REGENERATION AND DISTRIBUTION OF *NEWTONIA BUCHANANII* (BAKER) GILBERT & BOUTIQUE IN NILO NATURE RESERVE, TANGA, TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FORESTRY OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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ABSTRACT

This study was on the regeneration and distribution of *Newtonia buchananii* (Baker) Gilbert & Boutique in Nilo Nature Reserve (6,025 ha) located in Korogwe, Muheza and Mkinga Districts, Tanga Region, Tanzania. The vegetation survey was carried out in 30 systematically established square nested sample plot sizes of 3 m x 3 m, 10 m x 10 m, 20 m x 20 m and the entire 30 m x 30 m plot. The information recorded in each plot included: species name, diameter, altitude, slope, aspect, canopy height and the level of forest disturbance. Moreover, a soil sample was taken at the centre of each plot for examination of soil properties in the laboratory (soil water holding capacity, soil pH and organic Carbon). Analysis of inventory data was done by using logistic regression in SPSS version 12.0. The results were presented in tables and figures. The proportions of seedlings, saplings and trees showed that *N. buchananii* was not regenerating in all forest types. The species was randomly distributed in lowland and submontane forests but was contiguously distributed in montane forest. Furthermore, the results of binary logistic regression indicated that two parameters: altitude and soil water holding capacity significantly affected regeneration and distribution of *N. buchananii* (P =0.04 and P = 0.037 respectively). Overall, the model prediction accuracy was 76.7%. The odd ratio for altitude indicated that for every unit increase in altitude, the probability of encountering seedlings of *N. buchananii* was 50% while the odd ratio for soil water holding capacity indicated that for every unit increase in soil water holding capacity, the probability of encountering seedlings of *N. buchananii* was 41%. It is recommended that immediate conservation measures should be taken to improve the regeneration of *N. buchananii*. Also, further research is recommended for monitoring regeneration of *N. buchananii*.

DECLARATION

I, Bernard Kuruchumila Mwigulu, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work, and has not been submitted for a degree award at any other University.

.... 21/11/2014

Bernard Kuruchumila Mwigulu | Date

MSc. Candidate

The above declaration is confirmed by:

.... 21/11/2014

Professor L. L. L. Lulandala | Date

(Supervisor)

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DEDICATION

This dissertation is dedicated to my father Kuruchumila Mwigulu and my mother Nyanjiga Mwigulu who not only tirelessly endured to lay down the foundation of my education, but also devoted much of their moral support and financial resources for my education.

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LIST OF ABREVIATIONS

AF	Abundance to frequency ratio
asl	above sea level
DBH	Diameter at Breast Height
EAM	Eastern Arc Mountains
EUM	East Usambara Mountains
GPS	Global Positioning System
IVI	Importance Value Index
MNRT	Ministry of Natural Resources and Tourism
NNR	Nilo Nature Reserve
TAFORI	Tanzania Forest Research Institute
TFS	Tanzania Forest Services

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

The East Usambara Mountain (EUM) forests which are part of the Eastern Arc Mountain (EAM) forests, have been classified as a global centre of plant diversity boasting the second highest diversity of plant species in Africa (UNDP, 2012). The forests have been likened to the equivalence of the African terrestrial Galápagos Islands in terms of their endemism and biodiversity (Lovett, 1989; Burgess *et al.*, 2007). The rainforests also supply water to more than 300,000 people in the city of Tanga, while the local people in the mountains depend on the forests for several of their livelihood activities (UNDP, 2012). Given their biodiversity value, Amani Nature Reserve (ANR) and Nilo Nature Reserve (NNR) were gazetted by the Tanzanian Government in 1997 and 2007 respectively with the aim of conserving the rich biodiversity of EUM forests (MNRT, 2010).

The forests, however, have come through various anthropogenic disturbances, particularly logging which has been carried out in the EUMs forests since colonial times. However, it is thought to have been on a large scale only during the 1960's to mid-1980's (Hamilton, 1989). Apart from logging, the depletion of forest biodiversity in the EUMs has increasingly become subject of tremendous other various resource use pressures as a result of increased human population in the area (Lulandala, 1998). Presence of gold in the forest has recently put it under additional pressure (Leonard *et al.*, 2010).

According to Hamilton (1989), logging was highly selective with preference of large trees. *Newtonia buchananii* was one of the tree species that were over-exploited and resulted into creation of gaps that facilitated the spread of *Maesopsis eminii*, an alien invasive species which is extremely competitive in gaps in comparison with other species (Binggeli, 1989). Generally, there is consensus among scientists that the high intensity human disturbances adversely affect tree species regeneration, abundance and diversity (Sapkota and Odén, 2009; Kimaro and Lulandala, 2013). *N. buchananii* (Mimosoideae) is reported dying in EUM rainforests (Meshack and Harun, 2000; Madoffe *et al.*, 2006) as well as in West Usambara especially in Mazumbai Forest Reserve (Mrema and Nummelin, 1998). Elsewhere, such as Uganda, the species is reported as nationally threatened (Okiror *et al.*, 2012).

1.2 Problem statement and justification of the study

N. buchananii is one of the twenty three commonest species in the EAMs (Hamilton *et al.*, 1989). The tree species is important for provision of timber, firewood, fodder (pods, leaves), shade, etc. The brown to red-brown hardwood is also durable in water conditions and it is recommended for canoes in Lake Victoria (Mbuya *et al.*, 1994). The causes of its mortality are linked to old age and fungal attack (Mrema and Nummelin, 1998). Furthermore, Binggeli (1989) suspected climate change as one of the causes. Either, it has only been reported of mortality of large trees from simple surveys and observations. Information about its regeneration and distribution from detailed surveys is limited. Understanding of natural regeneration processes and the distribution patterns of the associated recruits is of paramount importance building-up of future forest structures and composition (Tesfaye *et al.*, 2002). The present study, therefore, aims to fill this gap. The study will unveil useful information to managers, planners, policy makers and scientists as regards to effective biodiversity conservation and maintaining ecosystem functions in the EAMs.

1.3 Objectives

1.3.1 Overall objective

An assessment of regeneration status and distribution of *N. buchananii* in Nilo Nature Reserve, Tanga, Tanzania.

1.3.2 Specific objectives

- To assess the status of natural regeneration of *N. buchananii* in Nilo Nature Reserve
- To establish the distribution pattern of *N. buchananii* in Nilo Nature Reserve
- To determine the factors influencing the regeneration and distribution of *N. buchananii* in Nilo Nature Reserve

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Natural regeneration

The long-term health of an ecosystem is dependent on sufficient tree regeneration (Pare *et al.*, 2009; Shirer and Zimmerman, 2010). Plants maintain and expand their populations in time and space by the process of regeneration. Population dynamics of plant species can be described by demographic variables such as recruitment, mortality and growth rates of individuals (Watkinson, 1997). The balance among these variables has been found to regulate the dynamics and the structure of a population (Kohyama and Hara, 1989).

Forest trees rely on two general methods to reproduce: natural means and artificial means. Natural regeneration (as the name implies) is that the plants are established naturally from seeds, sprouts, or root suckers of mother trees. Conversely artificial regeneration is the plants that are established from seeds or seedlings brought on site by man expressly for purposes of tree re-establishment. Artificial regeneration involves direct seeding or planting (Borghetti and Giannini, 2010). Compared to artificial planting, natural regeneration is less negatively affected by the harshness of a site. Moreover, natural regeneration is a critical phase of forest management because it maintains the desired species composition and stocking (Simonsen, 2013).

According to Shirer and Zimmerman (2010), little information is available on the abundance of regeneration required for healthy forests to support wildlife and maintain ecological services. However, for a population to maintain itself, it needs to have abundant juveniles which will recruit into adult classes (Mligo *et al.*, 2009). Thus, natural regeneration requires adequate seed production, successful germination, and seedling growth (Rao, 1988; Nunamaker and Valachovic, 2007). Absence of adults in a population negatively affects recruitment into population by seeds (Okiror *et al.*, 2012). Borghetti and Giannini (2010) characterized forest trees growth in three life cycles: a seedling phase, characterized by intensive competition and high mortality; a juvenile intensive height growth phase which determines how fast trees reach the overstorey canopy layer; and maturity phase, characterized by canopy dominance and onset of reproduction and recruitment. The pattern of population dynamics of seedlings, saplings and adults of plant species exhibit the regeneration profile, which is used to determine their regeneration status (Pokhriyal *et al.*, 2012). A population with sufficient number of seedlings and saplings depicts satisfactory regeneration behaviour, while inadequate number of seedlings and saplings of the species in a forest indicates poor regeneration (Chauhan *et al.*, 2008; Kumar and Kalavathy, 2012). Therefore, the density of seedlings and saplings is considered as regeneration potential of a species (Rao, 1988).

The processes involved in tree regeneration can be influenced by many factors, such as variations in seed dispersal intervals (Suzuki *et al.*, 2005), seed quality, wind direction and speed, slope gradients, aspect, soil moisture availability (Pare *et al.*, 2009), absence of soil seed banks (Hubbell, 1979; Omoro and Luukkanen, 2011), natural or anthropogenic disturbances which influence the patterns of forest regeneration through the interactions between disturbance regimes (intensity, frequency, scale) and biological features of species, such as their life cycles and behaviour (Hamilton, 1989; Kennard *et al.*, 2002). Furthermore, Kulla *et al.* (2009) found that regeneration can also be controlled by age, canopy closure and the presence of tree species in a mature stand.

2.2 Trees distribution

2.2.1 Spatial distribution

Regeneration of any species is restricted to a peculiar range of habitat conditions and the extent of those conditions is a major determinant of its geographic distribution (Li *et al.*, 2009; Uniyal *et al.*, 2010). Trees distribution shows how the individuals are dispersed in a population (Ewusie, 1980). The relationships between plants (cooperation as well as competition), methods of regeneration, natural mortality of individuals, biological and ecological characteristics of organisms, natural disasters (fire and wind-throws), human activities, etc, influence the distribution of trees (Szmyt, 2010). In a natural population, three main types of spatial distribution of trees can be distinguished: random, regular and contiguous (or clumped) distribution depending on the underlying processes (Fangliang *et al.*, 1997; Reddy and Ugle, 2008; Bhadra *et al.*, 2014). Spatial patterns of species differ between species, time and location. Some processes may dominate in a specific location and time while others play minor roles, depending on the biology of the species, the environmental constraints, and the spatial and temporal scales of the observations (Fangliang *et al.*, 1997). How individuals of a spatially sparse population interact, how the viability of the population is maintained, and how the sparse populations on different trophic levels (e.g.plant herbivores or host pollinators) co-evolve, plays major roles in determining the distribution of the species (Li *et al.*, 2009). Kumar and Kalavathy (2012) found that the seedling and sapling patterns of woody species are also affected by the distribution of mother trees. In a disturbed forest, for example, Anfodillo *et al.* (2012) noted that tree distribution range is related to the degree of forest disturbance. Furthermore, the fundamental attribute of a natural forest structure is not only the distribution of the species, but also their size of distribution (Lai *et al.*, 2013).

2.2.2 Species composition

Species composition refers to the relative amounts of particular species as percentage of the total number of species in a community (Munishi *et al.*, 2007). According to Ewusie (1980), usually species occurring in more than 70% of the sample areas and with the highest cover may be recognized as dominant species. However, in a natural tropical vegetation, community tends to have large numbers of species as dominant species. Removal of any dominant species results in a drastic change in the character of the community, whereas removal of non-dominant species would not have such a far-reaching effect.

