David Sylvester Kacholi

EFFECTS OF HABITAT FRAGMENTATION ON BIODIVERSITY OF ULUGURU MOUNTAIN FORESTS IN MOROGORO REGION, TANZANIA

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Effects of Habitat Fragmentation on Biodiversity of Uluguru Mountain Forests in Morogoro Region, Tanzania.

Effects of Habitat Fragmentation on Biodiversity of Uluguru Mountain Forests in Morogoro Region, Tanzania.

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Dedication

To my parents,
the late Father, *Sylvester W. Kacholi*
and
Mother, Mary Leo Kafuvi
for providing me the educational foundation

And

To my family,
the children, *Carlos, Carolina* and *Eusebius*
and
my lovely wife, *Oliver*
for their deep patience when they needed me most.

Summary

Uluguru Mountains is one of the Eastern Arc Mountain blocks that stretch from Taita Hills in Kenya to Udzungwa Mountains in south-central Tanzania. The Uluguru Mountains contain several forest fragments, which are recognized as important biodiversity hotspots. The population pressure and encroachment threatens their biodiversity values. This study analyses (1) species richness, diversity, floristic similarity and structure of trees species (DBH $\geq$ 10 cm) in the forest fragments in Uluguru, (2) Understory species composition and natural regeneration of the fragments (3) changes in species richness, diversity and tree density along the edge-interior gradient in the fragments and (4) indigenous tree use, use values and human population impacts on tree density and species richness in Uluguru forest fragments.

In the overstory layer (*i.e.* DBH $\geq$ 10 cm) examination of 900 individual trees revealed 101 species, 73 genera and 31 families. Fabaceae and Moraceae were the most speciose and important families in terms of familial importance value (FIV). The five species with the highest species importance value (IVI) were *Ehretia amoena, Khaya anthotheca, Synsepalum cerasiferum, Sorindeia madagascariensis, Diospyros squarrosa,* all accounting for 27 % of the total IVI. Of the total observed species, 31 % had up to two individuals while 15 % occurred only once in all the sample plots. The studied forests differed significantly in their species richness (26 - 93 species ha^{-1}), tree density (85 - 390 stems ha^{-1}), basal area (3 - 24 m^{2} ha^{-1}) and diversity indices (Shannon-Wiener 2.50 - 4.02; Fishers 6.8 - 35.5; and Simpson 9.4 - 63.1). The forest fragment size revealed positive correlation with species richness ($r = 0.92$), trees density ($r = 0.66$) and basal area ($r = 0.28$). In general, the larger forests (Kilengwe and Kimboza) had higher species richness, which might be due to high environmental heterogeneity within the forests. However, the small fragments should be given priority in conservation to avoid loss of species. The dendogram revealed four clusters of forests with low similarity between them, the closer the forests were to one another, the more similar in floristic composition. The significant negative association between geographical distance and floristic similarity among forest pairs was confirmed by correlation test ($r = -0.43$, $p < 0.001$). Although, all studied forests showed good regeneration pattern, more attention on conservation should be paid to rare, threatened species and those with lower IVI.

In the understory layer, a total of 2119 seedlings, 1798 small saplings and 2585 large saplings representing 91, 102 and 104 species belonging to 28, 32 and 30 families respectively were recorded in the studied forests. Fabaceae and Moraceae were the most speciose families in the the entire understory compartments. *Sorindeia madagascariensis, Scorodophloeus fischeri, Diospyros squarrosa* and *Ehretia amoena* appeared in the top ten species with the highest IVI in all the three compartments. The forests varied significantly in terms of their species richness, diversity indices and structural characteristics in all the three compartments. The overall frequency distribution of the species from the three forest compartments revealed high species richness in the two lower frequency classes (*i.e.* < 20 % and 20-40 %) in all the forests indicating a high degree of floristic heterogeneity and the presence of rare species within the forests. Also, this study revealed the understory layer being richer than overstory in all the forest fragments. The overall mean species richness for understory was 59 species ha^{-1} while overstory had 47 species ha^{-1}. The Sørensen coefficients of similarity between understory and overstory layers ranged from 0.53 to 0.77, and were higher within fragments than between them. Though, all forests displayed good regeneration, some species like *Dalbergia melanoxylon*, *Pterocarpus angolensis*, *Pandanus rabaiensis*, *Millettia sacleuxii*, *Pouteria altissima*, *Allanblackia stuhlmannii* revealed poor regeneration, hence require due attention.

The variation of species richness, diversity and density of tree community along edge-interior gradient were studied in all the surveyed forests. A total of 198 individual ha^{-1} representing mature trees, 566 individuals ha^{-1} large saplings, 6309 individual ha^{-1} small saplings and 46469 individuals ha^{-1} seedlings were encountered in all the seven studied forests. In general, the mean species richness, diversity and tree density in the interior plots of the overstory, large saplings and small sapling layers were significantly higher than edge and intermediate plots that did not differ appreciably. The regression slopes of the interior plots in overstory and large sapling were significantly higher than edge and intermediate plots. For small saplings and seedlings, interior and intermediate did not differ appreciably in their regression slopes but were considerably higher than edge. The comparison of species richness, diversity and density within each categorical distance showed significant variation in all the forest layers. The relationship between tree size classes and tree density from edge and interior plots in all the forests revealed exponential decay patterns. This implies that some trees die due to competitive advantage from

crowding and suppression as the stand approach a limiting number of trees of a given size that may coexist within a given area. The findings of this section concluded that the interior of the forests and the edges/intermediate were contrasting habitats. Moreover, long-term study is needed to investigate how microclimatic conditions affect species richness, composition and density within the studied forest regions.

Assessment of tree uses and use values was carried out using structured questionnaires. A total of 42 species belonging to 38 genera representing 19 families were listed by respondents as being useful for their livelihoods. Of these species, 88 % were listed to serve more than one function. *Milicia excelsa, Albizia gummifera and Annona senegalensis* had higher total use values among the identified species whereas *Sterculia quinqueloba* had the lowest use value. 64 % of listed species are used for both firewood and charcoal making. Species used for timber and medicinal purposes accounted for 45 % and 40 % of the identified species respectively. Species used for building poles and making domestic utensils accounted for 55 % each while those used for carving works and fodder, accounted 40 % and 29 % of all listed species respectively. Moreover, this study revealed that the human population surrounding the forests was negatively correlated with forest size (r = -0.90), species richness (r = -0.79) and tree density (r = -0.76). The results suggest that the increase of human population will continue putting pressure to forest resources because of increased demand for more land for agriculture, charcoal and firewood for fuel, timber and poles for building puroposes and medicines for their health. Moreover, the study suggests that indigenous knowledge is vital ingredient in the on-going effort to reverse the trend of environmental degradation in the Uluguru forests by integrating it into community based management plans. Also, there is a need to control human population in the villages surrounding the forests for the purpose of reducing pressure towards forests resources.

In general, the study revealed that habitat fragmentation is associated with drastic changes in the species composition and structure of the forests. If fragmentation process continues, the ability of forest remnants to sustain their original biodiversity and ecological processes will be considerably reduced. Thus, protection of these fragments needs to be prioritized.

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CHAPTER ONE

General Introduction

1.1 Background Information

Fragmentation is the major threat to tropical forest biodiversity (Tabarelli *et al.*, 1999) as it tends to lower species number, modify community composition (Laurance *et al.*, 1998), decrease population productivity (Robinson *et al.*, 1995) as well as changing the micro-environmental conditions (Didham and Lawton, 1999). Usually, fragmentation occurs when the continuity of original vegetation is disrupted and reduced into smaller isolated fragments or patches (Franklin *et al*., 2002; Fahrig, 2003). It is most often a consequence of anthropogenic activities, for instance deforestation/clearance for agriculture, road construction, logging and urbanization (Tabarelli *et al.*, 2004; Jha *et al.*, 2005), which significantly alter pattern, composition and extent of vegetation due physical and biological changes (Newmark, 2001; Yan *et al.*, 2007) as well as alteration in the flow of resources (such as organisms propagules and nutrients) in the forest environment (Walker *et al.*, 2006).

Besides reductions in total area, fragmentation also modifies natural habitat by increasing the proportion of forest associated with edges, decreasing interior habitat, and isolating habitat fragment from other areas of habitat (Franklin *et al.*, 2002). The formation of edges is considered to be an important feature of fragmentation (Murcia, 1995). It has been observed that as the proportion of the edge zone increases, changes in microclimate occur, given that forest edges tend to be warm, windy and receive more light than forest interior (Didham and Lawton, 1999; Newmark, 2005). The modification in spatial configuration and microclimate within edges tends to affect species composition, abundance, natural regeneration and spatial distribution of biodiversity within fragments (Benitez-Malvido, 1998; Laurance *et al.*, 2007; Oliveira *et al.*, 2004). For that reason, fragmentation of habitat has become major topic of research and debate among conservation biologists and plant ecologists worldwide (Jongejans and de Kroon, 2005). Thus, assessing impacts associated with habitat fragmentation is an important step in prioritizing forest fragments for biodiversity conservation (Hill and Curran, 2001).

1.2 Problem Justification

Rapid human population growth in recent decades has increased pressure to the forest resources, which resulted in an extensive fragmentation and loss of habitat in many tropical forests (Bailly *et al.*, 2004). More than 500 million people are living in or near the world's tropical rainforests (FAO, 2003), the majority of whom depend on the forests as their primary source of supply for food, firewood, medicines, building poles and other indispensable needs (FAO 2003; Becker *et al.*, 2005). Tropical rainforests which encompass 6 % of the world's land area and which have at least 50 % of the world's total biological species are being deforested and fragmented at an alarming rate exceeding all other types of habitats (Ehrlich, 1981; Pimm *et al.*, 1998). Achard *et al.*, 2002 reported the decrease of tropical rainforests globally by an average of 5.8 x 10^6 ha per year in the year 1997 from the estimate of 1116 x 10^6 ha in the year 1991 due to deforestation. Moreover, FAO (2010) reported the global annual loss in forest area of 8.327 x 10^6 ha per year between 1990 and 2000 and 5.211 x 10^6 ha per year between 2000 and 2010. Thus, protection and conservation of forests has become an issue of increasing priority in recent years due to threats they are facing (Hill and Curran, 2001).

In Tanzania, the populations has increased by more than quadruple between 1948 and 2002 from 7.9 million to 36 million people respectively, with 80 % of these people living in rural areas and depending up on subsistence farming. Forests cover is approximately 34 million ha with an annual loss of 322,000 ha/year noted between 1990 and 1995 (Newmark, 2002) and annual loss of 403,000 ha per year noted between 2000 and 2010 (FAO, 2010). This loss is mainly due to agricultural clearings, overgrazing, charcoal production, fuel wood harvest, fire and timber harvest (Newmark, 2002). The Eastern Arc forests have suffered extensive losses and fragmentation due anthropogenic disturbances and fire (Madoffe *et al.*, 2006). The rate of loss of original forest cover as a result of human disturbances in Uluguru forests is approximated to be 65 % (Newmark, 1998). The population growth rate in Uluguru is approximated to be 6.5 % per year where the loss of forests due to conversion to farmlands and encroachment were 1.7 % per annum between 1955 and 1977 and 0.6 % per annum between 1977 and 2000 (Burgess *et al.*, 2002). This loss of forests is directly linked with the increase of human population around the mountain areas (Nkombe, 2003), which results to over-exploitation of the forest resources due to increased demands for more land for agriculture, timber for building purposes and charcoal making for fuel (Hymas, 2000). Some forest patches have remained in farmlands around the Uluguru Mountains, and they are still under deforestation for small-holdings, except for sacred forests and some rocky outcrops areas (Burgess *et al.,* 2002). The increase of anthropogenic activities due to population growth and urbanization in Uluguru jeopardize not only common species, but strict endemic and near-endemic species are at high risk of extinction too.

Newmark (1998) and Burgess *et al.,* (2002, 2007) reported the existence of several fragments in various Eastern Arc Mountain blocks including Uluguru. No study has been conducted to assess and compare the species richness, diversity, structure and floristic similarity in various forest fragments of Uluguru Mountains. Therefore, it is an intention of this study to provide an understanding of existing knowledge discrepancy by assessing; (1) mature species richness, diversity, structure between forest fragments, (2) the differences in species richness, diversity and density between various understory layers, (3) the edge-interior variation in the species assemblages and (4) indigenous tree use, use values and human population effects on the species richness, diversity and tree density.

1.3 Literature Review

1.3.1 Definition of Fragmentation

Fragmentation is an ecological process that involves splitting up of large, continuous unaltered environment into smaller, isolated fragments (Fahrig, 2003), leaving isolated fragments with deleterious consequences for most of the native forest biota. The process has also been described as the disruption of structural and spatial continuity (Laurance *et al.,* 2002). Using this explanation, the concept seems to be more relevant to any ecosystem where continuity is important to ecosystem functions, regardless of scale (Walker *et al.,* 2006).

1.3.2 Causes of Fragmentation

Fragmentation can be due to human or natural processes. Anthropogenic activities are the main drivers of fragmentation as they alter environment on a much faster time scale as compared to natural ones (Tabarelli *et al.,* 2004). Example of anthropogenic activities include logging, clearing/deforestation of forests for agriculture, charcoal making, fire setting, road construction and urbanization while natural activities include natural fire and geological processes like volcanic eruption, earth quakes and landslides (Tabarelli *et al.*, 2004, Jha *et al.*, 2005).

1.3.3 Impacts of Fragmentation to Natural Habitats

1.3.3.1 Area Effects

When fragmentation occurs, the decrease in the size of the original forest habitat, also leads to changes in forest ecosystem and is hence known as area effects (Fahrig, 2003). The size of habitat is a key characteristic for forest species conservation, on basis of a positive relationship between habitat area and richness of species. The reduction in forest size significantly leads to decline in species composition, density and diversity in fragments (Laurance *et al.*, 1998; Hill and Curran, 2001), as a result, large forest fragments are necessary for conservation of species, especially strict endemic or near-endemic species (Cagnolo *et al.*, 2006).

According to island biogeography theory (MacArthur and Wilson, 1967), area effects could result in higher extinction rates in smaller habitats, resulting from their sustaining smaller populations which have a tendency being more vulnerable to environmental, demographic and genetic stochasticity (Hobbs and Yates, 2003). On contrary, large habitats usually encompass a wider range of environmental conditions allowing more habitat specialist species to develop (Saunders *et al.*, 1991). In addition, area effects and habitat heterogeneity have been noted to affect tree species abundance and diversity (Hill and Curran, 2001; Cagnolo *et al.*, 2006). In study conducted by Hill and Curran (2001) in Ghana forest fragments, it was observed that the correlation coefficients between the logarithm of tree species number and that of the area of isolated fragments were 0.92 ($p = 0.005$) and 0.87 ($p = 0.005$) for the regenerating trees and mature trees number respectively. The same trend of relationship was also observed by Lida and Nakashizuka (1995) on their study in Japan, which was concluded that large forest patches are significantly important for conservation of species, especially rare ones. This supports the theory that large fragments have greater density and diversity of tree species compared to small ones.

1.3.3.2 Edge Effects

Edges are transition zones separating two or more adjacent habitat types in an ecosystem (Lidicker, 1999). This term is also used in conjunction with boundaries between two adjacent ecosystems (Saunders *et al.,* 1991). Effects associated with edges are normally created through the interactions between the two nearby ecosystems (Murcia, 1995). The formation of edges seems to be an important characteristic of forest habitat fragmentation, for the reason that as forest edge-interior ratio increase, modifications in forest environment, microclimate, vegetation structure, natural regeneration and species composition occur (Murcia, 1995; Jose *et al.,* 1996; Benítez-Malvido, 1998; Didham and Lawton, 1999) as well as forest litter structure and nutrient cycling dynamics (Didham, 1998).

Edge effects and area effects are linked together, and have been observed to be inversely related, *i.e.* as area of forest fragment increases, edge effects decrease (Hanski *et al.,* 1995) and the relative proportions of evergreen and shade tolerating species increase with respect to pioneers (Lida and Nakashizuka, 1995). The edge creation mainly alters microclimatic factors (such as light intensity and duration, air temperature, relative humidity and wind) and soil factors (such as pH, organic carbon, total nitrogen, available phosphorus, soil moisture and temperature), which tend to differ strongly over short distances towards forest interior (Williams-Linera, 1990; Jose *et al.,* 1996; Didham and Lawton, 1999; Newmark, 2001, 2005). According to Laurance *et al.,* (1997), for many physical phenomena, a reasonable assumption for the maximum penetration of edge effects is *ca.* 100 m. Therefore, an alteration in the physical environment situation at the edges, leads to changes in forest vegetation structure, distribution and species composition as compared to interior forest (Oliveira *et al.,* 2004).

In many tropical rainforests, the harsh external climate condition is normally buffered by dense canopy cover, but this breaks down near forest edges (Williams-Linera, 1990; Laurance *et al.,* 2007). Edge effects lead to higher mortality of desiccation-sensitive plant species and seedling damage caused by litter-fall and tree fall near edges (Laurance *et al.,* 1998), but also, it increase sapling mortality by competition with lianas, vines and ruderal species, and increase adult mortality by elevated rates of uprooting and breakage near forest edges (Laurance *et al.,* 1998) as fragmentation enhances accessibility to forest interior (Jha *et al.*, 2005). Strong turbulence can result when winds strike immediate forest edges; increasing rates of wind throw and forest structural damage (Ferreira and Laurance, 1997). Fragmented forests frequently exhibit a proliferation of vines, lianas, and secondary vegetation near edges (Tabarelli et al., 1999) and some forests appear highly prone to invasions of exotic plant species (Laurance *et al.*, 1997).

1.3.3.3 Isolation Effects

Habitat isolation refers to a measure of the amount of habitat to the landscape. When a patch is more isolated, the less the habitat there is in a landscape that surrounds it (Fahrig, 2003). The amount of habitat is the most obvious and visible effect of the process of fragmentation (Gascon *et al.*, 2001). A habitat can be detached from landscape in many various ways resulting in various spatial shapes and patterns (Franklin *et al.*, 2002). These patterns play a significant role in intensifying edge and/or area effects whereby habitat patches of irregular shape becomes more susceptible to edge effects that break through into the interior of the habitat (Hill and Curran, 2005). Normally, the loss of forested habitat results in formation of a new matrix habitat around the isolated forest patches. These matrix habitats facilitate the movement of species between forest patches while hindering others to do the same. Species adapted to disturbances tend to be present in the matrix and may invade forest patches and edge habitat (Murcia, 1995; Gascon *et al.*, 2001). The matrix habitat may also include human settlements, which increases disturbances in forest patch through changing land use, logging, hunting and fire (Newmark, 1998). Due to these grounds, dramatic changes in species composition, abundance and diversity have been recorded in forest patches (Matlack, 1994; Hill and Curran, 2005).

1.3.4 Ecological Consequences of Fragmentation

The tropical rainforests around the globe have undergone remarkable degradation since the beginning of settled agriculture, which was followed by rapid human population growth, the development of technology and increased economic activities (Houghton, 1994). The loss and fragmentation of forest habitats is a direct threat towards biodiversity (Tabarelli *et al.*, 2004). Besides to its intrinsic values, biodiversity is needed for the functioning of ecosystems

(Bierregaard *et al.*, 1992) and for the production of numerous goods potential for human consumption (Schaberg *et al.*, 1999). Always biodiversity is lost through the extinction of local populations of species (MacArthur and Wilson, 1967), and there is often a time lag between the process of habitat loss and the eventual extinction of populations (Tilman *et al.*, 1994). In addition to the loss of biodiversity, the fragmentation and loss of forest habitat jeopardize important ecosystem services (Laurance *et al.*, 1997) such as soil and water conservation (Fearnside, 2005), and a significant terrestrial store of carbon, which contributes to the mitigation of climate change (Glenday, 2006).

Fragmentation of forest habitats is also described to cause ecological consequences, which can be categorized into abiotic effects, direct biological and indirect biological effects (Saunders *et al.*, 1991). All these effects are considered to affect the demographic processes of plants, which, in turn, affect the growth rate and survival of plant populations (Holsinger, 2000). Abiotic effects, involve changes in the microclimate conditions both within and on the edge of forest fragments (Murcia, 1995). Direct biological effects, involve changes in abundance and distribution of species, which are caused directly by the physical conditions near edges (for instance through desiccation, wind throw and plant growth) and determined by the physiological tolerances of species to the conditions on and near the edge (Didham and Lawton, 1999; Laurance *et al.*, 2007). Indirect biological effects, involve changes in species interactions, such as predation, parasitism, competition and pollination and seed-dispersal (Saunders *et al.*, 1991).

Due to changes in micro-environment conditions, forest fragment edges have been observed to have higher air and soil temperatures, which fluctuates more than within the forest interior, and they are more exposed to winds, which reduce humidity and soil moisture, and increase evaporation and desiccation (Didham and Lawton, 1999). The intensity of the edge effects depends much on the fragment size, shape and location in the landscape (Hill and Curran, 2005). Changes in the microclimate can have direct biological effects on plant regeneration and population growth by increasing mortality (Ferreira and Laurance, 1997; Laurance *et al.*, 1998; Mesquita *et al.*, 1999; Tomimatsu and Ohara, 2003) or decreasing seed germination (Bruna, 2002). In tropical forests, where seasonal droughts increase plant mortality, the effects of fragmentation on plant survival are likely to be more severe (Engelbrecht *et al.*, 2007). Thus, as forest becomes increasingly fragmented, populations of forest species are reduced, dispersal and migrations patterns are interrupted, ecosystem inputs and outputs are altered, and previously isolated core habitats become exposed to conditions, all of which result in a progressive erosion of biological diversity (Tilman *et al.*, 1994).

1.3.5 Status of Biodiversity in the Tropical Forests

The tropical forests are the most important areas for conservation in the world given that they contain more than 50 % of the world's species (Whitmore, 1998). Habitat loss and increased fragmentation are major threats towards tropical forests biodiversity (Laurance *et al.*, 1998, 2006, 2007; Benítez-Malvido and Marnítez-Ramos, 2003). Brooks *et al.*, (1999) revealed that forest fragments at the size of 1000 ha will lose 50 % of the forest depending species within the first 50 years following a fragmentation. Many species has already gone extinct in the 20th century due to loss and fragmentation of forest habitat, where 11 % of the world's birds, 18 % of the mammals, 5 % of the fishes and at least 8 % of the plants are threatened with extinction too (Vitousek *et al.*, 1997). Due to increased human population and their demands towards forest resources, about 10.4 million hectares of tropical forests were permanently destroyed worldwide in each year in the period from 2000 to 2005 (http://rainforests.mongabay.com/0801.htm). Moreover, the extreme poverty in many of the tropical developing countries causes loss of biodiversity, since the poverty forces local people to use short-sighted solutions without any concern of the future (Fjeldså, 2007). The utmost challenge for conservation of tropical rainforests for the future is to meet the needs of the present rapidly growing human population, but without compromising the ability of future generations to meet their own needs (UNEP, 2002).

Due to the threat of extinction, the Convention on Biological Diversity (CBD) in 1992 highlighted the global importance of biodiversity, and the need to protect our natural heritage for future generations (CBD, 1992). In supporting this, 190 countries worldwide including the government of the United Republic of Tanzania committed themselves to the Convention on Biological Diversity's 2010-goal, which aimed at significantly reducing the rate of biodiversity loss at global, regional and local levels, at the Johannesburg World Summit on Sustainable Development in 2002 (UNEP, 2002). For this goal to be more successful, focus needs to be put on conservation and development in the tropics, as biodiversity is not evenly distributed. Some areas are far richer on biodiversity than others (Mittermeier *et al.*, 1998, Myers *et al.*, 2000) and these areas are often those with few available resources for conservation (Balmford *et al.*, 2005).

1.4 Objectives of the Study

The study specifically looks at the following objectives within forest remnants in the Uluguru Mountains;

1. To determine and compare floristic composition, species diversity and structure of mature trees (≥ 10 cm DBH) among selected forests.
2. To determine understory composition, diversity and natural regeneration status of selected species among forest fragments.
3. To examine variation in species richness, diversity and density along the edge-interior gradient.
4. To examine indigenous use, tree use values and human population impacts on forest size, species richness and density in Uluguru forest fragments.

1.5 Significance of the Study

Understanding how plant populations respond to spatial and temporal environmental changes is an important aim of plant ecological research (Jongejans and de Kroon, 2005), as species strongly vary in space and time in response to micro-environmental variations in their habitats. Thus, the findings presented in this study provide valuable knowledge concerning the consequences of habitat fragmentation impacts on plant communities as well as the current understanding on species composition, diversity, natural regeneration and their distribution pattern within the fragments. Additionally, the study offers possible recommendations for future studies to be undertaken and it gives suggestions for management and conservation of the forest fragments and their biodiversity.

1.6 Description of the Study Area

1.6.1 Physical Profile

Uluguru Mountains forests (Figure 1.1) are located at about 200 km West of Dar Es Salaam City, and lies South of Morogoro town in Morogoro region. The Mountains form one of the component blocks of the Eastern Arc Mountains forests, stretching down the coast of East Africa from Taita hills in southern Kenya to Udzungwa Mountain in south-central Tanzania (Lovett, 1998; Munishi *et al.*, 2007). The Eastern Arc Mountains are known to be a biodiversity hotspot, a globally important ecoregion and an endemic bird area by conservation organizations such as Conservation International (Mittermeier *et al.*, 1998), the Worldlife Fund for Nature (Burgess *et al.*, 2004) and BirdLife International (Stattersfield *et al.*, 1998). The Uluguru Mountain cover an area of 1,500 km^2 and altitude ranges from *c.*150 m on the southern-eastern margin to a peak of 2630 m at its highest point above sea level (Burgess *et al.*, 2002). The Mountain bedrock is made up of Precambrian metamorphic rocks dominated by hornblende-pyroxenes granulites with injections of granite and gneiss (Munishi *et al.*, 2007).

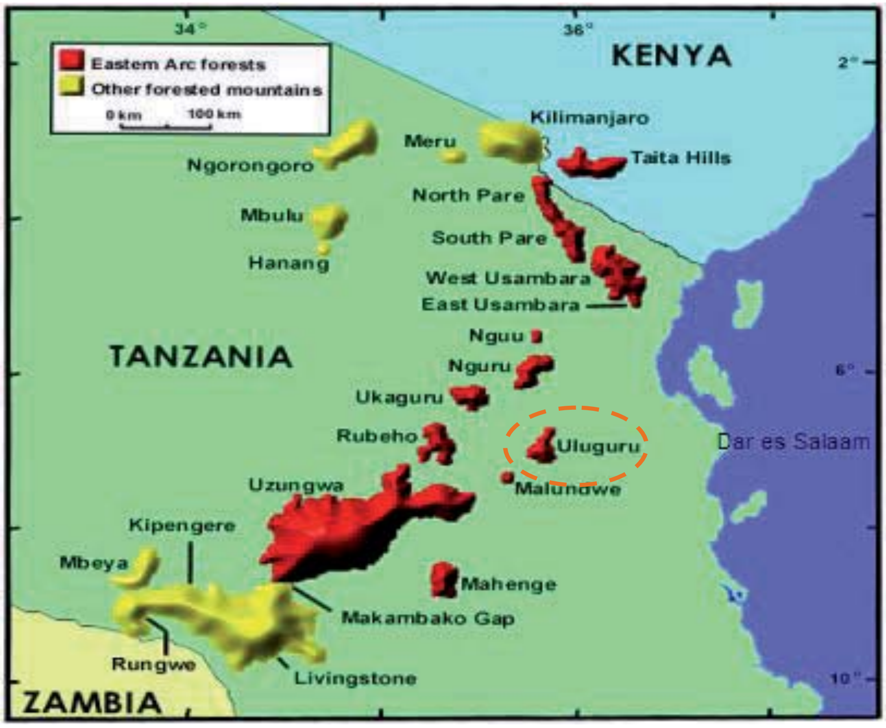


Figure 1.1: The map showing Eastern Arc forests (including Uluguru) and other Mountains forests. *(Source: Eastern Arc Conservation Endowment Fund)*

1.6.2 Climate Profile

The Uluguru Mountains forests are one of the wettest areas in Tanzania as they receive high rainfall and form vital water catchment in the country supplying Ruvu River the principal water supply to Dar Es Salaam where more than 6 million people live and most of the industries of Tanzania are based (Burgess *et al.*, 2002; Yanda and Munishi, 2007). The climate is oceanic due to proximity to Indian Ocean with bimodal rainfall regime, the long rains last from March to May peaking in April and the short rains last from October to December. The mean annual rainfall in Morogoro region is about 740 mm with the mean monthly minimum and maximum of 440 and 1094 mm of rainfall. The mean annual temperature is 25.1° C with the mean monthly maximum temperature of 30.6° C and the mean monthly minimum temperature of 19.7° C.

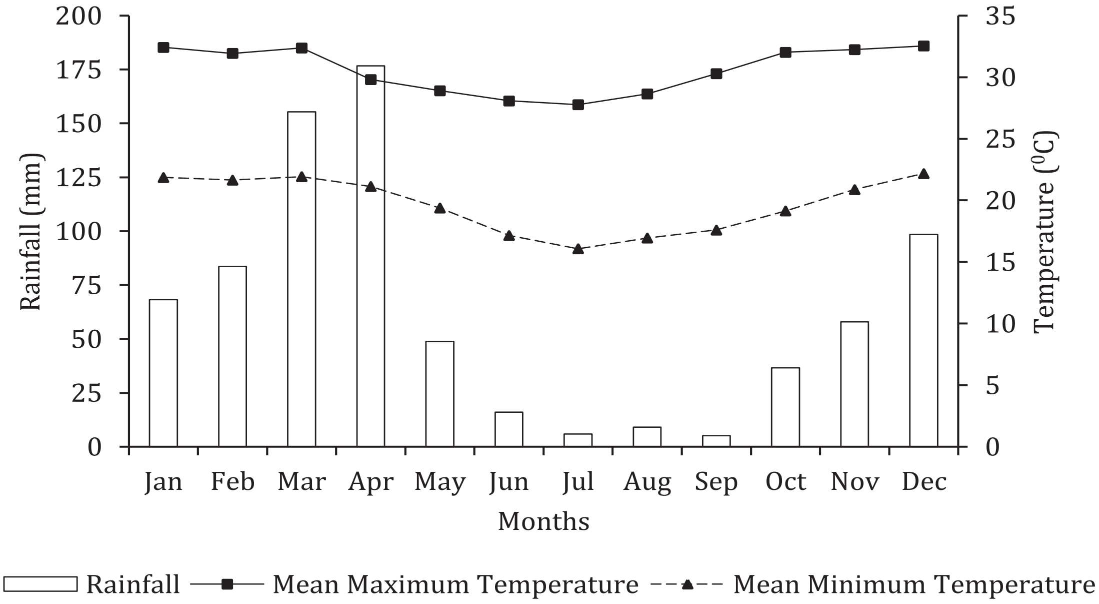


Figure 1.2: Monthly mean rainfall, mean maximum and mean minimum temperatures of Morogoro (2000 -2010).

Source: Morogoro Meteorological Station.

1.6.3 Population size and growth

According to the national population and housing census of 2002, Morogoro region had a population of 1,753,362 male accounting for 49.8 % and female 50.2 % with an average of 4.6 people per household. The regional population growth rate is 2.6 % per annum and had population density of 28 people per km in 2006. In 2002, Morogoro rural district had a population of 15 % of the total population of Morogoro region. The inter-censual population growth rate of the district was 2.2 % and 1.1 % between 1978-1988 and 1988-2002 respectively, the population density of 24 people per km and average household size of 4.7 in 2006. The decline in population between 1978 and 1988 was due to division of this district into two other districts (MRCO, 2006). The wards in which the studied forests are located had population of 2.8 %, 5.2 %, 6.1 % and 7.4 % of the total Morogoro rural district population by the year 2002 for Tawa, Kisemu, Kisaki and Mkuyuni ward respectively.

1.6.4 Socio-economic profile and land use

Agriculture is the main socio-economic activity for the majority of people living in the villages that surround the studied forests. Food and cash crops are grown at subsistence level under a low input system. Example of food crops includes maize, beans, rice, cassava, groundnuts, sorghum, sweet & Irish potatoes and vegetables while cash crops include bananas, oranges, cabbages, mangoes, coffee, groundnuts, sunflower and palm oil. The crops are normally taken to the market centres of Morogoro, Dodoma and Dar es Salaam via road whereas produce sent to distant markets like Mwanza and Kigoma region go via rail. Other land use practices include livestock keeping especially poultry, goats and cows to a lesser extent. Fishing and carpentry are done at a small scale (MNRT, 2004). People living near the forests are also engaged in collection of different forest materials such as firewood for domestic uses, leaves and barks of tree species for medicinal uses. Mining activities were also observed to exist in the vicinity/within the river banks of the Ruvu River at Kibangile village to near to Kimboza forest. It was noted that local small miners are to some extent involved in forest destruction at Kimboza through cutting of poles for building temporary and permanent huts/shelters (MNRT, 2004). Illegal timber harvesting was also observed in the forests. Moreover, other studies (Sheil, 1992; Kaale, 2004) have reported threats to coastal forest species due to uncontrolled and unsustainable extraction trees for timber, poles, charcoaling, expanding agricultural activities and wild fires.

1.6.5 Biodiversity Profile

Uluguru Mountain forests are one of the regions of biodiversity hotspots and centre of endemism for both, flora and fauna (Myers *et al.,* 2000). Moreover, Uluguru is known to harbour a significant proportion of endemic/near endemic species (Temu and Andrews, 2008) and common species population that occur in other parts of the world (Moreau, 1966; Lovett, 1988). Although the vegetation cover of these mountains is less than 2 % of Tanzania's land area, they harbour 30-40 % of countries flora and fauna and the level of endemism is much greater than the African average (Brenan, 1978). Thus, the Mountains are one of the 10 most important tropical forest sites for conservation on the African continent (Burgess *et al.,* 2002). About 108 endemic plant species are known to exist in the Mountain forests, the majority being shrubs followed by herbs, trees and climbers, many being confined to family Rubiaceae (38 species in 11 genera), Orchidaceae (13 species in 7 genera), and Balsaminaceae (11 species in 1 genus) (Temu and Andrew, 2008). At least 16 endemic vertebrate are known to exist, with hundreds of more taxa for both flora and fauna being shared only with other Eastern Arc forests (Burgess *et al.*, 2002).

1.6.6 Site selection

Seven forests were selected (Table 1.1 and Figure 1.3) based on the following criteria; (1) forest fragments of different sizes (2) minimum anthropogenic disturbances and (3) homogeneous topography *i.e.* lowland forests. Some common anthropogenic disturbances could be observed in almost all forests with common activities including removal of tree barks for medicinal purposes, trespassing, and trees cutting for timbers, firewood/charcoaling and poles for building purposes. All the forests were surrounded by villager's farmlands. Of the 7 forests, only Kimboza forest is owned by the central government under the Morogoro regional catchment forest office while others are under the local village government authorities. Kimboza forest extends from Mkuyuni to Kisemu ward, Kisego and Gunauye are in Mkuyuni ward, Milawilila and Ngambaula are in Tawa ward, while Kilengwe and Nemele are located in Kisaki and Mtombozi wards respectively.

Table 1.1: List of studied forests, location, area and altitude in Uluguru, Morogoro

Forest Name	Latitude/Longitude	Area (ha)	Altitude (m)
Kilengwe	07°29´S/37°32´E	995	182-228
Kimboza	07°00´S/37°48´E	405	300-400
Kisego	06°59´S/37°47´E	119	280-420
Milawilila	06°58´S/37°45´E	13	320-400
Nemele	07°11´S/37°46´E	8	280-500
Ngambaula	06°58´S/37°45´E	3	480-594
Gunauye	06°58´S/37°50´E	3	300-420

1.7 Scope of the Thesis

This dissertation is structured into six chapters. This chapter provides the theoretical background, objectives, significance of the study and describes in details the study areas. Chapter 2 to 5 form an empirical part of the thesis, and address the four objectives respectively. Chapter two addresses the floristic composition, species diversity and structure of trees with DBH ≥ 10 cm in the selected Uluguru forests. Chapter three describes the understory species composition, richness, diversity and natural regeneration of the forests. Chapter four addresses the variations of species richness and diversity of four compartments (overstory, large saplings, small saplings and seedlings) along the edge-interior gradient in all the selected forests. Chapter five describes the uses and use values of different tree species by the local community in Uluguru. Finally, chapter six provides a general discussion of all the findings in relation to the objectives and gives conclusion as well as recommendations for further studies.

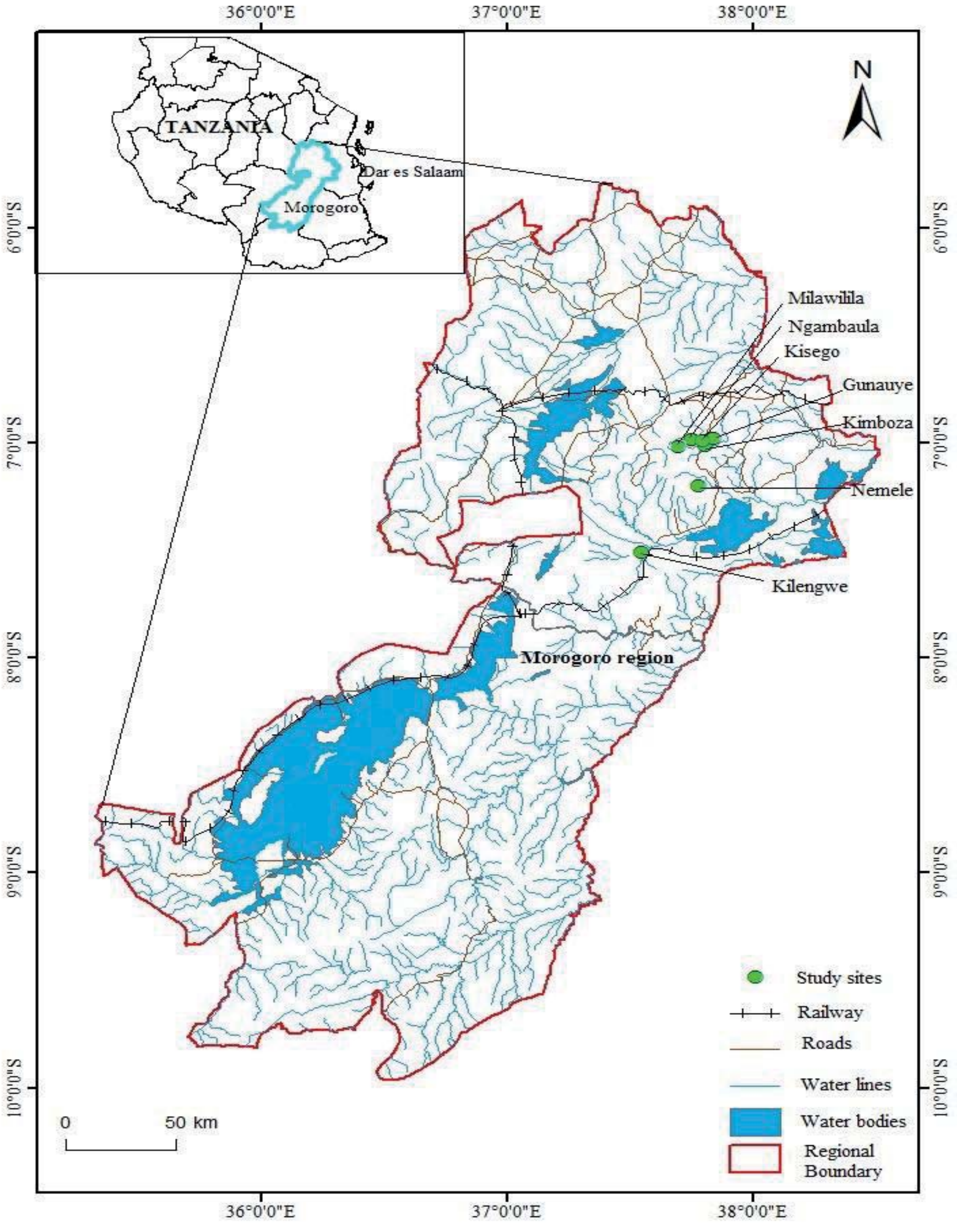


Figure 1.3: The map showing location of the study sites in Morogoro region.

