to managers for planning control operations of *A. mearnsii* in the reserve.

The costs of control per condensed ha reported in this study (i.e. TZS 783,641) is slight higher than the average costs for land preparation in government forest plantation (Malinga, 2011) which can be considered as its equivalent forest operation. In terms of cost comparison, controlling of *A. mearnsii* can also be equivalent to opening new farmlands which involves clearing of woodlands, slashing and collection of debris. This type of land preparation which although not recommended but it is a common practise in many areas of Tanzania costs between TZS 450,000 and 600,000/- per ha. Also, in areas around South Pare mountains, the average cost per ha is TZS 500,000/- and the weeding costs (equivalent of follow-up) is TZS 100,000 per ha (pers.com Kavumo, A – Agricultural Officer at Same District Council). Follow-up in this case refers to reworking of areas that were initially cleared to remove re-growth, either of sprouting or germinating *A. mearnsii*.

As the case in South Africa, clearing of *A. mearnsii* can create employment to local communities and also provide them with fuel wood necessary for both domestic and industrial uses (van Wilgen *et al.*, 2012). Provision of these opportunities may result to positive recommendation and support from the local communities throughout the control operation. However, caution must be taken to avoid partial clearance by communities aiming to allow regrowth and sprouting to sustain their employment. Expenditures on control operations and overheads normally vary significantly due to

many factors, such as density of *A. mearnsii*, age structure, terrain and distance from the access road (McConnachie *et al.*, 2012). Therefore, during clearing operation, it is important to categorise invaded areas and set costs based on these aspects.

#### 4.4 Future Scenarios

In our study, projections of future invasions were done using constant expansion rate of 8 condensed ha per annum. It was estimated that the 771 converted ha will be fully invaded in about 100 years, but with the important, albeit unrealistic, assumption that no further conversion of forest would take place and that *A. mearnsii* will be the only invasive species. However, invasions of areas by alien organisms usually show a sigmoid growth curve over time, involving an initial lag period, a period of rapid (exponential) expansion and the final period when expansion slows as the available habitat becomes fully invaded (Versfeld *et al.*, 1998). Normally it takes about 50 years for the species to establish and naturalise (initial lag) before starting to spread (exponential) (Görgens and van Wilgen, 2004). This means that, invasion of *A. mearnsii* in CNR is probably still at initial stage of rapid expansion since it was introduced in mid 1950s. Riparian areas are naturally prone to invasions and might have reached the exponential phase that is why the invasion in these areas seems to be faster than in the other landscapes. Even at a conservative annual invasion rate of 8 ha per annum estimated in this study, the amount of water use after another 50 years of no control will greatly be unbearable. This is due to increase in number of people in the uplands who have engaged in cultivation of cash crops like ginger which rely on water flowing from CNR.



#### 4.5 Other Control Options

While mechanical method does not offer cost effective and sustainable control of *A. mearnsii* in general lands, it is still very useful if supplemented with other control measures such as biological control, the use of sterile cultivars and chemical control (van Wilgen *et al.*, 2011). Two biological control agents for *A. mearnsii* have already been released in South Africa; a seed-feeding weevil (*Melanterius maculatus*) and a gall-forming fly (*Dasineura rubiformis*). The former has been effective in reducing seed production and the later induces development of gall in the flowers, thereby preventing pod development and reducing the reproductive capacity of *A. mearnsii* (Impson *et al.*, 2011). Also the invasive potential of commercially farmed *A. mearnsii* is substantially reduced by inducing sterility through gamma radiation of seed or the production of triploids through chromosome doubling techniques (Mack *et al.*, 2000). These other methods offer alternatives on how to deal with this conflict species which despite its effects to ecosystems has alleviated the ever increasing shortage of fuel wood. Also large commercial plantations of *A. mearnsii* like those in the Southern highlands of Tanzania may benefit from biological and chemical control than the mechanical control.

#### 5.0 CONCLUSION

Gaining control of invasive species and reducing their substantial impacts on native habitats and water resources is an extremely important component of natural resource management. Although *A. mearnsii* is widely used for tannin and fuel wood, it is not desirable in riparian and reserved biodiversity “hotspot” areas, therefore strategies to control it in CNR need to be sought now. The findings

presented here are based on South African examples, thus have involved a number of assumptions and generalization which probably havenot considered other externalities in controlling invasive alien plants. Therefore, it is recommended that, before implementing the operation, experimental plots on clearing should be set to assess other externalities that may need management consideration during scaling up to the entire reserve.

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## CHAPTER SIX

### 5.0 Conclusions and Recommendations

Generally, this study shows that anthropogenic disturbances have strong negative influence on regeneration, advance growth and therefore recovery of *Ocotea* forests in Chome Nature Reserve. Although at some point canopy opening through pitsawing similar to single tree felling was indicated to facilitate regeneration of the species, light requirements could have been met through natural disturbances such as tree falls or branch breakages and not necessarily through logging. Anthropogenic disturbances such as illegal logging, tree cutting, forest fires and debarking for medicinal purposes are the sources of wound and injuries, hence the increasing heart rot incidences in *Ocotea*. Natural recovery of the *Ocotea* forest at CNR is still very slow particularly in heavily logged areas which represent by far the largest part of the forest below 2000 m above sea level. The invasion from alien tree *A. mearnsii* is also a threat to the overall forest recovery. Therefore, controlling its invasion to reduce substantial impacts on native vegetation is considered an extremely important component in conservation plans of CNR.

To improve conservation and restoration of habitat suitable for regeneration and recovery of native species in CNR, therefore the following recommendation are provided:

- The ongoing conservation activities in CNR need to be supplemented with enrichment planting and slashing of brambles to free few regenerating sapling of *Ocotea*

- Protection from illegal logging and forest fires should still be emphasized, but this will work perfectly if supplemented with income generating activities such as ginger farming and beekeeping for the surrounding communities, because currently the opportunity cost is very high for the surrounding communities particularly youth to stop logging completely.
- It is also advised that the management of CNR should set short term experiments on clearing of *A. mearnsii* in riparian and non-riparian areas to see what is required of any bigger control project that may be initiated. This can be achieved by collaboration between TAFORI and TFS, whereby the former can provides technical advice the later financial and logistic supports.