2.3 Regeneration of trees in the Eastern Arc Mountains

According to Hamilton (1989), logging in the EUMs significantly affected forest regeneration. Furthermore, Binggeli (1989) noted that it is likely that the reproductive behaviour, growth rates and general health of the canopy trees have been affected as a result of recent climatic change in the EUMs. A study conducted by Madoffe *et al.* (2006) found inconsistent occurrence of large tree species and saplings and/or seedlings of similar species and the threat of the decay trees that could probably contribute to further loss of the species in the EAMs. *Ocotea usambarensis* is one the most important tree species reportedly not regenerating in the EAMs (Nsolomo and Venn, 1994). Also, Mwihomeke *et al.* (2000) reported *N. buchananii* as one of the species with lower density in Uluguru Mountains. According to Mbuya *et al.* (1994), *N. buchananii* regenerates through seedlings or root suckers and in general, the seedlings grow slowly and have low survival rates (http://www.database.prota.org/html).

2.4 Factors affecting regeneration and distribution of trees

There are many factors that determine which tree and which forests grow in any given area. Three of the most important are soil, moisture and climate. Soil serves as both an anchor and the source of essential nutrients for trees (DNR, 2013). The type of soil determines which nutrients are present and the quantities available. Clay and loamy soils are generally rich in nutrients. Sandy soils usually contain few nutrients. Organic Carbon influences many soil characteristics including colour, cation and anion exchange capacity, nutrient turnover and stability, which in turn influence water relations, aeration and workability (http://www.soilquality.org.au). Soil pH expresses the degree of acidity or alkalinity. It is the measure of H^+ion and OH^- ion activity of the soil water system and is the indicator of chemical processes that occur in the soil. Since change in pH affects the growth of microbes present in soil, estimation of pH is an important parameter (Bruce and Reyment, 1982). Moisture availability throughout the growing season helps to determine which species occupy which sites (Viji and Rajesh, 2012). Climate is the key determinant of where certain trees and forests occur. Temperature is the most important climatic factor affecting where different trees live within a particular climate or region (DNR, 2013). Altitude or elevation of the land with respect to the level of the sea surface influences plant growth and development primarily through temperature effect. Temperature decreases by 1° C for every 100 m increase in altitude in dry air hence the flora also change with altitude (Mondoni *et al.*, 2012; Yawalikar *et al.*, 2012).

Slope or inclination of a land surface is the percentage change in its elevation over a certain distance. The steepness of the slope affects wind velocity and soil type. Barij *et al.* (2007) found that topsoil volumetric water tend to decrease with increasing altitude which results in lower groundwater levels upslope than downslope. Furthermore, the steepness of the slope affects plant growth differential incidence in solar radiation. Aspect also has a strong influence on temperature. This is because of the angle of the sun in the northern and southern hemispheres which is less than 90 degrees or directly overhead (Bennie *et al.*, 2006). The forest canopy layer plays role in penetration of light to understorey layer. Light is an essential factor in maintaining plants. The rate of growth and length of time a plant remains active is dependent on the amount of light it receives. Light energy is used in photosynthesis, the plant's most metabolic process. The most considerations on the effect of light on plant growth are intensity, duration of exposure and quality of light. Southern exposure is the warmest, eastern and western are less warm and northern exposure is the coolest (http://www.aggie-horticulture.tamu.edu).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Location of the study area

The study was carried out in Nilo Nature Reserve (6,025 ha) in the north-west of the EUMs. Nilo Nature Reserve lies between latitudes $4^{\circ}50'$ - $4^{\circ}55'$ South and longitudes $38^{\circ}37'$- $38^{\circ}40'$ East, about 50 km west of Tanga City (Figure 1). The reserve, which falls under the jurisdiction of three district authorities, namely: Korogwe, Muheza and Mkinga in Tanga Region, is owned by the Central Government under the Tanzania Forest Services (TFS) in the Ministry of Natural Resources and Tourism (MNRT) (MNRT, 2010).

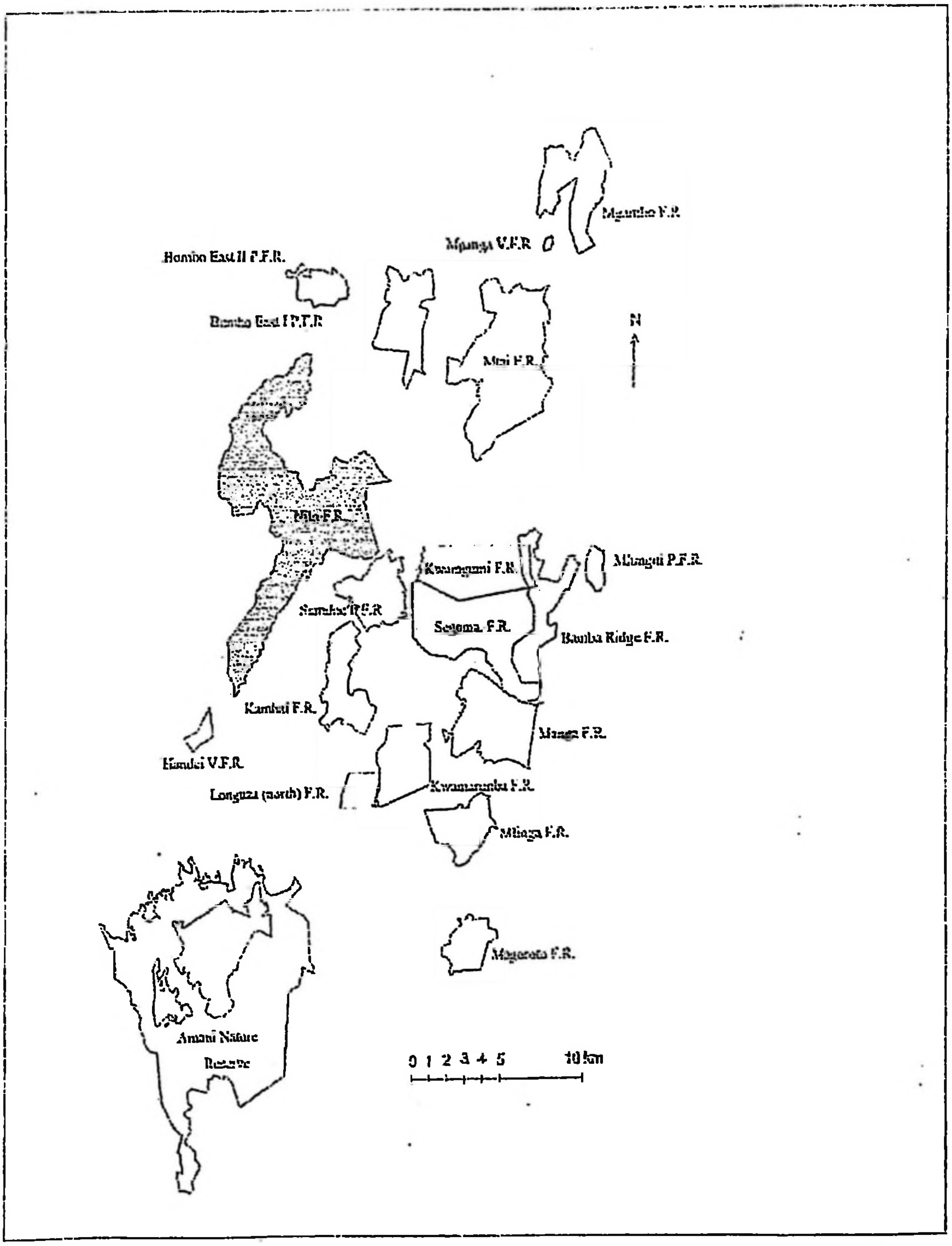

Figure 1: The location of Nilo Nature Reserve (shaded) in relation to other forests in EUMs

3.1.2 Description of the study area

(a) Climate

The climate of EUMs is monsoonal. The rainfall distribution is bimodal, peaking between March and May and between September and December. The dry seasons are from June to August and January to March with average monthly temperature of 20°C varying by 5°C between the hottest (January to March) and coldest (June - July) months. Rainfall is highest at higher altitudes and in the south-eastern part of the mountains, increasing from 1,200 mm annually in the foothills to over 2,200 mm at higher altitudes. The west-facing slopes of the mountains are drier compared to east-facing slopes due to climatic and topographical interactions. Due to their age, isolation and their role as condensers of the moisture from the Indian Ocean, the EUMs support the ancient and unique forests; rich in endemic species (Hamilton, 1989).

(b) Topography

The topography of Nilo Nature Reserve is extreme, made up of a Y-shaped ridge system with steep sided slopes which have two main peak areas (Figure 2). The highest point, at Nilo peak in the north-west of the reserve rises to 1,506 m asl (highest in EUMs). The secondary peak to the south-west is Lutindi peak at 1,340 m asl where there is a 360 degrees view of the East and West Usambara Mountains. The forest is a catchment for Hundu, Bombo and Muzi Rivers. There are numerous streams throughout the reserve which serve many surrounding villages (Frontier-Tanzania, 2002).