CHAPTER TWO

Floristic Composition, Diversity and Structure of Uluguru Forests in Morogoro, Tanzania.

2.1 Introduction

Tropical forests are known to be the most species-rich terrestrial ecosystems, which, in many developing countries, provide natural resources to help sustain nearby communities (Gentry, 1988; Kumar *et al.*, 2006). Tree diversity is fundamental to total tropical biodiversity as trees provide resources (food, shade) and habitat to other forest organisms (Huang *et al.*, 2003; Nirmal *et al.*, 2011). Tree species differ greatly from one place to the other in most tropical forests mainly due to variations in their biogeography, habitat and disturbances (Whitmore, 1998). There are variations in species composition at all scales (Huang *et al.*, 2003). Philips and Gentry (1994) reported a variation of 56-283 tree species ha $^{-1}$ with DBH > 10 cm in tropical forests. In neo-tropical forests (*i.e.* forests in South and Central America, the Mexican lowlands, the Caribbean islands and Southern Florida) the maximum tree (DBH > 10 cm) species richness is up to 300 species ha^{-1} (Gentry, 1988) while in Southeast Asia, the highest richness is up to 225 species ha^{-1} (Whitmore, 1984). Bernhard-Reversat *et al.*, (1978) reported a maximum of 60 species ha^{-1} in African forests, with a number of other studies reporting much higher species richness than this figure (*e.g.* Hall and Swaine, 1981; Huang *et al.*, 2003; Mwavu, 2007) for trees with DBH ≥ 10 cm.

Regardless of the fact that tropical rainforests are known to be speciose, they are vulnerable to deforestation and degradation (Madoffe *et al.*, 2006; LaFrankie *et al.*, 2006), which ultimately lead to habitat fragmentation (Tabarelli *et al.*, 2004). In order to guide nature conservation efforts worldwide, Myers *et al.*, (2000) emphasized the concept of biodiversity hotspots, which considers regions with an exceptional concentration of endemic species and which experience high rate of habitat loss due to natural and anthropogenic degradation. The authors proposed that the protection and conservation activities should focus more on these hotspots. The Eastern Arc and other coastal forests (Uluguru forests inclusive) of Tanzania are one of the 25 worldwide identified hotspots and are estimated to host 4000 plant species of which 38 % are known to be endemic (Myers *et al.*, 2000).

Although harbouring many endemic species, Uluguru forests are facing the danger of losing some of these species due to increased anthropogenic activities and fragmentation (Newmark, 1998; Temu and

Andrew, 2008). Increased forest fragmentation has been described as great threat to forest biodiversity as it results to species loss (Turner, 1996; Hill and Curran, 2001). A rapid human population increase in proximity to many forests is putting more pressure on these ecosystems as more farmlands are needed for agriculture to increase produce, timbers and poles for building purposes and increasing cutting of trees and poles for firewood/charcoaling as an energy source. On the other hand, low productivity of agricultural activities promotes illegal annexing of forest lands for cultivation and habitation, locals hunt small animals for food and fire risk further threatens the forests (Burgess *et al.*, 2002, 2007). Such threats, which should not be underestimated, are also occurring in other biodiversity hotspots within the country (Madoffe *et al.*, 2006). Consequently, more attention is needed on research and biodiversity conservation in these ecosystems.

Studies on floristic composition and structure in forests has become an essential instrument in assessing the sustainability of the forests and the role they play in the conservation of species and management of the forest ecosystems (Ssegawa and Nkuutu, 2006; Madoffe *et al.*, 2006; Nirmal *et al.*, 2011). The present study aimed at: (1) providing information on the current status of the floristic composition, structure and species diversity of trees with DBH ≥ 10 cm in the selected Uluguru forest fragments; (2) comparing the present findings with other selected forest inventories in Tanzania (3) determining the relationship between forest fragments area with number of trees species, tree density, basal area, and variously used diversity measures and (4) evaluating an influence of geographical distances on floristic similarities between forests. The results are expected to improve our knowledge on the status of the tropical rainforests and provide a positive contribution to biodiversity conservation.

2.2 Material and Methods

2.2.1 Data Collection

All trees with diameter at breast height (DBH) ≥ 10 cm measured at 1.3 m above the ground were sampled from total of 114 plots of 20 m x 20 m (0.04 ha) each. A total of 18 plots were established at Kimboza, Kisego, Kilengwe, Milawilila and Nemele forest while 12 plots of the same size were used at Ngambaula and Gunauye forest. Trees were counted, identified and stem diameters were measured using normal measuring tape and thereafter the values were divided by *pi*- value ($\pi = 3.14$) to obtain the real diameter at breast height (DBH). Trees with multiple stems at 1.3 m height were treated as the single individual whereby the diameters of all stems were taken and averaged. If a tree had buttress or an abnormality at 1.3 m height, the diameter was measured just above the buttress where the stem assumes near cylindrical shape. Additionally, other 30 forest inventories compiled by other authors (Table 2.8) were used. Only inventories that met the following criteria were considered: (1) minimum DBH of 10 cm (2) information on the number of species, basal area and number of individuals, and (3) identification of individual trees at species level.

2.2.2 Data Analysis

Composition and structure of the forests

Floristic composition of the forests was described by family/species dominance while the structure of the forests was described by stems density (stems ha^{-1}), basal area ($m^2\ ha^{-1}$) and size class distributions (SCDs). The dominance of species was determined by the species importance value index (IVI), which was calculated by summing up relative dominance/basal area (RDo), relative density (RDe) and relative frequency/occurrence (Rf) (Curtis and McIntosh, 1950 (formula 2.1)). The familial importance value index (FIV) of every family was calculated as the sum of relative density (RDe), relative diversity (RDi) and relative dominance (RDo) (Mori *et al.*, 1983 (formula 2.2)). Basal area was calculated according to formula 2.3 below.

$$\mathrm{IVI} = \mathrm{Rf} + \mathrm{RDe} + \mathrm{RDo} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..2.1$$

$$\mathrm{FIV} = \mathrm{RDe} + \mathrm{RDi} + \mathrm{RDo} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..2.2$$

Where;

$$\mathrm{RDo} = \frac{\text{Frequency of a species}}{\text{Total frequency of all species}} \text{ x } 100$$

$$\mathrm{RDo} = \frac{\text{Basal area of a species/family}}{\text{Total basal area of all species/family}} \text{ x } 100$$

$$\mathrm{RDe} = \frac{\text{Number of individuals of a species/family}}{\text{Total number of individuals of all species/family}} \text{ x } 100$$

$$\mathrm{RDi} = \frac{\text{Number of species in a family}}{\text{Total number of species in all families}} \text{ x } 100$$

$$Basal\ area = 0.00007854\ \times DBH^2 \ldots\ldots\ldots\ldots..2.3$$

Where: DBH = Diameter at breast height in centimetre (cm)

A total of 7 size class distributions arranged in 10 cm intervals were formed based on recorded trees diameters for all the forests. Differences of the structural characteristics (*i.e.* stand density and basal area) between forests were tested using one-way analysis of variance (ANOVA) followed by the *post-hoc* Tukey's HSD multiple comparison test.

Species richness, diversity and similarity

The number of observed species in each forest and three non-parametric richness estimators (Michaelis-Menten (MMMeans), first order Jackknife and Chao 2) were used as measure of species richness (Magurran, 2004). These richness estimators were computed using the *EstimateS* software (version 8.2, Collwell, 2009). Species accumulation curves were constructed for comparing the increase of number of species with increasing sample size for every forest (Magurran, 2004). A range of commonly used alpha diversity measures, Shannon-Wiener's, Simpson's and Fisher's α - diversity for each forest were computed and compared using species richness and diversity IV (SDR IV) Software (Seaby and Henderson, 2006). A multivariate agglomerative clustering technique using Ward's group linkage and Sørensen coefficient of similarities (Sørensen, 1948) was performed using the community analysis package version 4 (CAP IV) (Seaby and Henderson, 2006) to analyse species compositional similarities between the studied forests, also a variety of 30 other selected coastal forest inventories (Table 1.9) from Morogoro and Tanga region were involved too. The relationship between forest floristic similarities and geographical distances as well as that of forest size with number of trees species, density, basal area, and diversity measures were determined by Pearson correlation test.

2.3 Results

2.3.1 Overall floristic composition

A total of 900 individual trees (1335 stems ha^{-1}) with a DBH ≥ 10 cm at breast height (1.3 m) belonging to 101 species, 73 genera and 31 families were recorded in the seven forests (Table 2.1). The most speciose family was Fabaceae (31 species), followed by Moraceae (6 species), Sterculiaceae (5), Combretaceae, Apocynaceae and Clusiaceae (4 species each), Euphorbiaceae, Sapotaceae, Annonaceae, Anacardiaceae, Bignoniaceae, Araliaceae (3 species each), all accounted for 73.3 % of the recorded species in the 7 forests. The most five abundant species were *Ehretia amoena* which accounted for 9.0 % of the total recorded stems, followed by *Sorindeia madagascariensis* (5.9 %), *Khaya anthotheca* (4.6 %), *Albizia versicolor* (4.1 %) and *Diospyros squarrosa* (3.8 %). Moreover, *Ehretia amoena, Sorindeia madagascariensis, Diospyros squarrosa, Albizia versicolor* and *Scorodophloeus fischeri were* the most frequent species in all the forests. Only 15 % of the observed species occurred in one plot out of the surveyed plots in all the forests.

Table 2.1: Family, genera, richness, stem density and basal area in the studied forests in Uluguru

Forests	Family	Genera	Observed Species	Species ha^{-1}	Stems ha^{-1}	Basal Area (m^2 ha^{-1})
Kilengwe	26	54	67	93	276 ± 35^{ab}	8 ± 1^{bc}
Kimboza	22	39	52	72	390 ± 52^{a}	24 ± 5^{a}
Kisego	12	19	21	29	140 ± 14^{c}	3 ± 0^{c}
Milawilila	15	18	20	28	172 ± 14^{bc}	13 ± 3^{b}
Nemele	13	16	19	26	97 ± 10^{c}	5 ± 3^{c}
Ngambaula	9	15	17	35	85 ± 15^{c}	3 ± 1^{c}
Gunauye	14	19	22	46	175 ± 27^{bc}	5 ± 1^{c}

*Values with different letters indicate significant differences between the forests (Tukey's test, $p < 0.05$).

In terms of FIV, Fabaceae was the overall most important family accounting for 27.6 % of the total FIV followed by Moraceae and Meliaceae with 7.9 % and 6.9 % respectively. The ten most important families in terms of FIV accounted for 72.5 %, 74.1 %, 81.9 % and 61.4 % of the total FIV, stems density, basal area and total species respectively (Table 2.3). *Ehretia amoena* was the most important species with 7.5 % of the total IVI. The ten most important species (Table 2.4) in terms of IVI contributed 42.3 %, 52.1 %, and 41.6 % of the total IVI, basal area and total stems density. The remaining species had IVI values less than 8.8. Among observed species, 12.8 % (13 species) are threatened species on the 2010 plant red list, of which one is endangered, five vulnerable, five near threatened/lower riskand one is least concern (Table 2.2). Moreover, five endemic/near endemic species were recorded, namely *Allanblackia stuhlmannii*, *Ophrypetalum odoratum*, *Allanblackia uluguruensis*, *Cynometra uluguruensis*, and *Scorodophloeus fischeri*.

Table 2.2: List of threatened species encountered and their abundances in the surveyed Uluguru forests.

Species Name	No. of Stems	No. of Plots	Conservation Status
Khaya anthotheca (Welw.) C.DC.	41	9	Vulnerable
Milicia excelsa (Welw.) C. Berg.	17	14	Near threatened
Pterocarpus angolensis DC.	1	1	Near threatened
Pandanus rabaiensis Rendle	6	4	Near threatened
Ophrypetalum odoratum Diels	8	5	Vulnerable
Millettia sacleuxii Dunn	2	2	Vulnerable
Dalbergia melanoxylon Guill.&Perr.	3	3	Near threatened
Cynometra uluguruensis Harms	4	3	Endangered
Allanblackia stuhlmannii (Engl.) Engl.	4	4	Vulnerable
Allanblackia uluguruensis Engl.	4	4	Vulnerable
Cussonia zimmermannii Harms	1	1	Least Concern
Pouteria altissima (A.Chiev.) Aubrev.& Pell.	1	1	Conservation dependent
Holarrhena pubescens Wall. ex G. Don	2	3	Least Concern

Data Source: IUCN Red List of Threatened Species. Version 2012.2. Oder of conservation status by risk of extinction: Extinct (extinct and extinct in the wild); Threatened (critically endangered, endangered and vulnerable); Lower risk (conservation dependent, near threatened and least concern).

2.3.2 Floristic patterns at family level within forests

The most speciose family at Kilengwe forest were Fabaceae (21 species), followed by Moraceae (5 species), Sterculiaceae (4 species), Combretaceae, Sapotaceae and Bignoniaceae (3 species each).

These six families accounted for 58.2 % of the total species at Kilengwe. The rest of families had ≤ 2 species, with 12 of them having only one species each. Among the top ten families with higher FIV, Fabaceae was the dominant with 38.6 % of the total FIV, followed by Moraceae (7.0 %), Sterculiaceae (6.1 %), Bignoniaceae (4.5 %) and Sapotaceae (4.4 %). The top ten families in this forest accounted for 75.7 %, 82.6 %, 74.4 % and 70.1 % of the total FIV, relative dominance, stems density and observed species respectively. Family Fabaceae was the most abundant, diverse and had greater basal area with 34.3 %, 31.3 % and 47.2 % of the total density, observed species and relative dominance in the forest respectively (Table 2.3).

In Kimboza forest, the most species-rich family was Fabaceae (15 species), followed by Moraceae (5 species) and Sterculiaceae (4 species). Fabaceae had highest FIV, which accounted for 22.2 % of the total FIV, followed by Meliaceae (15.5 %) and Moraceae (13.8 %). The ten most important families at Kimboza (Table 2.3) contributed for 82.0 %, 84.0 %, 71.2 % and 90.9 % of the total FIV, stems density, observed species, and relative dominance respectively. Family Meliaceae had greater relative dominance accounting for 31.5 % of the total in the forest, followed by Moraceae and Fabaceae with 20.6 % and 18.3 % respectively. The three most abundant families were Fabaceae, Meliaceae and Moraceae, which totaled 19.6 %, 13.2 % and 11.0 % of the total stems density in the forest respectively.

In Kisego forest, the most speciose family was Fabaceae with 7 species. The remaining families had ≤ 3 species. The ten most important families in this forest (Table 2.3) accounted for 95.7 %, 98.7 %, 98.0 % and 90.5 % of the total FIV, relative dominance, stems density and total observed species in the forest respectively. Family Fabaceae was the most important family accounting for 35.0 % of the total FIV, followed by Boraginaceae (18.6 %), Annonaceae (10.2 %) and Moraceae (7.5 %). In terms of basal area, Fabaceae was the dominant family with 31.2 % of the relative dominance, followed by Boraginaceae, Annonaceae, and Euphorbiaceae with 29.3 %, 11.9 % and 11.6 % respectively. Fabaceae, Bignoniaceae and Annonaceae were the most abundant families with 40.6 %, 21.8 % and 13.9 % of the total stems density respectively.

In Milawilila forest, Annonaceae was the most important family with 17.9 % of the total FIV, followed by Sapotaceae (14.8 %), Fabaceae (11.2 %) and Boraginaceae (11.0 %). The ten most important families (Table 2.3) with higher FIV accounted for 84.9 %, 94.9 %, 84.7 % and 75.0 % of the total FIV, relative dominance, stems density and observed species respectively. Fabaceae and Clusiaceae were the most speciose families with 3 species each. The three most abundant families were Annonaceae, Boraginaceae and Fabaceae, which accounted for 21.8 %, 16.9 % and 11.3 % of the total stems density respectively. Sapotaceae, Annonaceae and Boraginaceae had higher relative dominance of 32.1 %, 21.9 %, and 11.0 % respectively.

In Nemele forest, the ten most important families (Table 2.3) contributed for 92.0 %, 97.4 %, 94.3 % and 84.2 % of the total FIV, relative dominance, stems density and recorded species respectively. Fabaceae was the most important family accounting for 37.7 % of total FIV, followed by Sapotaceae (10.0 %) and Boraginaceae (9.1 %). The most speciose family was Fabaceae with 36.8 % while the remaining families had only one species each. Fabaceae was the most abundant family with 26.6 % of total stems density, followed by Boraginaceae (11.4 %), Loganiaceae and Apocynaceae (10.0 % each). Fabaceae had higher relative dominance of 47.6 %, followed by Sapotaceae and Boraginaceae with 16.0 % and 10.7 % respectively.

In Ngambaula forest, only nine families (Table 2.3) were recorded. The most speciose families were Fabaceae (6 species) followed by Moraceae (4 species). The remaining families had only one species each. Fabaceae was the most abundant family accounting for 34.1 % of the total stems ha^{-1} in the forest, followed by Moraceae (17.1 %) and Ebenaceae (14.6 %). Sterculiaceae, Fabaceae and Ebenaceae had higher relative dominance of 52.6 %, 18.4 % and 11.7 % respectively. Fabaceae, Sterculiaceae and Moraceae were the most important species contributing 29.3 %, 23.6 % and 16.2% of the total FIV respectively.

In Gunauye forest, the top ten families with highest FIV accounted for 90.1 %, 97.0 %, 91.7 % and 81.8 % of the total FIV, relative dominance, density and recorded species respectively (Table 2.3). The families with highest FIV were Fabaceae with 33.2 % of total FIV, followed by Bombacaceae (12.7 %) and Moraceae (12.0 %). The most speciose families were Fabaceae (5 species) Moraceae (4) Ebenaceae (2). The remaining families had only one species each. The family Fabaceae was the most abundant contributing for 33.3 % of the total stems, followed by Moraceae and Anacardiaceae each contributing by 11.9 % of the total stems density. Fabaceae and Bombacaceae had higher relative dominance of 43.4 % and 25.1 % respectively.

Table 2.3: List of the top ten families with highest FIV in the studied Uluguru forests

(NS = Number of Species, D = Density (stems ha^{-1}), RDi = Relative diversity, RDe = Relative density, RDo = Relative dominance and FIV = Familial Importance Value).

Family	NS	D	RDi	RDe	RDo	FIV
Overall						
Fabaceae	33	53	32.7	26.9	23.1	82.7
Moraceae	6	14	5.9	7.2	10.5	23.7
Meliaceae	2	9	2.0	4.8	13.9	20.7
Boraginaceae	1	18	1.0	9.0	7.3	17.3
Annonaceae	3	13	3.0	6.3	6.5	15.8
Sapotaceae	3	6	3.0	2.8	9.1	14.9
Sterculiaceae	5	8	5.0	3.9	4.4	13.2
Anacardiaceae	3	13	3.0	6.7	2.8	12.5
Ebenaceae	2	8	2.0	4.2	3.1	9.3
Apocynaceae	4	5	4.0	2.3	1.1	7.4
∑ 1 - 10	62	146	61.4	74.1	81.9	217.4
∑ 11 - 31	39	51	38.6	25.9	18.1	82.6
Total	101	197	100	100	100	300
Kilengwe F.R						
Fabaceae	21	103	31.3	37.2	47.2	115.7
Moraceae	5	17	7.5	6.0	7.5	21.0
Sterculiaceae	4	18	6.0	6.5	5.8	18.3
Bignoniaceae	3	15	4.5	5.5	3.5	13.5
Sapotaceae	3	14	4.5	5.0	3.8	13.3
Combretaceae	3	10	4.5	3.5	2.9	10.9
Loganiaceae	2	10	3.0	3.5	2.9	9.4
Annonaceae	2	10	3.0	3.5	2.7	9.2
Euphorbiaceae	2	6	3.0	2.0	3.1	8.1
Clusiaceae	2	4	3.0	1.5	3.2	7.7
∑ 1 - 10	47	206	70.1	74.4	82.6	227.1
∑ 11- 26	20	70	29.9	25.6	17.4	72.9
Total	67	276	100	100	100	300
Kimboza F.R						
Fabaceae	15	76	28.8	19.6	18.3	66.7
Meliaceae	1	51	1.9	13.2	31.5	46.6
Moraceae	5	43	9.6	11.0	20.6	41.3
Anacardiaceae	2	40	3.8	10.3	4.0	18.2
Boraginaceae	1	33	1.9	8.5	5.1	15.6
Sterculiaceae	4	17	7.7	4.3	3.3	15.2
Tiliaceae	2	27	3.8	6.0	3.6	13.5

Verbenaceae	2	18	3.8	4.6	2.2	10.7
Combretaceae	3	13	5.8	3.2	0.9	9.9
Annonaceae	2	13	3.8	3.2	1.2	8.3
∑ 1 - 10	37	328	71.2	84.0	90.9	246.0
∑ 11- 22	15	62	28.8	16.0	9.1	54.0
Total	52	390	100	100	100	300
Kisego F.R						
Fabaceae	7	57	33.3	40.6	31.2	105.1
Boraginaceae	1	31	4.8	21.8	29.3	55.8
Annonaceae	1	19	4.8	13.9	11.9	30.5
Moraceae	3	7	14.3	5.0	3.4	22.6
Euphorbiaceae	1	4	4.8	3.0	11.6	19.3
Sapindaceae	2	4	9.5	3.0	2.2	14.7
Vitaceae	1	6	4.8	4.0	3.7	12.4
Apocynaceae	1	4	4.8	3.0	1.7	9.5
Meliaceae	1	3	4.8	2.0	2.6	9.3
Araliaceae	1	3	4.8	2.0	1.3	8.0
∑ 1 - 10	19	137	90.5	98.0	98.7	287.2
∑ 11- 12	2	3	9.5	2.0	1.3	12.8
Total	21	141	100	100	100	300
Nemele F.R						
Fabaceae	7	28	36.8	28.6	47.6	113.1
Sapotaceae	1	8	5.3	8.6	16.0	29.9
Boraginaceae	1	11	5.3	11.4	10.7	27.4
Apocynaceae	1	10	5.3	10.0	6.9	22.2
Loganiaceae	1	10	5.3	10.0	3.7	19.0
Ebenaceae	1	6	5.3	5.7	4.2	15.2
Anacardiaceae	1	7	5.3	7.1	2.2	14.7
Rubiaceae	1	4	5.3	4.3	2.3	11.8
Bombacaceae	1	4	5.3	4.3	2.2	11.7
Combretaceae	1	4	5.3	4.3	1.4	10.9
∑ 1 - 10	16	94	84.2	94.3	97.4	275.9
∑ 11- 13	3	3	15.8	5.7	2.6	24.1
Total	19	97	100	100	100	300
Milawilila F.R						
Annonaceae	2	38	10.0	21.8	21.9	53.6
Sapotaceae	1	12	5.0	7.3	32.1	44.3
Fabaceae	3	19	15.0	11.3	7.3	33.6
Boraginaceae	1	29	5.0	16.9	11.0	33.0
Ebenaceae	1	15	5.0	8.9	7.3	21.2

Clusiaceae	3	7	15.0	4.0	1.8	20.8
Bombacaceae	1	4	5.0	2.4	5.2	12.6
Anacardiaceae	1	9	5.0	5.6	1.3	12.0
Rhizophoraceae	1	3	5.0	1.6	5.2	11.8
Apocynaceae	1	8	5.0	4.8	1.8	11.6
∑ 1 - 10	15	146	75.0	84.7	94.9	254.6
∑ 11- 15	5	26	25.0	15.3	5.1	45.4
Total	20	172	100	100	100	300
Ngambaula F.R						
Fabaceae	6	29	35.3	34.1	18.4	87.9
Sterculiaceae	1	10	5.9	12.2	52.6	70.7
Moraceae	4	15	23.5	17.1	7.9	48.5
Ebenaceae	1	13	5.9	14.6	11.7	32.2
Anacardiaceae	1	8	5.9	9.8	3.2	18.8
Meliaceae	1	4	5.9	4.9	2.1	12.8
Boraginaceae	1	2	5.9	2.4	2.5	10.8
Sapindaceae	1	2	5.9	2.4	1.0	9.3
Tiliaceae	1	2	5.9	2.4	0.6	8.9
Total	17	85	100	100	100	300
Gunauye F.R						
Fabaceae	5	58	22.7	33.3	43.4	99.5
Bombacaceae	1	15	4.5	8.3	25.1	38.0
Moraceae	4	21	18.2	11.9	5.6	35.7
Anacardiaceae	1	21	4.5	11.9	7.4	23.9
Sapindaceae	1	13	4.5	7.1	6.2	17.8
Ebenaceae	2	10	9.1	6.0	2.5	17.6
Euphorbiaceae	1	8	4.5	4.8	2.8	12.1
Araliaceae	1	6	4.5	3.6	1.4	9.5
Loganiaceae	1	4	4.5	2.4	1.4	8.4
Rubiaceae	1	4	4.5	2.4	1.1	8.0
∑ 1 - 10	18	160	81.8	91.7	97.0	270.5
∑ 11- 14	4	15	18.2	8.3	3.0	29.5
Total	22	175	100	100	100	300

2.3.3 Floristic patterns at the species level within forests

In Kilengwe forest, the top ten species in terms their IVI accounted to 31.2 %, 26.9 % and 36.5 % of the total IVI, stems density and relative dominance respectively (Table 2.4). The dominant and co-dominant species were *Julbernardia globiflora* and *Dalbergia melanoxylon* accounting for 4.4 % and 3.8 % of the total IVI respectively. The most abundant species were *Brachystegia speciformis*, *Julbernardia globiflora*, *Burkea africana* and *Synsepalum cerasiferum* which all together contributed 14.5 % of the total stems density. *Dalbergia melanoxylon* and *Julbernardia globiflora* were also the dominant and co-dominant species with 8.1 % and 6.0 % of the total relative dominance respectively.

In Kimboza, the top ten species with highest IVI contributed for 56.2 %, 56.6 % and 74.7 % of the total IVI, stems density and relative dominance respectively (Table 2.4). *Khaya anthotheca* was the dominant species accounting for 16.0 % of the total IVI, followed by *Antiaris toxicaria* (7.7 %). *Khaya anthotheca*, *Sorindeia madagascariensis* and *Ehretia amoena* were the most abundant species accounting for 13.2 %, 9.6 % and 8.5 % of the total stems density respectively. *Khaya anthotheca* and *Antiaris toxicaria* had higher relative dominance of 31.5 % and 10.9 % respectively.

In Kisego forest, the top ten species with highest IVI accounted for 84.4 %, 85.1 % and 89.6 % of the total IVI, stems density and relative dominance respectively (Table 2.4). *Ehretia amoena* and *Albizia versicolor* were the dominant and co-dominant species, accounting for 22.1 % and 12.3 % of the total IVI respectively. The three most abundant species were *Ehretia amoena*, *Albizia versicolor* and *Annona senegalensis* accounting for 21.8 %, 14.9 % and 13.9 % of the total stems density respectively. *Ehretia amoena*, *Annona senegalensis* and *Bridelia micrantha* had higher relative dominance of 29.3 %, 11.9 %, and 11.6 % respectively.

In Milawilila forest, the top ten species contributed for 79.6 %, 79.0 % and 87.0 % of the total IVI, stems density and relative dominance respectively (Table 2.4). The most important species were *Xylopia parviflora* and *Synsepalum cerasiferum* each accounting for 18.2 % and 16.4 % of the total IVI respectively. These species had higher relative dominance too, where *Synsepalum cerasiferum* accounted for 32.1 % and *Xylopia parviflora* 20.4 % of the total relative dominance. The three most abundant species were *Xylopia parviflora*, *Ehretia amoena* and *Diospyros squarrosa* accounting for 20.2 %, 16.9 % and 8.9 % of the total stems density respectively.

In Nemele forest, the top ten species contributed for 78.7 %, 74.3 % and 90.9 % of the total IVI, stems density and relative dominance respectively (Table 2.4). The species with highest IVI were *Brachystegia bussei* and *Synsepalum cerasiferum* accounting for 13.5 % and 11.2 % of the total IVI respectively. *Sorindeia madagascariensis*, *Delonix elata*, *Strychnos spinosa* and *Voacanga africana* were the most abundant species, which all together accounted for 42.8 % of the total stems density. Additionally, *Brachystegia bussei* and *Synsepalum cerasiferum* had higher relative dominance of 37.3 % and 16.0 % respectively.

In Ngambaula forest, the top ten species accounted for 85.8 %, 82.9 % and 94.6 % of the total IVI, density and relative dominance respectively (Table 2.4). The most important species were *Dombeya natalensis* and *Diospyros squarrosa* contributing for 25.4 % and 13.5 % of the total IVI respectively. Moreover, these species had higher relative dominance, all together accounting for 64.3 % of the total. The most abundant species were *Diospyros squarrosa* and *Brachystegia boehmii* each with 14.6 % and *Dombeya natalensis* with 12.2 % of the total stems.

In Gunauye forest, the ten most important species accounted for 77.9 %, 76.2 % and 88.7 % of the total IVI, stems density and relative dominance respectively (Table 2.4). The two species with highest IVI were *Bombax rhodognaphalon* and *Albizia versicolor*, which accounted for 13.7 % and 12.3 % of the total IVI respectively. *Albizia versicolor*, *Sorindeia madagascariensis* and *Scorodophloeus fischeri* were the three most abundant species with 14.3 %, 11.9 % and 9.5 % of the total stems density respectively while *Bombax rhodognaphalon* and *Scorodophloeus fischeri* had higher relative dominance of 25.1 % and 16.1 % respectively.

Table 2.4: List of the top ten species with the highest IVI in the studied Uluguru forests

(Rf = Relative frequency, RDe = Relative density, RDo = Relative dominance and IVI = Species Importance Value Index)

Family	**Species**	**Rf**	**RDe**	**RDo**	**IVI**
Overall					
Boraginaceae	*Ehretia amoena* Klotzsch.	6.3	9.0	7.3	22.5
Meliaceae	*Khaya anthotheca* (Welw.) C.DC.	1.4	4.6	13.8	19.8
Sapotaceae	*Synsepalum cerasiferum* Welw.	2.9	2.4	9.1	14.4
Anacardiaceae	*Sorindeia madagascariensis* DC.	5.1	5.9	2.6	13.6
Ebenaceae	*Diospyros squarrosa* Klotzsch.	4.0	3.8	3.0	10.8
Annonaceae	*Xylopia parviflora* (A.Rich.) Benth.	2.1	2.8	4.7	9.6
Moraceae	*Antiaris toxicaria* (Pers.) Lesch.	1.9	2.7	4.8	9.4
Fabaceae	*Albizia versicolor* Welw. ex Oliv.	3.4	4.1	1.6	9.1
Fabaceae	*Albizia glaberrima* (Schum.&Thonn)Benth	3.0	2.9	3.0	9.0
Fabaceae	*Scorodophloeus fischeri* (Taub) J. Leon	3.2	3.4	2.1	8.8

∑ 1 - 10		33.4	41.6	52.1	127.0
∑ 11 - 101		66.6	58.4	47.9	173.0
Total		100	100	100	300
Kilengwe F.R					
Fabaceae	*Julbernardia globiflora* (Benth.)Troupin.	3.7	3.5	6.0	13.3
Fabaceae	*Dalbergia melanoxylon* Guill. & Perr.	1.9	1.5	8.1	11.5
Fabaceae	*Brachystegia speciformis* Benth.	3.7	4.0	3.2	11.0
Fabaceae	*Burkea africana* Hook.f.	3.1	3.5	3.6	10.2
Sapotaceae	*Synsepalum cerasiferum* (Welw.)T.D.Penn.	3.1	3.5	3.2	9.8
Fabaceae	*Albizia glaberrima* (Schum.&Thonn.)Benth	2.5	2.5	3.2	8.2
Annonaceae	*Ophrypetalum odoratum* Diels	2.5	3.0	2.4	7.9
Sterculiaceae	*Dombeya natalensis* Sond	2.5	3.0	2.0	7.5
Boraginaceae	*Ehretia amoena* Klotzsch.	1.9	2.5	2.8	7.1
Bignoniaceae	*Markhamia obtusifolia* (Baker) Sprague	2.5	2.5	1.9	6.9
∑ 1 - 10		27.3	29.6	36.5	93.5
∑ 11 - 67		72.7	70.4	63.5	206.5
Total		100	100	100	300
Kimboza F.R					
Meliaceae	*Khaya anthotheca* (Welw.) C. DC.	3.4	13.2	31.5	48.1
Moraceae	*Antiaris toxicaria* (Pers.) Lesch.	5.4	6.8	10.9	23.1
Boraginaceae	*Ehretia amoena* Klotzsch.	6.1	8.5	5.1	19.8
Anacardiaceae	*Sorindeia madagascariensis* DC.	2.7	9.6	3.7	16.1
Moraceae	*Milicia excelsa* (Welw.) C. Berg.	3.4	2.8	8.8	15.1
Tiliaceae	*Grewia similis* K. Schum.	3.4	5.0	3.2	11.6
Fabaceae	*Scorodophloeus fischeri* (Taub) J. Leon	4.8	4.3	1.1	10.1
Fabaceae	*Acacia polyacantha* Wild.	3.4	2.5	2.8	8.7
Fabaceae	*Brachystegia boehmii* Taub.	2.0	1.4	4.8	8.3
Loganiaceae	*Strychnos spinosa* Lam.	2.7	2.5	2.7	7.9
∑ 1 - 10		37.4	56.6	74.7	168.7
∑ 11 - 52		62.6	43.4	25.3	131.3
Total		100	100	100	300
Kisego F.R					
Boraginaceae	*Ehretia amoena* Klotzsch.	15.4	21.8	29.3	66.4
Fabaceae	*Albizia versicolor* Welw. ex Oliv.	10.8	14.9	11.4	37.0
Annonaceae	*Annona senegalensis* Pers.	10.8	13.9	11.9	36.5
Fabaceae	*Albizia gumminifera* (J.F. Gmel.) C.A.Sm.	10.8	9.9	9.1	29.8
Fabaceae	*Albizia glaberrima* (Schum&Thonn.) Benth.	10.8	8.9	5.5	25.2
Euphorbiaceae	*Bridelia micrantha* (Hochst.) Baill.	4.6	3.0	11.6	19.2
Vitaceae	*Cyphostemma adenocaula*	4.6	4.0	3.7	12.2
Fabaceae	*Brachystegia boehmii* Taub.	4.6	4.0	2.8	11.4

Apocynaceae	*Diplorhynchus condylocarpon* (Muell.Arg.) Pichon	3.1	3.0	1.7	7.8
Meliaceae	*Trichilia emetica* Vahl.	3.1	2.0	2.6	7.6
∑ 1 - 10		78.5	85.1	89.6	253.2
∑ 11 - 21		21.5	14.9	10.4	46.8
Total		100	100	100	300
Milawilila F.R					
Annonaceae	*Xylopia parviflora* (A.Rich.) Benth.	14.1	20.2	20.4	54.7
Sapotaceae	*Synsepalum cerasiferum* (Welw.)T.D.Penn.	9.8	7.3	32.1	49.1
Boraginaceae	*Ehretia amoena* Klotzsch.	13.0	16.9	11.0	41.0
Ebenaceae	*Diospyros squarrosa* Klotzsch.	7.6	8.9	7.3	23.8
Anacardiaceae	*Sorindeia madagascariensis* DC.	6.5	5.6	1.3	13.5
Fabaceae	*Scorodophloeus fischeri* (Taub) J. Leon	4.3	5.6	2.4	12.4
Apocynaceae	*Voacanga africana* Stapf.	5.4	4.8	1.8	12.0
Bignoniaceae	*Markhamia zanzibarica* (Bojer ex DC.)	5.4	4.8	1.4	11.7
Bombacaceae	*Bombax rhodognaphalon* K. Schum.	3.3	2.4	5.2	10.9
Fabaceae	*Albizia glaberrima* (Schum&Thonn.)Benth.	3.3	2.4	4.1	9.8
∑ 1 - 10		72.8	79.0	87.0	238.9
∑ 11 - 20		27.2	21.0	13.0	61.1
Total		100	100	100	300
Nemele F.R					
Fabaceae	*Brachystegia bussei* Harms.	1.8	1.4	37.3	40.6
Sapotaceae	*Synsepalum cerasiferum* (Welw.)T.D.Penn.	9.1	8.6	16.0	33.7
Boraginaceae	*Ehretia amoena* Klotzsch.	7.3	11.4	10.7	29.4
Fabaceae	*Delonix elata* (L.) Gamble	10.9	11.4	6.0	28.3
Loganiaceae	*Strychnos spinosa* Lam.	10.9	10.0	3.7	24.7
Apocynaceae	*Voacanga africana* Stapf.	5.5	10.0	6.9	22.4
Anacardiaceae	*Sorindeia madagascariensis* DC.	9.1	7.1	2.2	18.5
Ebenaceae	*Diospyros squarrosa* Klotzsch.	5.5	5.7	4.2	15.4
Rubiaceae	*Oxyanthus goetzei* K. Schum.	5.5	4.3	2.3	12.0
Fabaceae	*Albizia versicolor* Welw. ex Oliv.	5.5	4.3	1.4	11.1
∑ 1 - 10		70.9	74.3	90.9	236.1
∑ 11 - 19		29.1	25.7	9.1	63.9
Total		100	100	100	300
Ngambaula F.R					
Sterculiaceae	*Dombeya natalensis* Sond.	11.4	12.2	52.6	76.2
Ebenaceae	*Diospyros squarrosa* Klotzsch.	14.3	14.6	11.7	40.6
Fabaceae	*Brachystegia boehmii* Harms.	14.3	14.6	8.5	37.4
Fabaceae	*Scorodophloeus fischeri* (Taub) J. Leon	8.6	7.3	5.2	21.1
Moraceae	*Milicia excelsa* (Welw.) C. Berg.	8.6	7.3	4.9	20.8

Anacardiaceae	*Sorindeia madagascariensis* DC.	2.9	9.8	3.2	15.8
Fabaceae	*Albizia gumminifera* (Gmel.) C.A.Sm.	5.7	4.9	2.2	12.8
Meliaceae	*Khaya anthotheca* (Welw.) C. DC.	5.7	4.9	2.1	12.7
Moraceae	*Ficus lutea* Vahl.	5.7	4.9	1.8	12.4
Boraginaceae	*Ehretia amoena* Klotzsch.	2.9	2.4	2.5	7.8
∑ 1 - 10		80.0	82.9	94.6	257.5
∑ 11 - 17		20.0	17.1	5.4	42.5
Total		100	100	100	300
Gunauye F.R					
Bombacaceae	*Bombax rhodognaphalon* K. Schum	7.8	8.3	25.1	41.3
Fabaceae	*Albizia versicolor* Welw. ex Oliv.	9.4	14.3	13.2	36.9
Fabaceae	*Scorodophloeus fischeri* (Taub) J. Leon	7.8	9.5	16.1	33.5
Anacardiaceae	*Sorindeia madagascariensis* DC.	12.5	11.9	7.4	31.8
Fabaceae	*Albizia petersiana* (Bolle) Oliv.	4.7	7.1	11.5	23.3
Sapindaceae	*Deinbollia borbonica* Scheff.	6.3	7.1	6.2	19.6
Ebenaceae	*Diospyros squarrosa* Klotzsch.	6.3	4.8	2.0	13.1
Euphorbiaceae	*Bridelia micrantha* (Hochst).Baill.	4.7	4.8	2.8	12.2
Moraceae	*Ficus lutea* Vahl.	4.7	4.8	2.0	11.5
Moraceae	*Milicia excelsa* (Welw.) C. Berg.	4.7	3.6	2.3	10.5
∑ 1 - 10		68.8	76.2	88.7	233.6
∑ 11 - 22		31.3	23.8	11.3	66.4
Total		100	100	100	300

2.3.4 Species richness and diversity

The species richness among the forest fragments varied extensively ranging from 26 to 93 species ha^{-1} with an overall average of 47 species ha^{-1} (Table 2.1). Of the observed species, 42 % occurred exclusively in one forest, where 20 % occurred exclusively at Kilengwe forest, 13 %, at Kimboza, 4 % at Kisego, 3 % at Nemele and 2 % at Milawilila. No species commonly occurred in all the 7 forests. Only *Diospyros squarrosa* and *Ehretia amoena* occurred in the 6 forests (*i.e.* the two species were not found at Kisego and Gunauye forests respectively). The alpha diversity values ranged from 6.8 to 35.5, 2.50 to 4.02 and 9.4 to 63.1 for Fisher's alpha, Shannon-Wiener and Simpson index respectively (Table 2.5). The overall alpha species diversity averaged 29.2, 4.03, and 37.2 for Fisher's alpha, Shannon-Wiener, and Simpson index respectively (all the forests pooled, n = 114 plots). Generally, all α–diversity indices revealed Kilengwe and Kimboza being the most diverse forests as compared to the rest of the forests, which did not differ significantly in their diversity indices ($p > 0.05$). Shannon-

Wiener and Simpson indices showed Kisego forest to have lowest diversity values while Fisher's alpha index showed Milawilila forest being less diverse forest.