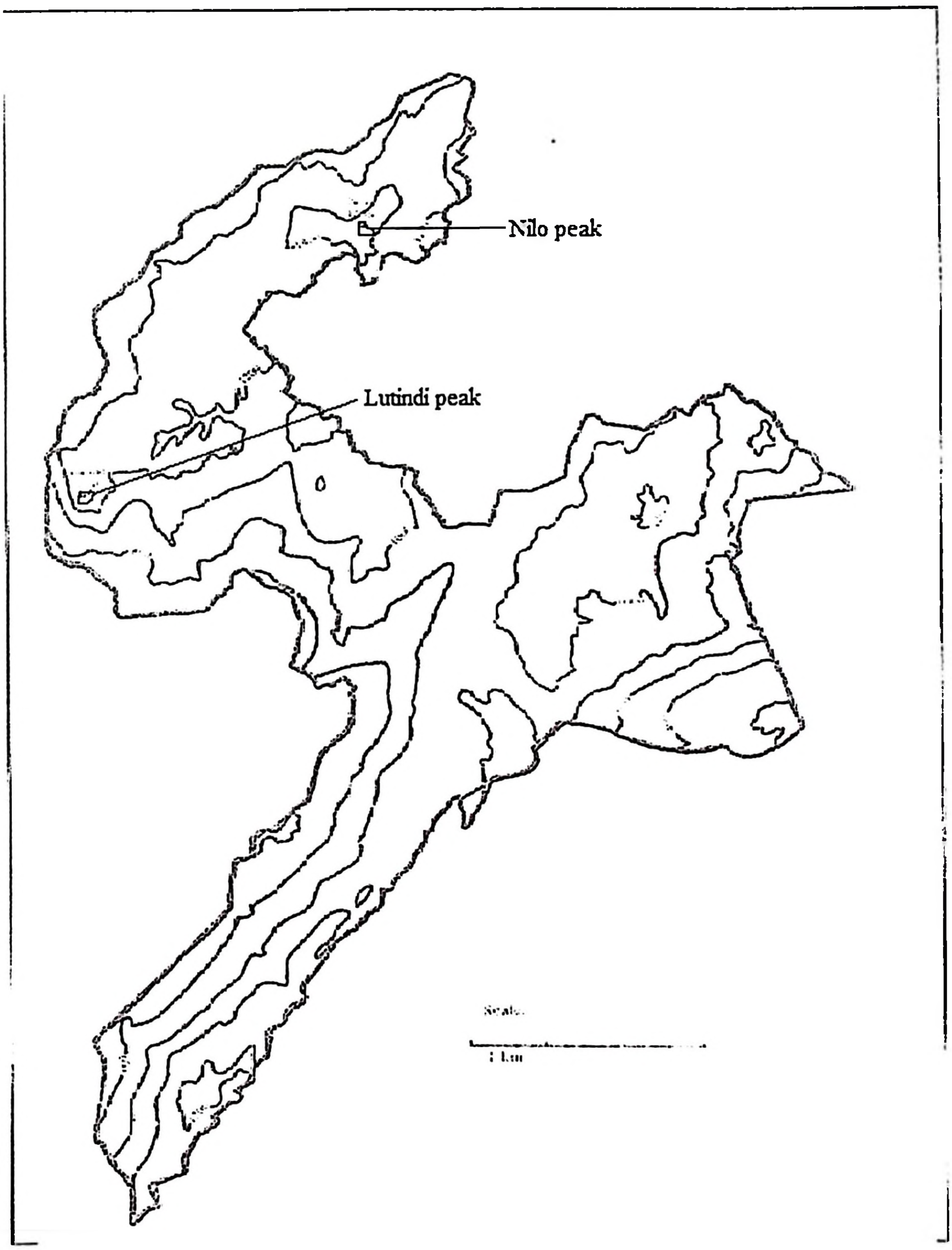

Figure 2: Topographical sketch map of Nilo Nature Reserve

(c) Land use

The latest survey of the area was carried out by Johansson and Sandy (1996). The dense forest (lowland, submontane and montane) covers an area of 3,216 ha. The remaining 2,809 ha is disturbed area (formerly under peasants' cultivation, settlements and bush – this includes the additional public land that was incorporated into the forest reserve) (Table 1).

Table 1: Distribution of forest types of Nilo Nature Reserve

Forest type	Area (ha)	Percentage
Lowland	1,072	17.8
Submontane	1,394	23.1
Montane	750	12.5
Disturbed	2,809	46.6
Total	6,025	100

Source: Johansson and Sandy (1996)

(d) Vegetation

The forests of EUMs belong to the Zanzibar-Inhambane regional mosaic which extends along the eastern coast of Africa from southern Somalia to the mouth of the Limpopo River (Mozambique). It is a distinct phytochorion resulting from the humidity and precipitation coming from the Indian Ocean (Lovett, 1989). The vegetation of EUM forests is characterized into three forest types i.e. lowland, submontane and montane forests (Hamilton, 1989).

3.2 Methods

3.2.1 Sampling procedures

(a) Reconnaissance survey

Reconnaissance survey was conducted to get the general condition of the habitat and related information on the occurrence and distribution of *N. buchananii* in the reserve. Furthermore, more information was provided by officials and the field staff working in the nature reserve. During the reconnaisance survey, observations were related to the vegetation map of the area.

(b) Sampling design

The forest was divided into three strata based on altitudinal range. The lower stratum (400 – 770 m asl) composed of lowland forest with some open areas. The middle stratum (770 – 1140m asl) composed of submontane forest and the upper stratum (1140 – 1506 m asl) composed of montane forest. In each altitudinal range one transect running along the contour was laid at the middle of the altitudinal range. The distance between transects was 370 m. A total of 10 plots of 30 m x 30 m were laid along each transect making a total of 30 plots for the entire area.

3.2.2 Data collection

A total of 30 sampling plots (as recommended by Munishi *et al.*, 2004) were established to cover as much variation as possible from valley bottoms to ridge tops in which 10 plots per stratum were measured on a transect. The vegetation sampling plots of 30 m x 30 m (0.09 ha) with nested square subplots of 3 m x 3 m; 10 m x10 m and 20 m x 20 m as suggested by Kent & Coker (1994) were used (Figure 3). At each centre of the plot, the grid references were marked by GPS (GARMIN12 unit) which were converted into geographic coordinates in order to allow their reallocation in the future (Appendix 2). Only tree species were recorded. Trees were defined as self-supporting individuals of plants capable of reaching or exceeding 10 m in height. The measurements were based on four categories. The inner most subplot of 3 m x 3 m (9 m^2) was used for recording the regeneration layer i.e. counted seedlings (up to 2.5 cm breast height diameter (dbh) and saplings (dbh > 2.5 - 4 cm). In the other three categories, trees dbh were measured to the nearest centimeter at 1.3 m above the ground as explained by Hamilton (1975). A diameter of 5 cm dbh was used to distinguish individual trees from juvenile stage. The subplots 10 m x 10 m (100 m^2) were used for measuring trees with dbh >4 cm - 10 cm; 20 m x 20 m subplot (400 m^2) for trees with dbh >10 cm - 20 cm and the entire plot of 30 m x 30 m (900 m^2) was used for trees of dbh >20 cm (Table 2). Tree species were identified using both local names (Sambaa) and botanical names. For those species that could not be identified in the field, specimens were collected and taken to the Tanzania Forestry Research Institute (TAFORI) herbarium at Lushoto Silvicultural Centre for further identification.

Other parameters measured and/or recorded were altitude, slope, aspect, canopy height and forest disturbances. Altitude was measured by GPS at the centre of the plot. Slope was measured at the plot centre with a Suunto hypsometer, which also was used to measure canopy height (m). Aspect was recorded in relation to the incoming sunlight (towards N, NE, E, SE, S, SW, W, or NW). Forest disturbance measured based on the level of disturbance. Forest disturbance was considered when the affected area of the sample plot exceeded 10% (Geddes, 1998). Moreover, a soil sample was taken at the centre of each plot for examination of soil properties in the laboratory. All records were entered in a prepared data sheet (Appendix 1).

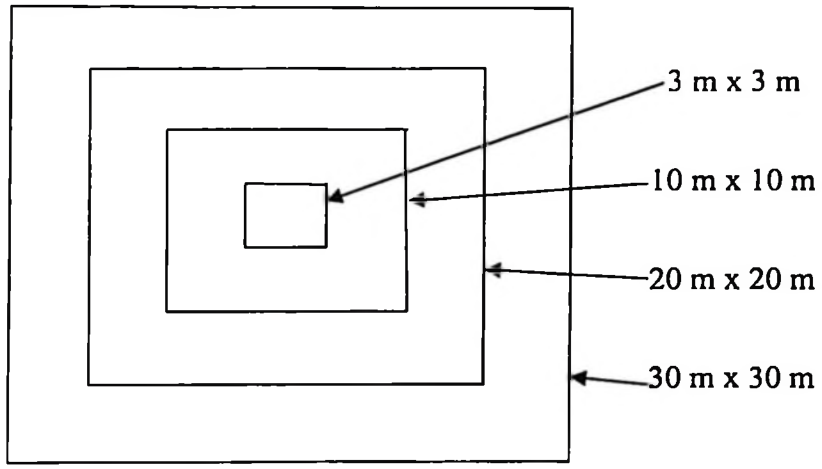

Figure 3: Sampling plot

Table 2: Categories of trees measured in sampling plots

Plot size (concentric)	dbh of trees (cm)
3 m x 3 m	0 -≤4
10 m x 10 m	>4- 10
20 m x 20 m	>10- 20
30 m x 30 m	> 20

3.2.3 Data analysis

Classification of regeneration status of a tree species was considered on the basis of Kumar and Kalavathy (2012). The regeneration status was considered to be "good" when seedling density > sapling density > adult tree density, "fair" when seedling density > sapling density ≤ adult density, "poor" when the species survived in only the sapling stage but not in the seedling stage (even though saplings could be less than, more than, or equal to adults), "none" for species with no seedling or sapling stages but present as adult trees only, and "new" when adults of species are absent but seedling and/or sapling stage(s) are present. The overall proportion between seedlings, saplings and adult trees were computed to determine the regeneration status of *N. buchananii.*

Abundance to frequency ratio (A/F) was computed to determine the distribution pattern of various species as indicates: regular (<0.025), random (0.025-0.050) and contiguous (>0.050) distribution (Fangliang *et al.*, 1997; Reddy and Ugle, 2008). In order to determine the overall importance of *N. buchananii* in the community structure, the Importance Value Index (IVI) was calculated by summing up the percentage values of the relative density, relative frequency and the relative dominance (Benerjee and Srivastava, 2009) as shown in the formula below:
Importance Value Index (IVI) = Relative density + Relative frequency + Relative dominance.

Soil samples from field plots were analysed in the laboratory to determine water holding capacity, soil pH and organic Carbon before being subjected to statistical analysis. The soil analytical data are presented as Appendix 3.

Water holding capacity of the soil was determined by Keen's method using copper cup of 5.6 cm internal diameter and 1.6 cm height (Viji and Rajesh, 2012).
Soil pH was measured by mixing 10 g of soil sample and 50 ml of distilled water and stirred for 20 minutes in a 100 ml beaker using magnetic stirrer. The soil-water moisture was kept overnight and taken the reading with Digital pH meter (Systronics 335) (FAO, 1980).

Soil organic Carbon was determined by rapid dichromate oxidation technique (or Walkley and Black Method). The organic matter in the soil was oxidized by chromic acid (Potassium dichromate plus Conc. $H_2 SO_4$) utilizing the heat of dilution of Sulphuric acid ($H_2 SO_4$). The unreacted dichromate was determined by back titration with ferrous sulphate (FAO, 1980).

Logistic regression was preformed to test the effects of altitude, slope, aspect, canopy height, soil pH, soil organic Carbon and soil water holding capacity on regeneration and distribution of *N. buchananii.* The model was preferred because the dependent variable (Y) was dichotomous (presence or absence of *N. buchananii*) and the dependent variable (X) was a mix of continuous and categorical (Peng *et al.*, 2002).

CHAPTER FOUR

4.0 RESULTS

4.1 Natural regeneration of *Newtonia buchananii*

4.1.1 Stocking density

Table 3 shows the density of *N. buchananii* based on regeneration categories (seedlings, saplings and trees). The results show that *N. buchananii* was relatively well represented in the montane forest as compared to submontane and lowland forests. Neither seedlings nor saplings were found in lowland forest. However, seedlings were found in submontane and montane forests. The highest tree density (dbh >4 cm) was found in montane forest (10 stems ha^{-1}) followed by submontane forest (8 stems ha^{-1}) and lowland forest (1 stemha^{-1}).

Table 3: The density of *N. buchananii*in all regeneration categories (seedlings, saplings and trees) in Nilo Nature Reserve

	Seedlings		Saplings		> 4 cm dbh	
Forest type	Freq	Seedlings	Freq	Saplings/ha	Freq	Trees/ha
Lowland	0	0	0	0	1	1
Submontane	4	444	0	0	7	8
Montane	6	667	0	0	9	10

4.2.2 Diameter size

Table 4 shows the trees (adult category) of *N. buchananii* by diameter size classes. The table illustrates that the dbh >4 - 10 cm, dbh >10 - 20 cm and dbh >20 - 30 cm classes were missing in all forest types. Only dbh >30 cm class were found in all

Table 4: Distribution *N. buchananii* by diameter size ha^{-1} in Nilo Nature Reserve

Forest type	Diameter class ha^{-1}				
	>4 -10 cm	>10 – 20 cm	>20 – 30 cm	> 30 cm	Total
Lowland	0	0	0	1	1
Submontane	0	0	0	7	8
Montane	0	0	0	9	10

4.2.3 Regeneration status of *Newtonia buchananii*

Table 5 shows the proportions of regeneration categories of *N. buchananii* in each forest type. The results show that *N. buchananii* was not regenerating in all forest types (due to absence of saplings). Overall, the regeneration performance of other species was good (Figures 4 to 6; Table 6).

Table 5: Proportion of regeneration categories of *N. buchananii* in Nilo Nature Reserve

Forest type	Proportion (seedlings:saplings:trees)
Lowland	0:0:1
Submontane	3:0:1
Montane	3:0:1

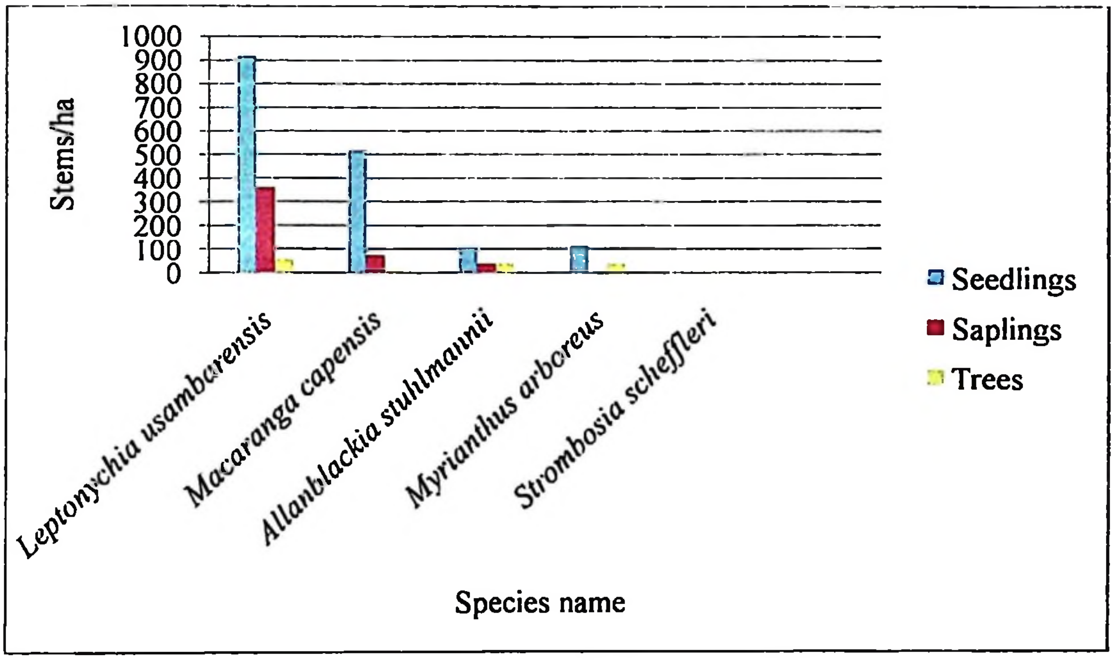

Figure 1: Regeneration of common tree species in lowland forest of Nilo Nature Reserve.

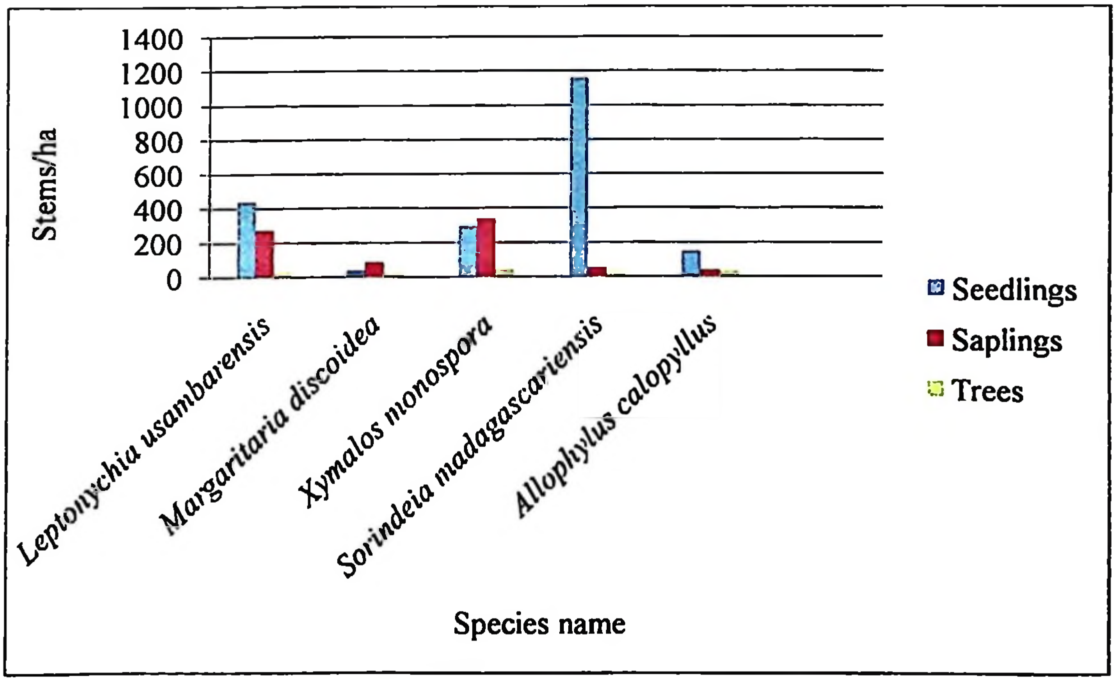

Figure 2: Regeneration of common tree species in submontane forest of Nilo Nature Reserve

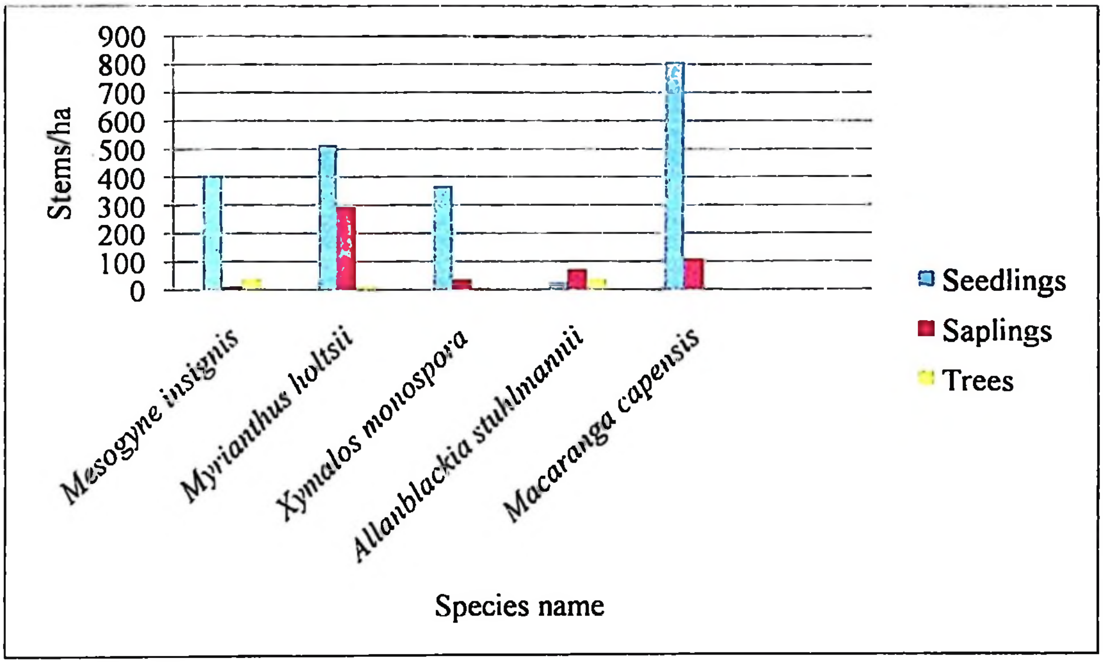

Figure 6: Regenerationof common tree species in montane forest of Nilo Nature Reserve

Table 6: Summary of regeneration performance of different tree species in Nilo Nature Reserve (figures in percentage)

Regeneration status	Lowland	Submontane	Montane
Good	37	38	48
Fair	23	17	30
Poor	27	23	9
None	13	14	13
New	0	8	0

4.3 Distribution pattern of *Newtonia buchananii*

Table 7 shows the abundance to frequency ratios (A/F-ratio) of *N. buchananii.* The results indicated *N.buchananii* having a random distribution in both lowland and submontane forests but was contiguously distributed in the montane forest.

Table 7: Abundance to frequency (A/F) ratio of *N. buchananii* in Nilo Nature Reserve

Forest type	A/F ratio	Distribution pattern
Lowland	0.041	Random
Submontane	0.041	Random
Montane	0.108	Contiguous

Figure 7 shows the distribution patterns of trees per forest type. The results indicated that most tree species showed contiguous distribution pattern followed by random and regular distribution patterns. Thedistribution patterns of each species are given in Appendices 4 to 6.

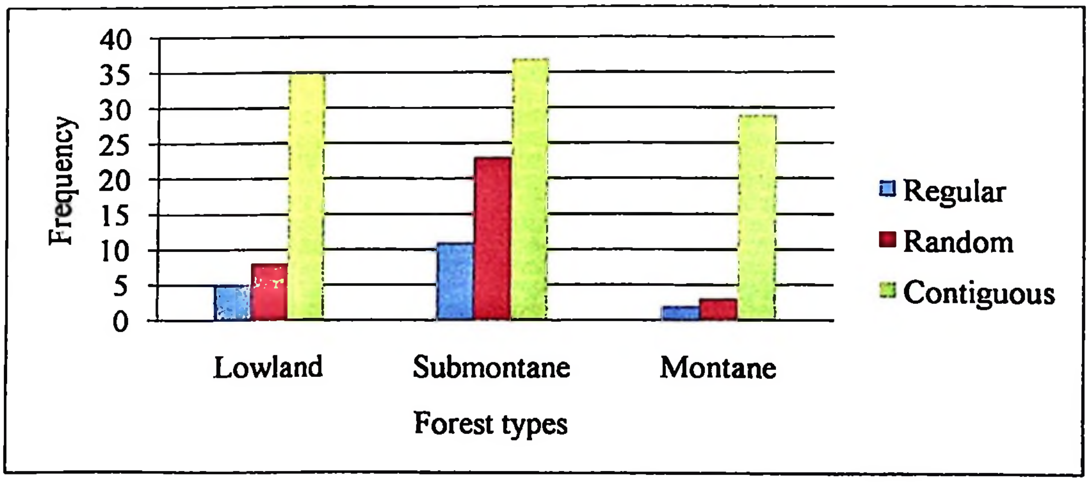

Figure 7: Distribution patterns of tree species in Nilo Nature Reserve

Figures 8 to 10 show the Importance Value Indices (IVI) of five common species in each forest type in NNR. Results showed that *N. buchananii* was among the common species found in the montane forest where it ranked 4th with IVI of 19.76. In the submontane forest, *N. buchananii* had IVI of 5.16 (ranking 21st) while in the lowland forest it had IVI of 3.10 (ranking 33rd). *Allanblackia stuhlmannii* (IVI = 25.30), *Leptonychia usambarensis* (IVI = 21.09) and *Myrianthus hotsii* (IVI = 19.76), ranking the highest in the lowland, submontane and montane forests respectively. The IVI for each species are given as Appendices 4 to 6.