Table 2.5: Species richness measures and diversity indices of the studied forests in Uluguru

	Richness Estimators			Diversity Indices		
	MMMeans	Jackknife 1 (± SD)	Chao 2 (± SD)	Fisher's α (± Jack SE)	Shannon H' (± Jack SE)	Simpson D (± Jack SE)
Kilengwe	124	86 ± 4	80 ± 6	35.5 ± 4.3	4.02 ± 0.07	63.1 ± 7.7
Kimboza	70	64 ± 3	59 ± 4	18.8 ± 1.8	3.40 ± 0.14	20.6 ± 6.1
Kisego	28	28 ± 2	26 ± 4	8.1 ± 1.5	2.50 ± 0.13	9.4 ± 1.4
Milawilila	26	21 ± 1	20 ± 0	6.8 ± 0.5	2.62 ± 0.09	10.6 ± 1.6
Nemele	28	26 ± 2	26 ± 5	9.4 ± 1.8	2.76 ± 0.11	16.5 ± 3.2
Ngambaula	27	26 ± 3	28 ± 8	10.9 ± 2.7	2.60 ± 0.19	14.9 ± 3.5
Gunauye	33	27 ± 2	24 ± 2	9.7 ± 1.7	2.80 ± 0.07	15.4 ± 2.1
Overall	138	140 ± 17	107 ± 4	29.2 ± 5.4	4.03 ± 0.25	37.2 ± 9.2

NB: SD is Standard deviation and Jack SE is Jackknife standard error

2.3.5 Species accumulation curves

The species accumulation curves for Kimboza and Kilengwe (Figure 2.1) show an increasing trend as the number of plots (sampled area) added suggesting that more sample plots could have brought more number of species in these forests. The species accumulation curves for Milawilila, Kisego, Ngambaula, Nemele and Gunauye closely approached an asymptote indicating that species richness in these forests was not very far from being completely recorded. The non-parametric species richness estimators, MMMeans, Jackknife 1 and Chao 2 (Table 2.5) estimated higher species richness compared to the observed ones (Table 2.1) for each forest. However, the estimated species richness at Milawilila forest did not differ appreciably from the observed ones using Jackknife 1 and Chao 2. The overall species richness estimates (all the forests pooled) using the three richness estimators ranged from 107 to 140 species.

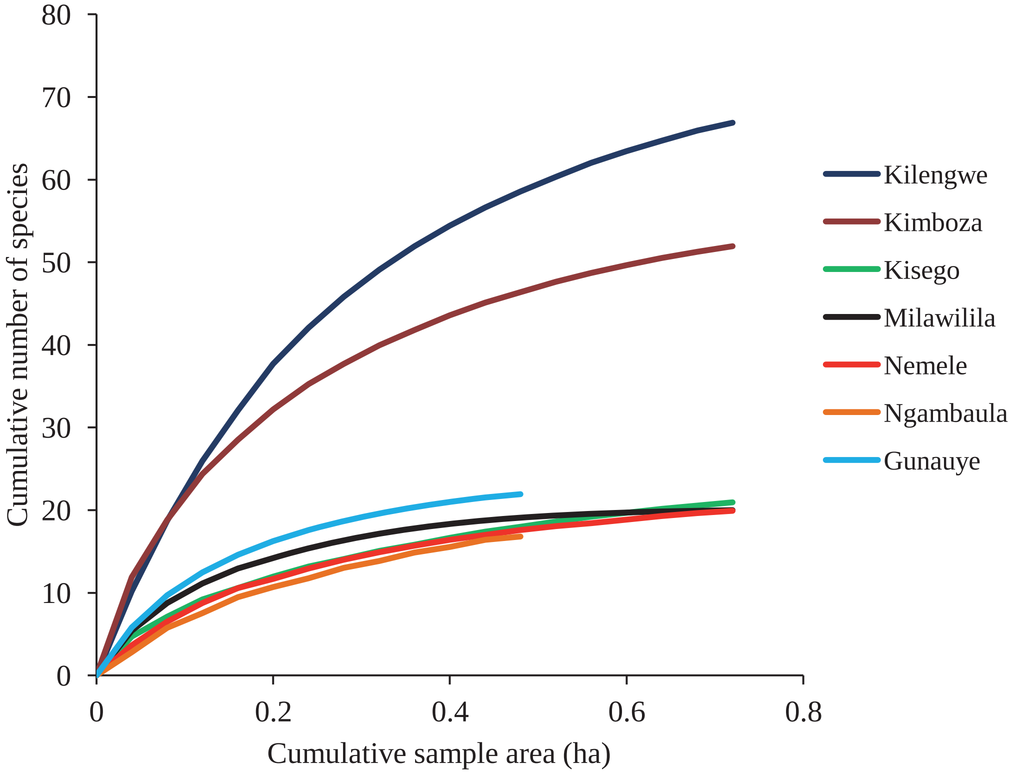


Figure 2.1: Species accumulation curves of trees (DBH ≥ 10 cm) based on cumulative plot samples in the studied Uluguru forests

2.3.6 Correlation between forest size, structure, species richness and diversity

Table 2.6 shows correlation coefficients between forest size, species richness, and diversity indices (*i.e.* Shannon, Fisher's and Simpson), stand density and basal area of Uluguru forests. The forest size revealed significant positive association with species richness and all used diversity indices. The species richness was significantly correlated with tree density while tree density and basal area were significantly correlated, but the two parameters were not significantly correlated with forest size. There was no significant correlation between tree density, and the reported diversity indices (Table 2.6).

Table 2.6: Correlation coefficients among forest size, species richness, diversity indices, tree density and basal area.

	Forest size	Species richness	Shannon	Fishers	Simpson	Tree density	Basal area
Forest size	1.00						
Species richness	0.92*	1.00					
Shannon	0.95*	0.96*	1.00				
Fishers	0.98*	0.94*	0.97*	1.00			
Simpson	0.94*	0.86*	0.92*	0.97*	1.00		
Tree density	0.66	0.80*	0.74	0.61	0.45	1.00	
Basal area	0.28	0.44	0.42	0.24	0.07	0.85*	1.00

NB: * indicate significant correlation $p < 0.05$, two tailed test.

2.3.7 Species compositional similarity

Floristic similarity between the 7 surveyed forests (Table 2.7) revealed higher similarity coefficient between Nemele and Milawilila (shared 11 species), followed by Kimboza and Kilengwe (32 species). The lowest similarity coefficient was between Nemele and Kisego, which shared only 4 species. The similarity percentages (SIMPER analysis) showed that the average species composition similarity among the seven studied forests was 23.9 %. When the studied forests are compared with other selected inventories (Table 2.8), there were close similarities with Vigoregore, Kanga, Dunduma, Nguru South, Mvuha and Mlungui forest in cluster 3 (Figure 2.2). From the dendogram Nilo and Amani forest were the most similar forests with similarity coefficient of 0.59, followed by Bombo East (I) and Bombo East (II) (0.58), Milawilila and Nemele forests (0.55), Kilengwe and Kimboza (0.54), Mlilingwa and Mkulanzi (0.53), Amani and Mlinga (0.51). Moreover, Mlilingwa and Nguru ya Ndege as well as Kitulangalo and Pangawe West had 0.50 similarity each. The remaining forest pairs had similarity confidents of less than 0.50 indicating low similarities among the forests and most likely that each forest is comprised of unique composition between the pair.

Table 2.7: Species similarity among the studied forests as per Sørenson similarity coefficients.

	Kilengwe	Kimboza	Milawilila	Nemele	Kisego	Ngambaula	Gunauye
Kilengwe	1.00						
Kimboza	0.54	1.00					
Milawilila	0.34	0.28	1.00				
Nemele	0.30	0.31	0.55	1.00			
Kisego	0.30	0.25	0.24	0.20	1.00		
Ngambaula	0.26	0.43	0.27	0.22	0.32	1.00	
Gunauye	0.36	0.41	0.38	0.33	0.23	0.46	1.00

2.3.8 Influence of geographical distance on forest floristic similarities

The forest floristic similarities were significantly negatively correlated to geographical distances (r = -0.43, n = 524, p < 0.001), which indicate a trend of decreasing similarity as the distance between forest pairs increases (Figure 2.3). Likewise, the cluster analysis (figure 2.2) revealed four clusters assembling together forests which were geographically close. From the studied forests, the forest pair with higher floristic similarity (Nemele and Milawilila) was located 24 km apart as compared to Kisego and Kilengwe which were 62 km apart. Moreover, Nilo and Amani forests shared 74 species (45.2 km distant), Bombo East (I) and Bombo East (II) shared 30 species (10.8 km), Mahenge scarp and Nambinga shared 29 species (30.4 km) and Mkulanzi and Mlilingwa forest shared 28 species (41.9 km). However, some forests seem to be clustered together regardless of their geographical proximity. For instance, Milawilila and Ngambaula are geographically close (5.1 km) but had low similarity. On the other hand, Bombo East (I) and Bombo East (II) in cluster 2 are geographically distant from other forests in the same cluster. Similarly, Mlungui forest reserve however seems to be similar with other forests in cluster 3, it is spatially distant as compared to the remaining pairs of the forests in the same cluster. Magombera and Bombo East (II) (Cluster 2), Mlungui and Kisego (Cluster 3), Nongeni and Pangawe West (Cluster 3) and Lubalanzi and Nguru ya Ndege (Cluster 4) were floristically most deviating forests in their clusters. The distances between pair of forests in cluster 1 varied from a minimum of 15.9 km (Nilo and Kwamgumi) to maximum of 45.2 km (Nilo and Amani) and for cluster 2, Bombo East (I) and Bombo East (II) varied from (10.8 km) to Nambinga and Bombo East (II) (508.4 km). For cluster 3, the distances among the pairs of forests varied from 5.1 km (Milawilila and Ngambaula) to 346.1 km (Mlungui and Vigoregore), for cluster 4 the distances varied from 3.7 km (Pangawe West and Pangawe East) to 117.1 km (Dindili and Kitulangalo).

Table 2.8: List of selected inventories from other forests of Tanzania

Reference	Forest Name	Region	Latitude	Longitude	Size (ha)	Study Area (ha)	Min. DBH (cm)	No. of Trees per ha	Basal Area (m^2 ha^{-1})	Number of Species
Salter *et al.*, 2002a	Bombo E(I)	Tanga	04^{0}48’ S	38^{0}42’ E	448	3.1	10	154	-	59
Salter *et al.*, 2002b	Bombo E(II)	Tanga	04^{0}43’ S	38^{0}39’ E	404	1.9	10	160	-	47
Marshall, 2008	Magombera	Morogoro	07^{0}55’ S	37^{0}03’ E	1100	8.0	10	227	-	83
Malimbwi *et al.*, 2005	Dindili	Morogoro	06^{0}42’ S	37^{0}52’E	1006.9	1	10	213	5.0	21
Malimbwi *et al.*, 2005	Dunduma	Morogoro	06^{0}10’ S	37^{0}37’E	52.6	1	10	258	18.4	13
Malimbwi *et al.*, 2005	Mindu	Morogoro	06^{0}50’ S	37^{0}35’E	2285	1	10	101	1.7	8
Malimbwi *et al.*, 2005	Kanga	Morogoro	05^{0}33’ S	37^{0}40’ E	6664.2	1	10	243	32.3	28
Malimbwi *et al.*, 2005	Kilengwe	Morogoro	07^{0}30’ S	37^{0}28’E	995	1	10	297	11.2	25
Malimbwi *et al.*, 2005	Kimboza	Morogoro	06^{0}59’ S	37^{0}47’ E	385	1	10	236	15.8	28
Malimbwi *et al.*, 2005	Kitulangalo	Morogoro	06^{0}39’ S	37^{0}57’ E	2638	1	10	250	7.7	18
Malimbwi *et al.*, 2005	Lubalanzi	Morogoro	07^{0}17’ S	37^{0}40’ E	28500	1	10	157	5.9	33
Malimbwi *et al.*, 2005	Pangawe (E)	Morogoro	06^{0}49’S	37^{0}48’E	768	1	10	241	9.2	21
Malimbwi *et al.*, 2005	Pangawe (W)	Morogoro	06^{0}49’S	37^{0}46’E	184	1	10	249	11.6	12
Malimbwi *et al.*, 2005	Ruvu	Morogoro	06^{0}53’ S	37^{0}49’ E	3093	1	10	289	16.7	28
Malimbwi et al., 2005	Mkulanzi	Morogoro	06^{0}57’ S	38^{0}05’ E	68627	1	10	317	16.1	66
Malimbwi *et al.*, 2005	Mkindo	Morogoro	06^{0}12’ S	37^{0}28’ E	5244	1	10	191	24.5	29
Malimbwi *et al.*, 2005	Mlilingwa (N)	Morogoro	06^{0}40’ S	37^{0}50’ E	21000	1	10	287	11.1	40
Malimbwi *et al.*, 2005	Mvuha (L)	Morogoro	07^{0}13’ S	37^{0}51’ E	852	1	10	256	20.9	27
Malimbwi *et al.*, 2005	Nongeni	Morogoro	06^{0}49’ S	37^{0}43’ E	231.5	1	10	61	3.0	27
Malimbwi *et al.*, 2005	Vigoregore	Morogoro	07^{0}60’ S	37^{0}52’ E	920.7	1	10	276	10.3	22

Malimbwi *et al.*, 2005	Nguru South (L)	Morogoro	06^{0}09’ S	37^{0}28’ E	18800	1	10	129	27.5	26
Malimbwi *et al.*, 2005	Nguru ya Ndege	Morogoro	06^{0}41’ S	37^{0}35’ E	3614	1	10	171	6.7	27
Jenkins&Roettcher,2001	Nambinga	Morogoro	08^{0}44’ S	36^{0}27’ E	1390	4.8	10	-	-	74
Hall *et al.*, 2002	Mlinga	Tanga	05^{0}04’ S	38^{0}44’E	890	3.0	10	260	-	106
Frontier, 2001	Amani	Tanga	05^{0}04’ S	38^{0}30’ E	8360	17.5	10	411	-	124
Doody *et al.*, 2001	Mpanga	Tanga	04^{0}47’ S	38^{0}47’ E	24	0.6	10	837	-	60
Doggart *et al.*, 1999	Kwamgumi	Tanga	04^{0}55’ S	38^{0}44’ E	1708.4	4.9	10	436	-	129
Beharrell *et al.*, 2002	Nilo	Tanga	04^{0}50’S	38^{0}37’ E	6025	12.2	10	336	-	126
Bracebridge and Sallu, 2004	Mahenge Scarp	Morogoro	08^{0}37’ S	36^{0}42’ E	454	2.0	10	202	-	78
Cunneywothy & Stublefield, 1996	Mlungui	Tanga	05^{0}00’ S	38^{0}42’E	200	1.3	10	-	-	51

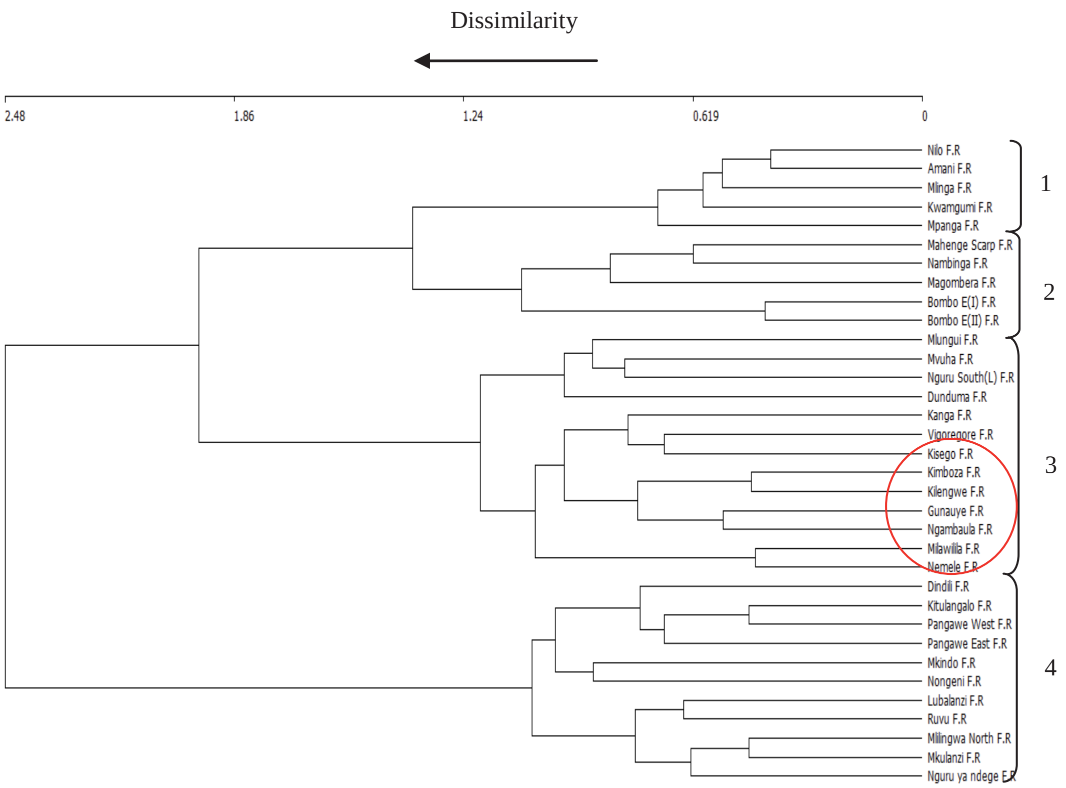


Figure 2.2: Dendogram constructed from Sørensen coefficients of similarity based on species composition in the studied forests (in red circle) and other selected forest inventories.

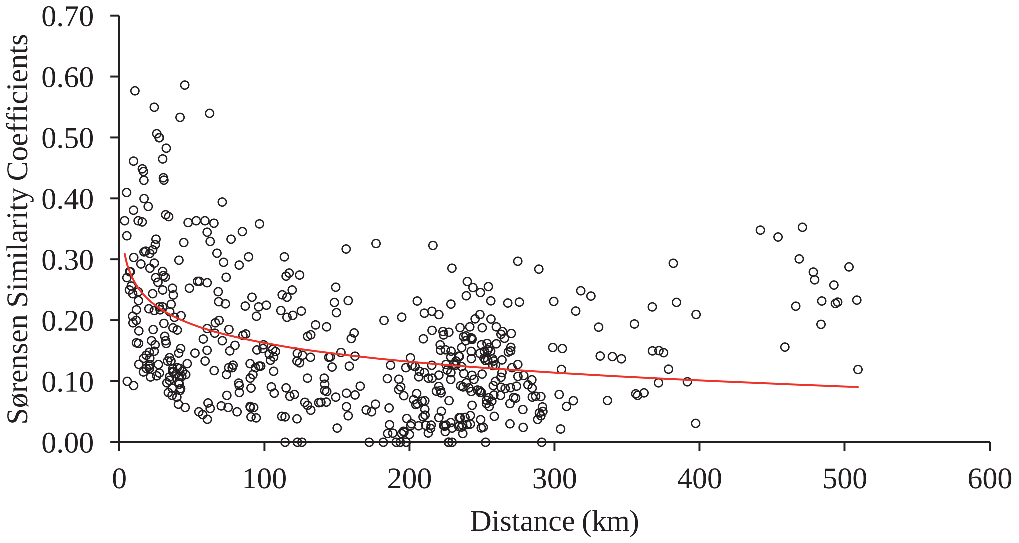


Figure 2.3: Correlation between floristic similarities and forests geographical distances.

2.3.9 Structural composition of the forests

The density of trees between forests varied significantly ($F_{(6,107)} = 14.37$, $p < 0.001$) ranging from 85 to 390 stems ha^{-1} with an overall average of 198 ± 14 stems ha^{-1} when all the forests pooled together (Table 2.1). The *post-hoc* Tukey's HSD test ($p < 0.05$) confirmed Kimboza to have higher stems density than the rest of the forests with an exemption of Kilengwe forest, which did not differ considerably. Conversely, the stems density at Kilengwe were not statistically significant different from that of Milawilila and Gunauye forest but was considerably higher than that of Nemele, Ngambaula and Kisego forest. The remaining forest pairs did not differ appreciably in their stem densities. The basal area between the forests differed extensively ($F_{(6,107)} = 9.92$, $p < 0.0001$) ranging from 3 to 24 m^2 ha^{-1} between forests (Table 2.1). Kimboza forest had higher basal area compared to the rest of the forests, followed by Milawilila and Kilengwe while Kisego forest had the least basal area value.

The size class distribution of trees (Figure 2.5) of the seven forests exhibited the hypothetical "negative exponential" or "inverse J -shape", however, some forests lacked individuals in the higher size classes. In general, the inverse J- curve is an indication of good regeneration/growing tree population structure (*i.e.* higher tree density at lower size classes and lower density at higher size classes). About 69.1 % and 18.2 % of the recorded trees (DBH ≥ 10 cm) in all the forests were represented in 10-19.9 cm and 20-29.9 cm size classes respectively. Kisego and Kilengwe forests had no individuals in the size classes' ≥ 50 cm DBH while Gunauye forest had no individuals at size class > 60 cm DBH. Though Nemele and Ngambaula possessed some individuals at 10-19.9 to 30-39.9 and > 70 cm DBH size classes, these forests had no individuals in size classes between 40 cm and < 70 cm DBH. Kilengwe forest hadThe maximum DBH value in the present study was 126 cm recorded for Khaya *anthotheca* at Kimboza forest, followed by *Brachystegia bussei* (Nemele) and *Synsepalum cerasiferum* (Milawilila) with 122 and 106 cm respectively.

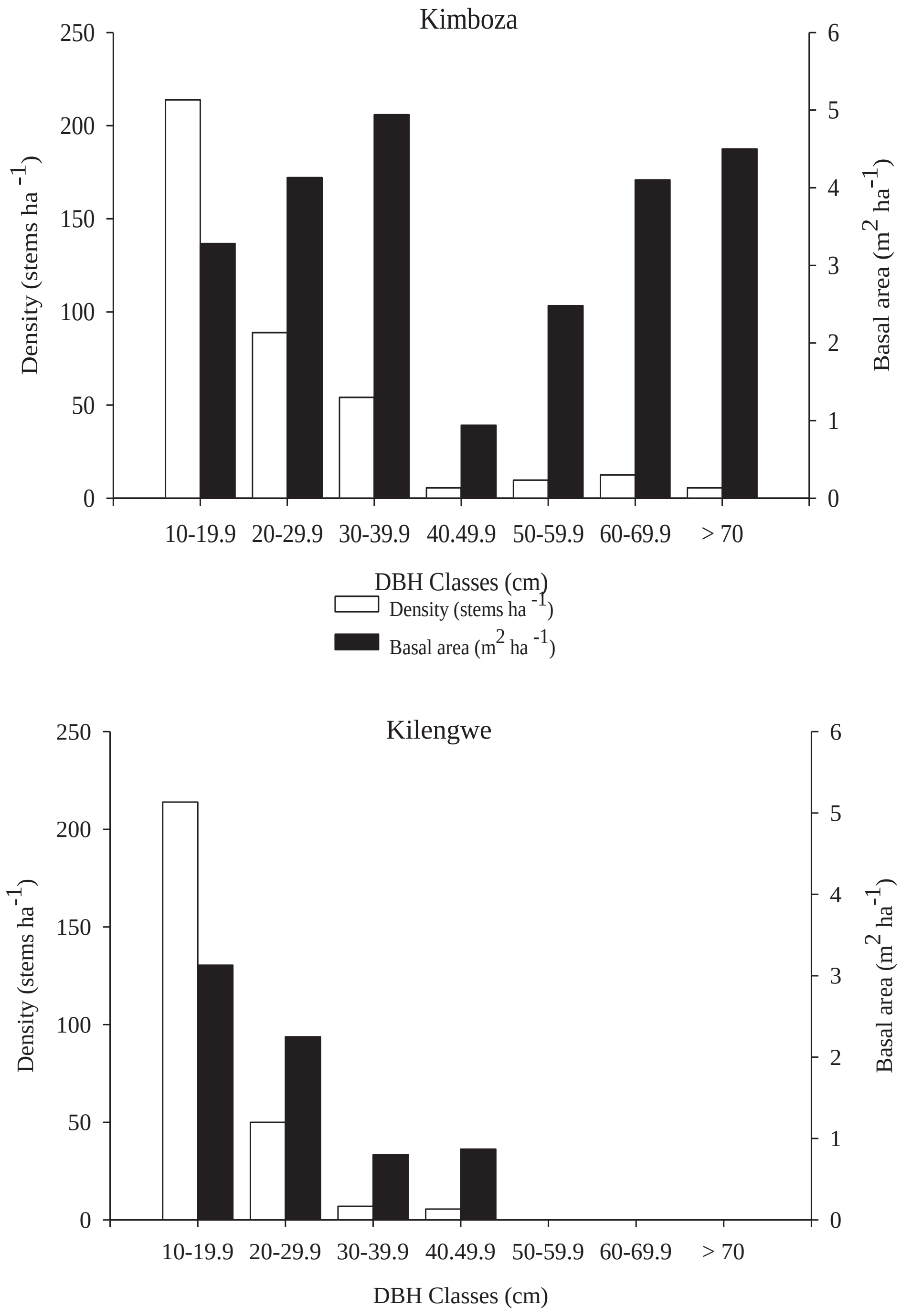
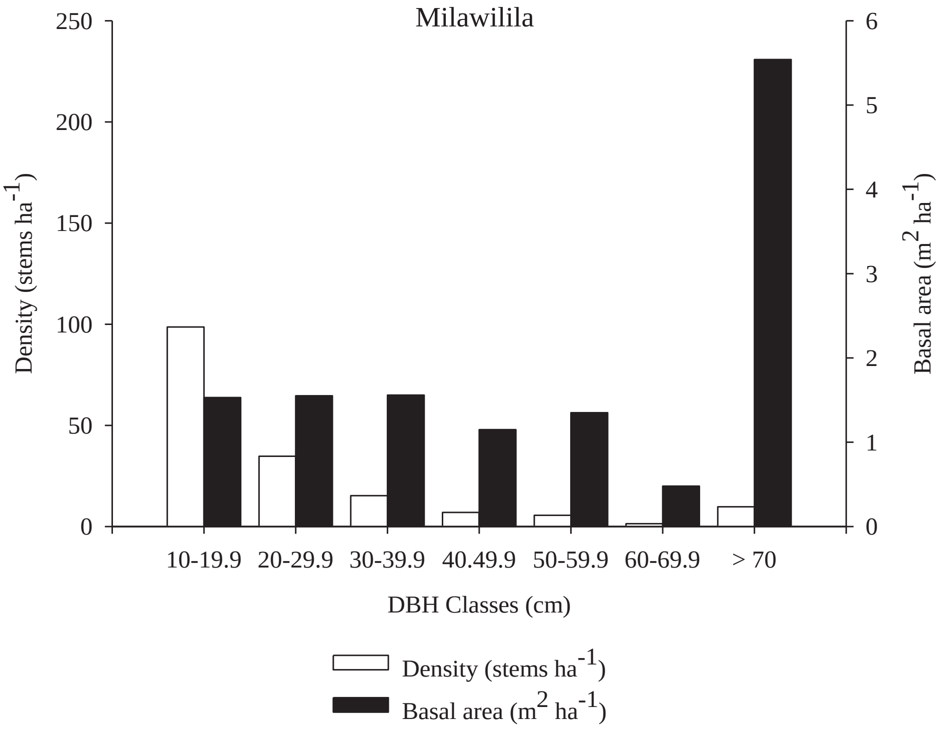


Figure 2.5: Size class distributions of the trees in the studied Uluguru forests.



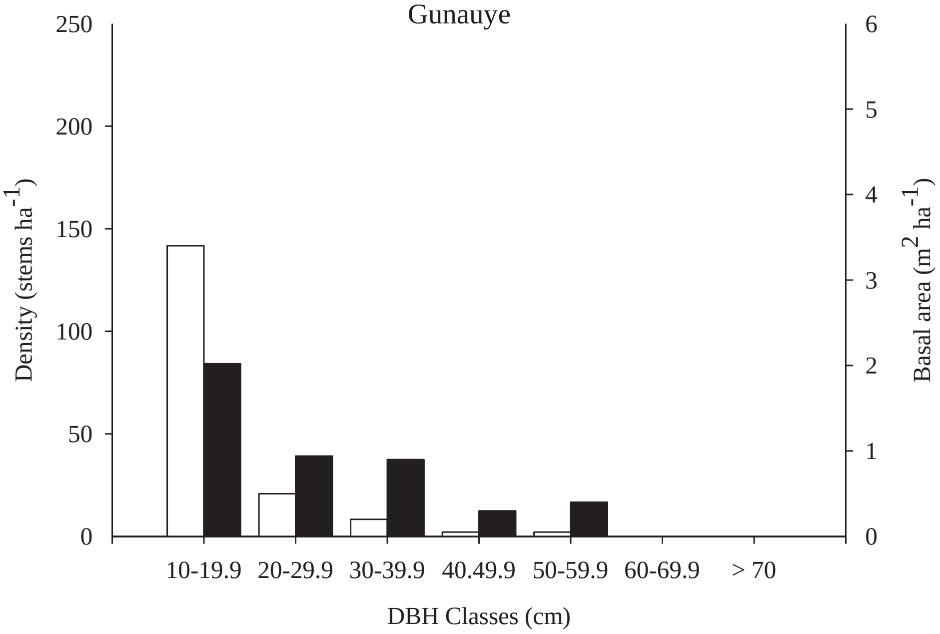


Figure 2.5: Size class distributions of the trees in the studied Uluguru forests *(cont...)*.

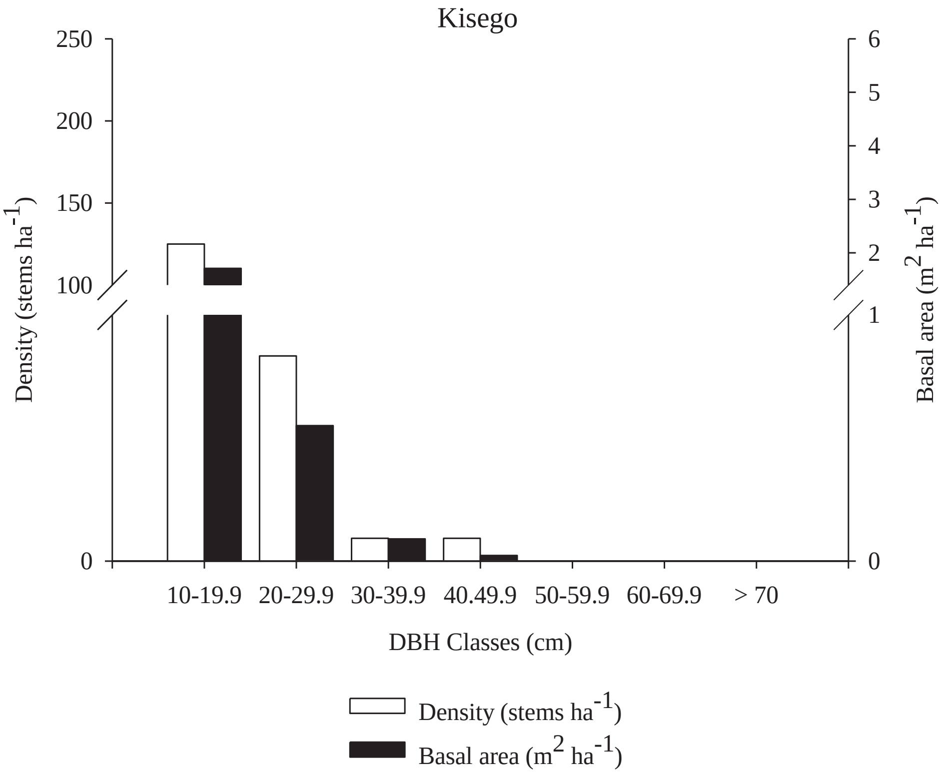
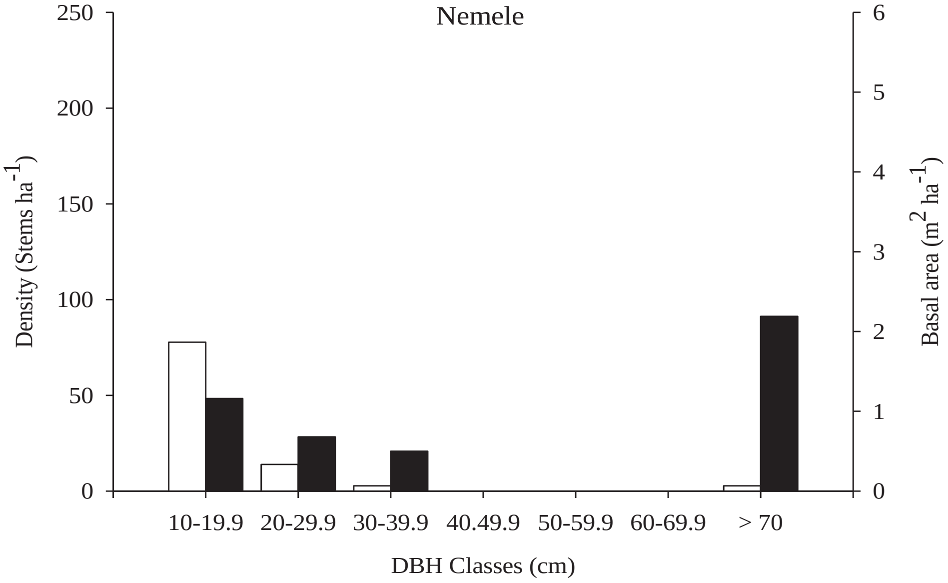


Figure 2.5: Size class distributions of the trees in the studied Uluguru forests *(cont...)*.



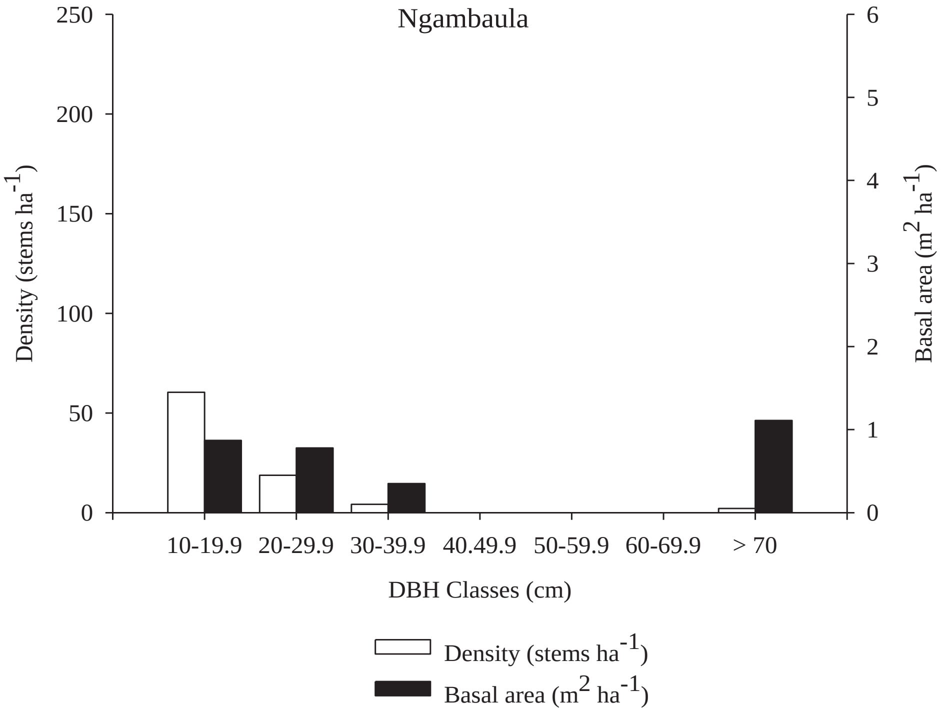


Figure 2.5: Size class distributions of the trees in the studied Uluguru forests *(cont...)*.

2.4 Discussion

2.4.1 Floristic composition at family and species level

The most important families were attributed mainly by high species richness and abundances of the constituent species. For instance, the domination of Fabaceae in most of the forests is mainly due to it being the most speciose and abundant family (Table 2.3). The constituent species were of high frequency in all the surveyed forests in this study. The domination of Annonaceae and Sapotaceae family at Milawilila forest was mainly due to their higher basal area although they were represented by less number of species compared to family Fabaceae and Clusiaceae (Table 2.3). Moreover, the inclusions of some other families (*e.g.* Boraginaceae) among the top ten most overall important species, even if only represented by one species, are because of their combined high relative density and relative dominance.

In comparison with other studies conducted in other lowland forests in Tanzania, this study revealed important similarities in terms of the most ecologically important and speciose families, though other studies used different plot and minimum stem size diameter. For instance, the family Fabaceae which was the most overall important family in this study, has similarly been recorded by Mrema (2006) being the most important family in Dindili forest. Likewise, Burgess and Muir (1994) and Burgess and Clarke (2000) reported the coastal forests being dominated 25 - 50 % by the Fabaceae family. In general, family Fabaceae dominated by 32.7 % in the present study. Moreover, the present findings conform to Gentry (1988), who reported the Fabaceae being the family with highest percentage of species in most lowland forests of Africa. The present findings also concur with other findings from Amazonian forests (Valencia *et al.,* 1994; ter Steege *et al.*, 2000; da Silva *et al.,* 2011), Madagascar forests (Cadotte *et al.*, 2002), Ghana forests (Addo-Fordjour *et al.,* 2009) and Uganda Forests (Eilu *et al.,* 2004; Mwavu, 2007) that Fabaceae is the most diverse trees family in the most lowland forests. Other important families recorded in this study (Table 2.3) have similarly been reported among the most important families in other studies (ter Steege *et al.,* 2000; Eilu et al., 2004; Mrema, 2006; Wittman *et al.*, 2006; Mwavu 2007; Addo-Fordjour *et al.,* 2009).