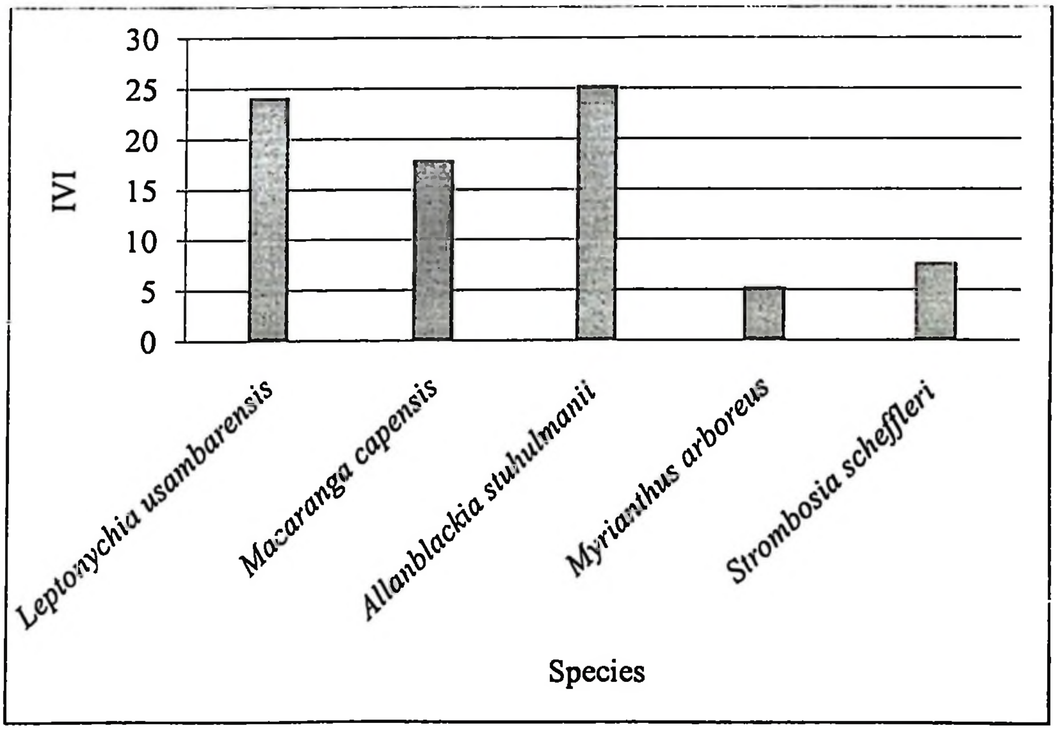

Figure 8: The IVI of common tree species in the lowland forest of Nilo Nature Reserve

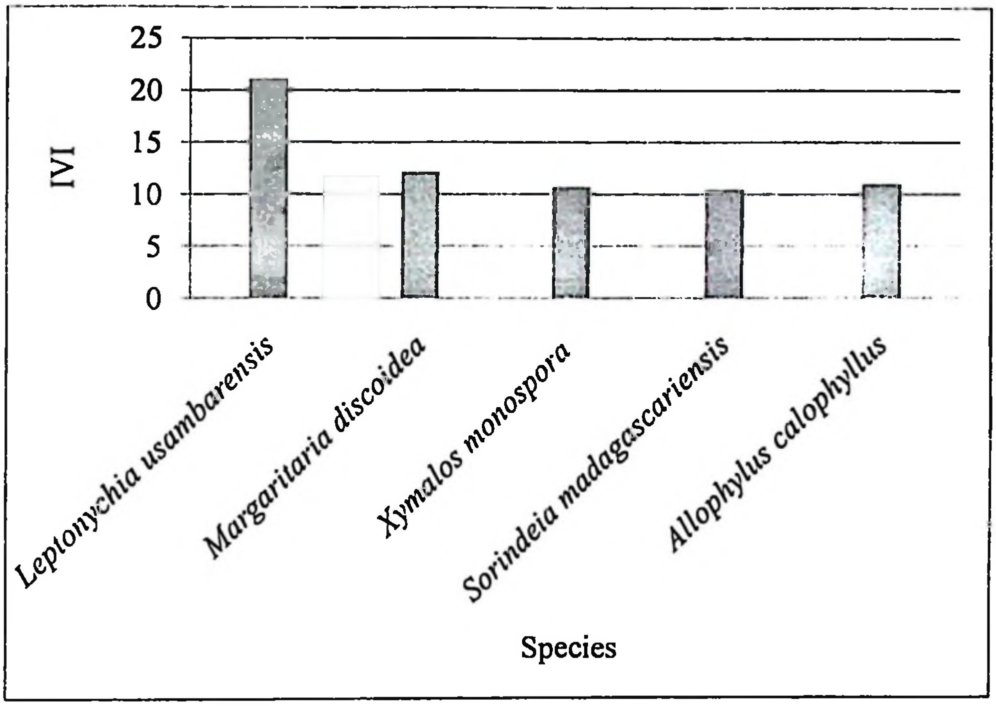

Figure 9: The IVI of common tree species in the submontane forest of Nilo Nature Reserve

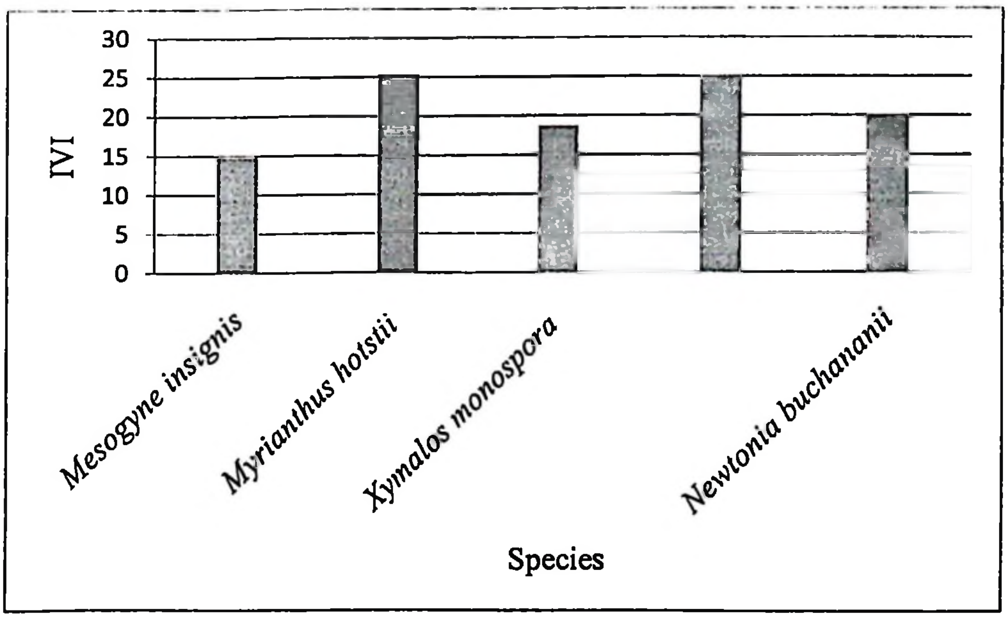

Figure 10: The IVI of common tree species in the montane forest of Nilo Nature Reserve

4.4 Factors affecting regeneration and distribution of *Newtonia buchananii*

Table 8 shows the plots found with disturbances. Only 3 plots were found with disturbances (1 plot with natural treefalls, 1 plot with tourism walking trail and 1 plot burnt with fire). The plots were among those in which *N. buchananii* plants was not found and were assumed to have no significant effect.

Table 8: Plots found with disturdbances in Nilo Nature Reserve

Plot No.	Type of disturbance	Percentage
1	natural treefalls	< 10%
16	tourism walking trail	< 10%
25	Fire burnt	< 10%

Table 9 presents the summary of results of soil samples analysed in the laboratory. Soil water holding capacity was highest in the montane forest. The soil pH was acidic (pH 5 - 4.5). The highest organic Carbon content was found in the lowland forest. The results of the soil data are provided as Appendix 3.

Table 9: Summary of soil characterstics of Nilo Nature Reserve

Parameter	Lowland	Submontane	Montane
Water (% vol/ml)	55.2± 3.58	54.62 ± 4.65	57.71 ± 4.89
Soil pH (1:2:5) in H_2O	4.75 ± 0.84	4.90 ± 0 55	4.98 ± 0.52
Organic Carbon (BlkW %)	3.01 ± 2.94	1.75 ± 0.70	1.64 ± 0.45

The results of logistic regression analysis are presented in Tables 10 - 14.

Table 10 shows that the model was significant ($P<0.05$), accepting the hypothesis that a model with parameters was statistically not equal to an empty model.

Table 10: Reliability of the model

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	-.847	.398	4.523	1	.033	.429

Table 11 shows that 40% (Nagelkerke $R^2 = 0.399$) of the results observed was due to the influence of explanatory variables.

Table 11: Pseudo-R^2

Step	-2 Log likelihood	Cox &Snell R Square	Nagelkerke R Square
1	26.739[a]	.281	.399

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than 0.001.

Table 12 shows the Hosmer and Lemeshow Test (H-L goodness-of-fit-test statistic). H-L goodness-of-fit-test statistic assumes sampling adequacy. If the H-L goodness-of-fit-test statistic is greater than 0.05, as wanted for well-fitting models, the null hypothesis that there is no difference between observed and model predicted-values cannot be rejected, implying that the model's estimates fit the data at an acceptable level. That is, well-fitting models show non-significance on the H-L goodness-of-fit-test. This desirable outcome of non-significance indicates that the model prediction does not significantly differ from the observed (Peng *et al.*, 2002). The result showed that the H-L statistic had a significance of 0.201 which means that it was not statistically significant and therefore the model was quite a good fit to the data which implied that a set of independent variables accurately predicted the actual probabilities.

Table 12: Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	11.011	8	.201

Table 13 shows the results of binary logistic regression. The results indicated that two parameters: altitude and soil water holding capacity significantly affected regeneration and distribution of *N. buchananii* (P =0.04 and P = 0.037 respectively). The odd ratio (n/1+n) for altitude (1.007/1+1.007 = 0.50 or 50%) indicated that for every unit increase in altitude, the probability of encountering or observing seedlings of *N. buchananii* was 50%. Likewise, the odd ratio for soil water holding capacity (0.708/1+0.708 = 0.41 or 41%) indicated that for every unit increase in soil water holding capacity, the probability of encountering or observing seedlings of *N.buchananii* was 41%.

Table 13: Binary logistic result

Parameters		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Altitude	.007	.003	4.229	1	**.040***	**1.007**
	Slope	.011	.062	.030	1	.862	1.011
	Aspect(1)	1.114	1.152	.934	1	.334	3.045
	Canopy	.116	.123	.897	1	.344	1.123
	Soil_pH	-1.679	1.197	1.966	1	.161	.187
	Soil_Carbon	.280	.304	.851	1	.356	1.324
	Water_holding	-.345	.166	4.332	1	**.037***	**.708**
	Constant	15.630	10.042	2.422	1	.120	6136166.750

a. Variable(s) entered on step 1: Altitude, Slope, Aspect, Canopy height, Soil_pH, Soil_Carbon,Soil_water_holding_capacity.

b. *= significant at 0.05

Table 14 shows that the model predicted no seedlings by 85.7% and presence of seedlings by 55.6%. Overall, the model accuracy was 76.7%. Thus, the logistic regression model was valid (Peng *et al.*, 2002).

Table 14: Validity of the model

ClassificationTable[a]

			Predicted		
			Presence/absence of seedlings		Percentage correct
	Observed		No seedlings	Presence of seedlings	
Step 1	Presence /absence of seedlings	No seedlings	18	3	85.7
		Presence of seedlings	4	5	55.6
Overall percentage					76.7

a. The cut value is .500

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Status of natural regeneration of *Newtonia buchananii*

The results on the status of natural regeneration of *N. Buchananii* are presented in Tables 3 - 5. Absence of saplings in all forest types indicated the incosistence in the regeneration. These findings agrees with Madoffe *et al.* (2006) who reported inconsistent occurrence of large tree species and saplings and/or seedlings of similar species. Furthermore, observation also showed that *N. buchananii* was not represented in diameter classes of dbh >4 - 10 cm, dbh >10 - 20 cm and dbh >20 - 30 cm. This is the result of regeneration failure in which seedlings failed to pass into saplings as well as poles class (dbh > 4 -10 cm). Absence of small trees of *N. buchananii* in all forest types indicated that there was no small tree population to replace the current population of large trees (Sheykholeslami *et al.*, 2011).

Lack of regeneration of *N. buchananii* in all forest types (Table 5) can be explained by two reasons. First, lack of regeneration is probably related to effect of logging that took place up to late 1980s (Hamilton, 1989) and thereafter pitsawing that continued in the 1990s (Frontier-Tanzania, 2002). It is important to note that the changes in the management regime that put the forest under strict protection (nature reserve) occurred in 2007 (MNRT, 2010). According to Ngo and Hölscher (2014), logging may alter so many confounding factors such that predicting where regeneration may occur is almost impossible. A study by Lovett (1998) reported that Eastern Arc Mountain forests exhibit low resilience to human disturbance. Furthermore, Figures 4 to 6 and Table 6 show that the regeneration performance of other tree species was relatively well in montane forest compared to lowland and submontane forests. It is more likely that logging concetrated in the lowland and submontane forests due to easiness of accesibility. A study by Hamilton (1989) in EUMs found that the lowland forest was under even greater threat than submontane forest within East African coastal belt because it was found in places more accessible to farmers and it was also regarded as having lower catchment value.

Secondly, the destruction of plants and excessive opening of canopy gaps stimulated growth of dense, herbaceous and semi-woody tangle that suppressed tree regeneration as observed by Schnitzer *et al.* (2000) and Omeja *et al.* (2004). Characterstically, *N. buchananii* seeds has low viability, however, the species is fairly fast growing once established but has poor survival and slow growth (Mugasha, 1978; Orwa *et al.*, 2009). Since *N. buchananii* is a shade-torelant canopy species (Aine-Omucunguzi *et al.*, 2012), one would expect that the species could regenerate even in small gaps (Denslow, 1987; Yamamoto, 2000). Lack of regeneration suggests that the species failed to compete in gaps that were created over time as the result of unfavourable growing conditions. This is explicitly explained by the performance of other common species (with exception of *Myrianthus arboreus* and *Strombosia scheffleri*) such as *Leptonychia usambarensis*, *Macaranga capensis*, *Margaritaria discoidea*, *Xymalos monospora*, *Sorindeia usambarensis*, *Allophylus calophyllus* and *Myrianthus holtsii* which were regenerating well (Figures 4 to 6; Table 6).

5.2 Distribution pattern of *Newtonia buchananii*

The results on the distribution pattern of *N. buchananii* are presented in Table 7. The A/F-ratios indicated that *N. buchananii* was randomly distributed in both lowland and submontane forests meaning that the species was distributed independently from each other and the probability of finding it in the whole population was the same. However, in montane forest, the species was contiguously distributed meaning that the individuals occured in clumps of different densities and sizes (Szmyt, 2010). The random distribution pattern is probably due to the fact that *N. buchananii* is rarely found in lowland forest. Fangliang *et al.* (1997) reported that rare species are generally less aggregated than common ones and most of the randomly distributed species are rare. Spatial patterns shift from high clumping to looser intensity or random distribution when moving from juveniles to adults for the same species. Generally, the contiguous distribution of species was the highest and regular distribution was the lowest (Figure 7; Appendices 4 to 6). Few species in nature are distributed in a regular way probably due to intraspecific competition at a local scale; on the contrary, most of them are contiguously distributed, or appear to be randomly distributed at some given observation scale (Reddy and Ugle, 2008; Bhadra *et al.*, 2014).

Figures 8 to 10 and Appendices 4 to 6 present IVIs of tree species in NNR. The IVI is the most important parameter to understand the distribution of a species in relation to the competitive ability and thus it indicates the species dominance (Uniyal *et al.*, 2010; Prasad and Nageeb, 2012; Bhadra *et al.*, 2014). The maximum IVI for *N. buchananii* was recorded in montane forest (ranked fourth) while the lowest IVI was recorded in lowland forest. The observation indicated that *N. buchananii* is one of the most dominant tree species in the montane forest together with *Myrianthus hotstii*, *Millettia dura*, *Allanblackia stuhlmannii*, *Xymalos monospora*, *Cola sp*, *Myrica salicifolia Strombosia scheffleri*, *Mesogyne insignis*, *Synsepalum msolo*, *Voacanga africana* and *Isoberlinia scheffleri* which all together contributed 70% of the total IVIs. However, the species is not one of the dominant tree species in both lowland and submontane forests. Kimaro and Lulandala (2013) reported that lower dominance of a species is a result of imbalance in species distribution within the disturbed stratum as a result of the differential species preferences during harvesting since most loggers prefer trees with large diameter and straight shape.

5.3 Factors affecting regeneration and distribution of *Newtonia buchananii*

The results of logistic regression are presented in Tables 10 - 14. Only altitude and soil water holding capacity were factors that were found to affect regeneration and distribution of *N. buchananii* (P = 0.040 and P = 0.037 respectively). The logistic regression on the presence/absence of seedlings of *N. buchananii* showed that 76.7% of the seedlings was correctly predicted by the logistic regression. However, the defference in relative proportion of seedlings, saplings and adults among the three forest types (Table 5) might also be due to the interactive influence of other array of biotic and abiotic factors (Kumar and Kalavathy, 2012).

Altitude may have profoundly affected the soil water holding capacity and other physical and chemical properties of the soil through its influence on temperature

(Barij *et al.*, 2007; Yang *et al.*, 2008; Charan *et al.*, 2013). Agrawala *et al.* (2003) reported that the continued loss of forests led to significant reduction in water yields. The population of *N. buchananii* increased with increased altitude (Table 3). The effect of altitude on regeneration and distribution of *N. buchananii* probably is related to climate change. This is in agreement with a growing number of studies on the effect of global climate change on regeneration and distribution of plants and its implications for the forest ecosystems (Binggeli, 1989; Bates *et al.*, 2008; Walck *et al.*, 2011; Bohre *et al.*, 2012; Mondoni *et al.*, 2012; Yawalikar *et al.*, 2012). Burgess *et al.* (2001) reported that there was evidence of smaller scale changes of climate of EAMs, which might be due to global climate changes which have greatly contributed to loss of the majority of the forests occurring in the lowland and lower parts of the submontane forests up to around 1,000 m asl in the EAMs. The presence of seedlings of *N. buchananii* (Table 3), however, demonstrated that the effect of climate change have not greatly affected seed germination (Mondoni *et al.*, 2012) but rather the growth of seedlings. Fitter and Hay (1987) reported that if plants experience higher temperatures over extended periods, especially in combination with water shortage, tissue damage from desiccation and suncald may occur. Although it is difficult to separate climate change from other stresses, climate change may have contributed to mortality through dieback of trees from drought and temperature, increased water erosion (Braatz, 2012) and pests and disease outbreaks (Mrema and Nummelin, 1998).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Based on the results and preceeding discussion, the following conclusions are made:

(i) This study has revealed that *N. buchananii* is not regenerating in Nilo Nature Reserve. The study has shown that lack of saplings in all forest types has led to inconsistence representation of seedlings, saplings and adult trees. It is obvious that saplings are dying before attaining pole stages. This has creation a wide gap as some diameter classes between seedlings and mature trees were missing.

(ii) The random distribution pattern of *N. buchananii* in the lowland and submontane forests is a result of high intra-specific competition that has occured in time and space compared to the montane forest where it is clumped and it is still one of the dominant tree species. Though, however, there are no small trees to replace the mature ones.

(iii) Although it is difficult to prove that climate has changed significantly in the EAMs, of which was outside the scope of this study, but the finding of altitude (which also has effects on soil properties) as one of the factors affecting regeneration and distribution of *N. buchananii* is a circumstantial evidence to claim the effect of global climate change on the regeneration and distribution of *N. buchananii* in Nilo Nature Reserve.

(iv) The fact that other species were well regenerating imply that *N. buchananii* is a poor competitor, thus cannot regenerate in the gaps that were created over time. Since regeneration is a long continuous process, the past disturbances (logging), coupled with global climate change, greatly retarded the regeneration process. This suggests that species that regenerated were those that were able to adapt to global climate change.

6.2 RECOMMENDATIONS

Following the preceeding discussion and conclusions, the recommendations for immediate application and further research are proposed as follows:

6.2.1 Recommendations for immediate application

(i) Deliberate efforts should be done to assist regeneration of *N. buchananii* by clearing vegetation around seedlings (spot weeding) to reduce competition. This will boost growth of seedlings to saplings as well as poles which can withstand competition against other species.

(ii) Fire control should be done to free seedlings and saplings from fire risk posed to all species.

6.2.2 Recommendation for further research

(iii)A long term research should be conducted to assess the genetic variation within the population of *N. buchananii* with the aim of producing seedlings that can adapt to climate change for enrichment planting in the forest.

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APPENDICES

Appendix 1: Field data collection sheet

Plot No……..

Altitude (m)……………..Geo-cordinates………………. ……………..

Slope %..................Aspect…………..Canopy height(m)……………..

Disturbance……………………………………………………….

……………………………………………………….