The most important species with higher IVI in all the forests were attributed chiefly by combination of high relative density, dominance and/or high relative frequency of the constituent individuals (Table 2.4). For instance, *Julbenardia globiflora* and *Dalbergia melanoxylon* (Kilengwe), *Khaya anthotheca* and *Antiaris toxicaria* (Kimboza), *Ehretia amoena* (Kisego), *Brachystegia bussei* and *Synsepalum cerasiferum* (Nemele), *Dombeya natalesis* (Ngambaula) and *Bombax rhodognaphalon* (Gunauye) were highly influenced by their higher relative dominance while *Xylopia parviflora* (Milawilila) was highly attributed by both relative density and dominance. The occurrence of *Diospyros squarrosa* and *Ehretia amoena* in six studied forests and *Sorindeia madagascariensis, Scorodophloeus fischeri,* O*xyanthus goetzei,* and *Albizia versicolor* in five studied forests indicate their wider range of ecological adaptations as compared to other species. Among the most important species recorded in this study have also been reported by other authors (*e.g.* Mrema, 2006, Rwamugira, 2008) being the most important species in their findings. For instance, Temu (1990) and Mligo *et al.,* (2009, 2011) reported *Scorodophloeus fischeri* being the most common species in the coastal forests of East Africa. The IVI is an index that shows an ecological significance of species in a given ecosystem. The higher the IVI for a species the more the important compared to those with less IVI. The IVI values can be used for prioritizing species conservation. The species (*e.g. Milletia sacleuxi, Zanthoxylum deremens, Pouteria altissima,Combretum adegonium, Pseudolachnostylis maprounefolia, Pterocarpus tinctorius and* many others) with lower IVI values need high conservation priority compared with those with higher IVI (Zegeye *et al.*, 2006).

It is also important to emphasize the occurrence of 30.7 % of the rare species having up to two individuals considering all the seven forests pooled together. The occurrence of rare species has been reported in different studies in tropical forests (*e.g.* Mwavu, 2007; da Silva *et al.*, 2011). Hubbell *et al.*, (2001) reported that one possible reason for the rarity in tropical forests may be that the rare species suffer stronger density-dependency than common species do, which results in a low number of individuals. Moreover, in the existence of a resource gradient, species can evolve in order to occupy different positions in these gradients resulting in variations on the abundance distribution (Comita *et al.*, 2007). In the present study, some degree of variability among forests has been observed, which may be due to environmental variations, possible species adaptation to such variability, disturbances and competition (Phillips *et al.*, 1994; Schwarz *et al.*, 2003). Additionally, poor dispersability of the species may also account for presence of many rare species in the forests.

2.4.2 Species richness and diversity

The species accumulation curves for Kilengwe and Kimboza forests (Figure 2.1) illustrate an escalating trend as the number of plots added, suggesting that increasing the number of sample plots/area could increase the number of species recorded in these forests. This concurs with the results shown in Table 2.5 where the species richness estimators provide a higher number of species for these forests as compared to observed ones. The species accumulation curves for Milawilila, Nemele, Ngambaula and Gunauye seem to approach an asymptote signifying that most of the species in these forests were almost accounted for. This is also supported by the species richness estimators (Table 2.5), which provided estimates that did not differ markedly with the observed species richness. On contrary, the curves for Kilengwe and Kimboza do not show an asymptotic behaviour due to presence of many rare species, and species with narrow habitat ranges. The high species richness in Kilengwe and Kimboza could also be attributed to their large areas that tend to have high environmental heterogeneity. On the other hand, increasing trend in the number of species with increasing forest size suggests that a reduction in forest size due to fragmentation can cause species loss. This concept is also supported by the correlation coefficient between forest size and species richness in Table 2.6 that suggest that a decline in forest size will cause a decline in species richness too.

The range of species richness in this study (26 to 93 species ha^{-1}) concurred with the findings from other forests in East Africa, for instance Mwavu (2007) recorded a range of 24-122 species ha^{-1} for trees with DBH ≥ 10 cm in his study in Budongo forests in Uganda. On the other hand the present findings seem to be relatively comparable with findings from other coastal forest inventories (*see* Table 2.8). In contrast, the recorded species richness appear to be relatively lower when compared to Amazonian forests, for instance, Valencia *et al.*, (1994) recorded 473 species ha^{-1}, 187 genera and 54 families using DBH ≥ 5 cm tree data in Amazonian Ecuador. The level of anthropogenic disturbances could be the main reason for the differences because many of the Amazonian forests are undisturbed. In discussing the patterns and trends of tree diversity (DBH ≥ 10 cm) on the six continents, Gentry (1988) showed that the highest alpha diversity occurs in upper Amazonia, with record diversity of 275 to 283 species ha^{-1}. Conversely, comparisons involving different studies are complicated due to fact that different plot sizes are used and the subjectivity used to arrive at a range of values is unclear. However, some forests in this study had Shannon-Wiener value of less than 3.00 (Table 2.5), while an overall Shannon-Wiener index of 4.03 is considered to be usual for forests of high diversity (Oliveira and Mori, 1999; Silva *et al.*, 2011) signifying that Uluguru forests are one of the forests with higher diversity. The low diversity values in some of the studied forests may be due to anthropogenic disturbances in the forests through selective and illegal logging. Although, edaphic factors were not studied in the present work, various studies (*e.g.* Ruokolainen *et al.*, 2007 and Pinto *et al.*, 2008) have reported edaphic factors to play a significant role in maintaining high species diversity in tropical forests because tree species distribution is essentially influenced by soil characteristics. Moreover, the significant difference in species diversity among the studied forests can be due to high variations in species richness and stem densities too.

2.4.3 Association between forest size, species richness, diversity and forest structure

The significant associations between species richness/diversity in Table 2.6, support the supposition that large forest contain greatest number of trees species. Also, it suggests that increased forest fragmentation which normally results in area reduction will cause the forests to lose considerable number of species and diversity. Small forest fragment can only support small population of flora and fauna. The smaller the population is, the more vulnerable to extinction when fluctuations in microclimate, resources and other unremarkable dynamics occurs. Thus, large forest fragments are needed by many species in order to maintain viable populations, though it is important also to recognize the complementary value of small forest fragments (Hill and Curran, 2001). Though forest size and stand density did not show a significant association, they were positively correlated suggesting that the abundance of trees is greater in larger forest fragments. Thus, in case of forest fragmentation, stand density is expected to decline too. The significant association between basal area and tree density signify that decline in stand density will considerably led to decrease in forest basal area. Actually, the species richness, diversity, stand density and basal area decrease because of increase in anthropogenic disturbance intensity in forests (Nkombe, 2003).

2.4.4 Floristic similarity among the studied forests

The species composition similarity coefficients among the studied forests ranged from 0.20 to 0.55 (Table 2.7). The highest similarity between Milawilila and Nemele as well as Kimboza and Kilengwe could be attributed by having similar environmental conditions as compared to Kisego and Nemele which had least similarity value. With exception of the two forest pairs that showed high floristic similarity, the remaining pairs had similarity coefficients below 0.50 signifying that there are low similarities among the forest pairs and possibly each forest has its own unique species composition. Thus, all the forests are important in terms of the floristic diversity and sensitive from a conservation point of view.

2.4.5 Influence of geographical distance on floristic similarity

A significant negative relationship (Figure 2.3) between floristic similarity and geographical distance signifies a declining trend in the floristic similarity with increasing geographical distance between the forest pairs. Such trend has also been reported by Tuomisto *et al.*, (2003), Slik *et al.*, (2003) and Silva *et al.*, (2011) in their studies. Though not studied in the present work, environmental factors could be the possible factors for the observed trend as different studies (*e.g.* Slik *et al.*, 2003; Bohlman *et al.*, 2008; Conorado *et al.*, 2009) reported edaphic factors especially soil type and nutrient availability to be the most important variable for species distribution and abundance patterns among forests. It is expected that the closer the forests are, the more similar are the environmental factors and tend to have similar floristic composition as compared to the distant ones (Barrantes and Sandoval, 2009). Moreover, the variations in species adaptation abilities to different edaphic factors (Gentry, 1988), dispersal limitation (Hubbell, 2001), herbivory and competition (Tuomisto and Ruokolainen, 2005) play a significant role in determining spatial variation in species composition too. However, the comparisons revealed that some forests are clustered together regardless of their geographical proximity *i.e.* dissimilar forests can be nearby and similar forests pairs can be found much further away. These reversals from the observed general trend (Figure 2.3) correspond to the forests with dissimilar/similar environmental factors regardless of their distances (Tuomisto *et al.,* 2003). Thus, influencing factors especially soil type and nutrients need to be investigated in future studies.

2.4.6 Structural composition of the forests

The observed tree densities and basal areas among the studied forests are within the range reported by Malimbwi *et al.,* (2005) in their inventories in the coastal forests of Tanzania (Table 2.5). The considerable higher basal area in Kimboza and Milawilila was contributed by high stem density in the higher DBH classes as compared to other forests. Kimboza revealed 54 % increase in basal area from the basal area value (15.8 m ^{2} ha^{-1}) observed by Malimbwi *et al.,* (2005) signifying that the forest has not been greatly affected by human disturbances. In contrast, the observed basal area at Kilengwe was lower by 29 % than the value (11.2 m ^{2} ha^{-1}) observed by Malimbwi *et al.,* (2005), which implies that the forest is impacted by anthropogenic disturbances. The significantly lower basal areas at Kilengwe, Kisego, Nemele, Ngambaula and Gunauye suggest that these forests are really overexploited. Also, the absence of individuals in large size classes (≥ 40-49.9 cm DBH) could have contributed to the low basal area in these forests (*see* figure 2.5). Other studies done in Morogoro region like Rwamugira (2008) reported average basal area of 4.7 m^2 ha^{-1} (trees with DBH ≥ 10 cm) at disturbed stand in Ruvu forest while Malimbwi *et al.,* (2005) recorded a very low basal area of 1.7 m^2 ha^{-1} at Mindu forest in Morgoro, which concluded that the forest was really disturbed. Illegal and selective loggings are the main causes for low basal areas in many forests in Morogoro (Malimbwi *et al.,* 2005)and it is reported to be done by well coordinated syndicates involving traders, irresponsible local government leaders and unfaithful villagers (The Guardian, 2012). On the other hand, the considerable variation in the number of species and basal areas between the studied stands indicate existence different forest formations (*i.e.* dry and moist forests) among them.

The size class distributions of Kilengwe, Kisego, Nemele, Ngambaula and Gunauye indicate that the population in the forests is recruiting strongly and there are signs of recovery from the effects of previous and on-going disturbances. Illegal timber logging was also observed in these forests, indicating that the forests are still under anthropogenic pressure and perhaps was the one of the factors resulted into the present status of these forests. The significant differences in the observed structural features (*i.e.* density and basal area) among the studied forests are mainly attributed by anthropogenic exploitation pressure, which target trees of high size classes for trade as timber and building poles. Other factors like variations in edaphic factors among the forests, habitats preferences/adaptations ability between species, and presence of favourable soil conditions for species regeneration have been reported affect forest structure too (Richards, 1952; Zegeye *et al.*, 2006). The results show that small forests had lower stand density and basal area. The reason could be that the small fragments are highly vulnerable to human disturbances because they are easily accessible for logging and clearance activities that affect the forest structure (Echeverria *et al.*, 2007). In Madagascar, the spatial pattern analysis of forest structure revealed that levels of basal area were associated with accessibility to the fragments (Ingram *et al.*, 2005). Thus, the low basal area values observed in some forest fragments in this study could be due to high accessibility by the nearby community and lack of enough protection from the village's environmental committees.

The negative exponential in the size class distribution (Figure 2.5), suggests high recruitment and healthy population structure with population being dominated by juvenile classes (Whitmore, 1989; Hadi *et al.*, 2009). The absence of trees in various higher size classes in Kisego, Kilengwe, Nemele, Ngambaula and Gunauye forests (Figure 2.5) can be explained by two reasons, which are not mutually exclusive. First, probably there might be a limited number of species that grow up more than this diameter and second, the number of big trees could have already been reduced through illegal and selective harvesting by the locals for various uses. Though these forests revealed to be at crucial stage of regeneration and have been recovering from past exploitation, the lack of individuals in higher size classes implies that illegal logging is still ongoing in the forests. The occurrence of relatively high basal area and density of trees in the largest size classes in Kimboza and Milawilila suggest that the two forests are dominated by more mature trees as compared to the rest of the forests. Additionally, among the observed threatened species in Table 2.2 (*i.e. Pterocarpus angolensis*, *Dalbergia melanoxylon*, *Khaya anthotheca and Milicia excelsa*) were reported by several authors (*e.g.* MNRT, 2004; Ahrends, 2005; Modest *et al.*, 2010) to be extremely exploited for timber in the coastal forests of Tanzania and some are logged below the minimum harvestable diameter.

2.5 Conclusion

In summary, this study has revealed that family Fabaceae was the most speciose family in the studied forests. *Diospyros squarrosa* and *Ehretia amoena* were the most common species occurring in six forests, which indicate their wider ecological adaptation. The species richness, diversity indices and tree density were positively correlated with forest size. The higher species richness in larger forests may be due increased habitat heterogeneity within the fragments. Although smaller forests had lower species richness, they must be given priority in conservation to avoid the loss of more species. The structural parameters differed significantly between the studied stands due to variation in the anthropogenic disturbances among them. The study revealed floristic similarity decreasing substantially as geographical distances increases between forests pairs, the trend is associated with increasing environmental dissimilarity. Also, this study shows that more attention on conservation should be put to rare species and those with less IVI values. Although Uluguru forests are globally known to be biodiversity hotspots where nature conservation is given high priority, the anthropogenic pressure and encroachment threatens their biodiversity value. Based on the findings presented in this chapter, the study strongly recommends for effective and timely actions on conservation of these forest fragments to be taken. It also suggests future researches to consider investigating major causes, types and level of anthropogenic disturbances within and among the forests. Moreover, study on edaphic factors variation within and between these Uluguru forest fragments need to be done in future to understand their influence on tree composition and distribution.

Pictures showing observed illegal logging in the forests during the survey

CHAPTER THREE

Understory Composition, Diversity and Natural Regeneration Status of Uluguru Forests in Morogoro - Tanzania

3.1 Introduction

Tropical forests are recognized to harbor unique biota, for both, flora and fauna. In sub-Saharan Africa, one of the regions of global importance as a centre of biodiversity is the Eastern Arc forests (Uluguru forests included) harbouring 1.3 % and 3.7 % of the global plant and vertebrate species respectively. The Eastern Arc and coastal forests of Tanzania and Kenya are recognized to harbour 1500 endemic plants and 121 endemic vertebrate, which represent 0.5 % and 0.4 % of the global plant and vertebrate species respectively (Myers *et al.,* 2000). Many studies in tropical forests have concentrated on trees with diameter at breast height (DBH) ≥ 10 cm, whereas the understory remains the least understood (Philips *et al.*, 1994) despite of the fact that the understory is responsible for a high percentage of total diversity and inherent sustainability of tropical forests (Tchouto *et al.,* 2006). The species richness of smaller trees (DBH < 10 cm) and shrubs have been reported by different authors to be higher than that of larger ones (DBH ≥ 10 cm) in various tropical forests (Tchouto *et al.*, 2006; Lu and Tang, 2010; Lu *et al.,* 2011).

The understory is an essential component of any forest ecosystem sustaining a large fraction of total community floristic diversity (Lu *et al.,* 2011) and provides habitat and food resources for different organisms (Gentry and Emmons, 1987; Hirao *et al.,* 2009). The understory can influence community dynamics and succession patterns (Royo and Carson, 2006), contribute to nutrient cycling (Nilsson and Wardle, 2005), conservation of forests and is a vital constituent of forests aesthetic value (Bauhus *et al.*, 2001). The understory composition differs considerably between forest types (Hart and Chen, 2008). Several factors are known to contribute to these variations, including overstory structure and composition (Sangar *et al.,* 2008), environmental factors such as distribution of rainfall, temperature, topography, edaphic factors (*e.g.* soil nutrients & moisture), light availability, seed viability, seed dormancy, seed predation and herbivory (Khurana and Singh, 2001; McLaren and McDonald, 2003; Enoki and Abe, 2004), succession history (LaFrankie *et al.,* 2006), forest management strategies (Hart and Chen, 2008; Ares *et al.*, 2009) and forest fragmentation (Benitez-Malvido, 1998).

Uluguru forests are facing a number of problems including destruction by fire, deforestation and encroachment by local people for farmland establishment due to the effects of increasing anthropogenic population pressure by the community living nearby the forests. The increasing population has resulted into unsustainable utilization of the forests and poor cultivation methods such as shifting cultivation. Such activities accelerate soil erosion and land degradation, leading to low crop productivity of the agricultural land, which consequently promote illegal annexing of forestlands for habitation and cultivation (Burgess *et al.*, 2002; Temu and Andrew, 2008). Although, understory is very sensitive to forest fragmentation and biological invasion (Muthuramkumar *et al.*, 2006), the status of understory vegetation in face of fragmentation in Uluguru is lacking. Assessing understory layer is an important measure of the quantity and composition of advanced tree regeneration in the forests, which will impact future canopy structure and composition. Moreover, the presence of regenerating trees in the understory is an imperative for continuing forest succession when natural disturbances like winds storms, and fire creates gaps or eliminate the majority of the canopy trees.

Understanding forest regeneration provides an insight as to likely forest structure and resilience to environmental changes. The present study aims at; (1) comparing species richness, diversity and density of seedling, small sapling and large sapling layers among the forests; (2) examining how does understory species richness differ from the overstory in the studied forests; (3) assessing natural regeneration status of; (i) threatened species (according to IUCN) and endemic/near endemic species encountered in the forests (*see* Table 2.2), (ii) all the forests, using overall size class distributions (SDCs). The results of this study will increase our understanding of the Uluguru forest fragments by presenting full outlook of their understory and are fundamental step for sustainable management of the forests.

3.2 Materials and Methods

3.2.1 Data Collection

Sampling was done in the selected seven forests in Uluguru Mountains in Morogoro region (*see* section 1.6). Classification of vegetation was done into three main layers as follows; seedling (individuals with height < 1 m), small sapling (DBH ≤ 3 cm) and large sapling (3 < DBH < 10 cm) layers. In each forest, large saplings were sampled in 20 m x 20 m plots while subplots of 5 m x 5 m and 2 m x 2 m were placed at the centre of every plot for sampling small saplings and seedlings respectively. A total of 114 plots for each category were established in all the forests together. Kimboza, Kilengwe, Kisego, Milawilila and Nemele forest had 18 plots while Gunauye and Ngambaula had 12 plots for each layer. In every plot and subplot, large saplings and small saplings were identified, counted and DBH measured at 1.3 m above the ground was recorded. The seedlings were also identified and counted. Trees with buttress and some irregularities at 1.3 m height, their DBH were measured at just above the buttress where the stem assumes cylindrical shape. But also, trees with multiple stems at that height were treated as single individual by averaging the diameter of every stem.

3.2.2 Data Analysis

The floristic diversity was determined using the species richness, Shannon-Wiener index, Fisher's-α index and evenness index (Magurran, 2004). The floristic composition was described by species importance values (IVI) and familial importance values (FIV) according to Curtis and McIntosh, (1950) and Mori *et al.*, (1983) respectively (*see* formula 2.1 and 2.2 in chapter 2). The IVIs and FIVs for seedling were computed following the modified formula by Rasingam and Parthasarathy, (2009) (*see* formula 3.1 and 3.2). Species density and diversity were compared among the forests in order to examine variations among understory layers. A one way ANOVA followed by a Tukey's HSD post-*hoc* test were used to check for significant differences among the forest density in each categorical layer. Inventory data for endemic/near endemic and threatened species were classified into 9 size class distributions (SCDs) as follows; 1: seedlings, 2: small and large seedling, 3:10-19.9, 4: 20-29.9, 5: 30-39.9, 6: 40-49.9, 7:50-59.9, 8:60-69.9, 9: > 70 cm. This kind of classification is habitually applied to balance samples across SCDs, because the number of stems usually tends to decline with increasing diameter size (Condit *et al.*, 1998; Lykke 1998).

$$\mathrm{IVI} = \mathrm{Rf} + \mathrm{RDe} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3.1$$

$$\mathrm{FIV} = \mathrm{RDe} + \mathrm{RDi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3.2$$

Where:

$$\mathrm{Rf} = \frac{\text{Frequency of a species}}{\text{Total frequency of all species}} \text{ x } 100$$

$$\mathrm{RDe} = \frac{\text{Number of individuals of a species/family}}{\text{Total number of individuals of all species/family}} \text{ x } 100$$

$$\mathrm{RDi} = \frac{\text{Number of species in a family}}{\text{Total number of species in all families}} \text{ x } 100$$

3.3 Results

3.3.1 Species richness and diversity

A total of 2119 seedlings, 1798 small saplings and 2585 large saplings belonging to 91, 102 and 104 species in 28, 32 and 30 families respectively were recorded in the seven forests (Table 3.1). Fabaceae was the most speciose family in all three layers accounting for 30.0 %, 29.4 % and 30.7 % of the total species in seedling, small sapling and large sapling layers respectively, followed by Moraceae with 6.7 %, 5.9 % and 7.5 % in the seedling, small sapling and large sapling layers respectively (Table 3.2).

The forests varied considerably in terms of their species richness and diversity indices in all the three understory layers (Table 3.1). Large and small sapling layers were the most diverse layers as compared to seedling layer. Of all the forests, Kilengwe was the most diverse forest in all the three layers followed by Kimboza and Kisego forests. All species diversity indices revealed Milawilila and Ngambaula forests to be the least diverse forests in large sapling and small sapling layers. In the seedling layer, Nemele forest was the least diverse when Fisher's α-index was considered while Milawilila was the least diverse when both, Simpson and Shannon-wiener indices were used. All forest layers in each forest revealed higher species evenness. The forests with the lowest density in the seedling and small sapling layers were the ones with lowest species richness and Fisher's-α and Shannon-wiener indices. On contrary, the forest with lower density and species richness in the large sapling layer did not possess least diversity index value. Moreover, as opposed to small saplings, the forests with the higher stems density in the seedlings and large sapling layer had relatively low species richness and diversity indices.

3.3.2 Understory composition and structure of the forests

The density of the seedlings ($F_{(6,107)} = 8.74$, $p < 0.0001$), small saplings ($F_{(6,107)} = 7.18$, $p < 0.0001$) and large saplings ($F_{(6,107)} = 11.52$, $p < 0.0001$) varied significantly between the forests (Table 3.1). Kimboza forest had significantly higher seedling density as compared to rest of the forests (Tukey's HSD test, $p < 0.05$), Kilengwe forest had significantly higher seedling density than Nemele and Ngambaula forests ($p < 0.05$) while the rest of the forests pairs did not differ substantially in their seedlings densities. In the small sapling layer, Kimboza and Kilengwe forests had highest density while Nemele and Ngambaula forest had lowest density values. In the large sapling layers, Kisego forest had significantly higher density compared to all other forests. Kimboza had significantly higher large sapling density than Nemele and Ngambaula forests ($p < 0.05$) while the remaining pairs of forests did not differ appreciably in their large sapling densities. Kimboza and Kilengwe did not differ significantly in their densities in all the three understory layers.

The top ten most important families accounted for 47.7 % (67.0 %), 68.3 % (59.8 %) and 73.5 % (60.7 %) of the family importance value indices (total number of species) in the seedling, small sapling and large sapling layers respectively. The Fabaceae family was the most species-rich and most important family in all the layers (Table 3.2). Anacardiaceae was the second most important family in the seedling layer while Moraceae and Euphorbiaceae were the second in small and large sapling layers respectively. Family Moraceae was among the three most important families in all the three layers.

The top ten most important species in seedlings, small sapling and large sapling layers contributed 41.3 %, 39.2 % and 42.9 % of the total IVI respectively. The three top species with highest IVI in seedlings and small saplings were due to their highest number and frequency of individuals (Table 3.3). Four species (*Sorindeia madagascariensis*, *Scorodophloeus*, *Diospyros squarrosa* and *Ehretia amoena*) appeared in the top ten in all the three layers. *Sorindeia madagascariensis*, *Scorodophloeus fischeri* and *Diospyros squarrosa* were the three most abundant species in the seedling layer with 8.5 %, 6.3 % and 5.4 % of the total individuals in all forests respectively. The most frequent species in the seedling layer were *Sorindeia madagascariensis* which occurred in 35.9 % of the total plots in all forests, followed by *Oxyanthus goetzei* (28.9 %), *Diospyros squarrosa* (28.0 %), *Scorodophloeus fischeri* and *Ehretia amoena* (23.6 % each). Of the total recorded seedling species, 46.6 % were rare species with only 2-10 individuals, while 5.6 % were very rare each having only 1 individual. For small saplings, *Ehretia amoena*, *Oxyanthus goetzei* and *Sorindeia madagascariensis* were the most abundant and frequent species accounting for 5.7 %, 5.5 % and 5.3 % of the total density and 36.8 %, 39.5 % and 35.1 % of the total occurrence in all the forests respectively. 51.9 % of small sapling species were rare with 2-10 individuals and 3.9 % of species were very rare with only 1 individual. *Sorindeia madagascariensis*, *Ehretia amoena*, *Scorodophloeus fischeri* and *Margaritaria discoidea* were the most abundant species in the large sapling layer with 7.6 %, 5.6 %, 5.5 % and 5.3 % of the total density of all the forests respectively. 43.9 % of recorded species in the large sapling layer were rare with 2-10 individuals while 5.6 % of all species were very rare with only 1 individual.

Table 3.1: Number of species, families, tree density and diversity indices of three compartments in the studied forests.

Location	No. of Species	No. of Family	Mean (± SE) (Individuals ha^{-1})	Fisher's-α (± Jack SE)	Simpson (± Jack SE)	Shannon (± Jack SE)	Evenness (± Jack SE)
Seedlings							
Kilengwe	51	21	56944 ± 6222^{ac}	15.35 ± 1.34	29.35 ± 4.14	3.57 ± 0.08	0.91 ± 0.02
Kimboza	43	20	76806 ± 10079^{a}	10.91 ± 1.44	12.38 ± 1.84	2.96 ± 0.14	0.78 ± 0.04
Kisego	33	20	45556 ± 3989^{bc}	9.14 ± 1.14	15.39 ± 3.44	3.07 ± 0.12	0.88 ± 0.03
Milawilila	19	13	39583 ± 4178^{bc}	4.59 ± 0.56	7.94 ± 1.76	2.36 ± 0.12	0.80 ± 0.04
Nemele	13	9	25833 ± 2492^{b}	3.18 ± 0.10	11.2 ± 2.37	2.46 ± 0.10	0.96 ± 0.04
Ngambaula	13	10	28542 ± 5334^{b}	3.52 ± 0.27	10.56 ± 1.69	2.41 ± 0.10	0.94 ± 0.04
Gunauye	24	10	45833 ± 5718^{bc}	6.85 ± 0.35	19.44 ± 2.45	3.02 ± 0.07	0.95 ± 0.02
Small saplings							
Kilengwe	60	26	8756 ± 670^{a}	19.77 ± 0.91	50.86 ± 3.57	3.94 ± 0.05	0.96 ± 0.01
Kimboza	53	21	7556 ± 630^{ac}	17.62 ± 2.86	22.30 ± 5.05	3.46 ± 0.19	0.87 ± 0.05
Kisego	38	24	6156 ± 520^{bc}	11.92 ± 1.53	22.38 ± 3.79	3.30 ± 0.11	0.91 ± 0.03
Milawilila	24	17	5844 ± 415^{bc}	6.43 ± 0.18	17.32 ± 1.47	2.96 ± 0.06	0.93 ± 0.02
Nemele	18	12	4911 ± 415^{b}	4.63 ± 0.14	13.20 ± 1.93	2.70 ± 0.08	0.93 ± 0.03
Ngambaula	15	11	4733 ± 603^{b}	4.23 ± 0.61	10.36 ± 1.31	2.44 ± 0.10	0.89 ± 0.04
Gunauye	21	12	5367 ± 471^{bc}	6.44 ± 0.38	18.56 ± 1.98	2.92 ± 0.07	0.96 ± 0.02
Large saplings							
Kilengwe	72	28	550 ± 46^{ab}	25.75 ± 1.68	53.42 ± 4.46	4.03 ± 0.06	0.94 ± 0.01
Kimboza	55	21	646 ± 48^{b}	16.22 ± 1.67	21.73 ± 2.81	3.43 ± 0.09	0.85 ± 0.02
Kisego	40	19	867 ± 80^{c}	9.54 ± 0.70	15.75 ± 1.87	3.06 ± 0.10	0.83 ± 0.03
Milawilila	25	15	542 ± 26^{ab}	5.96 ± 0.09	14.28 ± 1.37	2.89 ± 0.06	0.90 ± 0.02
Nemele	24	15	394 ± 20^{a}	6.18 ± 0.10	15.17 ± 1.56	2.90 ± 0.06	0.91 ± 0.02
Ngambaula	23	13	383 ± 33^{a}	6.94 ± 0.27	19.81 ± 2.04	3.00 ± 0.06	0.96 ± 0.02
Gunauye	26	13	475 ± 62^{ab}	7.56 ± 0.66	18.17 ± 2.27	3.01 ± 0.07	0.92 ± 0.02

NB: Values with different letters indicate significant differences between the forests (Tukey's HSD test, $p < 0.05$).

Table 3.2: Top ten families with the highest IVI in the three understory layers of the studied forests.

Family	No. of Species	Density (Individuals ha^{-1})	IVI
Seedling Layer			
Fabaceae	27	12193	56.2
Anacardiaceae	3	4452	12.9
Moraceae	6	2741	12.6
Combretaceae	5	2127	10.1
Apocynaceae	4	2500	9.8
Annonaceae	4	2478	9.8
Sterculiaceae	4	2040	8.8
Ebenaceae	2	2851	8.4
Meliaceae	2	2412	7.4
Euphorbiaceae	4	1162	6.9
Small Sapling Layer			
Fabaceae	30	1691	83.1
Moraceae	6	326	16.2
Apocynaceae	5	379	16.2
Rubiaceae	4	383	16.0
Anacardiaceae	3	379	15.3
Sterculiaceae	5	288	13.6
Boraginaceae	1	365	12.6
Ebenaceae	2	288	11.1
Sapindaceae	2	270	10.6
Annonaceae	4	200	10.3
Large Sapling Layer			
Fabaceae	32	176	97.8
Euphorbiaceae	5	38	19.1
Moraceae	6	41	19.0
Anacardiaceae	3	46	17.9
Ebenaceae	2	32	12.7
Bignoniaceae	3	28	11.7
Boraginaceae	1	32	11.4
Apocynaceae	4	22	10.8
Combretaceae	5	16	10.0
Annonaceae	5	16	9.8

Table 3.3: Top ten species with highest IVI in the seedling, small sapling and large sapling layers.

Family	Species	Density (Ind. ha^{-1})	Frequency (%)	IVI
Seedling Layer				
Anacardiaceae	*Sorindeia madagascariensis* DC.	3947	36.0	14.4
Fabaceae	*Scorodophloeus fischeri* (Taub) J.Leon	2939	23.7	10.2
Ebenaceae	*Diospyros squarrosa* Klotzsch.	2544	28.1	10.1
Rubiaceae	*Oxyanthus goetzei* K.Schum.	2040	28.9	9.1
Boraginaceae	*Ehretia amoena* Klotzsch.	2018	23.7	8.2
Meliaceae	*Khaya anthotheca* (Welw.) C. DC.	2193	10.5	6.4
Annonaceae	*Xylopia parviflora* (A. Rich.) Benth.	1754	14.9	6.2
Fabaceae	*Dichrostachs cinerea* Wight et Arn.	1733	14.9	6.2
Bignoniaceae	*Markhamia zanzibarica* (Bojer ex DC.)	1184	21.1	6.0
Sterculiaceae	*Dombeya natalensis* Sond.	1294	17.5	5.7
Small Sapling Layer				
Boraginaceae	*Ehretia amoena* Klotzsch.	365	36.8	16.2
Rubiaceae	*Oxyanthus goetzei* K.Schum.	347	39.5	16.1
Anacardiaceae	*Sorindeia madagascariensis* DC.	333	35.1	15.4
Fabaceae	*Albizia glaberrima* (Schum&Thonn.)Benth.	295	27.2	12.9
Fabaceae	*Scorodophloeus fischeri* (Taub) J.Leon	291	27.2	12.3
Apocynaceae	*Voacanga africana* Stapf.	175	27.2	10.9
Ebenaceae	*Diospyros squarrosa* Klotzsch.	228	25.4	10.4
Fabaceae	*Dichrostachs cinerea* Wight et Arn.	211	14.0	8.5
Loganiaceae	*Strychnos spinosa* Lam.	172	14.9	7.8
Sapindaceae	*Deinbollia borbonica* Scheff.	140	21.1	7.1
Large Sapling Layer				
Anacardiaceae	*Sorindeia madagascariensis* DC.	43	74.6	18.1
Fabaceae	*Albizia versicolor* Welw. ex Oliv.	15	43.0	16.5
Boraginaceae	*Ehretia amoena* Klotzsch.	32	82.5	15.3
Fabaceae	*Scorodophloeus fischeri* (Taub) J.Leon	31	64.0	13.8
Euphorbiaceae	*Margaritaria discoidea* (Baill)G.L.Webster	30	67.5	13.6
Ebenaceae	*Diospyros squarrosa* Klotzsch.	24	58.8	11.5
Bignoniaceae	*Markhamia zanzibarica* (Bojer ex DC.)	24	59.6	11.1
Fabaceae	*Albizia glaberrima* (Schum&Thonn.)Benth.	22	60.5	11.0
Moraceae	*Antiaris toxicaria* (Pers.) Lesch.	19	50.0	9.3
Fabaceae	*Millettia usaramensis* Taub.	18	48.2	8.4

The species frequency distributions (Figure 3.1) show that Kilengwe, Kimboza and Kisego forests had higher species richness in the first frequency class (*i.e.* < 20 %) in all the forest compartments while the other four forests possessed more species in the second (20 - 40 %) and third (40 - 60 %) frequency classes. The frequency reflects the distribution pattern and provides an approximation indication of the heterogeneity of the stands.

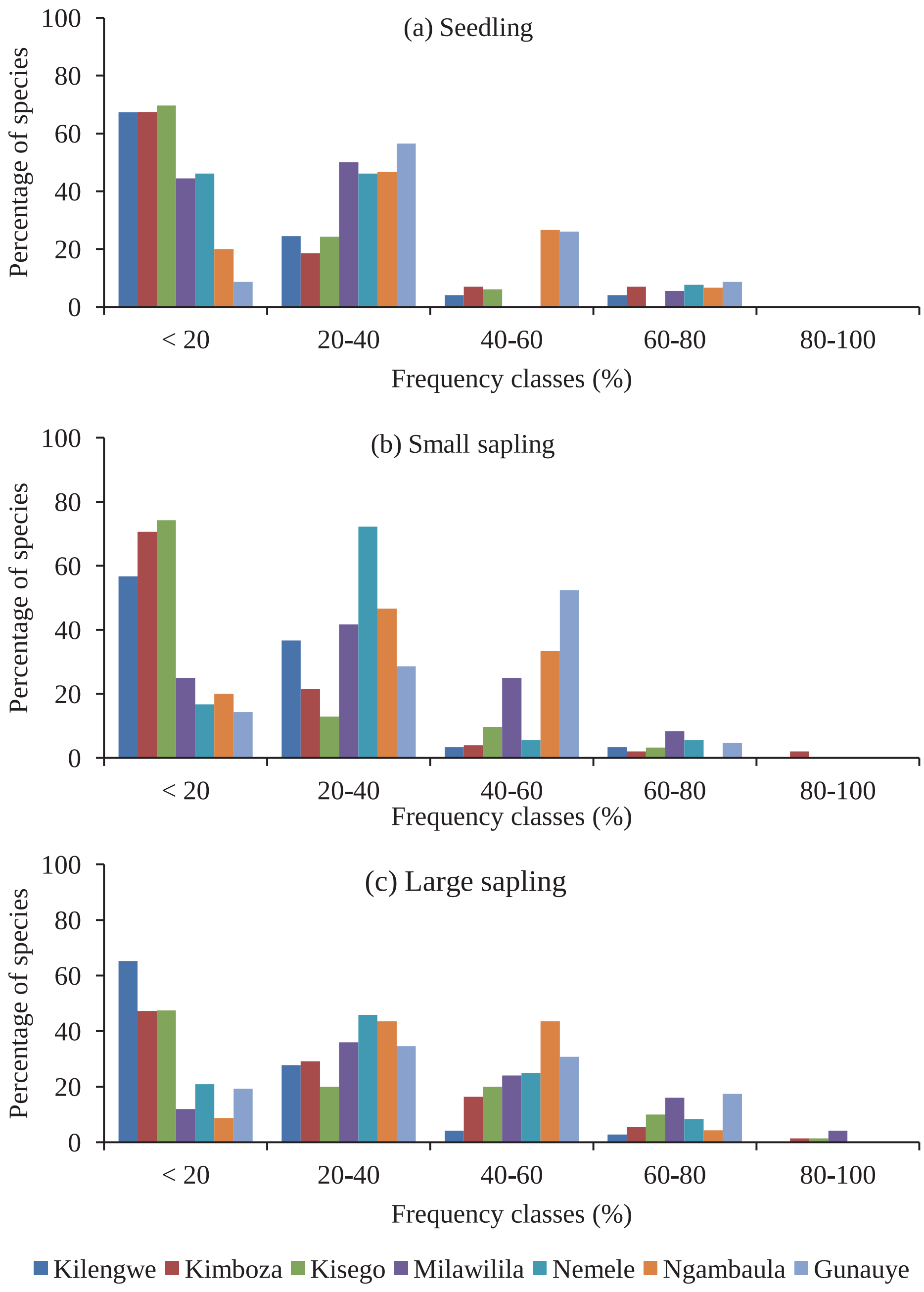


Figure 3.1: Species frequency distributions in the three forest layers in all the studied forests

3.3.3 Comparison between understory and overstory layers

The species richness in each of the forest was relatively higher in the understory layer than overstory (Figure 3.2). Only the number of species at Kisego forest revealed to have significant difference between the two layers. When all the forests are pooled together, the overall mean species richness of the understory layer (59 ± 9 species ha^{-1}) was significantly higher than the overstory (47 ± 10 species ha^{-1}) (Paired t test: t = 4.05, d.f = 6, p = 0.0034).

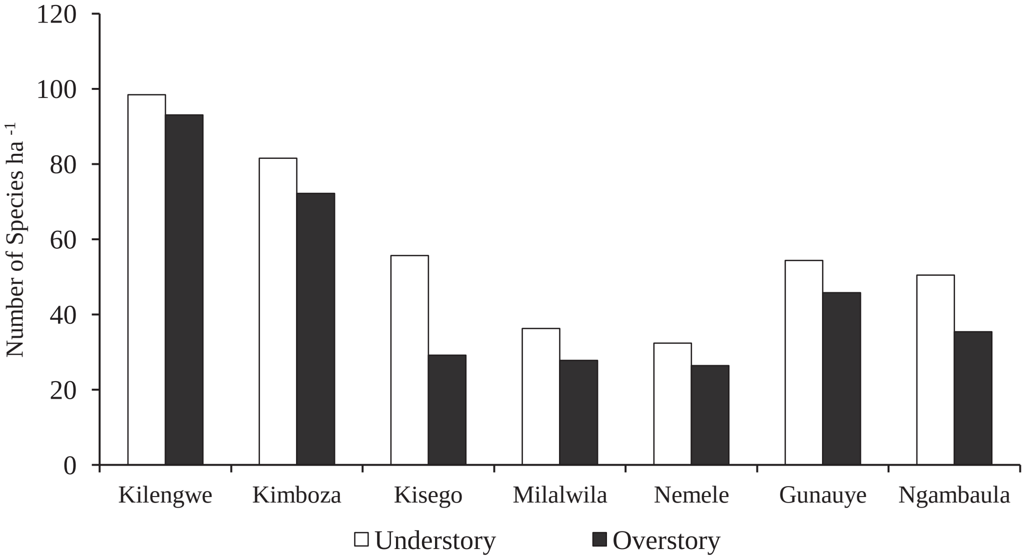


Figure 3.2: Comparison of species richness between overstory and understory layers within each studied forest in Uluguru.

Comparison of floristic similarity coefficients between overstory and understory layers within forests ranged from 0.53 – 0.77. Kilengwe forest had higher similarity coefficient value while Kisego had lower value (Figure 3.3). The cluster reveals that floristic similarity between the overstory and understory was higher within each forest than among the forests.

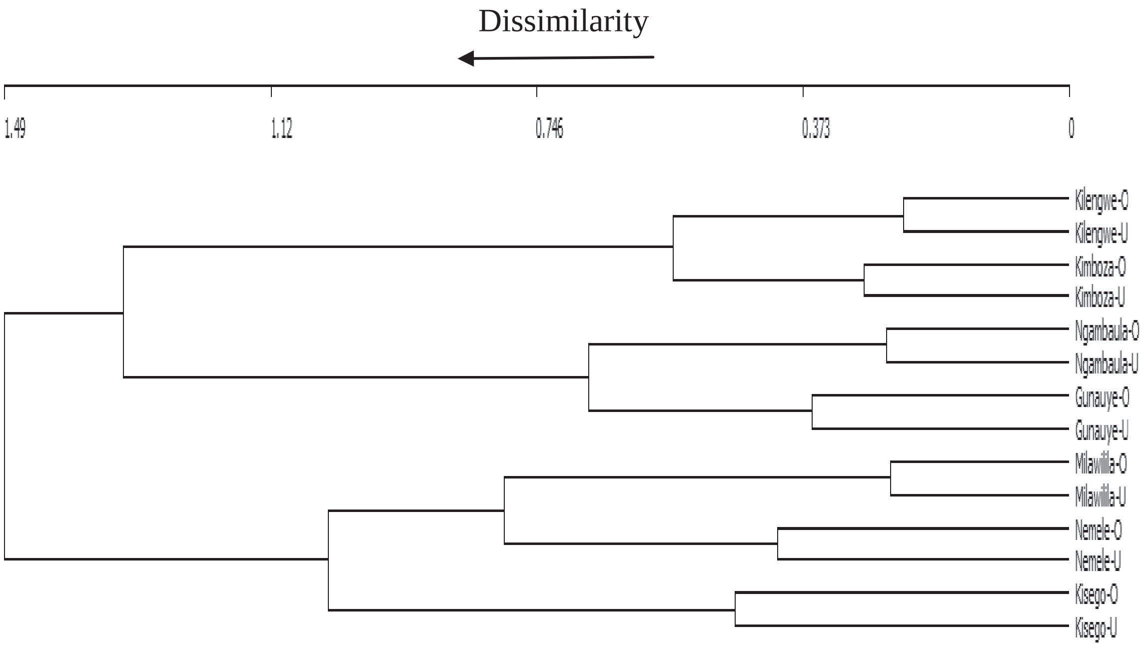
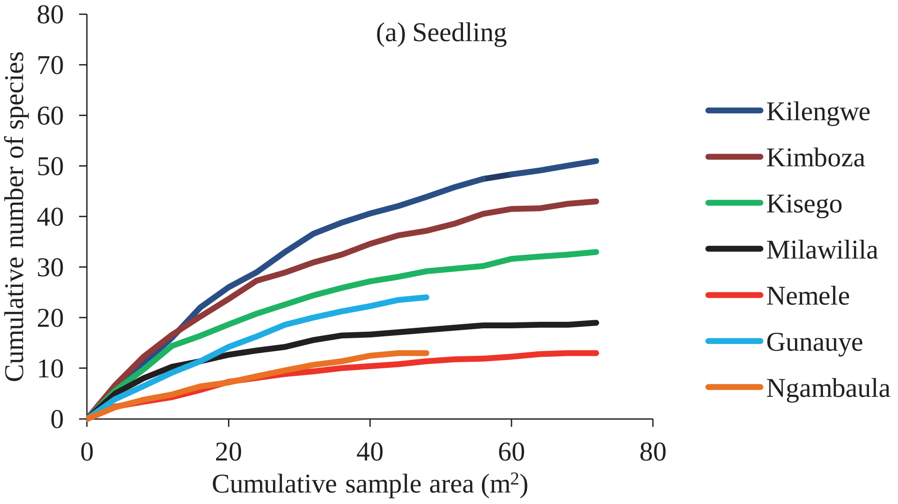
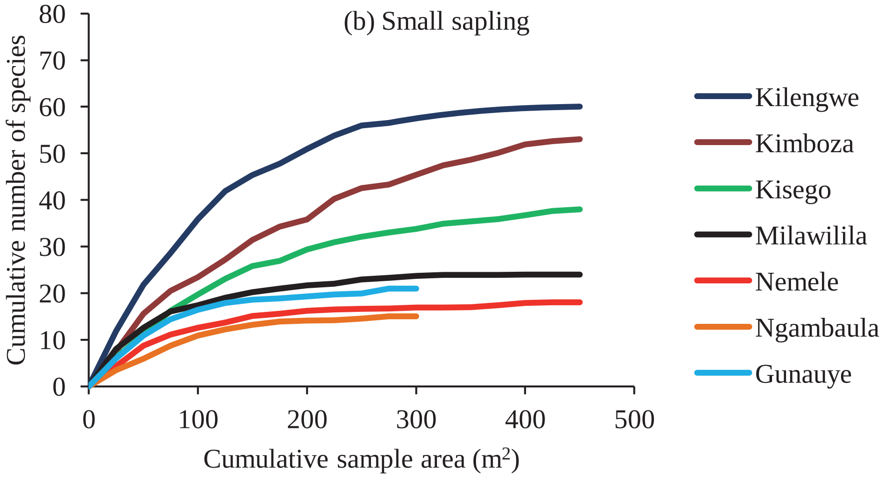


Figure 3.3: Dendogram showing floristic similarity between overstory and understory within and among the Uluguru studied forests (letter O indicates Overstory layer and U indicates understory layer).

3.3.4 Species accumulation curves

The species accumulation curves (Figure 3.4) showed the rate of species richness increase with increasing sample area to be higher at Kilengwe, Kimboza and Kisego forests in each forest layer as compared to other forests. In the seedling layer, the curve for Gunauye showed an increasing trend towards the end while the curves for Milawilila, Nemele and Ngambaula tended to flatten or closely reached asymptote toward the end. In the small sapling layer, only Kimboza and Kisego tended to increase towards the end while the remaining forests approached asymptote. In the large sapling layer, Kilengwe, Kimboza and Kisego increased towards the end while the remaining forests approached asymptote.





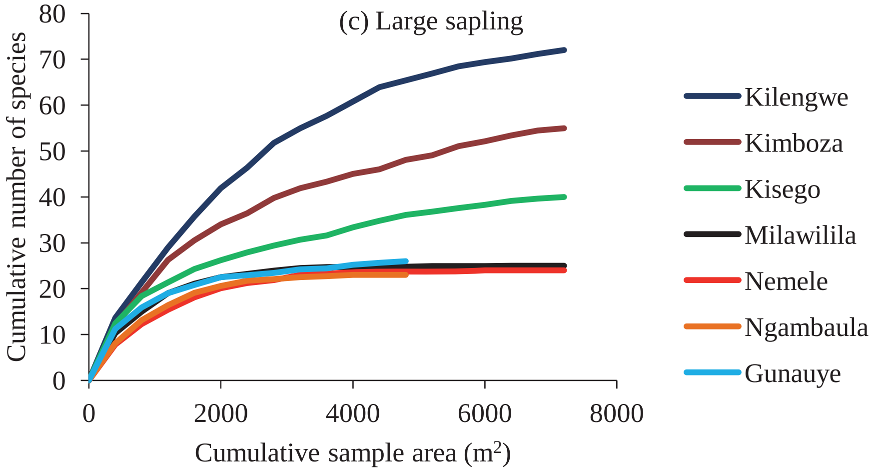


Figure 3.4: Species accumulation curves of the three studied compartments in all the forests.

3.3.5 Regeneration status

The SCDs of the threatened and endemic/near endemic species displayed different patterns (*see* appendix 1). There were species with individuals concentrated in the lower classes, some at the middle and others at the higher size classes. In general, two types of regeneration (*i.e.* good and poor regeneration) were recognized from these SCDs. For those species which possessed higher density in the lower size classes, particularly in the first class (*i.e.* seedling) suggests that they have good regeneration potential. On the contrary, species which possessed either no or low density in these size classes indicate that the species are in poor regeneration status.

Scorodophloeus fischeri showed good regeneration in all the forests where it was observed, although, at Kilengwe forest, it was somehow hampered. *Khaya anthotheca* showed good regeneration at Kimboza, Kilengwe and Ngambaula forests. *Allanblackia uluguruensis* showed good regeneration status at Kilengwe and Nemele forest but was hampered at Milawilila forest. Other species that showed good regeneration pattern are *Holarrhena pubescens* at Kimboza, *Cussonia zimmermannii* and *Cynometra uluguruensis* at Kilengwe and *Milicia excelsa* at Kisego forest. *Hollarrhena pubescens* and *Cynometra uluguruensis* showed hampered regeneration at Kilengwe and Kimboza respectively. Other species that showed poor/hampered regeneration include *Dalbergia melanoxylon*, *Pterocarpus angolensis*, *Pandanus rabaiensis*, and *Millettia sacleuxii* at Kimboza, *Pouteria altissima* and *Dalbergia melanoxylon* at Kilengwe, *Milicia excelsa* at Ngambaula and Kilengwe while *Allanblackia stuhlmannii* showed hampered regeneration at Milawilila. The overall SCDs of all species (all forests pooled) and SCDs in each of the forest exhibited a fairly reverse "J"- curve distribution (appendix 1), which is deemed as an indication of stable population structure or good regeneration status. However, it is important to understand that some species are not in good regeneration status and, thus, need due attention. Moreover, apart from the threatened species presented in this chapter, other species that revealed poor regeneration in their forests are presented in Table 6.1.

3.4 Discussion

3.4.1 Species richness and diversity

The ranges of all used diversity indices (Table 3.1) indicate high species richness and diversity in the large sapling layer than in the seedling and small sapling layer within the forests. This could be principally influenced by the larger sampling plots used for large sapling, which is due to the fact that the larger the sampling plot the more species are likely to be encountered. The overall Shannon-wiener diversity values for the three forest layers (each layer pooled together across the forests, n = 114 plots) ranged from 3.86-4.09 which are considered high values in any tropical forests (Oliveira and Mori, 1999). Actually, these values indicate that Uluguru forests are speciose. In tropical forests, edaphic heterogeneity play an important role in the maintenance of high floristic diversity where tree species are influenced by soil characteristics (Tuomisto and Ruokolainen, 2005; Ruokolainen *et al.*, 2007). The observed high floristic diversity in some of the studied *e.g.* Kilengwe, Kimboza and Kisego forests signifies occurrence of low-abundance species across the forests (Silva *et al.*, 2011). This can be seen from the frequency distribution (Figure 3.1) where considerable numbers of species in these three forests are concentrated in the first lower frequency class in all layers while the other forests had more species in the second and third frequency classes. Normally, the frequency reflect the distribution patterns and provide and approximation indication of rarity of species and heterogeneity of stands. Occurrence of more species in higher frequency classes is a good indication that forest is characterized by common species than rare ones. Milawilila, Nemele, Ngambaula and Gunauye revealed to have more common species than rare ones. The trend in these four forests was also confirmed by the species accumulation curves (figure 3.4), which approach the asymptote.

In all the forests, the evenness indexies in large and small sapling layers (Table 3.1) were relatively high signifying that no one species dominated a forest. However, in the seedling layer, Kimboza and Milawilila forests had the evenness index values lower than other forests. In the seedling layer, Kimboza was dominated by *Khaya anthotheca* with 89 individuals while Milawilila was dominated by *Xylopia parviflora* with 75 individuals. In contrast, no species in the seedling layer had more than 50 individuals recorded in the remaining forests. Also, the present findings from all the seven forests revealed understory layer was more diverse than the overstory layer (Figure 3.2), which suggests that studies depending only on the diversity of overstory may not reflect the overall diversity of the forests. The high diversity of understory may be associated with the wetter conditions provided by the overstory canopy which allows trees to be more shade tolerant, so a larger number of tree functional types could potentially survive (Huang *et al.*, 2003). Other studies *e.g.* Tchouto *et al.*, 2006 and Lu *et al.*, 2011 reported understory being diverse than overstory. Thus, the present study confirms that the understory deserves more attention during biodiversity inventories in the future. Moreover, the higher species compositional similarity between understory and overstory within the studied forests is an indication that understory is responsible for a higher percentage of total diversity in the forests (Tchouto *et al.*, 2006). As an integral part of the community, the understory provides food for insects, birds and mammals (Gentry and Emmons, 1987), and it plays a vital role in the food web and nutrient cycling of the forest ecosystems (Lu *et al.*, 2010). However, natural and anthropogenic disturbances can affect the species composition and diversity of the understory in different forests (Hart and Chen, 2008; Rasingam and Parthasarathy, 2009), which may have great implications for succession, dynamics and ecosystem function and service of forests (Royo and Carson, 2006). The Uluguru forest fragments are destroyed due to human population growth; encroachment and fire pose many threats to existing biodiversity. Elsewhere, it has been reported that tropical forest degradation and fragmentation has caused losses of tree species diversity (Zhu *et al.*, 2004), changes of soil seed bank (Lin and Cao, 2009), habitat modification (Didham and Lawton, 1999; Yan *et al.*, 2007) and reduction of carbon storage (Li *et al.*, 2008). Knowing the important role played by understory species in the forests, more attention is needed on the pattern and ecological consequences of changes of understory in face of fragmentation in Uluguru forests.

Species accumulation curves illustrate the rate per unit area sample at which new species are found to the inventory, which provides important clues about species richness and indeed species abundance distribution of the assemblage as a whole (Magurran, 2004; Gotelli and Colwell, 2011). The species accumulation curves that do not show asymptotic behaviour are mainly characterized by presence of many rare species and species with narrow habitat ranges (Condit *et al.*, 1996; Gotelli and Colwell, 2011). The species accumulation curves for Kilengwe, Kimboza and Kisego in all the forest layers (Figure 3.4) did not show asymptotic behaviour mainly due to presence of many rare species. This is well illustrated by the frequency distribution graphs (Figure 3.1), which show these forests having more number of species in the lower frequency class (< 20 %). The non-asymptotic behaviour suggests that additional species would have been encountered if the sample size was to be increased. The curves for Milawilila, Nemele, Ngambaula and Gunauye in small sapling and large sapling reached asymptote, which signifies almost all the species in these forests were captured and the sample size used was fairly sufficient for the inventory. The increase in number of species with increasing area suggests that a reduction in forest size due to fragmentation may cause species loss, especially rare ones.

3.4.2 Understory composition and structure

Fabaceae was the most dominant family with highest FIV in all the three layers mainly due to high species richness and greater abundances of the constituent species (Table 3.2). Similarly, the family Fabaceae observed dominated the overstory tree layer (*see* chapter 2). When compared with other studies done in other lowland forests in Tanzania (e.g. Burgess and Muir, 1994; Burgess and Clarke, 2000; Mrema *et al.*, 2006), the family Fabaceae has been reported to dominate too. Burgess and Clarke (2000) reported Fabaceae being the dominant family in the coastal forests of Tanzania by 25 % to 50 % of the species while Gentry (1988) reported this family Fabaceae being the one with highest percentages of species in the lowland forests of Africa. In the present study, Fabaceae dominated by 23 %, 29 % and 31 % of the total species in seedling, small sapling and large sapling layer respectively. Other authors elsewhere have also reported the same family being the most important family in their studies (Addo-Fordjour *et al.*, 2009; Silva *et al.*, 2011). Other five families, Moraceae, Annonaceae, Apocynaceae, Ebenaceae and Anacardiaceae were among the dominant ones not only in the overstory layer but also occurred in all the three understory layers, suggesting that the seedlings, small and large saplings of these families contribute strongly to the composition of the understory in the forests. Among the top 10 families registered in this study were similarly reported among the most dominant families in different studies elsewhere (*see* Mrema, 2006; Mwavu, 2007).

In the seedling and large sapling layers, *Sorindeia madagascariensis* was the most dominant species in terms of IVI (Table 3.3). Its dominance in seedling layer is mainly attributed by both, higher density and frequency while in large sapling layer its dominance was chiefly influenced by density. The small sapling layer is dominated by *Ehretia amoena*, which was influenced by density of individuals. Only three species (*Sorindeia madagascariensis, Scorodophloeus fischeri* and *Diospyros squarrosa*) occurred in all the three layers and had relatively higher occurrence compared to other species especially in seedling and large sapling compartments. The possession of high frequency by these three species (Table 3.3) indicates their wider range of their ecological adaptations as compared to other species. Species like *Scorodophloeus fischeri* have been reported by other authors (*e.g.* Temu, 1990;

Mrema, 2006) being the most common species and dominant in the coastal forests of Tanzania. The considerable variation in density and frequency among species may be due to habitat differences, habitat preferences among the species, adaptation ability of species, degree of anthropogenic exploitation (Richards, 1952) and presence of favourable environmental conditions for species regeneration such as light penetration and edaphic conditions such as soil moisture and nutrients. Other factors like seed dispersal, seed viability, seed dormancy, seed predation and herbivory (McLaren and McDonald, 2003; Enoki and Abe, 2004) might be also accounting for the differences.

3.4.3 Regeneration status

The classic reverse "J" curve represent the population which recruits fairly frequently over time (Mwavu and Witkowski, 2009) and the curve implies a stable population structure (West *et al.*, 2000). The observed size class distributions of the species exhibited two regeneration patterns *i.e.* good and poor regeneration (*see* appendix 1). The possible reasons for some species to have poor regeneration can be due to anthropogenic disturbances through selective and illegal logging of the species, which also cause damage to sapling and seedlings when trees fall. The signs of selective removal for *Pterocarpus angolensis*, *Milicia excelsa* and *Dalbergia melanoxylon* were observed in the studied forests. The first two species have been cut for timber and construction purposes while the later was mainly for carving activities. Though not studied, variations in the environmental factors between the forests may possibly account for poor regeneration of some species too (Mwavu and Witkowski, 2009). The seedling recruitment processes (*i.e.* growth, survival and establishment) differ with species, light intensity, edaphic conditions (*e.g.* nutrients and moisture) as well as meteorological parameters like temperature and rainfall (Clack *et al.*, 1999; Sasaki *et al.*, 2008). The lower number of seedlings may also depend on whether the particular species has sufficient seed bank (Lyaruu and Backéus, 1999). Seed bank and seed rain are known to be the major sources of new individuals and species recruitment in forests (Grombone-Guaratini and Rodriguez, 2002).

The under-representation or absence of individuals in some size classes, especially the middle size classes for some species for instance, *Milicia excelsa*, *Pterocarpus angolensis* and *Dalbergia melanoxylon* at Kimboza, *Cussonia zimmermannii*, *Dalbergia melanoxylon* and *Milicia excelsa* at Kilengwe indicate poor but also broken/discontinuous regeneration pattern (Poorter *et al.*, 1996). This lack of individuals at middle size classes and mature reproductive individuals at higher classes for some species is associated to their regeneration failure in combination with over exploitation for timber, poles and charcoaling. Species like *Khaya anthotheca*, *Milicia excelsa*, *Dalbergia melanoxylon* and *Pterocarpus angolensis* are illegally harvested for timber and are logged by the locals at sizes below the legal minimum harvestable diameter (MHD) in most of the coastal forests of Tanzania (Ahrends, 2005; Modest *et al.*, 2009)), which also seem to affect their SCDs. The intense exploitation of small stems (*i.e.* poles) for building purposes has similarly been blamed for poor recruitment of some species in Kakamega forests in Kenya (Fashing *et al.*, 2004). The lack of individuals in seedling and saplings size classes for some species like *Cussonia zimmermannii* (Gunauye) and *Pandanus rabaiensis* (Kimboza) is clear enough to raise some doubts and questions concerning their long-term populations' survival. Usually, few seedlings and sapling individuals make unlikely that species populations can be maintained at the present level, in view of the fact that for a species to maintain a relative constant population, more individuals are required in the smaller size classes than in larger ones (Lykke, 1998; West *et al.*, 2002). This means that the species with no seedlings and saplings could be eliminated completely from the forests if harvesting of the mature trees in overstory layer will continue. The existence of species with poor/hampered regeneration pattern suggests the need for development and implementation of the forest management plans in order to reverse these trends and facilitate a healthy regeneration pattern.

3.5 Conclusion

Though most of the studies of species diversity in tropical forest communities heavily focus on overstory layer, this study has demonstrated that understory have high species richness than overstory, which suggests that the understory should be given more attention during the future inventories. On the other hand, the overstory and understory layers revealed to have higher floristic similarity composition within forest fragments than between forests. Also, the high floristic diversity and large occurrence of low-abundance species in Kilengwe, Kimboza and Kisego forests, calls for the necessity of considering the rare species in the management projects in order to prevent local extinction. Special attention on conservation should be directed to species with poor regeneration patterns. The species that revealed poor regeneration will have good potential to recover in the future if and only if the anthropogenic factors of disturbances will be kept minimum or eliminated. Though Uluguru forests are facing anthropogenic pressure, special conservation priority should be given not only to overstory but also the understory layer of the forests.

CHAPTER FOUR

Species richness, diversity and stand density disparity along edge-interior gradients in Uluguru forests in Morogoro – Tanzania

4.1 Introduction

Worldwide, tropical rainforest are facing great threats of habitat fragmentation and some are already archipelagos of small fragments (Tuner, 1996). The forest fragmentation has increased in recent decades mainly due to increased human population, which consequently lead to the increase of anthropogenic activities such as agriculture, logging and timber harvest towards forest resources (Bailly *et al.*, 2004). The fragmentation process has been described as a disruption of structural and spatial continuity, as it reduces area, increases edges formation and isolates remaining fragments (Fahrig, 2003; Walker *et al.*, 2006). Formation of forest edges is recognized to be a vital cause of ecological change as it involves alteration of micro-climatic conditions. Usually, associated effects of edges result from the interactions between forest remnant and the adjacent matrix (Murcia, 1995). When compared with the forest interior environment, forest edges are characterized by higher air and soil temperatures, higher light transmittance, lower relative humidity (Jose *et al.*, 1996; Didham and Lawton, 1999; Newmark, 2001; Yan *et al.*, 2007), increased wind forces (Laurance *et al.*, 1998), lower availability of soil organic carbon, total nitrogen and phosphorus (Jose *et al.*, 1996) and lower soil and litter moisture (Jose *et al.*, 1996; Didham and Lawton, 1999). The alteration of microclimate results in drastic changes in abundance and distribution of several organisms, particularly mammals, birds, amphibians and trees in forest fragments (Bierregaard *et al.*, 2001).

Various studies done in tropical forests have reported negative impacts of forest fragmentation, mainly associated with the edge effects. These include; (1) reduction in recruitment rates of trees due to habitat desiccation and seedling damage by litter and tree fall near forest edges (Benitez-Malvido 1998), (2) increasing sapling mortality rate by competition with lianas, vines and ruderal species (Tabarelli *et al.*, 2004) and (3) increased mature tree mortality due to increased rates of uprooting and breakage near forest edges (Chen *et al.*, 1992; Laurance *et al.*, 1998; Mesquita *et al.*, 1999), which results to the decrease in canopy height (Didham and Lawton, 1999; Oosterhoorn and Kappelle, 2000). Due to the above explained effects and other edge-related processes, it is reasonable to expect that tree species assemblages in small forest fragments and forest edges will differ markedly from those in larger forests in terms of species richness, diversity and structure, but also ecological and taxonomical composition (Fox *et al.,* 1997; Oliveira *et al.,* 2004). Moreover, when forest edges lose tree species within particular groups, archipelagos of small fragments will tend to support only an impoverished subset of trees from the original biota (Laurance, 2001).

Uluguru forest, which form one of the component blocks of Eastern Arc mountains forests, are one of the most distinctive centres of endemism and diversity for flora and fauna (Burgess *et al.,* 2002, 2007). The biological uniqueness was recognised at national level in the Tanzania Forest Action Plan, which proposed conservation projects for the Eastern Arc Mountains forests (Bensted-Smith and Msangi, 1989). These are recognized by international organisations, such as Bird Life International (Stattersfield *et al.,* 1998), Conservation International (Mittermeier *et al.,* 1998; Myers *et al.,* 2000), and the World Wildlife Fund (Olson and Dinerstein, 1998) as an area of global importance for the conservation of biodiversity. Uluguru forests are suffering extensive loss due to anthropogenic activities and fire (Madoffe *et al.,* 2006). The loss is directly linked to rapid human population increase around the forests, which lead to overexploitation of the forests resources due to increased demand for more land for agriculture, timber and pole gathering for building purposes, charcoal for fuel and illegal hunting and logging (Burgess *et al.,* 2002). The forest loss and fragmentation not only jeopardize existence of common species, but also strict endemic and near endemic species (Temu and Andrew, 2008). Thus, determining how species distribution, abundance and diversity vary within forest fragments is vital step in ecological studies (Murcia, 1995). No known studies in Uluguru Mountain forests have examined the edge-interior differences in tree species composition and structure. Due to existence of this knowledge gap, this study intends to provide an understanding on the existing knowledge discrepancy by comparing species composition, richness, diversity and structural change along the edge-interior gradient within and between selected Uluguru forests. The main goals were to analyse to what extent species richness, diversity and abundance differs along the edge-interior gradient. The findings of this study will contribute to the management of the forest reserves and other similar tropical forest fragments.

4.2 Material and Methods

4.2.1 Data collection

To characterize species richness and diversity along the edge-interior gradient, six plots were established at edge (0-100 m), intermediate (100-200 m) and interior (> 200 m) in each forest. For the small forests *i.e.* Ngambaula and Gunauye forests, only six plots were established at edge (0-100 m) and interior (>100 m). The plots were randomly set in each of the categorical distance. This design was due to the fact that edge effects can penetrate to 100 m into forest (Laurance *et al.*, 1998). Each plot in every categorical distance was considered as an independent sample. Vegetation were classified into four layers, which are seedling (individuals with height < 1m), small sapling (DBH ≤ 3 m, height > 1.5), large sapling (3 cm < DBH < 10 cm) and overstory/mature trees (DBH > 10 cm) layers. Within each plot, overstory/mature trees and large saplings were sampled in a 20 m x 20 m (400 m^2) plot while subplots of 5 m x 5 m (25 m^2) and 2 m x 2 m (4 m^2) were placed at the centre of each plot for sampling small saplings and seedlings respectively. In every plot and subplot, mature trees, large saplings and small saplings were identified, counted and DBH measured at 1.3 m above the ground was recorded. Trees with multiple stems at that height were treated as single individual by averaging the diameter of every stem. Seedlings were identified, counted and some were collected for later identification.

4.2.2 Data Analysis

Species diversity was calculated using the Shannon-Wiener diversity index formulae for each plot using the Species Diversity and Richness IV (SDR IV) software (Seaby and Henderson, 2006). Species richness was also quantified within each plot. Single analysis of variances (one-way ANOVA) was use to check for differences in species richness, diversity, density (stems ha^{-1}) and basal area (m^2 ha^{-1}) between categorical distances (*i.e.* edge, intermediate and interior) followed by the *post-hoc* Tukey's (HSD) test using Graphpad Prism software. The relationship between forest size and species richness was checked using the Pearson correlation coefficient. Determination of thinning effect for edge and interior plots in each forest was done by ploting tree sizes or individual biomass against logarithm of number trees ha^{-1} using sigma plot software. The individual biomass were grouped into seven categories (1 = seedling, 2 = small sapling, 3 = 3-10 cm DBH, 4 = 10-20 cm, 5 = 20-30 cm, 6 = 30-40 cm and 7 => 40 cm).

4.3 Results

4.3.1 Overall description

A total of 7402 individuals belonging to 113 species, which represent 36 families were sampled in all the seven studied forests. Fabaceae was the most species-rich family with 30.1 % (34 species) of the total recorded species in all the forest layers. Of the total individuals, 12.2 % (198 ha^{-1}) represented mature trees or overstory layer, 35.0 % were large saplings (566 ha^{-1}), 24.3 % (6309 ha^{-1}) small saplings and 28.6 % (46469 ha^{-1}) represented seedlings.

4.3.2 Species richness as influenced by edge-interior gradient

The species richness varied extensively between and within the forests for each forest layer (Table 4.1). Kilengwe and Kimboza displayed significant higher mean species richness in the interior plots in the overstory, large sapling and small sapling layers. In Kisego forest, interior plots had significant higher mean species richness than edge and intermediate plots in the large sapling and small sapling layers while Milawilila and Nemele revealed significant higher species richness in the interior plots than edge and intermediate in the small sapling layer only. Ngambaula and Gunauye had significantly higher number of species in the interior plots than edge plots in small sapling layer but these two forests revealed no significant differences between the edge and interior plots in the overstory, large sapling and seedling layer. The seedling layer revealed insignificant variation in the number of species among the edge, intermediate and interior plots of each forest. Although the comparison of species richness along the edge-interior gradient did not differ appreciably in some of the forests, the overall analysis showed that there is an increasing trend in species richness from the forest edge toward the forest interior in all layers where the forest interior had significantly higher richness than edge/intermediate in the three layers (*i.e.* excluding seedling layer only).

The comparison of species richness among the edge plots (Table 4.1) across all the forests revealed Kilengwe to have higher number of species in large sapling, small sapling and seedling layers while Kimboza had highest number on overstory layer. Ngambaula had the least number of species in overstory, large sapling and small sapling layers and Nemele had the least species number in the seedling layers. For the intermediate, Kilengwe had higher number of species in the overstory and small sapling layers while Kisego and Kimboza had higher number of species in the large sapling and seedling layers respectively. Nemele had least number of species in all the forest layers across all intermediate plots. The forests which had higher species number in the interior plots were Kilengwe (in all layers), Kimboza and Kisego (large sapling) and Gunauye (seedling) while Nemele had least species number.

4.3.3 Species diversity as influenced by edge-interior gradient

In the overstory layer, Kilengwe revealed higher significant diversity in the interior plots than edge and intermediate plots, while other forests did not differ appreciably (Table 4.2). In the large sapling layer, diversity in the interior and intermediate plots in Kimboza and Kisego were significantly higher than edge plots and Ngambaula had significant higher diversity value in the interior while edge while diversity values in the other forests did not vary significantly with edge interior gradient. In the small sapling layer, diversity values in Gunauye did not differ appreciably while the remaining forests displayed interior plots having significant higher diversity than edge and intermediate plots. In the seedling layer, there were no significant differences in diversity values among edge, intermediate and interior of all the forests. The overall analysis (all data pooled in their respective distances) showed an increasing trend in species diversity from the forest edge to interior nearly in all the forests.

The comparison among the edge plots across all the forests revealed forests with the highest species diversity were Kilengwe (in large sapling, small sapling and seedling layers) and Kimboza (overstory) while the forests with least species diversity were Ngambaula (overstory, large and small sapling) and Nemele (Seedling). For intermediate plots, forests with highest species diversity were Kimboza (in overstory, large and small sapling), Kisego (large sapling) and Kimboza (large sapling and seedling) while Nemele was the forest with least species diversity were in all the layers. The comparison of interior plots across the forests revealed that the forests with highest species diversity were Kilengwe (in all layers) and Kimboza (large sapling) while the forests with least species diversity were Nemele (large sapling and seedling) and Ngambaula (overstory and small sapling).

Table 4.1: Comparison of species richness (standard error) along edge-interior gradient for the four layers in all the studied Uluguru forests.

Layers	Forests	Edge	Intermediate	Interior	F/t value	p-value
Overstory	Kilengwe	5.7(0.7)^a	8.0(2.1)^a	13.0(2.3)^b	19.95	<0.0001
	Kimboza	6.5(0.3)^a	6.7(0.9)^a	11.3(2.3)^b	8.89	0.003
	Kisego	3.8(0.4)	2.8(0.5)	4.3(0.7)	1.81	0.20
	Milawilila	4.3(0.6)	4.8(0.5)	6.3(0.4)	3.51	0.06
	Nemele	3.5(0.6)	2.8(0.4)	3.2(0.7)	0.37	0.70
	Ngambaula	2.7(0.5)		3.0(0.6)	0.35	0.37
	Gunauye	5.2(0.5)		3.0(0.6)	0.10	0.46
	Overall	4.5(0.3)^a	5.0(0.5)^a	6.6(0.6)^b	5.33	0.01
Large sapling	Kilengwe	10.2(1.1)^a	12.3(1.6)^a	15.0(2.2)^b	3.72	0.04
	Kimboza	9.7(1.5)^a	12.3(0.7)^a	15.0(0.7)^b	6.91	0.01
	Kisego	9.7(0.8)^a	12.5(1.6)^a	15.3(1.8)^b	9.95	0.002
	Milawilila	9.7(0.8)	10.7(0.7)	12.0(0.6)	1.67	0.22
	Nemele	7.7(0.6)	7.2(0.5)	9.0(1.0)	1.61	0.23
	Ngambaula	6.8(1.5)		8.5(2.5)	1.33	1.21
	Gunauye	8.8(0.9)		10.5(1.2)	1.72	0.07
	Overall	8.6(0.3)^a	10.8(0.5)^b	12.6(0.6)^b	16.33	<0.0001
Small sapling	Kilengwe	8.5(0.4)^a	9.5(0.6)^a	15.8(2.2)^b	9.02	0.003
	Kimboza	7.0(0.3)^a	8.3(0.8)^a	13.8(2.5)^b	5.78	0.014
	Kisego	5.3(0.6)^a	5.8(0.4)^a	10.2(0.7)^b	21.93	<0.0001
	Milawilila	6.2(0.6)^a	6.5(1.1)^a	11.5(1.0)^b	10.06	0.006
	Nemele	4.0(0.6)^a	4.0(0.5)^a	8.2(0.9)^b	11.62	0.001
	Ngambaula	3.0(0.4)^a		6.0(1.3)^b	2.05	0.04
	Gunauye	6.8(0.6)^a		9.8(1.1)^b	2.33	0.02
	Overall	5.8(0.3)^a	6.8(0.5)^a	10.8(0.7)^b	24.60	<0.0001
Seedling	Kilengwe	7.7(0.7)	6.3(1.4)	9.7(1.0)	2.53	0.11
	Kimboza	6.5(0.60	8.8(1.4)	9.7(1.5)	1.79	0.20
	Kisego	6.5(0.6)	4.5(0.4)	6.7(0.8)	3.41	0.06
	Milawilila	5.0(0.5)	4.3(0.6)	4.5(1.0)	0.21	0.81
	Nemele	2.0(0.4)	2.5(0.3)	3.0(0.5)	1.29	0.31
	Ngambaula	4.7(0.8)		4.8(0.5)	0.18	0.43
	Gunauye	7.6(1.0)		9.3(1.3)	1.02	0.17
	Overall	5.7(0.4)	5.3(0.6)	6.8(0.8)	2.51	0.09

NB: Different letters indicate significant differences among the row values in each forest (Tukey's test $p < 0.05$)

Table 4.2: Comparison of species diversity (standard error) along edge-interior gradient for the four layers in all the studied Uluguru forests.

Layers	Forests	Edge	Intermediate	Interior	F/t-value	p-value
Overstory	Kilengwe	1.66(0.14)^a	2.02(0.09)^a	2.48(0.08)^b	15.02	0.0003
	Kimboza	1.78(0.06)	1.78(0.16)	2.00(0.15)	1.16	0.34
	Kisego	1.27(0.11)	1.09(0.14)	1.67(0.23)	3.27	0.07
	Milawilila	1.38(0.16)	1.48(0.11)	1.75(0.07)	2.44	0.12
	Nemele	1.16(0.17)	0.96(0.13)	1.03(0.20)	0.35	0.71
	Ngambaula	0.89(0.15)		0.95(0.18)	0.21	0.42
	Gunauye	1.55(0.14)		1.49(0.22)	0.20	0.42
	Overall	1.38(0.06)	1.46(0.09)	1.62(0.09)	2.26	0.11
Large sapling	Kilengwe	2.21(0.10)	2.25(0.14)	2.52(0.13)	1.67	0.22
	Kimboza	1.97(0.16)^a	2.32(0.05)^b	2.55(0.06)^b	8.72	0.003
	Kisego	1.94(0.07)^a	2.19(0.10)^b	2.32(0.09)^b	6.57	0.01
	Milawilila	1.96(0.12)	2.20(0.08)	2.30(0.06)	3.46	0.06
	Nemele	1.79(0.14)	1.77(0.07)	2.02(0.13)	1.52	0.25
	Ngambaula	1.69(0.07)^a		2.05(0.14)^b	3.92	0.01
	Gunauye	2.08(0.14)		2.04(0.13)	0.34	0.37
	Overall	1.95(0.05)^a	2.16(0.05)^b	2.26(0.05)^b	11.07	<0.0001
Small sapling	Kilengwe	2.03(0.05)^a	2.14(0.07)^a	2.59(0.13)^b	10.67	0.001
	Kimboza	1.82(0.02)^a	1.95(0.11)^a	2.35(0.21)^b	3.82	0.04
	Kisego	1.54(0.13)^a	1.61(0.08)^a	2.15(0.08)^b	11.77	0.001
	Milawilila	1.69(0.12)^a	1.58(0.22)^a	2.30(0.09)^b	6.35	0.01
	Nemele	1.15(0.16)^a	1.25(0.13)^a	1.96(0.11)^b	11.03	0.001
	Ngambaula	0.91(0.10)^a		1.39(0.25)^b	2.63	0.02
	Gunauye	1.76(0.07)		2.05(0.12)	1.47	0.10
	Overall	1.56(0.07)^a	1.71(0.07)^a	2.12(0.08)^b	16.72	<0.0001
Seedling	Kilengwe	1.90(0.07)	1.58(0.16)	2.02(0.12)	3.28	0.07
	Kimboza	1.67(0.08)	1.82(0.18)	1.86(0.16)	0.51	0.61
	Kisego	1.69(0.11)	1.30(0.10)	1.63(0.13)	3.47	0.06
	Milawilila	1.21(0.16)	1.20(0.19)	1.22(0.20)	0.004	0.99
	Nemele	0.50(0.22)	0.77(0.17)	0.90(0.15)	1.29	0.30
	Ngambaula	1.35(0.17)		1.33(0.13)	0.08	0.47
	Gunauye	1.80(0.16)		1.96(0.13)	0.80	0.23
	Overall	1.44(0.09)	1.34(0.09)	1.56(0.08)	1.57	0.21

NB: Different letters indicate significant differences among the row values in each forest (Tukey's test $p < 0.05$)

4.3.4 Species richness and forest area

The association between species richness and forest area from each categorical distance (*i.e.* edge, intermediate and interior) in each forest layer are presented in Table 4.3 and Figure 4.1 & 4.2. The comparison between overstory and large sapling (Figure 4.1) revealed the later layer to have higher species richness in all the categorical distances. Figure 4.1 and 4.2 illustrate interior of the forests to be richer in species than edge and intermediate. On the other hand, the regression slopes increased progressively from edge to forest interior for the overstory and large sapling while small sapling layers and seedling layer the slopes increased towards the intermediate and then dropped at the interior of forests. In the overstory layer, only the interior plots revealed to have significant species increase per unit forest area while in large sapling layer, the rate of species increase per unit area was significant in all the categorical distances (Table 4.3). In the small sapling layer, only intermediate and interior of the forests revealed to have significant increase in the species richness per unit area. The rates of species increase per unit area in the seedling layer were not statistically significant in all categorical distances.