S/No.	Species name	Quadrat				Description
		3 x 3m (≤4 cm)	10 x 10m (5 - 10cm)	20 x 20m (11-20cm)	30 x 30m (>20cm)	
1						
2						
3						

Appendix 2: Grid references of sample plots at Nilo Nature Reserve

Plot No.	Longitude	Latitude	Grid reference	Grid reference
			37M	UTM
1	E 038°39'46.9"	S 04°54'39.6"	462640	9457164
2	E 038°39'46.6"	S 04°55'29.4"	462631	9455636
3	E 038°39'46.7"	S 04°56'19.1"	462634	9454109
4	E 038°39'11.6"	S 04°57'08.8"	461555	9452582
5	E 038°39'11.4"	S 04°56'21.5"	461549	9454036
6	E 038°39'12.0"	S 04°55'36.5"	461565	9455418
7	E 038°39'11.6"	S 04°53'07.2"	461550	9460000
8	E 038°39'11.0"	S 04°51'23.0"	461532	9463200
9	E 038°38'37.2"	S 04°51'46.7"	460490	9462473
10	E 038°38'36.8"	S 04°53'47.5"	460481	9458763
11	E 038°38'36.6"	S 04°54'30.1"	460476	9457455
12	E 038°38'36.7"	S 04°55'24.6"	460478	9455782
13	E 038°38'36.3"	S 04°58'03.3"	460469	9450909
14	E 038°38'02.0"	S 04°59'09.6"	459415	9448872
15	E 038°38'02.4"	S 04°58'15.1"	459426	9450545
16	E 038°38'02.6"	S 04°53'47.5"	459428	9458763
17	E 038°38'02.4"	S 04°52'45.9"	459420	9460655
18	E 038°38'02.0"	S 04°52'03.2"	459408	9461964
19	E 038°37'27.4"	S 04°52'31.7"	458340	9461090
20	E 038°37'27.1"	S 04°54'01.7"	458333	9458327

21	E 038°36'52.4"	S 04°53'35.6"	457265	9459127
22	E 038°40'21.8"	S 04°54'51.5"	463715	9456800
23	E 038°40'21.4"	S 04°55'43.6"	463702	9455200
24	E 038°40'56.7"	S 04°55'48.3"	464790	9455055
25	E 038°40'57.1"	S 04°54'58.6"	464801	9456582
26	E 038°40'56.6"	S 04°54'08.9"	464786	9458109
27	E 038°41'31.6"	S 04°54'01.8"	465865	9458327
28	E 038°41'31.3"	S 04°54'39.7"	465854	9457164
29	E 038°41'31.8"	S 04°55'29.4"	465870	9455636
30	E 038°42'06.5"	S 04°54'01.4"	466940	9458338

Appendix 3: Soil analytical data

Plot No.	Forest Type	WHC (%vol/ml)	Soil pH (1:2.5) (in H2O)	OC-BlkW (%)
1	L	60	5.62	2.28
2	S	53	4.29	1.26
3	S	55	4.73	1.3
4	S	51	5.11	1.71
5	L	54	4.16	0.65
6	L	55	5.18	0.78
7	S	61	4.51	3.01
8	M	54	5.12	2.04
9	M	60	4.45	1.67
10	S	59	5	0.78
11	L	52	4.76	0.65
12	L	50	3.84	2.97
13	S	50	5.06	1.67
14	M	50	5.22	1.14
15	L	60	4.09	6.96
16	S	50	4.15	1.18
17	S	54	4.38	1.39
18	M	61	4.53	1.14
19	M	57	5.86	1.43
20	S	57	5	1.51
21	M	65	4.5	1.71

22	S	65	4.15	3.26
23	L	60	4.1	2.18
24	L	53	5.6	0.82
25	S	52	6	2.89
26	S	51	5.75	1.26
27	M	57	5.15	2.36
28	L	54	6.19	3.5
29	L	54	4	10.33
30	S	52	5.19	2.5

Appendix 4: Distribution patterns of species in lowland forest

S/No.	Species name	Vernacular name	Famiy	Abundance	Frequency	A/F ratio	Distribution	IVI
1	*Allanblackia stuhlmannii*	Msambu	Guttiferae	6.31	60	0.105	Contiguous	25.30
2	*Leptonychia usambarensis*	Mzonozono	Sterculiaceae	10.79	40	0.270	Contiguous	24.13
3	*Synsepalum msolo*	Msambia	Sapotaceae	3.05	50	0.061	Contiguous	20.97
4	*Macaranga capensis*	Mkumba	Euphorbiaceae	9.37	40	0.234	Contiguous	17.97
5	*Margaritaria discoidea*	Mshembeshembe	Euphorbiaceae	3.67	40	0.092	Contiguous	12.26
6	*Funtumia africana*	Kimboti	Apocynaceae	1.63	50	0.033	Random	10.75
7	*Allophylus calophyllus*	Mbangwe	Sapindaceae	2.85	30	0.095	Contiguous	9.37
8	*Annickia kummeriae*	Ng'waka	Annonaceae	3.46	20	0.173	Contiguous	9.07
9	*Cynometra longipedicellata*	Mkwe	Caesalpinoideae	1.43	10	0.143	Contiguous	8.02
10	*Odyndea zimmermannii*	Mbanku	Simaroubaceae	1.22	20	0.061	Contiguous	8.02
11	*Voacanga africana*	Mbwewe	Apocynaceae	3.05	30	0.102	Contiguous	7.81
12	*Strombosia scheffleri*	Sangana	Olacaceae	3.67	30	0.122	Contiguous	7.70
13	*Shirakiopsis elliptica*	Mkongoo	Euphorbiaceae	0.41	30	0.014	Regular	7.36
14	*Mesogyne insignis*	Mkuhekuhe	Moraceae	2.04	30	0.068	Contiguous	7.28

15	*Alangium chinense*	Mkondogogo	Alangiaceae	1.22	20	0.061	Contiguous	7.01
16	*Albizia adianthifolia*	Mshai mamba	Mimosoideae	1.22	20	0.061	Contiguous	6.58
17	*Cephalosphaera usambarensis*	Mtambaa	Myristicaceae	1.22	30	0.041	Random	6.57
18	*Parinari excelsa*	Mhula	Chrysobalanaceae	1.22	20	0.061	Contiguous	6.54
19	*Ficus sycomorus*	Mkuyu	Moraceae	1.02	20	0.051	Contiguous	5.79
20	*Millicia excelsa*	Mvule	Moraceae	1.02	10	0.102	Contiguous	5.77
21	*Cussonia spicata*	Mtindi	Araliaceae	0.41	20	0.020	Regular	5.46
22	*Albizia gummifera*	Mshai	Mimosoideae	1.02	30	0.034	Random	5.33
23	*Myrianthus arboreus*	Mkonde	Cecropiaceae	4.89	20	0.244	Contiguous	5.30
24	*Pouteria adolfi-friederici*	Kuti	Sapotaceae	0.61	10	0.061	Contiguous	5.12
25	*Trichilia emetica*	Ngoimazi	Meliaceae	3.46	30	0.115	Contiguous	4.90
26	*Sorindeia madagascariensis*	Mkungwina	Anacardiaceae	1.02	10	0.102	Contiguous	4.52
27	*Ficus natalensis*	Mvumo	Moraceae	0.61	20	0.031	Random	3.79
28	*Harungana madagascariensis*	Mnkutu	Chrysobalanaceae	1.22	30	0.041	Random	3.50
29	[illegible]	Mkonga	Meliaceae	1.22	20	0.061	Contiguous	3.38
30	*Brachystegia spiciformis*	Mtondolo	Caesalpinioideae	2.04	10	0.204	Contiguous	3.24
31	*Ocotea usambarensis*	Mkulo	Lauraceae	0.61	10	0.061	Contiguous	3.24

32	*Belschmiedia kweo*	Mfimbo	Lauraceae	1.63	20	0.081	Contiguous	3.19
33	*Newtonia buchananii*	Mnyasa	Caesalpinoideae	0.41	10	0.041	Random	3.10
34	*Bridelia micrantha*	Ng'wiza	Euphorbiaceae	1.43	20	0.071	Contiguous	3.07
35	*Cordia africana*	Mfufu	Boraginaceae	0.81	20	0.041	Random	3.06
36	*Annona senegalensis*	Mtonkwe	Annonaceae	2.65	20	0.132	Contiguous	2.92
37	*Phoenix reclinata*	Msaa	Palmae	1.63	10	0.163	Contiguous	2.90
38	*Blighia unijugata*	Mzindanguuwe	Sapindaceae	0.81	10	0.081	Contiguous	2.87
39	*Ficus exasperata*	Msasa	Moraceae	1.63	10	0.163	Contiguous	2.06
40	*Combretum podoides*	Mbukwe	Combretaceae	0.41	10	0.041	Random	2.04
41	*Bequaertiodendron natalense*	Mduyuyu	Sapotaceae	2.24	10	0.224	Contiguous	1.86
42	*Antiaris toxicaria*	Mkuzu	Moraceae	0.41	10	0.041	Random	1.80
43	*Isoberlinia scheffleri*	Mbarika	Caesalpinioideae	2.04	10	0.204	Contiguous	1.80
44	*Tinnea aethiopica*	Mgimbu	Lamiaceae	0.81	10	0.081	Contiguous	1.67
45	*Diclyandra arborescens*	Ntwavuha	Rutaceae	1.22	10	0.122	Contiguous	1.58
46	*Lonchocarpus capassa*	Mfumbii	Papilionoideae	0.20	10	0.020	Regular	1.40
47	*Millettia dura*	Mhafa	Fabaceae	0.20	10	0.020	Regular	1.36
48	*Celtis africana*	Mjambegha	Ulmaceae	1.63	10	0.163	Contiguous	1.29

Appendix 5: Distribution patterns of species in submontane forest

S/No.	Species name	Vernacular name	Family	Abundance	Frequency	A/F ratio	Distribution	IVI
1	*Leptonychia usambarensis*	Mzonozono	Sterculiaceae	10.71	53.85	0.199	Contiguous	21.09
2	*Margaritaria discoidea*	Mshembeshembe	Euphorbiaceae	5.18	46.15	0.112	Contiguous	12.17
3	*Voacanga africana*	Mbwewe	Apocynaceae	2.42	46.15	0.052	Contiguous	11.65
4	*Allophylus calophyllus*	Mbangwe	Sapindaceae	4.26	61.54	0.069	Contiguous	10.99
5	*Xymalos monospora*	Mzikoziko	Monimiaceae	4.84	38.46	0.126	Contiguous	10.73
6	*Sorindeia madagascariensis*	Mkungwina	Anacardiaceae	4.49	46.15	0.097	Contiguous	10.49
7	*Isoberlinia scheffleri*	Mbarika	Caesalpinoideae	1.27	23.08	0.055	Contiguous	10.08
8	*Cephalosphaera usambarensis*	Mtambaa	Myristicaceae	1.73	30.77	0.056	Contiguous	9.95
9	*Synsepalum msolo*	Msambia	Sapotaceae	1.50	46.15	0.032	Random	9.74
10	*Allanblackia stuhlmannii*	Msambu	Guttiferae	2.30	46.15	0.050	Random	9.73
11	*Myrianthus hotstii*	Mkonde	Cecropiaceae	3.23	38.46	0.084	Contiguous	8.55
12	*Myrica salicifolia*	Mshaghasha chole	Myricaceae	2.30	30.77	0.075	Contiguous	8.25
13	*Macaranga capensis*	Mkumba	Euphorbiaceae	2.65	53.85	0.049	Random	7.86
14	*Drypetes usambarica*	Kihambie	Euphorbiaceae	1.84	23.08	0.080	Contiguous	7.04
15	*Ficus natalensis*	Mvumo	Moraceae	1.84	30.77	0.060	Contiguous	6.56