Table 4.3: Relationship between species richness and forest area in the edge, intermediate and interior for the four studied forests.

Layers	Category	*r* - values	p-values	Regression equations
Overstory	Edge	0.65	0.06	species = 3.27 + 0.83 log area
	Intermediate	0.76	0.07	species = 1.28 + 1.93 log area
	Interior	0.84	0.01	species = 1.82 + 3.18 log area
Large saplings	Edge	0.84	0.01	species = 7.33 + 0.97 log area
	Intermediate	0.81	0.04	species = 7.11 + 2.00 log area
	Interior	0.91	0.002	species = 8.70 + 2.41 log area
Small sapling	Edge	0.67	0.05	species = 4.00 + 1.21 log area
	Intermediate	0.88	0.02	species = 2.84 + 2.86 log area
	Interior	0.86	0.01	species = 6.61 + 2.74 log area
Seedling	Edge	0.46	0.15	species = 4.37 + 0.89 log area
	Intermediate	0.80	0.05	species = 1.22 + 2.10 log area
	Interior	0.57	0.09	species = 4.50 + 1.53 log area

NB: One-tailed significance test ($p < 0.05$), n = 7 for edge and interior and n = 5 for intermediate.

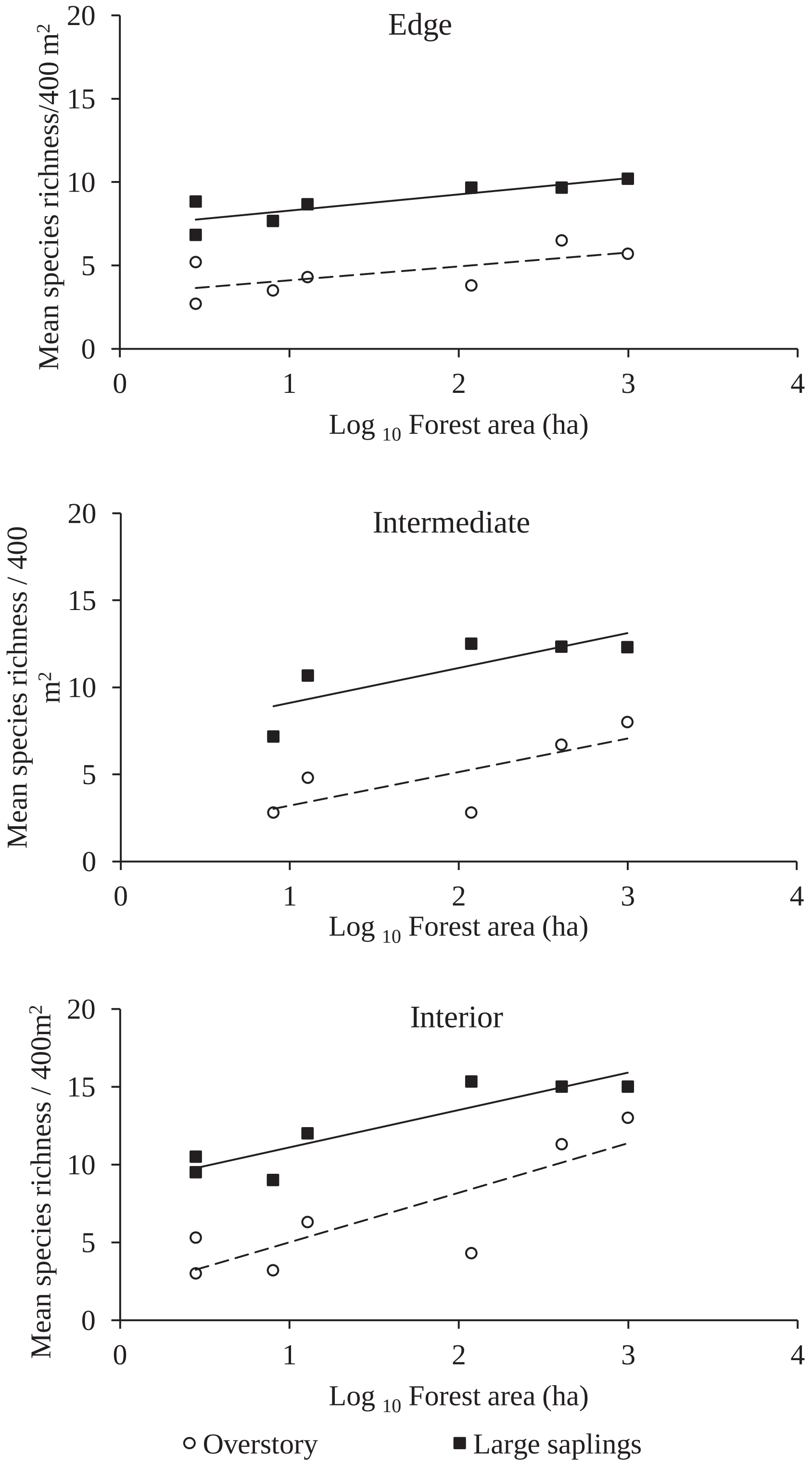


Figure 4.1: Forest size and species richness relationship for overstory and large sapling layers in the three categorical distances *i.e.* edge, intermediate and interior.

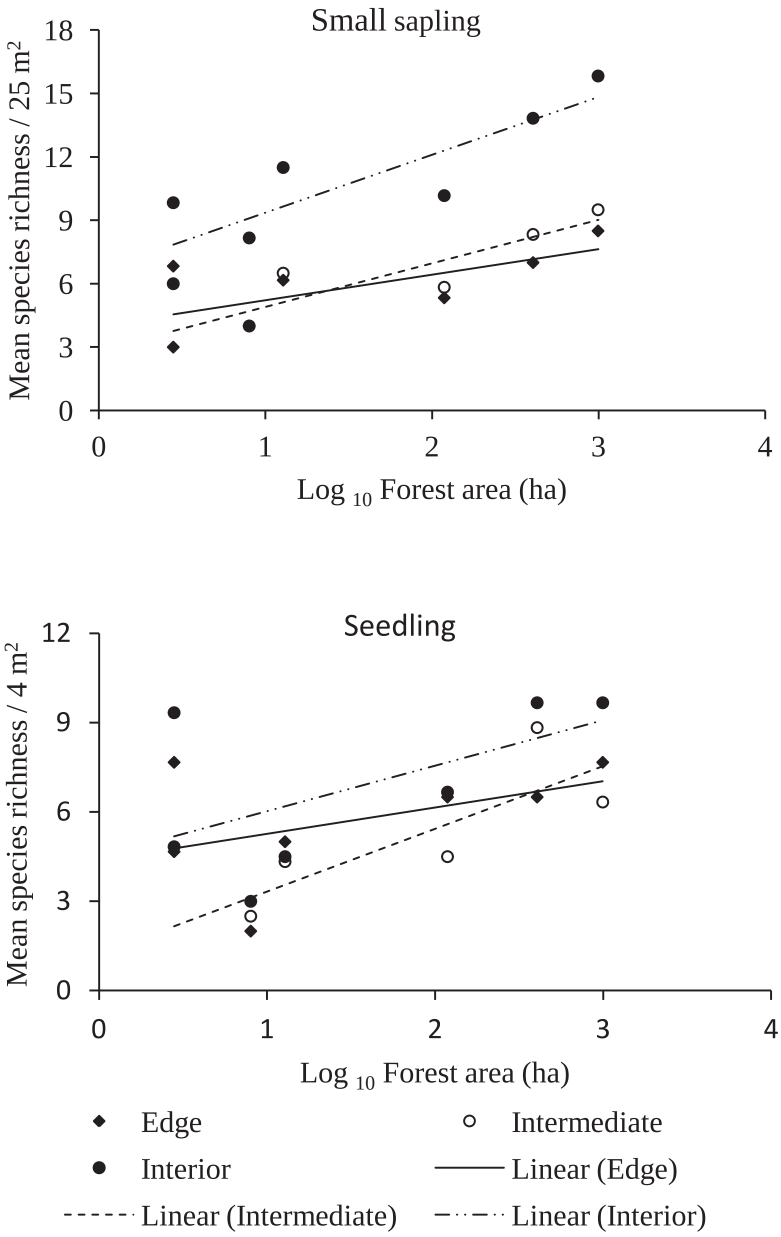


Figure 4.2: Forest size and species richness relationship for small sapling and seedling layers in the three categorical distances *i.e.* edge, intermediate and interior.

4.3.5 Stand density

In the overstory layer, Kilengwe, Kimboza and Milawilila showed to have significantly higher stand density in the interior plots than edge and intermediate plots while stand density other forests did not differ appreciably along edge interior gradient. In large sapling layer, Only Kisego forest revealed significant higher tree density in the interior plots than edge and intermediate plots while other forests did not reveal any significant difference. In the small sapling layer, Kilengwe, Kimboza and Kisego showed interior plots to have significantly higher density than edge and intermediate while in other forests there were no any significant difference among the plots. In the seedling layer, Kilengwe, Kimboza, Kisego and Milawilila had significant higher density in the interior plots than edge and intermediate plots. The overall analysis from all the forest layers revealed an increase in stem density along the edge-interior gradient.

The forests with highest tree density within edge plots were Kimboza (in overstory layer), Kilengwe (small sapling and seedling) and Kisego (large sapling) while Ngambaula (in overstory, large sapling and small sapling) and Nemele (in small sapling and seedling). The comparison of intermediate plots showed Kimboza (in overstory and seedling layer), Kisego (in large sapling layer) and Kilengwe (in small sapling) having highest tree density while Nemele had least density in all the layers. The forests with the highest tree density in the interior plots were Kimboza (in overstory and seedling layer), Kisego (in large sapling layer) and Kilengwe (small sapling layer) while the forests with least density were Ngambaula (in overstory, large sapling and small sapling) and Nemele (seedling).

4.3.6 Relationship between tree size hierarchy and stem density

In all the forests, stem density decreased exponentially as the individual biomass categories increases in both edge and interior of the forests (Figure 4.3 and appendix 4). This implies that the individual biomass decrease very fast at lower stem densities but it tapers off at higher stem densities.

Table 4.4: Comparison of stand density (individuals' ha^{-1} (standard error)) along edge-interior gradient for the four layers in all the studied Uluguru forests.

Layers	Forests	Edge	Intermediate	Interior	F/t-value	p-value
Overstory	Kilengwe	163(26)^{a}	229(33)^{a}	442(50)^{b}	15.18	0.0002
	Kimboza	238(16)^{a}	267(38)^{a}	667(52)^{b}	41.79	<0.0001
	Kisego	129(10)	113(26)	179(29)	2.19	0.15
	Milawilila	133(17)^{a}	154(22)^{a}	229(15)^{b}	7.78	0.01
	Nemele	108(26)	83(15)	100(11)	0.46	0.64
	Ngambaula	79(20)		92(25)	0.36	0.37
	Gunauye	158(17)		192(54)	0.50	0.32
	Overall	144(10) ^{a}	169(17) ^{a}	271(33) ^{b}	9.02	0.0002
Large sapling	Kilengwe	408(42)	588(87)	654(77)	3.20	0.07
	Kimboza	492(90)	700(80)	746(38)	3.45	0.06
	Kisego	750(90)^{a}	796(75)^{a}	1063(67)^{b}	4.73	0.03
	Milawilila	533(52)	558(55)	533(30)	0.09	0.91
	Nemele	392(24)	379(25)	458(27)	2.79	0.09
	Ngambaula	350(42)		417(36)	1.48	0.10
	Gunauye	442(66)		508(68)	0.58	0.29
	Overall	481(29)^{a}	604(39)^{b}	626(37)^{b}	5.37	0.006
Small sapling	Kilengwe	6133(513)^{a}	8333(719)^{a}	11600(900)^{b}	14.27	0.0003
	Kimboza	4933(396)^{a}	7333(667)^{a}	10330(657)^{b}	21.28	<0.0001
	Kisego	4333(378)^{a}	5533(455)^{a}	8600(683)^{b}	17.78	0.0001
	Milawilila	4400(372)	5400(805)	7733(409)	9.20	0.003
	Nemele	5200(912)	3800(338)	5733(419)	2.20	0.15
	Ngambaula	4333(606)		5133(419)	1.59	0.09
	Gunauye	4733(762)		6000(484)	1.16	0.15
	Overall	4867(228)^{a}	6080(392)^{a}	7876(416)^{b}	20.46	<0.0001
Seedling	Kilengwe	42080(4583)^{a}	46670(9675)^{a}	82080(9408)^{b}	7.08	0.007
	Kimboza	40830(7032)^{a}	68750(10220)^{a}	120800(14930)^{b}	13.13	0.001
	Kisego	39170(4773)^{a}	36670(6635)^{a}	60830(4886)^{b}	5.78	0.01
	Milawilila	28330(5221)^{a}	34580(5531)^{a}	55420(7258)^{b}	6.57	0.01
	Nemele	21250(3637)	25420(3731)	30830(5191)	1.28	0.31
	Ngambaula	23750(5655)		33330(9167)	0.86	0.22
	Gunauye	34580(5100)		57080(8201)	1.73	0.07
	Overall	32860(2124)^{a}	42420(5460)^{a}	62920(5460)^{b}	14.67	<0.0001

NB: Different letters indicate significant differences among the row values in each forest (Tukey's test $p < 0.05$)

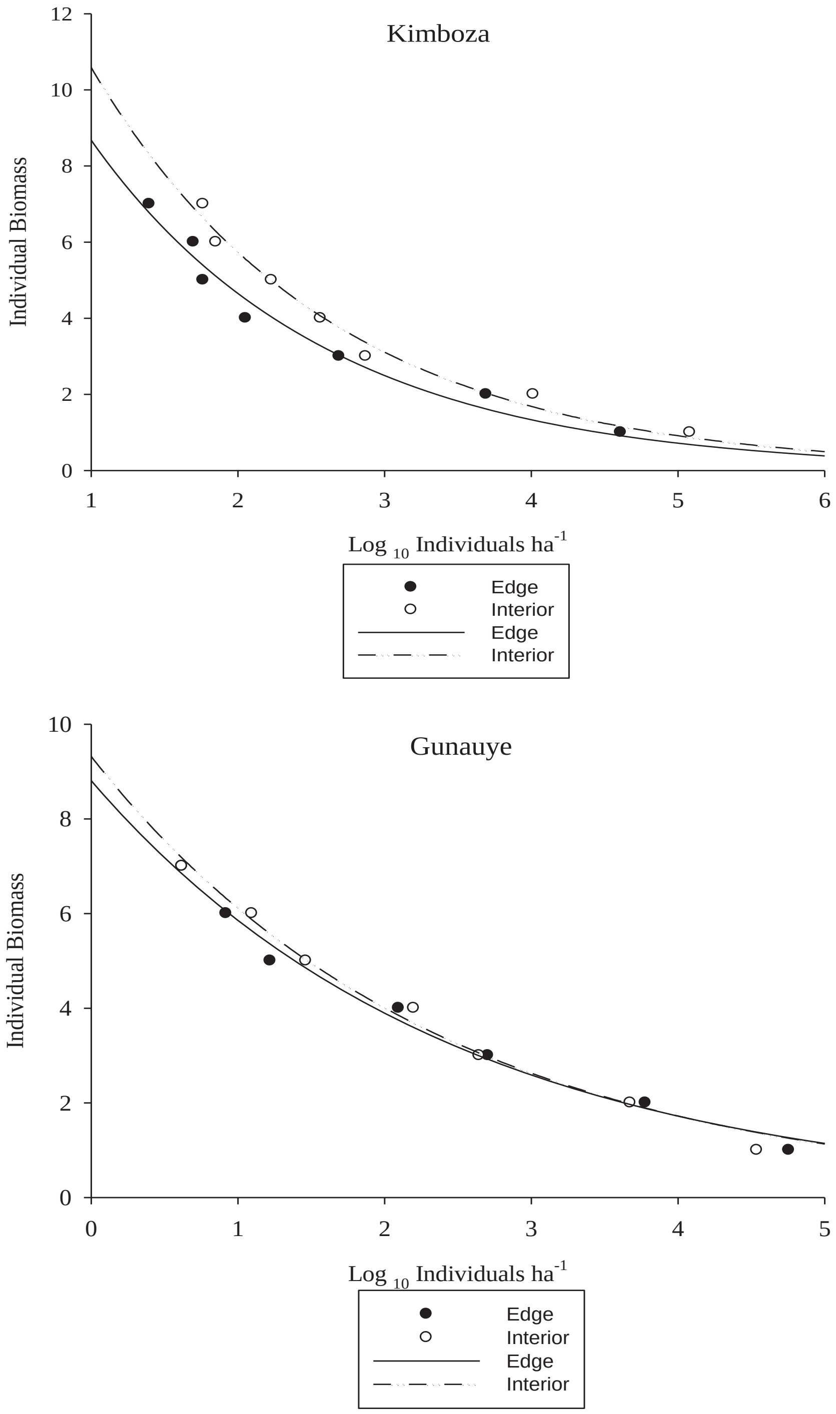


Figure 4.3: Relationship between number of trees per unit area ($\log_{10}$ individuals ha^{-1}) and individual biomass categories (1 = seedling, 2 = small sapling, 3 = 3-10 cm DBH, 4 = 10-20 cm, 5 = 20-30 cm, 6 = 30-40 cm and 7 => 40 cm).

4.4 Discussion

4.4.1 Species richness, diversity and stem density

The overall analysis across all the forest layers revealed forest interior to have higher species richness, diversity and stem densities as compared to edge and intermediate. The presence of less species richness, diversity and tree density at the edges is likely due to the fact that the edges are easily accessible by local people and their livestock. The locals access the edges simply to fetch for their basic needs like firewood, charcoal, building poles, traditional medicines and timber. Grazing and cattle trampling at edges can also be the causal factor for the observed lower values. Moreover, Luguru people prefer to use fire to prepare their farms before starting a new season and for hunting bush animals like *Hyrax pimbi*, Wild pig and Ndezi, which are used as food. The penetration of fire at forest edges might also account for the less species and stem density because when fire penetrates to forest many species especially those that are fire sensitive die and will never regenerate. Periodic fires reduce canopy cover and drastically change vegetation structure and composition along the forest edges (Tabarelli *et al.,* 2004).

Since the overall results revealed edges and intermediate did not differ significantly in species richness and diversity almost in all the forest layers, it is likely that edge effects can extend to the distance of 200 m from forest margin. These findings suggest that the forest interior and edges/intermdetaite are two contrasting habitats. This could be due to harsh micro-environmental conditions in edges which restrict recruitment of some species in detriment of others (Murcia, 1995; Gelhausen *et al.,* 2000). The findings also conforms with Oliveira *et al.,* (2004) who observed forest interior placed at > 200 m to have significantly higher species richness and tree densities as compared to edge (0-100 m). The formation of edges due to fragmentation is normally accompanied with drastic modifications in the physical environment, such as low relative humidity, higher light intensity and duration, higher air and soil temperature and increased wind shear forces (Jose *et al.,* 1996; Didham and Lawton, 1999; Newmark, 2005). Such alterations in physical environment at forest edges tend to alter tree species composition and density simply because some species are not adapted to such kind of modifications (Murcia, 1995; Laurance *et al.,* 2006). It is known that some species require forest interior conditions and are sensitive to edges (Laurance *et al.,* 2000). Benitez-Malvido (1998) reported high predation, loss of pollinators and seed dispersers at forest edges being limiting factors for some seedling species due to increased edge effects. Moreover, alterations in allocthonous seed rain (*i.e.* seeds from other habitats) can lower the frequency and abundance of large seeded tree species at the forest edge and thus severely change tree species composition in this habitat (Melo, 2004). Thus, study on micro-environmental factors among the studied categorical regions in these forest fragments need to be done in future to determine and confirm their association to tree species richness, composition and structure in Uluguru fragments.

The observed insignificant edge effect on seedling species richness is in contrast to the findings of Benitez-Malvido and Martinez-Ramos (2003) who observed tree seedling species to be significantly higher in forest interior than on the edges in Amazonian forests. The lack of similar trends compared to Amazonian study may be related to differences in seedling species richness between the Amazonian and Uluguru forests but also the degree of disturbances. The tree species richness in Amazonian forests is extremely high (Gentry, 1988; Valencia *et al.*, 1994) and they are relatively undisturbed as compared to the studied Uluguru fragments. In a forest landscape of many more species, there is a greater likelihood of differences in seedling species richness between edge and interior of the forests (Benitez-Malvido, 1998). However, fragmentation history and age need to be considered when interpreting differences in species richness among fragments because ecological conditions tend to be more stable at older edges, hence make the edges well protected from changes in microclimatic conditions (Didham and Lawton, 1999). Additionally, the insignificant variation in species richness and diversity in seedling layer suggests that edge effects may be affecting species individually in positive or negative manners, which can be compensatory and prevent the revealing of effects on the community level.

The comparison of species richness within each categorical distance (*i.e.* edge, intermediate and interior) revealed the decline in number of species as forest size decrease too (Table 4.1).This could be attributed with increase in edge: interior ratio as forest size decreases. When the ratio between edge and interior of a forest increases, the forest become more prone to edge effects (Saunders *et al.*, 1991). Increased microclimatic differences due to higher edge: interior ratio can lead to different plant communities and reduced native species in forests (Laurance and Yensen, 1991). The lower species richness in the smaller forests could also be associated with observed ongoing anthropogenic disturbances within them. The significant difference in species richness between interior and edge/intermediate plots within Kilengwe and Kimboza forest could be associated to lower edge:

interior ratio and presence of more heterogeneous habitats due to their large sizes. In general, larger forest fragments hold greater habitat diversity and are more likely to retain larger populations of original species when compared with smaller forest fragments (Lida and Nakashizuka, 1995; Bierregaard *et al.,* 2001). Additionally, larger forests are known to have more intact interiors than smaller ones, and consequently plant-animal interactions (*i.e.* pollination, seed dispersal, herbivore damage) remain unchanged (Saunders *et al.,* 1991).

On the other hand, the tree density in all forest compartments revealed an increasing trend towards the forest interior in all the forests (Figure 4.2a). The presence of less density in the edges across the forest layers may be the result of interplay of factors of two kinds: first, those that reduce the possibility of seedling establishment and second, those factors that increase seedling, sapling and adult tree mortality rate. The seedling is the first size class to be affected by edge effect because it is the life stage that is more sensitive to environmental changes and biotic interactions (Saunders *et al.*, 1991). Some processes related to edge effects that can explain the observed pattern in tree density include, reduction in seedling recruitment at edges due to habitat desiccation (Benitez-Malvido, 1998), higher mortality rates of adult trees at edges due to uprooting and breakage due to wind turbulence (Ferreira and Laurance, 1997; Laurance *et al.*, 1998), seedling damage caused by increasing litter-fall and tree fall near forest edges (Benitez-Malvido, 1998), sapling mortality by competition with lianas, vines and ruderal species (Laurance *et al.*, 1998, 2001), easy accessibility to forest edges by locals and livestock (Fontoura *et al.,* 2006) and the occasional penetration of fires to edges may cause significant changes in vegetation structure and composition (Cochrane and Laurance, 2002).

4.4.2 Species richness and forest size

The increase of regression slopes from edge to interior for overstory and large sapling layers provide clear indication that forest interior is richer than edge and intermediate regions. The findings are in compliance to those in Table 4.1, which revealed the same. It is very possible that anthropogenic disturbances (*i.e.* illegal logging for timber, poles and charcoal making) could be the cause for the lower species numbers at edges and intermediate because they are easily accessed by humans. Also, animal grazing and fire could account for the least values observed. More regenerating tree species (*i.e.* large sapling layer) than mature tree species (*i.e.* overstory) were accumulated per unit increase in forest area, which promise for future persistence. The large sapling layer had an average of 4 and 6 species more than overstory in the edge and intermediate/interior respectively. In general, both figure 4.1 and 4.2 reveal forest interior to have higher species richness than edge and intermediate. Various studies have also reported differences in the species richness between edges and interior of forests (Oosterhoorn and Kapelle, 1999; Tabarelli *et al,* 1999; Oliveira *et al.*, 2004). The lower richness observed at forest edges could be due to fact that edges have higher dynamics (Bierregard *et al.*, 1992; Laurance *et al.*, 1998), which can reduce the number of species tolerant to edge conditions.

4.4.3 Size hierarchy and stem density

The exponential decline in stem density at the forest edge and interior as categorical individual biomass (*i.e.* tree sizes) increases signify that trees die at a competitive disadvantage from crowding and suppression as stand approach a limiting number of trees of a given size that can coexist within a given area. The observed non-linear decline show that tree density decreases rapidls at larger tree size categories/biomass and tapers off at higher densities. Crowding is known to reduce the growth of individuals but is dependent on the size of individuals (Bagchi, 2007). The larger individuals can use a disproportionately large amount of resources, which lead to the observed size hierarchy in natural tree populations. The tree populations have numerous small individuals and few large ones that comprise most of the tree biomass.

4.5 Conclusion

In summary, the findings provide evidence that forest fragmentation leads to the establishment of distinct habitats within forest fragments. The interior of forests possess higher species richness, diversity and density of trees while the forest edge and intermediate regions had an impoverished assemblage of tree species, diversity and density. Species adapted to edges could be those with ability to withstand change in micro-environmental conditions. If the remaining Uluguru forest fragments continue being fragmented, there will be an increase of edge related habitats which will cause structural and floristic composition changes due to increased edge effects. Moreover, the forests will face threats of losing original flora especially rare and threatened tree species (*see* Table 6.1). The study also revealed that the rate of species increase per unit forest area (*i.e.* regression slopes) was higher in forest interior than edge and intermediate regions for overstory and large saplings layers. The relationship between tree sizes/individual biomass and tree density followed an exponential decay function.

Therefore, the study recommends that long-term research is needed to study micro-environmental factors (such as light availability, air and soil temperature, relative humidity *e.t.c.,*) along the edge-interior gradient in the studied Uluguru forest fragments in order to determine their influence to tree species richness, composition and structure.

Picture showing observed evidence of on-going pit-sawing in Kisego forest

CHAPTER FIVE

Indigenous tree use, use values and human population impacts on forest size, species richness and tree density in Uluguru forests, Morogoro

5.1 Introduction

Globally, tropical forests are known to be speciose and provide a variety of products and services to humans. The rapid rise in human population has increased the threats of degradation to these forests (FAO, 2003). In developing countries, more than 10 million ha of tropical forests are cleared or converted to other land use types per annum leaving remaining forest remnants disturbed and fragmented (Tole, 1998). These deforestation and fragmentation processes seriously affect the ecological structure and biodiversity of the existing forests (Blasco *et al.*, 2000) and put at risk the livelihoods of millions of people who depend on them for timber, food, medicines, water, fuels and other resources.

The Eastern Arc forests are universally known for their unique biodiversity values (Myers *et al.*, 2000) and they are exceptionally important to the local inhabitants. These forests support the livelihoods of indigenous people living nearby as the source of food, medicines, energy (*e.g.* firewood and charcoal), income and ecosystem services (Lulandala, 1998; Wilfred *et al.*, 2006). Uluguru forests are marked by high species richness, endemism and large number of restricted-range species and genera (Burgess *et al.*, 2007; Temu and Andrew, 2008). Due to high biodiversity value, the Eastern Arc forests have been targeted as a high priority area for biodiversity conservation through local, regional and global initiatives (Lovett, 1988; ICBP, 1992; Myers *et al.*, 2000). Uluguru Mountains consist of forest fragments that are surrounded by an ever-growing human population (Newmark, 1998). Although overall population grows at an average of 2.9 % annually (URT, 2006) in Tanzania, the growth rates in the naturally resource-rich areas of the highlands, including the Eastern Arc Mountains, are normally higher (Jones, 2000). Bhatia and Ringia (1996) report population growth rate up to 6.5 % in the Uluguru Mountains. This growth in population results in more pressure for new land resources both for settlements and farmland (Mitinje *et al.*, 2007). Moreover, about 77 % of the Tanzanians live in rural areas where forest resources are central to their livelihoods (URT, 2006). While the fate of tropical forests and indigenous people has recently attracted substantial popular interest, surprisingly the research into the role forest play in supporting livelihoods has received limited attention (Philips and

Gentry, 1993). The uses and ethnobotanical aspects of trees in Tanzania have not been adequately documented, and in terms of conservation, it is very important to examine species which are of high use values and whether overutilization may be occurring and endanger their existence. The present study aims at examining local people's knowledge and use of tree species. The chapter also examine impacts of human population surrounding the forests on the forest size, tree density and species richness.

5.2 Materials and Methods

5.2.1 Study sites and Socio-economic profile

A structured questionnaire survey was carried out in three wards, namely Tawa, Kisemu and Kisaki in Morogoro rural district, Morogoro region, Tanzania. The villages covered were Milawilila, Mwarazi, Kibangile and Zongomero. The villages were selected based on their proximity to the forests which had been studied in this thesis. People living in the villages depend mainly on agriculture as their main socio-economic activity, growing food and cash crops at subsistence level. Food crops include maize, beans, rice, cassava, groundnuts, sorghum, sweet & Irish potatoes and vegetables. Cash crops grown are bananas, oranges, cabbages, mangoes, coffee, groundnuts, sunflower and palm oil. The cash crops produced are sold in Morogoro town and some exported to Dar Es Salaam city where the greater market is available. The people are also engaged in livestock keeping, fishing and carpentry at a small scale. The local inhabitants' depend on the nearby forest resources for their needs of firewood, wood to make charcoal, traditional medicines, timber and building poles.

5.2.2 Data collection

Data were collected from the villagers living nearby the forest reserves and forest officers using structured questionaires (*see* Appendix 2 and 3). The questionnaire for villagers (*see* Appendix 2) was in two parts; respondent personal particulars and forest resources utilization while that of forest officers (*see* Appendix 3) was to collect information on how the forests are managed, conserved and challenges encountered in the management process. The villagers' questionnaires were administered to a total of 46 respondents (whoever was willing) in all selected villages and wherever possible the researcher provided clarification on the questions. The respondents were encouraged to admit if they did not know tree species used in the listed use-categories and they were not allowed to discuss among themselves about the species used in various use-categories. The process of getting the respondents was facilitated by executive officers of each respective village. The total human population data for villages surrounding the forests were obtained from the Ward executive officers. The tree density (DBH ≥ 10 cm) and species richness were obtained according to methodology used in chapter two.

5.2.3 Data analysis

Data from the respondents' interview were analysed using descriptive statistics in the Statistical Package for Social Sciences (SPSS) computer software. The use value analysis was performed on the listed tree species to determine the utility of the resources by the locals. In the analysis, tree species were classified as highly preferred, preferred or less preferred to various use-categories and the use value scores assigned to these classes were 1.5, 1.0 and 0.5 respectively. The basic assumption here was that a most useful and preferred tree species in a certain use-category would score 1.5, and this was adjusted down by point five for preferred species. The less preferred or low rated tree species in a certain use-category was assigned 0.5 score. This assessment of relative importance of tree species to local people follows the method of quantitative ethnobotany as described by Phillips and Gentry (1993) and modified by Kvist *et al.,* (1995). The same methodology has also been used by Krog *et al.,* (2005) and Theilade *et al.,* (2007). The average use-value was calculated as a sum of scores for each species in each use category divide by the number of respondents. Total use values were calculated for each species as the sum of average use-values across use categories. The average and total use values are measures of the relative importance of a particular trees species for a given use and for all uses combined respectively (Theilade *et al.,* 2007). The species richness was measured by the number of observed species per hectare while the tree density was represented by the number of individual tree per hectare in the studied forests. The Pearson correlation coefficient test was used to check for significant relationships between the total human population surrounding the forests and forest size, tree density and species richness.

5.3 Results

5.3.1 Tree use and use values

Of the total respondents, 70 % being males and 30 % were females. 59 % were of ages between 20-40 years, 24 %, 13 % and 4.3 % had ages between 41-60, < 20 years and > 60 years respectively. 75 % of the respondents have been in their villages since birth while 17.5 % and 7.5 % have migrated to the villages in last 20 and 5 years ago respectively. Among the respondents, 59 % were farmers, 20 % petty business, 17 % carpenter and 4.4 % accounted for student and employed. About 26 % of the respondents admitted to access the forest reserves freely without permission, 19 % with permission and 54 % did not state how they get access to the forest reserves.

A total of 42 useful tree species from 38 genera and 19 families were recorded in this survey. The top three species with highest use value were *Milicia excelsa*, *Albizia gummifera* and *Annona senegalensis* while the species with the lowest use values was *Sterculia quinqueloba* (Table 5.1). About 88 % of the species were listed to serve more than one function but a broad range of the total listed species is used for firewood (60 % of the species) and charcoal (52 %). The most common species collected for firewood and charcoal making and which showed to have high use values are *Combretum* spp., *Scorodophleous fischeri*, *Mangifera indica*, *Annona senegalensis* and *Grewia similis*. About 98 % of the respondents admitted to depending on firewood for cooking purposes. The source of fuel wood was found to be from both general land and forest reserves. People living around the forest reserves are allowed to collect dead wood, fruits, mushrooms and vegetables from the forest reserves as the public lands are not sufficiently able to supply locals' needs. The species used for timber accounted for 45 % of all listed species, *Milicia excelsa, Dalbergia melanoxylon, Allanblackia uluguruensis, Antiaris toxicaria, Bombax rhodognaphalon* and *Cedrela odorata* being the species with highest timber use values.

55 % of the species are known to be used for construction purposes, which include *Milicia excelsa, Bombax rhodognaphalon, Millettia usaramensis, and Burkea africana* having highest construction use values. Tree species used for making domestic utensils and carvings accounted for 55 % and 40 % of all listed species respectively. Species with high use values in making domestic utensils were *Mangifera indica, Scorodophloeous fischeri*, *Oxyanthus goetzei* and *Vangueria infausta* while *Dalbergia melanoxylon* and *Annona senegalensis* were the species with highest carving use values. Of

the interviewed respondents, 59 % mentioned *Dalbergia melanoxylon* being the most preferred species for carving works. Of all the listed species, 29 % mentioned to be used as fodders, *Mangifera indica* and *Vitex doniana* had high fodder use values. *Milicia excelsa, Mangifera indica, Bridelia micrantha* and *Grewia similis* had highest use values in the farm implements use category. 40 % of the tree species were recorded to have medicinal properties, *Xylopia longipetala, Diplorynchus condylcarpon, Xylopia aethiopica, Ficus spp. Erythrophleum suaveolens* and *Azadirachta indica* revealed highest medicinal use-values.

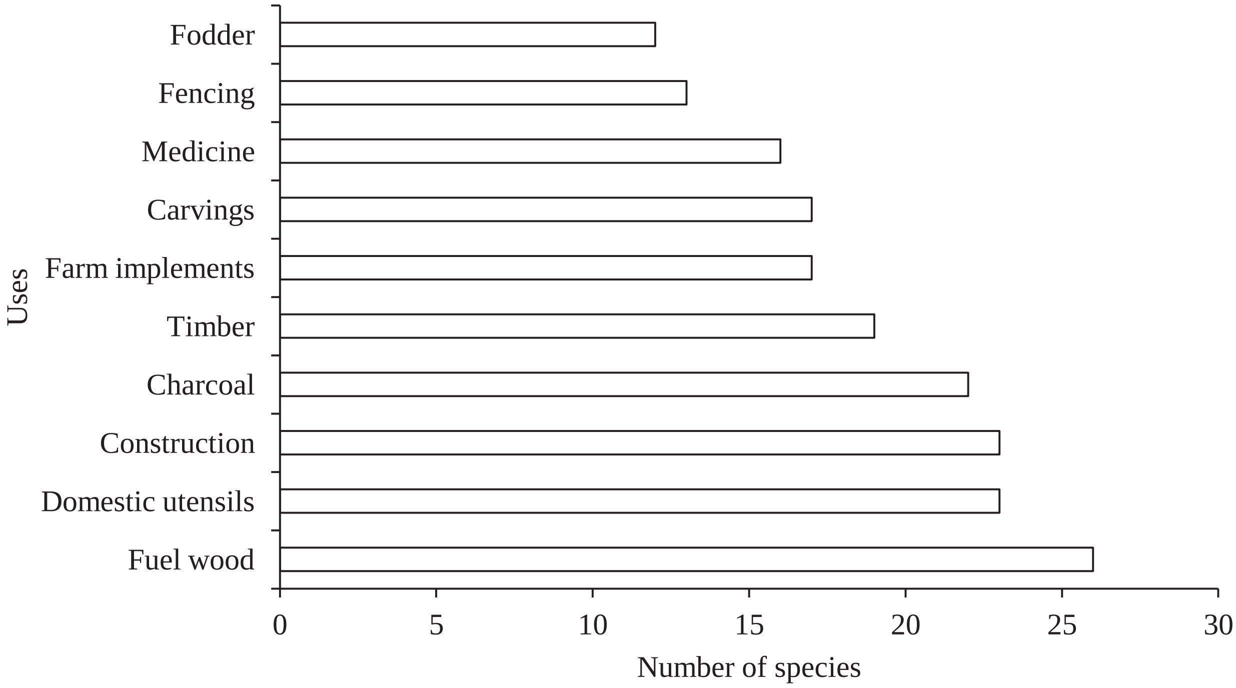


Figure 5.1: Comparison of the number of identified tree species commonly used by local people in Uluguru Mountains.

About 80 % of the respondents had knowledge of species that have been prohibited from harvest by IUCN and the government, which include *Afzelia quanzensis, Milicia excelsa, Pterocarpus angolensis, Khaya anthotheca, Dalbergia melanoxylon, Erythrophloeum suaveolens, Sinsepalum cerasiferum, Allanblackia uluguruensis, Ocotea Usambarensis, Dombeya natalensis* and *Brachystegia* spp. These species are economically important and the most depleted for timber. The opinions provided by the respondents towards better management of the forests include provision of forest and environmental education to the locals, encouraging locals to plant trees on their farmlands, improve and enhance participatory forest guard surveys, increase the penalties for those who breach villages by laws (*i.e.* those dealing with illegal forest product harvest) and they also suggested for a community to be more involved in the management and conservation issues of the forest reserves.

According to the interviewed forest officers, the local inhabitants are permitted to enter the forests to collect dead wood, fruits and leaves for various purposes. They also suggested that the available arable land is not sufficient to supply the locals' needs, which make them to depend more on resources from these forest reserves. The economically important and most exploited tree species pointed out by the local inhabitants were also mentioned by the forests officers. The forests officers also explained that the government of Tanzania has put some initiatives in managing and conserving the threatened species, which include; (1) formation of a forest surveillance unit for the purpose of intervening any illegal activities taking place within and around the forest sizes (2) prohibition of the harvest of threatened species and (3) involvement of local community through participatory forest management (PFM) projects. The main challenges encountered by the forest department in managing the forest reserves includes; (1) illegal logging and encroachment for cultivation as population around the reserves grows, (2) inadequate number of technical forest labour force (forest officers) and lack of adequate working facilities, (3) lack of environmental conservation awareness by the locals and (4) insufficient funds and which is untimely provided by the government.

Table 5.1: The trees species commonly used by the local community in Uluguru and their corresponding main uses arranged in order of preferences and total use values.

(Fi=Firewood, Ch=Charcoal, Ti=Timber, Me=Medicinal, Co= Construction, Do=Domestic utensils, Ca=Carving, Fo=Fodder, Fe= Fencing, Fa=Farm implements and TUV=Total use values).

Species	Main uses	Total use value
Milicia excelsa (Welw.) C.C. Berg.	Ti,Co,Fa,Do,Fi,Ca,Fo,Fe,Ch	10.6
Albizia gummifera (J.F. Gmel.) C. A. Sm.	Co,Fo,Ch,Fa,Fe,Ca,Do,Me,Ti,Fi	10.5
Annona senegalensis Pers.	Ca,Fa,CoFa,Fe,Fi,Ch,Me,Fo	10.3
Dalbergia melanoxylon Guill. & Perr.	Ca,Ti,Me,Ch,Do,Ca,Fa,Fe,Co	9.8
Erythrophleum suaveolens (Guill.&Perr.)Brenan.	Me,Do,Fi,Ca,Fo,Fa,Ca,Ch,Fe,	9.5
Mangifera indica L.	Fe,Fa,Fi,Me,Ch,Ti,Do,	9.2
Cedrela odorata L.	Co,Ti,Fi,Ch,Ca,Fo,Fe,Fa	8.5
Combretum spp.	Fi,Ch,Fa,Co,Me,Do,Ca,Fa	8.4
Albizia versicolor Welw. ex. Oliv.	Fe,Do,Ch,Co,Ca,Ti,Me,Fi	7.2
Vitex doniana Sweet	Fo,Do,Me,Fa, Ch,Fi, Fe	6.8
Scorodophleous fischeri (Taub.) J. Leon	Do,Fi,Ch,Ti,Co,Fa	6.6
Khaya anthotheca (Welw.) C. DC.	Ti,Fi,Ch,Do,CaFa	6.4
Acacia albida Delile	Ch,Fi,Fo,Do,Ca	6.2
Pterocarpus angolensis DC.	Ti,Co,Do,Ca,Fi,Ch	6.2
Bombax rhodognaphalon K. Schum.	Ti,Me,Do,Ca,	6.1
Grewia similis K. Schum.	Fe,Fa,Fi,Fo,Me	5.9
Dombeya natalensis Sond.	Ch,Fa,Do,Ca,Fe	5.1
Azadirachta indica A. Juss.	Me,Fe,Fo,Ch	4.2
Millettia usamarensis Taub.	Co,Fe,Fo,Fi	4.0
Terminalia sericea Burch. ex DC.	Me,Do,Fi.Ch	4.0
Burkea africana Hook.	Co,Fi,Ch,Fa	3.8
Ehretia amoena Klotzsch.	Fo,Co,Ti,Do	3.8
Afzelia quanzensis Welw.	Ti,Do,Fi,Co,Ca	3.5
Oxyanthus goetzei K. Schum	Do,Fi,Fe,Fa	3.5
Terminalia sambesiaca Engl. & Diels.	Fi,Fa,Co,Ch	3.5

Antiaris toxicaria (Pers.) Lesch.	Ti,Co,Do	3.4
Allanblackia ulugurensis Engl.	Ti,Ca,Do	3.0
Bridelia micrantha (Hochst.) Baill.	Fa,Me	2.8
Markhamia obtusifolia Sprague	Co,Ca,Do	2.7
Ficus spp.	Me,Fi	2.5
Parinari excelsa Sabine	Ti,Fi,Co	2.3
Ocotea usambarensis Engl.	Me,Ti,Co	2.0
Vangueria infausta Burch.	Do,Fi,Ch	2.0
Harungana madagascariensis Lam. ex. Poir.	Do,Co	1.7
Lonchocarpus bussei Harms.	Ch,Fi	1.6
Tectona grandis L. f.	Ti,Fa,Fe	1.5
Brachystegia bussei Harms.	Do,Co	1.5
Diplorhynchus condylocarpon (Müll.Arg.)Pichon.	Me	1.5
Xylopia aethiopica (Dunal) A. Rich.	Me	1.5
Xylopia longipetala De Wild & T. Durand	Me	1.5
Voacanga africana Stapf.	Co	1.3
Sterculia quinqueloba (Garcke) K. Schum	Ti	1.0

5.3.2 Human population, forest size, tree density and species richness

Table 5.2 shows general statistics of tree density, species richness and total human population surrounding each studied forest. A total of 1335 trees ha^{-1} belonging to 101 species and 31 families were recorded in the seven forests. The human population density ranged from 3914-7310; tree density 97-390 trees ha^{-1}; species richness 26-93 species ha^{-1}. The species richness and tree density were greater in the forests surrounded by smaller human population density. Table 5.3 displays the correlation coefficients between forest size, stand density, species richness and the human population density surrounding the studied Uluguru forest fragments. The human population desnity was significantly negatively correlated with forest size, tree density and species richness. Forest size was significantly positively correlated with species richness.

Table 5.2: Forest size, total human population surrounding the forests, stand density and species richness in the studied Uluguru forests.

Forest	Forest size (ha)	Human population	Stand density (stems ha^{-1})	Species ha^{-1}
Kilengwe	995	3914	276	93
Kimboza	405	4901	390	72
Kisego	119	5741	140	29
Milawilila	13	5927	172	28
Nemele	8	6340	97	26
Ngambaula	3	7310	85	35
Gunauye	3	6768	175	46

Table 5.3: Correlation coefficients between forest size, species richness and human population density surrounding the studied forests.

	Forest size	Species richness	Tree density	Population density
Forest size	1.00			
Species richness	0.92^{*}	1.00		
Tree density	0.66	0.80^{*}	1.00	
Population density	-0.90^{*}	-0.79^{*}	-0.76^{*}	1.00

NB: * indicate significant correlation ($p < 0.05$, two tailed test)

5.4 Discussion

5.4.1 Tree uses and use values

A broad range of species are used for firewood and charcoal making, which all together account for 64 % of the listed species (Table 5.1). Normally, the collection of dead firewood is non-destructive (*i.e.* not cause of deforestation) as it involves collection of dead branches and naturally dying trees. Some ecological consequences due to collection of firewood include nutrient cycling, loss of habitat for a diverse range of small fauna, soil and regenerating trees protection as well as loss of some microbes and insects that live in decayed wood material (Brown, 2009). However, the collection of live woods for brewing and brick burning was observed in the surveyed areas. Although the collection of live woods is destructive as it accelerates deforestation, it is preferred by the locals because they prolong the fuel burning time. The most commonly collected species for firewood in Uluguru are *Acacia albida*, *Combretum* spp., *Grewia similis*, and *Scorodophloeus fischeri*. Elsewhere, Kalema (2010) reports *Mangifera indica*, *Combretum* spp. and *Acacia* spp. being the most used species for charcoal production in Uganda. Though not natural forest tree species, *Mangifera indica* has been reported in this study being used for firewood and charcoal making. Species like *Bridelia cathartica* is avoided as firewood and charcoal because they produce a pungent smell when burnt. Tree species that have high calorific values, such as *Milicia excelsa*, *Pterocarpus angolensis* and *Dalbergia melanoxylon* are nationally protected from harvest as they are threatened species in IUCN list. The three species were found to have poor regeneration (*see* chapter 3) and were relatively less frequent in the studied forests. Species frequently harvested for charcoal production vary between users and locations largely due to their availability and accessibility to producers rather than quality of charcoal (Kalema, 2010).

Moreover, it is estimated that 95 % of the Tanzanian mainland population living in urban areas depend solely on charcoal because it is reliable and majority can afford it compared to other energy sources like electricity and gas (Malimbwi *et al.*, 2004), however, the charcoal prices do not reflect its real cost. Both fire wood and charcoal accounts for 93 % of the total energy consumption in the country (URT, 2007). The high dependency on firewood and charcoal as the main source of energy has brought about excessive vegetation cover removal (Wilfred *et al.*, 2006; Mitinje et al., 2007), threatening the land, water base and food production, which subsequently locks local people into soil deterioration and environmental degradation (Kaale, 1994; Jones, 2000).

Species like *Sterculia* spp. are valued in the study area for traditional worship as they are associated with ancestral sacrifices. For instance, *Sterculia quinqueloba* had least use value in this study (Table 5.1) and displayed to have good regeneration. Despite the traditional value, *Sterculia* species are currently harvested for commercialization of their wood for timber (*see* Table 5.1). The observed low use value of *Sterculia quinqueloba* may also be related to respect to traditional importance it has to the people but could also be associated to its low markets value. According to Luoga *et al.*, (2000) some other tree species that are associated with ritual beliefs in Morogoro region include *Ehretia amoena, Sclerocarya birrea, Grewia bicolor, Maytenus senegalensis and Erythrina abyssinica*. The respect and preservation of tree species with tradiaitonal values have an impact in terms of conservation. The Gunauye forest was formerly used as holy sanctuary for traditional ceremonies but nowadays the practices are less frequently done and the forest has already been encroached. The harvest of trees with traditional values and destruction of forests which were used for traditional ceremonies can be associated with lack of morals/ethics by some people. During the survey some elders admitted that most of the traditional values have been significantly diluted, though special respects are still maintained for burial places. Moreover, people in Uluguru are realizing that destruction of forests are causing loss of resources for various traditional uses (*e.g.* medicines) and decrease in water quantity in their river/streams.

Of the 42 tree species, 45 % were listed to have timber value, which include the high quality timber tree species and which are prohibited from harvest by the government such as *Pterocarpus angolensis*, *Milicia excels*, *Dalbergia melanoxylon* and *Afzelia quanzensis*. The first three species were encountered in the study plots and showed to have poor regeneration (*See* chapter 2) and of low frequency. *Afzelia quanzensis* is perhaps accessed by the locals from general land. Modest *et al.*, (2010) and Ahrends (2005) reports *Afzelia quanzensis, Pterocarpus angolensis* and *Dalbergia melanoxylon* being faced by high harvesting pressure and harvested below minimum harvestable diameter requirements (MHD), 50 cm for the first two species and 25 cm for the later species (Malimbwi *et al.*, 2005). *Pterocarpus angolensis* is reported to be rapidly deteriorating in other parts of the country (Mbwambo *et al.*, 1995). Other common species recorded with timber use-values include *Cedrela odorata, Antiaris toxicaria, Bombax rhodognaphalon, Allanblackia uluguruensis, Albizia versicolor, Albizia gummifera, Mangifera indica, Erythrophloeum suaveolens, Scorodophloeus fischeri,* and *Parinari excelsa*. Some illegal harvests of timber tree species were observed in the studied forests. In addition to minor subsistence uses, timber harvest is driven by both local and urban markets most trading sawn wood for instance for furniture and a round wood export market (Ahrends, 2005). Both these markets are supplied with illegally cut timber (Milledge, 2004), which are mainly done and transported at night along off-road back roads in locked tracks to avoid inspection and normally timber are hiden underneath other products (Ahrends, 2005). The presence of less highly valued timber species and harvest prohibition done by the government could be the possible reason for a diversification to secondary and non-merchantable tree species such as *Sterculia quinqueloba*.

In case of trees used for construction purposes, 23 species were listed to be used as building poles, 35 % of which had an average use value of greater than one. The majority of rural people still rely on local forests for their house construction needs. About 98 % of the traditional houses (Figure 5.2) in villages are constructed using the wooden poles where the architectural design use four types of poles, namely *mijengo* (wall erecting poles), *miamba* (beam poles), *pau* (roofing poles) and *fito* (withies/cross joint members). The walls and floor are plastered with mud and the roof thatched with grass. The most preferred tree species as wall erecting and beam poles are *Dombeya natalensis, Terminalia sericea*, *Terminalia sambesiaca* and *Albizia gummifera*. *Combretum* spp. and *Markhamia obtusifolia* are commonly used as roofing poles while *Markhamia zanzibarica* is mainly preferred as withies. The uses of tree species as poles mainly depend on their resistance ability against biodegraders, their availability and cultural taboos of a place. For instance, Luoga *et al.*, (2000) reports reduced availability of *Spirostachys africana* which was mostly used as building poles due to its resistance to termites in Lubungo and Gwata village in Morogoro region, as a result more use has shifted to *Julbernardia globiflora* and *Combretum* spp., which were formerly not commonly used as building poles.

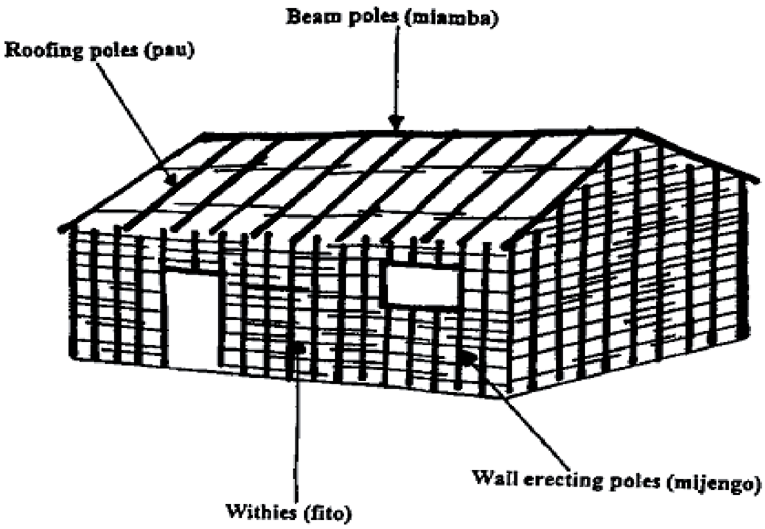


Figure 5.2: Architectural design of traditional houses showing different categories of poles.

(*Source:* Luoga *et al.*, 2000).

Picture showing traditional house constructed using wooden poles, wall plastered by mud and roof thatched with grasses.

Raw materials from the forests reserves are used to make a wide range of products that are categorized as domestic/household utensils and farm implements. Many species are used to make tools and utensils such as hair combs, pestles, mortars, stirring sticks, drums, chairs, beds, tables, spoons, bow, arrows, and tool handles for hoe, spade, spear, axe, cutlasses and bush knives, which are used to meet day to day household needs. Some trees from the forests are primary sources of fodder and are instrumental in supporting the livestock population in Tanzania. Live fences are also grown around houses, with properly selected species; the trees used for fencing can also be a source of fuel wood, medicine, food, fruits and other useful household products. Moreover, live fence act as wind barrier but also can be used to improve soil conditions for home gardens when species are appropriately used (Hines and Eckman, 1993).

About 40 % of the listed tree species had medicinal properties, majority of them harvested from tree roots, barks and leaves (*see* Table 5.2). For instance, barks of *Albizia gummifera* are used for treating malaria while a bath made from pounded roots soaked in water is used to cure skin diseases and an extract crushed from pod is drunk for treating stomach pains (Lovett *et al.*, 2006). Other studies like Hamilton and Bensted-Smith (1989), Luoga *et al.*, (2000), Wilfred *et al.*, (2006) and Makonda *et al.*, (1999) reported 26 %, 34 %, 39 % and 49 % of the identified species in their studies respectively being used as medicines, suggesting that forest plants have been good source of products with medicinal values. Shangali *et al.*, (2008) recorded 83 species belonging to 50 families as being used for medicinal purposes by Hehe tribe in Udzungwa scarp forest reserve. Hines and Eckman (1993) reported that 80 % of rural communities in Tanzania depend entirely on traditional healers who obtain about 90 % of their remedies from plants. Villagers from the study areas admitted that they hardly access the few modern medical services available at Kibungo chini and Morogoro due to distance and financial constraints. The cost sharing policy in public health services has made many rural people to refrain from visiting health facilities as majority cannot afford to pay for the services (Makonda *et al.*, 1999), suggesting high dependence on forest resources for medicinal purposes. The frequent harvesting of roots and barks may destroy the trees, and is therefore not advisable. To foster sustainability the local community should be encouraged to use leaves whenever possible (Chinsembu and Hedimbi, 2010). Moreover, the overexploitation of plants for medicine may lead to some plants to be rare and eventually extinct if sustainable uses are not advocated. Other studies such as Augustino and Gillah, (2005) and Lovett *et al.*, (2006) revealed uses of some species (also recorded in this study) as shown in Table 5.2.

Among the listed species by respondents in Table 5.1, 12 % (*i.e. Parinari excelsa, Ocotea usambarensis, Afzelia quanzensis, Cedrella ordorata and Tectona grandis*) were not encountered in the plots during inventory in all the seven forests. The first three are known to be native forest species and it is possible that they are present in the forests but were missed during the survey due to plot setting.

The last two are acquired tree species, which were found to exist in some private farms. Moreover, it is possible that the locals access these tree species from the general land available in their areas.

Table 5.4: Trees with medicinal properties, parts used, treated disease and mode of use.

Family	Species Name	Part used	Ailment cured	Application mode
Anacardiaceae	*Mangifera indica*	Barks	Tuberculosis, Dysentery, and Infertility	Drinking
		Roots	Anaemia	Drinking
	Xylopia aethiopica	Fruits	Stomach ache, coughs, dizziness, amenorrhoea, bronchitis and dysentery	Drinking
	Xylopia longipetala	Bark	Stomach ache and snake bite	Drinking
Annonaceae	Annona senegalensis	Roots	Stomach ache, Snake bite and	Drinking Rubbing
		Barks	Body fracture	
Apocynaceae	*Diplorhynchus condilocarpon*	Leaves	Gonorrhoea, syphilis and bilharzias	Drinking
Bombaceae	*Bombax rhodognaphalon*	Barks	Diarrhoea	Drinking
Combretaceae	*Combretum spp.*	Leaves	Headache, Epilepsy and Pneumonia	Drinking
		Roots	Oedema	Rubbing
			Abdominal pains, Infertility, Stomach ache, Hernia and Schistomiasis	Drinking
	Terminalia sericea	Bark & Leaves	Meningitis, Dysentery	Drinking
	Terminalia sambesiaca	Roots & Leaves	Stomach ache and Infertility for women	Drinking
		Barks	Fever and Colds	Drinking
Euphorbiaceae	*Bridelia micrantha*	Barks	Malaria	Drinking
			Toothache	Rinsing

Fabaceae	*Albizia gummifera*	Barks	Malaria	Drinking
		Roots	Skin diseases (rashes)	Rubbing
		pod	Stomach pains	Drinking
	Dalbegia melanoxylon	Roots Barks	Stomach ache, Dysentery	Drinking
			Dysentery and	Drinking
		Leaves	Convulsion	Drinking
			Stomach ache and Infant high Fever	
	Pterocarpus angolensis	Roots	Women's abdominal pains after delivery	Drinking
	Erythrophleum suaveolens	Roots	Stomach worms	Drinking
Lauraceae	*Ocotea usambarensis*	Barks	Women's stomach ache, infertility, Anaemia, Infants complications, and whooping cough	Drinking
			Body swelling, tumours and tonsillitis	Rubbing
		Roots	Headache and Malaria	Drinking
Moraceae	*Ficus sycomorus*	Roots	Stroke, Swollen throats, Diarrhoea and Dysentery	Drinking
	Ficus exasperata	Leaves	Malaria	Drinking
	Ficus natalensis	Roots	Cough	Drinking
	Ficus sur	Barks	Cough	drinking
Verbenaceae	*Vitex doniana*	Roots	Women's stomach ache	Drinking

Source: Augustino and Gillah, 2005; Lovett *et al.*, 2006

5.4.2 Effects of human population on forest size, stand density and species richness

Anthropogenic activities are believed to be significant influencing factors in any natural forest ecosystems (Wang *et al.*, 2001). In the present study, the human population density surrounding the forests revealed a significant negative association with forest size, species richness and tree desnity (Table 5.3). The findings imply that the increase in human population has increased demands for more land for agriculture, firewood and charcoal for fuel as well as timber and poles for construction purposes, which put pressure to the forest ecosystems. The demand for more land for agriculture has led to forest encroachment, which result to loss of forest size and subsequently decline in species richness and tree density. For instance, between 1990 and 1995 Tanzania lost 322,000 ha of forests annually due to agricultural clearings, overgrazing, charcoal production, fuel wood harvest, fire and timber harvest (Newmark, 2002). The forest disturbances are strongly associated with the increase in human population density (Nkombe, 2003). Thus, the increase in human population surrounding the forests seems to be the driving factor for forest fragmentation and loss, which subsequently leads to decline in species richness and stand density due to declining forest size. Similar findings have been observed by different authors in their studies in other tropical forests. For instance, in India, Chittibabu and Parthasarathy (2000) observed that differences in human interference had a considerable influence on species richness while Zhu *et al.*, (2004) found species richness to be less in more disturbed forest fragments. Top *et al.*, (2009) revealed negative association between human population density and measures of forest structure (tree density, basal area, stand volume and aboveground biomass) and species richness and diversity.

5.5 Conclusion

High human population growth coupled with difficult economic circumstances in rural areas have led rural inhabitants in developing countries to depend on forest resources. The study revealed that Uluguru forest fragments are central components of the local rural livelihoods, with the majority of household livelihood depending on exploitation of the forest resources. Though many trees are exceptionally useful, their levels of utilization may far exceed their regeneration, thereby spreading more environmental destructions. For instance, high dependency on firewood and charcoal as fuel by the rural households is the major cause of forests deforestation which enhances fragmentation of forest habitats. The study also found a negative relationship between human population density and forest size, stand density as well as species richness. Thus, it is evident that forest size, tree density and species richness, are under threats from anthropogenic activities as the population increases. The study suggests that the control of anthropogenic activities/disturbances should be given priority for management and conservation of forest resources in Uluguru. This could be attained by promoting community forestry or plantations, and introduction of other affordable renewable energy sources.

CHAPTER SIX

General Discussion and Conclusion

6.1 General Discussion

Uluguru forests in the Eastern Arc Mountains of Tanzania are recognized as important biodiversity hotspots but increased human population pressure and encroachment threatens their conservation value (Myers *et al.*, 2000; Burgess *et al.*, 2002). Understanding forest tree community, species richness, diversity, natural regeneration and indigenous tree usage is very important in the management of any ecosystem for environmental and conservational value. This Ph.D study aimed at (1) determining floristic composition, species diversity and structure of mature trees (≥ 10 DBH) of in representative forests in the Eastern Arc Mountains (2) determining understory composition, diversity and natural regeneration status of trees in the studied forests (3) analysing to what extent species richness, diversity and abundance differs along the edge-interior gradient within each forest and (4) examining indigenous uses and relative importance of tree species by the local people. The methods applied and the results obtained are presented and discussed in the previous chapters 2, 3, 4 and 5.Therefore, this chapter provides an overall discussion based on the objectives and results of the study but also it provides suggestions for future research and a general conclusion.

6.1.1 Species richness, diversity and structural composition

Knowledge on species richness and the factors influencing the diversity patterns in tropical forests is an essential objective for many community ecologists and conservation biologists (Magurran, 2004). The number of species in a local assemblage is an intuitive and natural index of community structure, and patterns of species richness measured at both small (*e.g.* Blake and Loiselle) and large (*e.g.* Rahbek and Graves, 2001) spatial scale. Our study revealed that species richness (ranged from 26 to 93 species ha^{-1}) for trees with DBH ≥ 10 cm was within the range of species observed by other researchers in Eastern Arc forests of Tanzania (Table 2.8). Also, the study shows that Uluguru forests have a similar suite of plant families to other tropical forests of Africa. Families such as Fabaceae, Moraceae, Meliaceae, Sapotaceae and Annonaceae, are almost well represented in Uluguru forests as in other African forests (*e.g.* Cadotte *et al.*, 2002; Mwavu, 2007; Addo-Fordjour *et al.*, 2009). Moreover, the findings concur with other works (*e.g.* Burgess and Clarke, 2000; Eilu *et al.*, 2004; da Silva *et al.*, 2011) that observed family Fabaceae being the most dominant family in the lowland tropical forests.

Specie accumulation curves (Figure 2.1 and 3.3) and species richness estimators (Table 2.5) revealed larger forests (*i.e.* Kilengwe and Kimboza) to have high number of species as compared to the smaller ones. This suggests that the more species in the assemblage and the more even the species abundance distribution, the more rapidly the species accumulation curve will rise. In contrast, if the species abundance distribution is highly uneven (*i.e.* few common species and many rare ones), the curve will rise more slowly, even at the outset, because most of the individuals sampled will represent more common species that have already been added to the sample, rather than rarer ones that have yet to be detected (Gotelli and Colwell, 2011). The larger the forest size is, the more the diverse/heterogeneous habitats, which contribute to the maintenance of species richness (Toumisto *et al.*, 2005), although the degree of specialization may vary between forests (Kubota *et al.*, 2004). This is also supported by the findings in this study, which revealed that species richness and diversity were increasing as the forest size increased (Table 2.6). Also, the larger forests (*i.e.* Kimboza and Kilengwe) had higher number of rare species compared to smaller forests (Figure 2.1 and Table 6.1). Thus, increasing habitat fragmentation will result not only in the loss of a valuable portion of the forest ecosystem but also decline in species richness, especially of the observed rare species and threatened species (*see* Table 2.2 and 6.1).

The forest structural parameters (*i.e.* tree density and basal areas) of the studied forests were found to be consistent with other findings reported in the coastal forests of Tanzania (Table 2.5). The significant differences in these structural parameters (Table 2.1) can be due to variations in edaphic parameters among the forests and differences in anthropogenic disturbances. Though, size class distributions in each forest revealed good regeneration, the lack of some individuals in some size classes (Figure 2.5) can be explained as the result of illegal and selective logging by the local inhabitants for their various uses. Also, the findings showed forest size to have positive association with the tree density and basal area (Table 2.6). Similar to this result, high tree density and basal area also associated with larger fragments in southern-eastern Madagascar (Ingram *et al.*, 2005). Reductions of basal area in any forest represents a modification of the forest structure in which the forest returned to an earlier successional stage and forests with lower basal areas are mainly characterized by high abundance of young trees (*see*

Figure 2.5). The changes in forest structure can have negative consequences on floristic composition (Pardini *et al.,* 2005). For instance, density of bird species in forests may be reduced due to changes in availability if canopy emergent tree species (Diaz *et al.,* 2005). The accelerated dynamics due to fragmentation are likely to exacerbate changes in forest structure, species composition and microclimate of the forests, which could drive local extinctions of some disturbance-sensitive species and rare species (Laurance *et al.,* 2006). Moreover, the stand structure in the studied forest fragments is also affected by increasing human disturbances.

6.1.2 Influence of geographical distance on floristic similarity

How species composition changes (*i.e.* beta diversity) with geographical distance has seldom been studied (Condit *et al.,* 2002). Various studies elsewhere (*e.g.* Bohlman *et al.,* 2008; Coronado et al., 2009; da Silva *et al.,* 2011) revealed geographical distance to be the most important variable influencing floristic similarity among the forest pairs. In the present study, a general trend reveals the decline in floristic similarity with increasing geographical distances, however, some forests pairs separated by a great distance (e.g. Bombo East I and II versus Magombera, Nambinga and Mahenge scarp forest) were also found to have high similarity values. This can be due to high similarity in edaphic factors especially soil types between the pairs, regardless of their distances (Tuomisto *et al.,* 2003). Adaptations to different edaphic factors (Gentry, 1988) and dispersal limitation (Hubbell, 2001) play an important role in determining spatial variation in species composition. Coronado *et al.,* (2009) observed group of species to be related to the gradients in soil fertility at both, regional and continental scales, where the species of Lecythidaceae and Sapotaceae were characteristically found on poor soils while species of Aracaceae and Myristaceae were most common on richer soils. Additionally, Tuomisto *et al.,* (2003) demonstrated that environmental factors, especially soil type, were most important variable for species distribution and abundance patterns within terra firme forests in Western Amazonia. Therefore, it can be concluded that because of habitat heterogeneity, tree species are distributed in a patchy way (Slik *et al.,* 2003), and because of dispersal limitation, there is a gradual turn over in species pools between distant areas (Condit *et al.,* 2002).

6.1.3 Natural regeneration and stand structure

Natural regeneration is the fundamental component of tropical forest ecosystem dynamics and restoration of degraded forest lands (Poorter *et al.,* 1996). Sustainable forest utilization is only possible if sufficient information on the regeneration dynamics and factors affecting tree species regeneration are well known. Tropical forests show variation in regeneration pattern both through differences in their constituent species and the environmental variables in which they grow (Denslow, 1987; Whitmore, 1996). Studies on natural regeneration provide options to forest development through improvement in recruitment, establishment and growth of seedlings of the desired species (Whitmore 1996). Our study revealed variability in regeneration in terms of species diversity, abundances and distributions between the forests. Some species like *Sorindeia madagascariensis, Scorodophloeus, Diospyros squarrosa* and *Ehretia amoena* were widely distributed while other species listed in Table 6.1 were rare and endangered. The natural regeneration depend on environmental factors such as distribution of rainfall, temperature, topography, edaphic and light availability (Felfili, 1997; Khurana and Singh, 2001; McLaren and McDonald, 2003; Enoki and Abe, 2004) as well as factors such as seed viability, seed dormancy, seed predation and herbivory (Khurana and Singh, 2001). The topography affects the soil characteristics and plays a critical role in the variation of stand structure and floristic composition of the forests by causing drainage, moisture, and nutrients to vary from ridge top to valley bottom (McLaren and McDonald, 2003; Enoki and Abe, 2004).

The overall size class distribution in each of the forests revealed good regeneration patterns (*see* Appendix 1). However, some species (*see* Table 6.1) completely lacked individuals or were under-represented in the lower size classes (especially seedlings and saplings), which is an indication of a poor regeneration (Poorter *et al.,* 1996). The species in Table 6.1 had low abundance and frequency in their forests, implying that the species are rare and can undergo local extinction in future if their protection and conservation measures will not be given priority. Poor regeneration signifies that the population has been temporarily interrupted through excessive harvesting of fruits or seeds, direct physical damage to seedlings, lack of pollinators or dispersal agents (Peters, 1994), variations in environmental conditions (Mwavu and Witkowski, 2009) and lack of sufficient seed bank (Lyaruu and Backéus, 1999). Tree species like *Khaya anthotheca, Milicia excelsa, Dalbergia melanoxylon, Pterocarpus angolensis, Pterocarpus tinctorius and Bombax rodognaphalon* have been reported to be illegally harvested for timber in other coastal forests of Tanzania (MNRT, 2004; Ahrends, 2005;

Modest *et al.*, 2010; The Guardian, 2012), which reduces the opportunity of regeneration and increase risks of extinction. The lack of individuals' observed in the two lower size classes (*i.e.* seedling and sapling) is clear enough to raise some doubts and questions concerning the long term survival of these species.On the other hand, the lack of individuals in some higher size classes in the overall size class distributions of Kilengwe, Kisego, Nemele, Gunauye and Ngambaula (*see* figure 2.5) can be related to anthropogenic activities especially illegal harvesting of big trees for timber and other uses by locals. The presence of species with poor regeneration signify the need for the Uluguru forests management to develop and implement forest management plans, which will enhance and facilitate both vigorous and poorly regenerating species, to guarantee sustainable forest existence. Moreover, Table 6.1 shows that larger forests (*i.e.* Kilengwe and Kimboza) had more rare/endangered species, indicating that if the forest size will decrease due to fragmentation; these species are likely to extinct.

6.1.4 Floristic variation in edge-interior gradient

In general, the forest interior possessed higher species richness, diversity and density than either edges or intermediate sampling areas. This finding is also supported by the species richness and area relationship, which revealed the forest interior to have higher regression slopes in the forest interior than edges and intermediate in overstory, large sapling and small sapling layers (*see* Table 4.3). The possession of less species richness, diversity and density to forest edges and intermediate regions could be associated with easy accessibility by locals. The presence of less canopy trees to the edge and intermediate sampling areas signify that the forest floor in these areas receives much direct insolation, which in increase the soil temperature and reduce soil moisture. The harsh micro-environmental conditions tend to restrict recruitment of some species (Murcia, 1995). For instance, the alterations of the physical environment at the edges tend to alter species composition, diversity and density (Jose *et al.*, 1996; Didham and Lawton, 1999; Laurance *et al.*, 2006). The relationship between tree size categories/individual biomass revealed exponential decay pattern with stem density in all the forests. This observed pattern indicate the fast decline in tree density at larger tree sizes and tapering off at higher densities. This is associated with competition for resources *i.e.* space, water and light, whereby the weaker ones die because of inability to compete with the stronger ones.

Table 6.1: List of species with low abundance and frequency in each of the studied forests.

	Kilengwe	Kimboza	Kisego	Milawilila	Nemele	Ngambaula	Gunauye
Pterocarpus angolensis $^+$		*					
Dalbergia melanoxylon $^+$	*	*					
Cynometra uluguruensis $^+$		*					
Pandanus rabaiensis $^+$		*					
Millettia sacleuxii $^+$		*					
Pouteria altissima $^+$	*						
Holarrhena pubescens $^+$	*						
Pterocarpus rotundifolius		*					
Zanthoxylum deremens		*					
Pseudolachnostlis maprounefolia	*						
Allanblackia stuhlmannii $^+$				*			
Allanblackia uluguruensis $^+$				*			
Milicia excelsa $^+$	*					*	
Dalbergia boehmii	*						
Antiaris toxicaria	*				*		
Bombax rodognaphalon					*	*	*
Cussonia zimmermannii							*
Combretum molle		*	*				
Combretum adegonium		*	*				
Polyscias fulva			*				
Stereospurmum kunthianum		*					
Grewia goetzeana		*					
Burkea africana			*				
Lonchocarpus bussei		*					
Steganotaenia araliaceae	*					*	*
Grewia similis						*	*
Sterculia africana		*					
Oncoba spinosa	*						*

NB: * indicate presence of species in that particular forest and $^+$ represent threatened species.

6.1.5 Uses of tree species and human population impacts

As in many rural areas in Tanzania, agriculture is the main socio-economic activity for the majority of Luguru people. Also, the locals depend on forest reserves and general lands available for firewood, charcoal, traditional medicines and other needs. Of the 42 identified trees species, 67 % are known to be used for both charcoal and firewood while 40 % are used for medicinal purposes. In Tanzania, firewood and charcoal represent the primary source of energy for both rural and urban populations (Malimbwi *et al.*, 2004; Wilfred *et al.*, 2006). Charcoal is mainly preferred source of energy in urban areas while firewood in rural areas. Country wide, charcoal and firewood account for 92 % of the primary energy consumed, petroleum and electricity supply account for 7 % and 1 % respectively (Kaale, 1998). Wilfred *et al.*, (2006) report that 84 % of the rural inhabitants to use firewood as their main source of energy or domestic purposes. The sources of fuel wood (charcoal and firewood) being the general land and forest reserves. All the surveyed villages in our study are not connected to the national electricity transmission grid. Also, affordability to alternative energy sources (*e.g.* stand-alone electricity system, gas and renewable energy facilities) for both urban and rural inhabitants has been a problem due to availability and high costs. Moreover, rapid human population growth in urban and rural areas has increased pressure on the forest resources (Malimbwi *et al.*, 2004) and therefore necessitates an integrated land use management strategy.

The collection of trees for construction purposes is widespread is the Uluguru forests, the most intensive collection occurring in the most easily accessible parts of the forests (*i.e.* edges). Of the listed species used for construction in this study (*see* Table 5.1), *Pterocarpus angolensis, Dalbergia melanoxylon, Bombax rodognaphalon, Combretum mole, Combretum adegonium, Grewia gowtzeana and Burkea africana* were found to have low regeneration. Among these species *Dalbergia melanoxylon* and *Pterocarpus angolensis* were reported by Ahrends (2005) as being harvested below minimum harvestable diameter (MHD) in other coastal forests of Tanzania. Although, the Tanzanian government has declared protection status for these two species (*i.e.* they cannot be harvested without government permission, even if they are on agricultural lands), this has not stopped exploitation pressure for various uses in the studied stands and other coastal forests in Tanzania. Commercial logging has been reported to be the cause of deforestation and fragmentation in most of the Eastern Arc forests (Newmark, 2002). Illegal logging has been observed in most of the surveyed forests, where the logs are mainly transported at night in locked trucks to avoid inspection and the logs/timber products are hided beneath other products. Milledge (2004) reported that local and urban market in Tanzania to be largely supplied with illegally cut timber. The illegal logging could have also contributed to the size class distribution (*see* Figure 2.5) and lower basal area (*see* Table 2.1) observed at Kisego, Ngambaula, Gunauye, Nemele and Kilengwe. The poor regeneration cause reduced availability of the species used for construction purposes, which subsequently lead to shift to other species like *Sterculia* spp. that were formally used as for traditional adorations.

The wide use of trees as medicines by the rural communities in Tanzania is associated with the inaccessibility to modern health facilities, which is mainly a consequence of poor infrastructural facilities, long distances to modern health facilities and financial implications (Makonda *et al.*, 1989). Shangali *et al.*, 2008 report that even if the dispensaries are present in the rural areas, they are poorly stocked with medicines. Hence, majority of the rural people decide to opt for the traditional medicines which are cheap, abundant and accessed very easy. In Southern Africa, more than 80 % of the rural population is poor and depend on forest for their livelihoods while 80 % of the rural communities depend on medicinal plants for their health needs and income generation. Moreover, weak infrastructure and poverty pose problems for the provision of health care services in most of the South African countries, which led to more than 100 million people to depend solely on herbal medicines dispensed by traditional healers (Syampungami and Chirwa, 2012). Increased demand for traditional medicines coupled with an increase in human population is likely to put more pressure on the forest reserves due to increased demands *e.g.* land for agriculture, firewood and charcoal for domestic purposes, timber and poles for constuctions and medicines for health needs. Thus, conservation measures are necessary to protect the forests. The population need to be educated on propagation and conservation of trees especially those which are used for treatment of most common ailments. Since most of the plants were observed to be exceptionally useful, their levels of utilization may far exceed their regeneration and production, thereby increasing environmental destruction. Therefore, measures to curb the destructions should take into account the indigenous knowledge and use different species in order to ensure the smooth adoption and fruitful output.

The human population density was negatively associated with forest size, species richness; species diversity and tree density (*see* Table 5.3). These findings signify that increased human population around the forests lead to decline in forest size is mainly due to increased demand for more land for agriculture, firewood and charcoal for fuel as well as timber and poles for construction purposes. The demand for more land for agriculture and settlements has led to forest encroachment (Madoffe *et al.*, 2006). Tanzania lost 322,000 ha of forests between 1990 and 1995 due agricultural clearings, overgrazing, charcoal production, fuel wood harvest, fire and timber harvest (Newmark, 2002) while in Uluguru the rate of forest loss due to conversion to farmland were reported as 1.7 % between 1955 and 1977 and 0.6 % between 1977 and 2000 (Burgess *et al.*, 2002). In general the decline in forest size due to increased human population will lead to decrease in species richness and tree density in the forests and will also lead to loss of resources like traditional medicines. Moreover, if human population will not be well controlled, the forests will continue being fragmented and ultimately the ability of the remaining forests to sustain biodiversity will be greatly reduced.