16	*Shirakiopsis elliptica*	Mkongoo	Euphorbiaceae	2.19	30.77	0.071	Contiguous	6.56
17	*Cynometra longipedicellata*	Mkwe	Caesalpinoideae	1.38	23.08	0.060	Contiguous	6.18
18	*Cordia africana*	Mfufu	Boraginaceae	2.30	23.08	0.100	Contiguous	5.89
19	*Albizia gummifera*	Mshai	Mimosoideae	1.04	38.46	0.027	Random	5.41
20	*Ficus sycomorus*	Mkuyu	Moraceae	0.92	38.46	0.024	Regular	5.23
21	*Newtonia buchananii*	Mnyasa	Caesalpinoideae	1.27	30.77	0.041	Random	5.16
22	*Millettia dura*	Mhafa	Papilionoideae	2.53	15.38	0.165	Contiguous	5.15
23	*Ciltis mildbraedii*	Kimungwe	Ulmaceae	1.27	23.08	0.055	Contiguous	5.04
24	*Bridelia micrantha*	Ng'wiza	Euphorbiaceae	1.38	30.77	0.045	Random	4.03
25	*Pouteria adolfi-friederici*	Kuti	Sapotaceae	1.15	30.77	0.037	Random	3.92
26	*Polyscias fulva*	Kogoo	Araliaceae	0.92	15.38	0.060	Contiguous	3.84
27	*Rytigynia xanthotricha*	Ntwavuha	Rutaceae	0.46	15.38	0.030	Random	3.82
28	*Trichilia emetica*	Ngoimazi	Meliaceae	0.58	23.08	0.025	Random	3.78
29	*Albizia adianthifolia*	Mshai mamba	Mimosaceae	1.15	23.08	0.050	Random	3.76
30	*Mesogyne insignis*	Mkuhekuhe	Moraceae	1.27	23.08	0.055	Contiguous	3.65
31	*Cylicomorpha parciflora*	Mtonto	Caricaceae	1.61	15.38	0.105	Contiguous	3.42
32	*Rauvolfia cafra*	Ng'weeti	Apocynaceae	1.50	15.38	0.097	Contiguous	3.38
33	*Cola sp*	Mzengankuku	Sterculiaceae	0.35	15.38	0.022	Regular	3.32

34	*Funtumia africana*	Kimboti	Apocynaceae	1.15	23.08	0.050	Random	3.29
35	*Anthocleista grandiflora*	Mpumu	Loniaceae	0.58	23.08	0.025	Regular	3.27
36	*Antiaris toxicaria*	Mkuzu	Moraceae	0.58	15.38	0.037	Random	2.90
37	*Anisophyllea obtusifolia*	Msaa mti	Anisophylleaceae	1.73	7.69	0.225	Contiguous	2.76
38	*Bombax rhodognaphalon*	Msufimwitu	Bombacaceae	0.92	15.38	0.060	Contiguous	2.75
39	*Celtis africana*	Mjambegha	Ulmaceae	0.23	15.38	0.015	Regular	2.71
40	*Isoberlinia globiflora*	Muwa	Caesalpiniaceae	0.58	15.38	0.037	Random	2.70
41	*Maesopsis eminii*	Mhesi	Rhamnaceae	1.04	23.08	0.045	Random	2.62
42	*Synsepalum cerasiferum*	Muohoyo	Sapotaceae	0.69	15.38	0.045	Random	2.58
43	*Markhamia lutea*	Mtalawanda	Bignoniaceae	1.15	7.69	0.150	Contiguous	2.56
44	*Parinari excelsa*	Mhula	Chrysobalanaceae	0.69	15.38	0.045	Random	2.52
45	*Bequaertiodendron natalense*	Mduyuyu	Sapotaceae	0.58	23.08	0.025	Random	2.50
46	*Zanthoxylum usambarense*	Mhombo	Rutaceae	0.69	7.69	0.090	Contiguous	2.31
47	*Cordia sinensis*	?	Boraginaceae	2.76	30.77	0.090	Contiguous	2.03
48	*Blighia unijugata*	Mzindanguuwe	Sapindaceae	0.69	7.69	0.090	Contiguous	1.89
49	*Entandrophragma excellum*	Mbokoboko	Meliaceae	0.35	15.38	0.022	Regular	1.84
50	*Harungana madagascariensis*	Mnkutu	Chrysobalanaceae	1.73	15.38	0.112	Contiguous	1.77
51	*Tinnea aethiopica*	Mgimbu	Lamiaceae	1.27	15.38	0.082	Contiguous	1.67

52	*Belschmiedia kweo*	Mfimbo	Lauraceae	0.46	15.38	0.030	Random	1.64
53	*Millicia excelsa*	Mvule	Moraceae	0.35	7.69	0.045	Random	1.41
54	*Annickia kummeriae*	Ng'waka	Annonaceae	0.81	7.69	0.105	Contiguous	1.36
55	*Ficus subcalcarata*	Msoso	Moraceae	1.27	7.69	0.165	Contiguous	1.30
56	*Myrianthus arboreus*	Mkonde	Cecropiaceae	0.12	7.69	0.015	Regular	1.29
57	*Zanthoxylum gillettii*	Mhombo	Rutaceae	0.23	7.69	0.030	Random	1.28
58	*Strombosia scheffleri*	Sangana	Olacaceae	0.58	7.69	0.075	Contiguous	1.11
59	*Brachystegia spiciformis*	Mtondolo	Caesalpinioideae	0.92	7.69	0.120	Contiguous	1.09
60	*Trilepisium madascariense*	Mzugu	Moraceae	0.23	15.38	0.015	Regular	1.02
61	*Faurea salgna*	?	Proteaceae	0.23	15.38	0.015	Regular	1.02
62	*Alangium chinense*	Mkondogogo	Alangiaceae	0.23	7.69	0.030	Random	0.88
63	*Lecaniodiscus fraxinifolius*	Mbwewe	Sapindaceae	1.15	7.69	0.150	Contiguous	0.76
64	*Steganoaenia araliacea*	Mnyongampembe	Araliaceae	0.46	7.69	0.060	Contiguous	0.72
65	*Lannea schweinfurthii var.stuhlmannii*	Muumbu	Anacardiaceae	0.46	7.69	0.060	Contiguous	0.70
66	*Caloncoba welwitschii*	Mkoko	Flacourtiaceae	0.46	7.69	0.060	Contiguous	0.65
67	*Lonchocarpus capassa*	Mfumbii	Papilionoideae	0.12	7.69	0.015	Regular	0.64
68	*Memecylon semsei*	Saami	Melastomataceae	0.12	7.69	0.015	Regular	0.51
69	*Cynometra brachyrrhachis*	Mkanga	Caesalpinioideae	0.23	7.69	0.030	Random	0.51

70	*Rapanea melanophloeos*	Mshwizo	Myrinaceae	0.12	7.69	0.015	Regular	0.51
71	*Deinbollia kilimandscharica var kilimandscharica*	Mbwakabwaka	Sapindaceae	0.35	7.69	0.045	Random	0.51

Appendix 6: Distribution pattern of species in montane forest

S/No.	Species name	Vernacular name	Family	Abundance	Frequency	A/F ratio	Distribution	IVI
1	*Myrianthus hotstii*	Mkonde	Cecropiaceae	9.54	71.43	0.134	Contiguous	25.32
2	*Millettia dura*	Mhafa	Papilionoideae	4.92	28.57	0.032	Contiguous	25.20
3	*Allanblackia stuhlmannii*	Msambu	Guttiferae	4.92	42.86	0.115	Contiguous	24.99
4	*Newtonia buchananii*	Mnyasa	Caesalpinoideae	4.62	42.86	0.108	Contiguous	19.76
5	*Xymalos monospora*	Mzikoziko	Monimiaceae	8.62	42.86	0.201	Contiguous	18.71
6	*Cola sp*	Mzengankuku	Stercuiiaceae	2.46	14.29	0.172	Contiguous	16.39
7	*Myrica salicifolia*	Mshaghasha chole	Myricaceae	2.77	28.57	0.097	Contiguous	16.10
8	*Strombosia scheffleri*	Sangana	Olacaceae	4.31	57.14	0.043	Contiguous	15.15
9	*Mesogyne insignis*	Mkuhekuhe	Moraceae	12.00	14.29	0.840	Contiguous	14.78
10	*Synsepalum msolo*	Msambia	Sapotaceae	2.46	28.57	0.086	Contiguous	11.77
11	*Voacanga africana*	Mbwewe	Apocynaceae	2.77	42.86	0.065	Contiguous	10.78

12	*Isoberlinia scheffleri*	Mbarika	Caesalpinoideae	2.77	28.57	0.097	Contiguous	10.76
13	*Macaranga capensis*	Mkumba	Euphorbiaceae	4.00	28.57	0.140	Contiguous	7.86
14	*Margaritaria discoidea*	Mshembeshembe	Euphorbiaceae	2.46	28.57	0.086	Contiguous	7.49
15	*Allophylus calophyllus*	Mbangwe	Sapindaceae	2.15	28.57	0.075	Contiguous	6.19
16	*Brachystegia spiciformis*	Mtondolo	Caesalpinioideae	0.62	14.29	0.043	Random	6.08
17	*Cynometra longipedicellata*	Mkwe	Caesalpinoideae	3.08	14.29	0.215	Contiguous	5.92
18	*Bombax rhodognaphalon*	Msufimwitu	Bombacaceae	1.54	14.29	0.108	Contiguous	5.86
19	*Zanthoxylum usambarense*	Mhombo	Rutaceae	1.23	28.57	0.043	Random	5.83
20	*Cussonia spicata*	Mtindi	Araliaceae	1.23	14.29	0.086	Contiguous	4.89
21	*Synsepalum cerasiferum*	Muohoyo	Sapotaceae	1.23	14.29	0.086	Contiguous	3.98
22	*Annickia kummeriae*	Ng'waka	Annonaceae	0.62	14.29	0.043	Random	3.62
23	*Ocotea usambarensis*	Mkulo	Lauraceae	1.54	14.29	0.108	Contiguous	3.55
24	*Cylicomorpha parciflora*	Mtonto	Caricaceae	2.15	14.29	0.151	Contiguous	3.47
25	*Ficus natalensis*	Mvumo	Moraceae	0.92	14.29	0.065	Contiguous	3.20
26	*Zanthoxylum gillettii*	Mhombo	Rutaceae	1.54	14.29	0.108	Contiguous	3.02
27	*Diclyandra arborescens*	Ntwavuha	Rutaceae	2.15	14.29	0.043	Contiguous	2.72
28	*Cordia africana*	Mfufu	Boraginaceae	0.31	14.29	0.022	Regular	2.54
29	*Bridelia micrantha*	Ng'wiza	Euphorbiaceae	2.15	14.29	0.151	Contiguous	2.43

30	*Alangium chinense*	Mkondogogo	Alangiaceae	1.54	14.29	0.108	Contiguous	2.42
31	*Polyscias fulva*	Kogoo	Araliaceae	0.31	14.29	0.022	Regular	2.42
32	*Caloncoba welwitschii*	Mkoko	Flacourtiaceae	1.85	14.29	0.108	Contiguous	2.31
33	*Celtis africana*	Mjambegha	Ulmaceae	4.31	14.29	0.302	Contiguous	2.29
34	*Psidium guajava*	Mpera	Proudeceae	0.92	14.29	0.065	Contiguous	2.12