6.1.6 Community involvement in forest management

In Tanzania, forests are centrally managed through Forest and Beekeeping Division (FBD) under the Ministry of Natural Resources and Tourism (MNRT) signifying that the management type is characterized by extensive state control. The lack of local community involvement in forest management has caused many forests in Tanzania to be under pressure from encroachment, illegal logging, fuel wood harvesting, charcoal production, uncontrolled grazing and fires, which result in deforestation. This is due to fact that the rural communities regard forests as belonging to the government only because they are not fully involved in management issues. Protection and sustainable management of the forest resources cannot be done by the government alone. Community involvements in forest management together with provision of environmental management education and user rights seem to be the possible solution. Though, the national forest policy (1998) opens the way for forest-adjacent communities to become co-managers of both central and local government forest reserves through Joint Forest Management (JFM) agreements (MNRT, 1998), the local communities in the surveyed area revealed to have no direct responsibility for the protection and management of the forest reserves. This kind of negative perception by local community makes them look the forest reserves as a liability than an asset. Thus, the local people requested to be involved in management and protection of the forests because they very much depend on the forest resources. In order to ensure sustainable forest management the study suggests for the following; (1) the local communities need to be practically involved in protection and management of the forests, (2) environmental education should be provided to all villagers, (3) penalties to people who engage in illegal activities in the forests reserves must be reviewed because currently, defaulters are charged 30-1212 USD (1 USD = 1650 Tanzanian Shillings) as fine for damage or 3 years imprisonment. The fine is two low as the environment can not be recovered with the amount stated by law. More stringent penalties are needed in order to protect the forests and environment at large, (4) rural people should be encouraged to plant different tree species in their farms for their own benefits and future generations too as well as for easing conservation efforts in the future, (5) more education must be given to forest officers on how to undertake and implement joint forest management process as they are responsible with moving the process forward and (6) the government needs to ensure that there is adequate number of technical staff (*i.e.* forest officers), supply them with adequate working facilities as well as providing sufficient funds timely to the forest department and beekeeping division.

6.1.7 Suggestions for future research

The following are suggestions for future research to be done in the studied forest fragments.

- Future research is needed to consider the edaphic factor variation (*e.g.* soil type and nutrient availability) variation within and between the studied forest fragments. This will help to understand how these factors influence tree species composition and distribution within and between the forest fragments.
- In order to guarantee restocking and existence of indigenous species that demonstrated poor regeneration in the studied forests, physiological study is needed so that we understand reasons for the lack of good regeneration. Moreover, studies on various anthropogenic factors must be done so as to know them and how to eliminate completely or to keep them minimally.
- Long term research on micro-environmental factors (*i.e.* light availability, air and soil temperature, soil moisture, relative humidity *etc.*,) along the edge interior gradient should be studied in the future in this forests in order to get a clear idea on how these factors affect tree species richness, diversity and density.
- Future research should identify livelihood strategies and assess the economic contribution of charcoal, firewood and timber production to livelihood of rural inhabitants in Uluguru. Special focus should be put on (1) what are the major livelihood strategies adopted by the rural households in Uluguru? (2) How much money/income do households earn from charcoal production, firewood collection or timber harvest?

- Analysis of land use/cover change within and around the Uluguru forests should be done in order to understand dynamics of land use/cover change to deforestation and associated land use practices that have changed over time within and around the forests.
- Major causes and types leading to stem damag should also be identified and sprouting ability between different trees species should be studied in the forests.
- Furthermore, assessment soil seed bank composition, density and spatial distribution in the studied forests in Uluguru should be also undertaken.
- There is a need to establish permanent plots for monitoring population structure and regeneration pattern of the trees species with high use values, which will enable to have clear understanding of vegetation change in Uluguru forests.

6.2 General Conclusion

This study revealed that the larger forests (*i.e.* Kilengwe and Kimboza) had higher species richness, diversity and tree density than the small ones. The forest size was positively correlated with species richness ($r = 0.92$), species diversity ($r = 0.95$ for Shannon; $r = 0.98$ for Fishers and $r = 0.94$ for Simpson indcies) and tree density ($r = 0.66$). The dendogram revealed four major clusters assembling forests according to their geographical proximity (*i.e.* the closer the forests are the more the floristic similarity). This association was confirmed by the correlation analysis that revealed significant negative association between the geographical distance and floristic similarity ($r = -0.43$, $p < 0.001$) among the forest pairs. Though many forest studies in the tropics seem to concentrate to overstory layer (tree with DBH ≥ 10 cm), this study has revealed the understory layer to be more speciose than the overstory layer. Thus, the understory layer should be given attention during future biodiversity inventories in tropical forests. Though the overall size class distributions of each studied forests showed to have good regeneration, more conservation attention should be put to species that showed to have poor regeneration and rare ones. In general, the assessment of edge-interior gradient revealed the forest interiors to be richer in species richness, diversity and tree density compared to edge and intermediate regions. However, further study is needed to investigate factors (*e.g.* nutrient availability, soil type and micro-environmental conditions) that contributed could have to the observed general trend. Our study also revealed 42 species as being useful for the livelihood of the rural population while 88 % of the species serve more than one function. Species used for firewood, timber and medicine accounted for 64 %, 45 % and 40 % of the total species mentioned by respondents. The total human population from the villages surrounding the forests revealed significant negative correlation with forest fragment size (r = -0.90), species richness (r = -0.79) and tree density (r = -0.76), suggesting that increase in human population in the villages will lead to increased demand for more land for agriculture, firewood and charcoal for domestic use, timber and poles for building and medicines for the locals health, which put more pressure to the forest resources. In order to harmonise population pressure with natural resource management in the forests, this study advocates for a strong community involvement in the management of the forests as is considered to be the appropriate way of bringing about sustainable forest management. But also the involvement of community will help the locals to have feelings that they are also main stakeholders instead of regarding forests as belonging to the government only. Moreover, it is proposed that provision of environmental education to the villagers surrounding the forests should be done. This will help in increasing awareness as well as sense of ownership and responsibility among the local communities. In general, our study shows that if human population in the surrounding villages will continue to increase and if fragmentation process among the studied forests continues, the ability of the forest remnants to sustain their original biodiversity and ecological processes will be significantly reduced. Thus, protection of forest remnants should be emphasized so that future generations can enjoy and meet their needs too.

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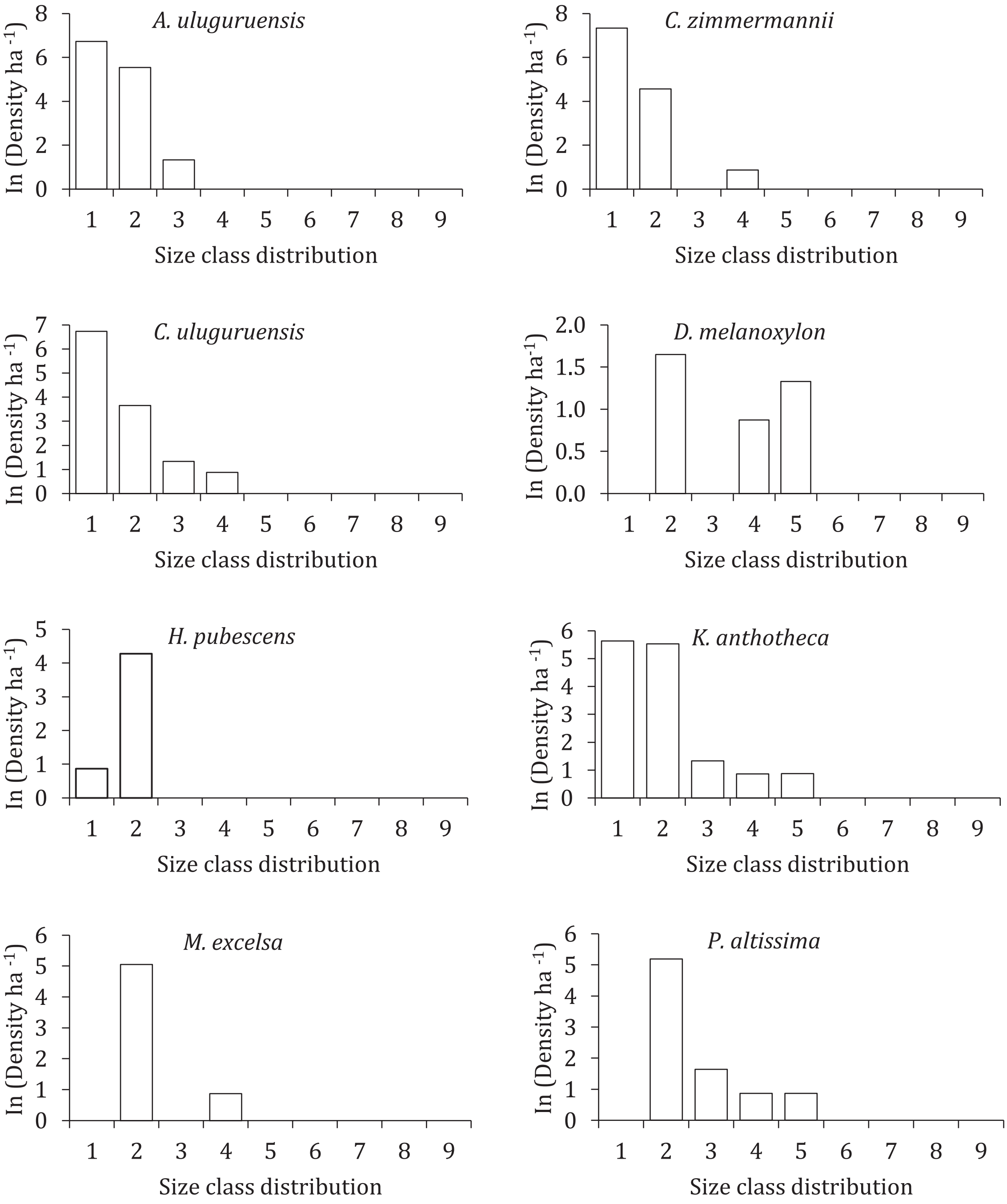
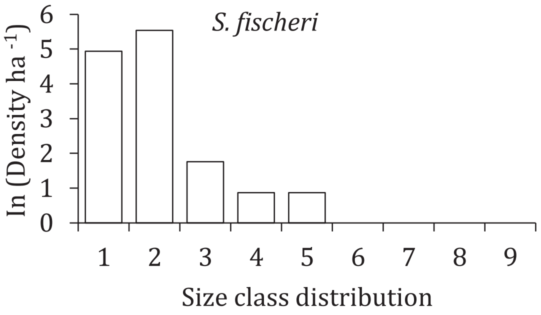
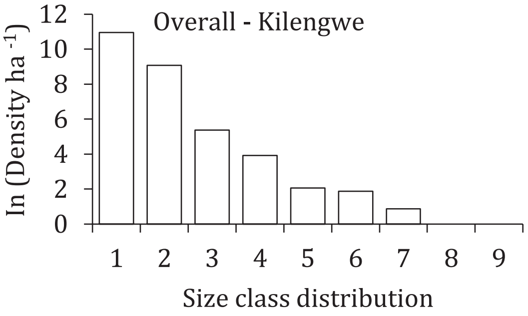
Appendix 1

Size class distribution (SCDs) of threatened, endemic/near endemic tree species and overall species in each of the forest. (1: seedlings, 2: small and large seedling, 3:10-19.9, 4: 20-29.9, 5: 30-39.9, 6: 40-49.9, 7:50-59.9, 8:60-69.9, 9: > 70 cm)

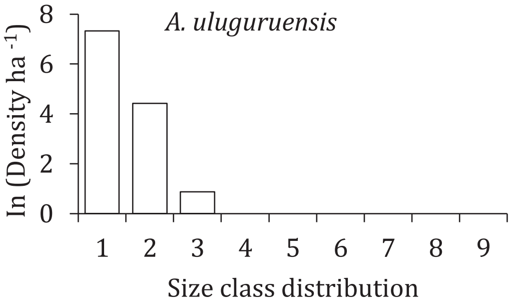
Kilengwe Forest

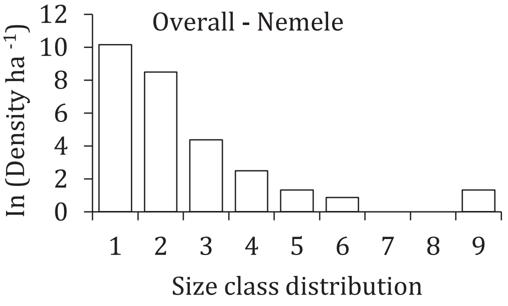




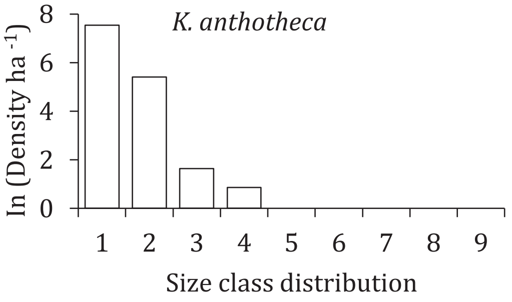


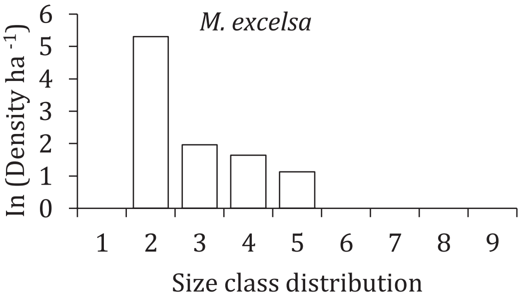
Nemele Forest

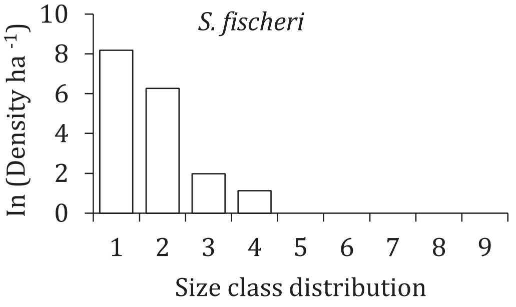


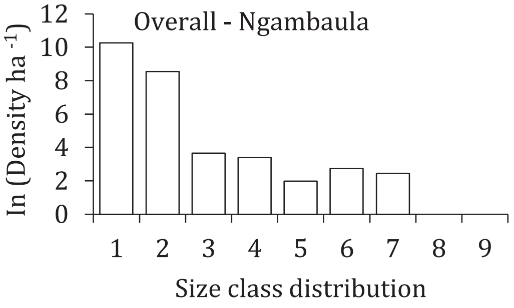


Ngambaula Forest

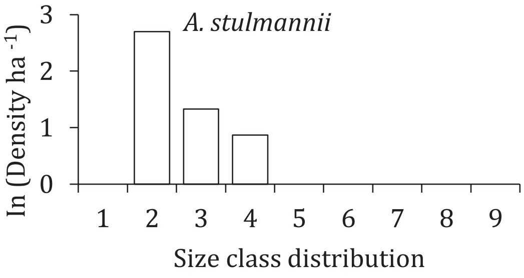


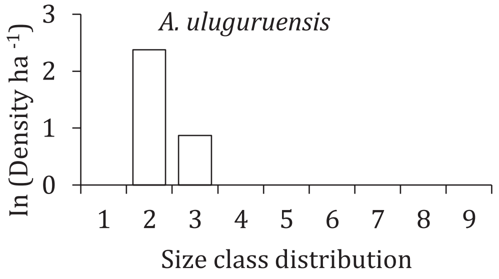


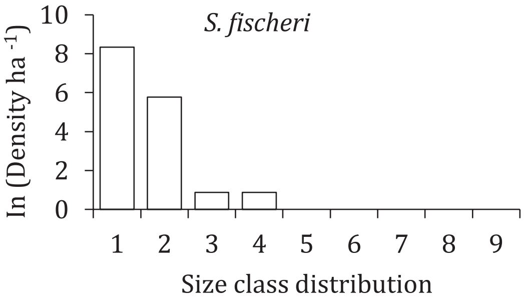


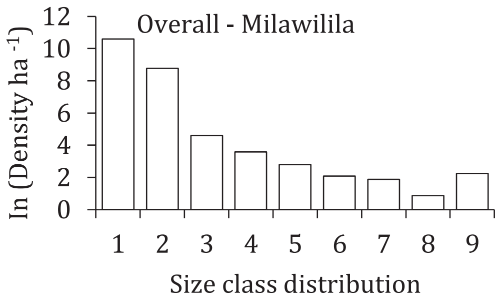


Milawilila Forest

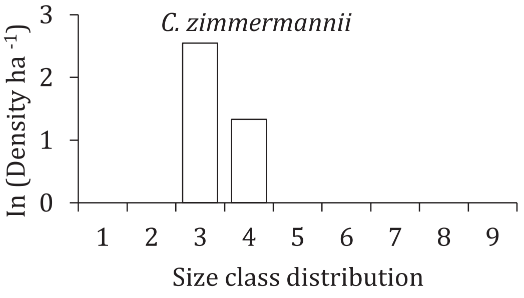


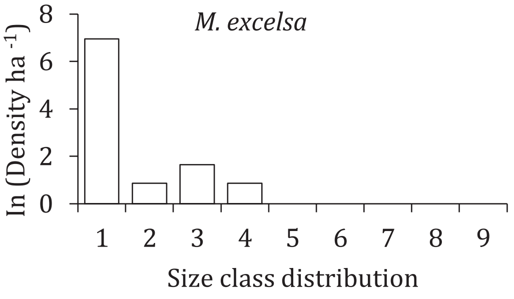


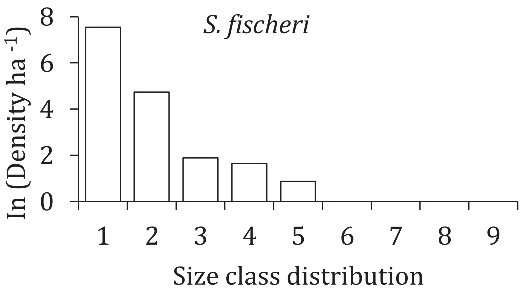


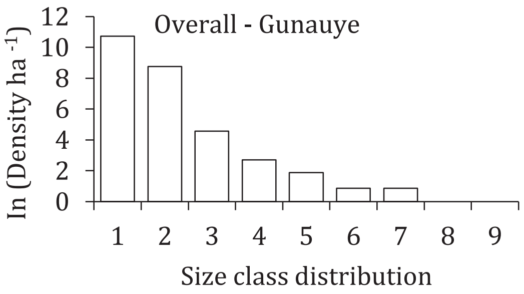


Gunauye Forest

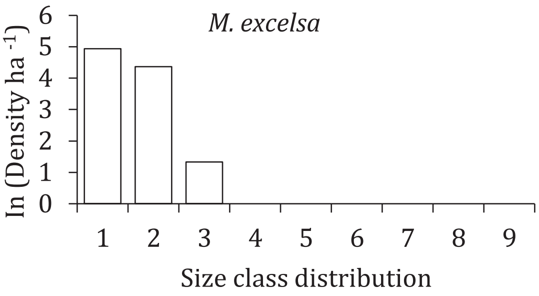


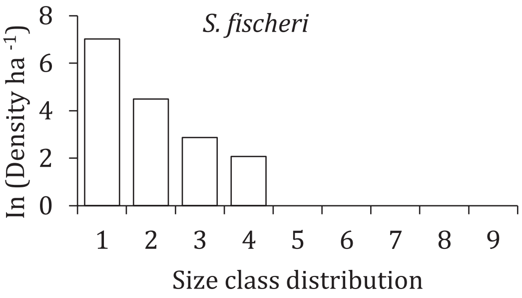


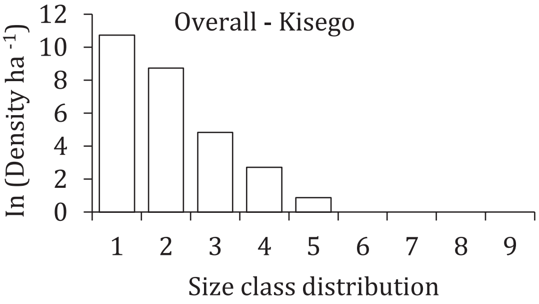




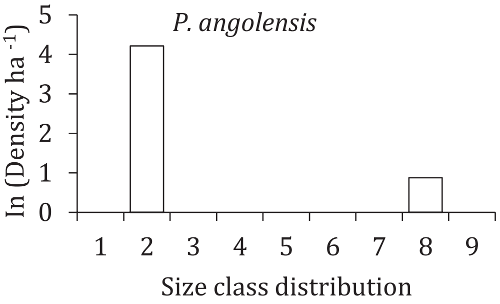
Kisego Forest

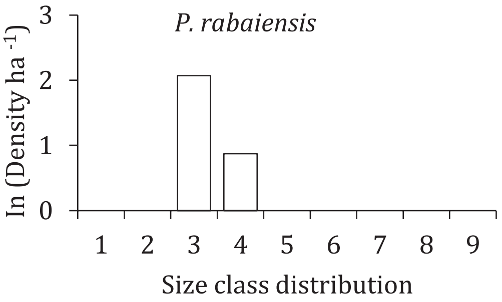


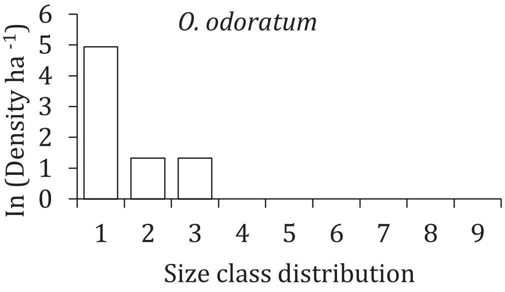


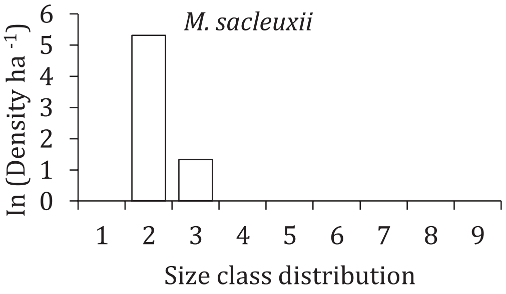


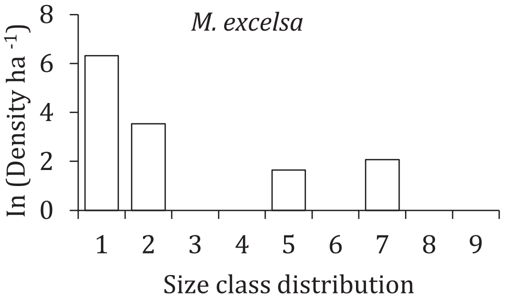
Kimboza Forest

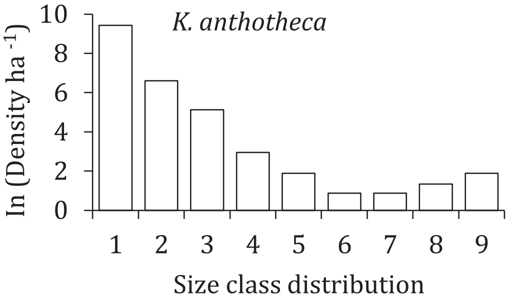


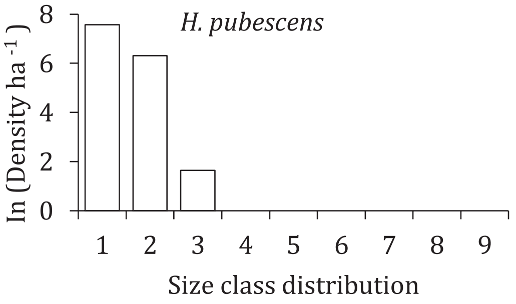


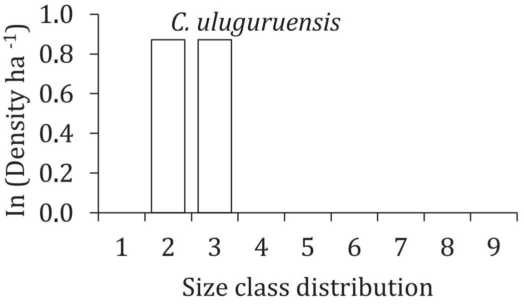


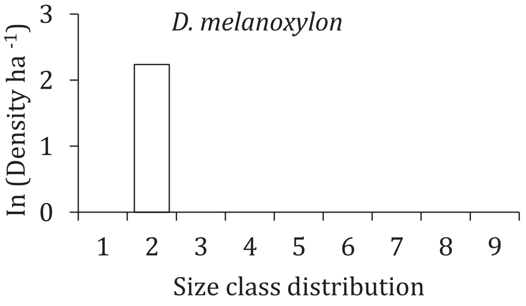


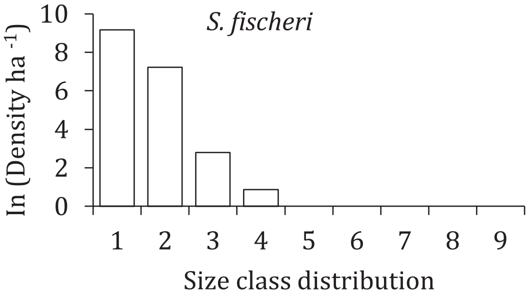

M. excelsa
In (Density ha -1)
0
2
4
6
8
1 2 3 4 5 6 7 8 9
Size class distribution

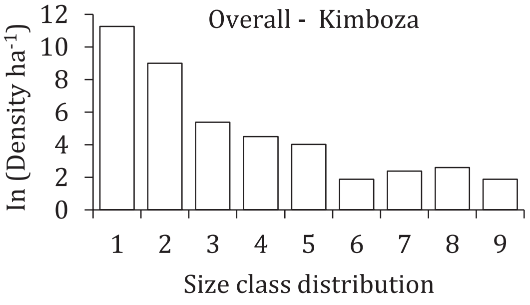

K. anthotheca
In (Density ha -1)
0
2
4
6
8
10
1 2 3 4 5 6 7 8 9
Size class distribution

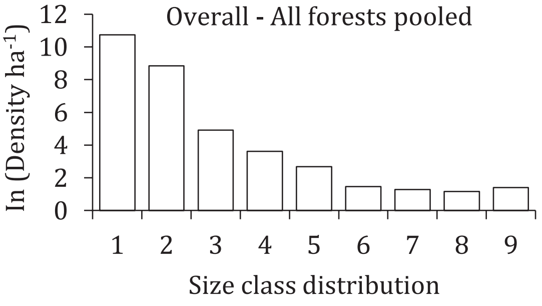

H. pubescens
In (Density ha -1)
0
2
4
6
8
1 2 3 4 5 6 7 8 9
Size class distribution


C. uluguruensis
In (Density ha -1)
0.0
0.2
0.4
0.6
0.8
1.0
1 2 3 4 5 6 7 8 9
Size class distribution


D. melanoxylon
In (Density ha -1)
0
1
2
3
1 2 3 4 5 6 7 8 9
Size class distribution


S. fischeri
In (Density ha -1)
0
2
4
6
8
10
1 2 3 4 5 6 7 8 9
Size class distribution


Overall - Kimboza
In (Density ha-1)
0
2
4
6
8
10
12
1 2 3 4 5 6 7 8 9
Size class distribution


Overall - All forests pooled
In (Density ha-1)
0
2
4
6
8
10
12
1 2 3 4 5 6 7 8 9
Size class distribution

Appendix 2

Questionnaire on Forest Resource utilization

(*Dodoso kuhusu matumizi ya Rasilimali za misitu*)

Respondent Particulars (*Maelezo ya mhojiwa*):

1. For how long have you lived here? (*Umeishi hapa kwa muda gani?*)
   a) Since birth (*tangu kuzaliwa*) ☐ b) last 20 years (*miaka 20 iliyopita*) ☐

   c) Last 5 years (*miaka 5 iliyopita*) ☐ d) Others (specify) *Ingine (Eleza)*......................................

2. Age of respondent (*Umri wa mhojiwa*)
   a) < 20 years (*miaka*) ☐ b) 20-40 ☐ c)41-60 ☐ d) >60 ☐

3. Gender of respondent (*Jinsia ya mhojiwa*)
   a) Male (*Mume*) ☐ b) Female (*Mke*) ☐

4. What is your occupation? (*Shughuli/Kazi ya msailiwa*)
   a) Farmer (*Mkulima*) ☐ b) Carpenter (*Seremala*) ☐ c) Business (*Biashara*) ☐
   d) Employed (*Mwajiriwa*) ☐ e) Other, specify (*Eleza*)..

5. What is another source of income apart from you occupation?
   (*Taja chanzo kingine cha kipato mbali na kazi yako?*)
   ....

Forest resources utilization (*Matumizi ya Rasilimali Misitu*):

6. How often do you go to the forest? (*Ni mara ngapi unakwenda msituni?*)
   ....

7. How do you get access to the forest? (*Ni kwa jinsi gani unaingia msituni?*)
   a) Permission (*Ruhusa*) ☐ b) free (*Bure*) ☐ c) fee (*Ada*) ☐

8. If by fees, How much do you pay?.................... Is that amount manageable by many people living around here?

   (*Kama ni kwa ada, ni kiasi gani unalipa................... na je, kiasi hicho kinaweza kulipwa na watu wengi waishio katika eneo hili?*)

   a) Yes (*Ndiyo*) ☐ b) No (*Hapana*) ☐

   Explain(Elezea)..

   ....

9. What tree species do you use for various purposes in the table below? List three of them in order of priority and the sources. (*Ni aina gani ya miti mnaitumia kwa matumizi tajwa katika jedwali hapo chini? Orodhesha kadiri ya upendeleo na vyanzo*)

No.	**Use (*Matumizi*)**	**Rank**			**Source**
		1	2	3	
1.	Fuels wood (*Kuni*)				
2.	Charcoal(*Mkaa*)				
3.	Timber (*Mbao*)				
4.	Building purposes (*Ujenzi*)				
5.	Medicinal (*Tiba*)				
6.	Domestic utensils (*Vyombo vya nyumbani*)				
7.	Carving wood (*Uchongaji*)				
8.	Fodder (*Chakula cha wanyama*)				
9.	Fencing (*Uzio*)				
10.	Farm implements (*Vifaa vya Kilimo*)				
11.	Others (specify) (*Mengineyo*)				

NB: 1= highly preferred (Inapendelewa sana), 2 = preferred (Inapendelewa) and 3 = less preferred (haipendelewi sana).

10. Do you know how the forest is managed? (*Je, unajua jinsi msitu unavyosimamiwa?*)

    a) Yes (*Ndiyo*) ☐ b) No (*Hapana*) ☐ c) I do not know (*Sijui*) ☐

11. If yes, what management type is applied? (*Kama ndiyo, ni njia gani ya usimamizi inayotumika?*)
    a) Community participation (*Uhifadhi shirikishi*) ☐
    b) Only government (*Serikali tu*) ☐ c) I do not know (*Sijui*) ☐

12. How is local community involved in forest management? (*Ni kwa jinsi gani wananchi wanashirikishwa katika usimamizi wa msitu?*)
    a).. b)..
    c).. ……d)..

13. Do you know some tree species which are prohibited from harvest? (*Je, unafahamu aina ya miti iliyozuiwa kuvunwa?*) a)Yes (*Ndiyo*) ☐ b) No (*Hapana*) ☐
    If yes, mention them (*Kama ndiyo, orodhesha*)..
    …………………………………………………………………………………………….

14. Are there local rules set for management of the forest reserve here? (*Je kuna sheria zilizowekwa na kijiji kuhusu usimamizi wa msitu?*) a)Yes(*Ndiyo*) ☐ b) No (*Hapana*) ☐
    If yes, state them, (*Kama ndiyo, zitaje*)..
    ....
    ....

15. What happens to people who breach the rules? (Ni a*dhabu gani hupewa kwa wanaovunja sheria?*)..

16. What are your opinions towards better management of the forest reserve? (Je, una mawazo gani kuhusiana na uhifadhi bora wa msitu?)...
    ....
    ....
    ....

Appendix 3

Questionnaire on Forest Resources Utilization (for Forest Officer)

(*Dodoso kuhusu Matumizi ya Rasilimali misitu* (*kwa Afisa Misitu*)

a. How do you manage the forest reserves? (*Ni kwa jinsi gani unasimamia msitu wa hifadhi?*)..
………………………………………………………………………………………………........
....

b. Are people allowed to utilize some forest resources?
(*Je, watu wanaruhusiwa kutumia baadhi ya rasilimali za msitu*)
a) Yes ☐ b) No ☐ c) I do not know ☐
If yes, mention which resources or species and how?
....
....
....

c. Are public lands sufficient to supply villagers with forest resources? (*Je, ardhi ya umma inatosheleza kuwapatia wanavijiji rasilimali za misitu?*) a) Yes ☐ b) No ☐
If no, where do they get the forest resources? (*Kama hapana, wapi wanapata rasilimali za misitu?*)………………………………………..
....
....

d. What economically important tree species are more depleted or favoured?
(Ni aina gani ya miti ambayo ni muhimu kiuchumi inavunwa sana?)
....
....
....

e. How many threatened species (according to IUCN) are known to exist in the forest reserves in your district? Mention them, (*Ni aina gani za miti zilizo katika tishio la kutoweka (kwa mujibu wa IUCN) inapatikana katika misitu ya hifadhi iliyo wilayani kwako*).

....

....

f. Are there government initiatives to manage and conserve the threatened species? (*Je, kuna jitihada zozote za serikali katika kusimamia na kuhifadhi aina za miti iliyokatika hatari ya kutoweka?*)

....

....

....

g. What are your general opinions in the management and conservation of the species in the forest reserves in your district? (*Je, una maoni gani kwa ujumla juu ya usimamizi na uhifadhi wa aina za miti katika misitu ya hifadhi?*)

....

....

....

h. What are the main challenges do you encounter in management of the forest reserves in your area? (*Nini changamoto kuu unazokabiliana nazo katika usimamizi wa misitu ya hifadhi katika eneo lako?*) ....

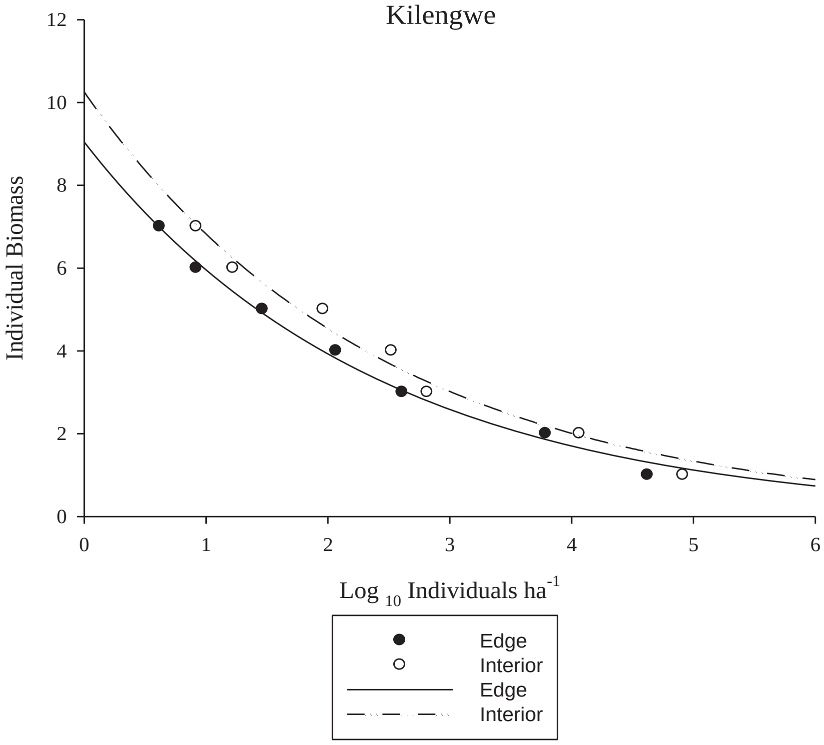
…..

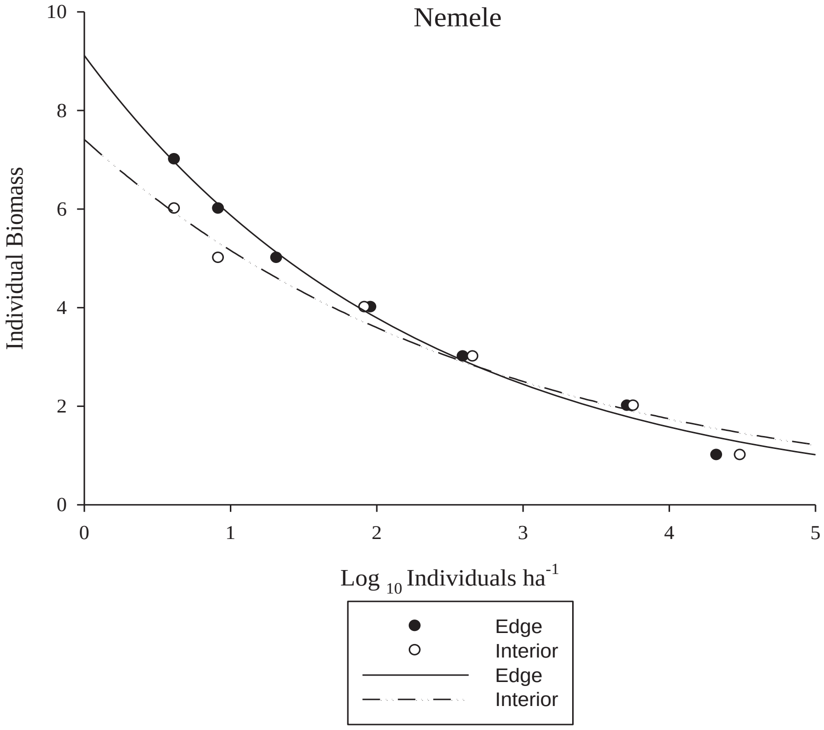
....

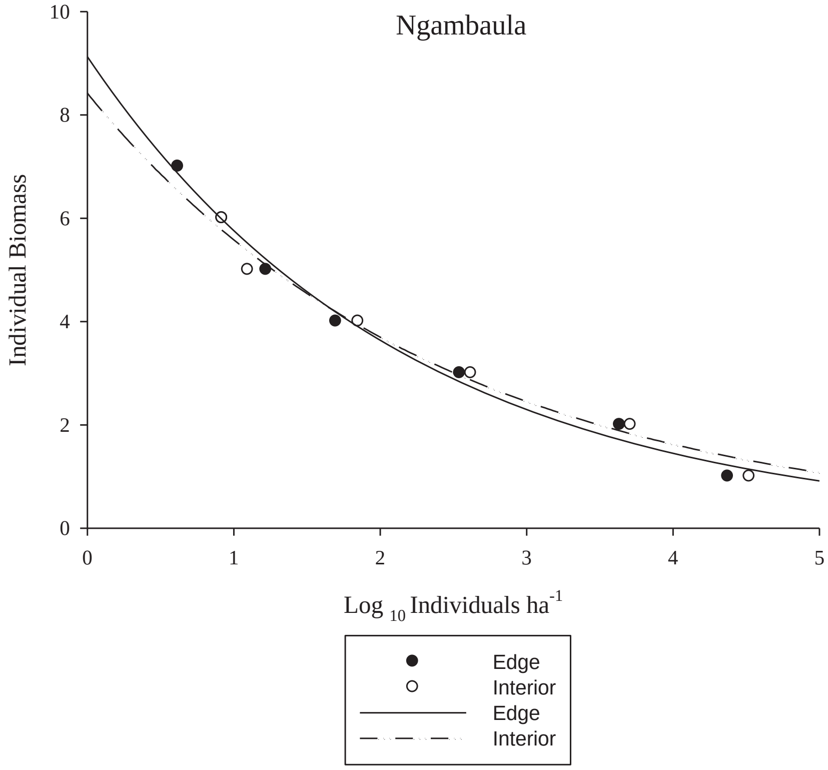
....

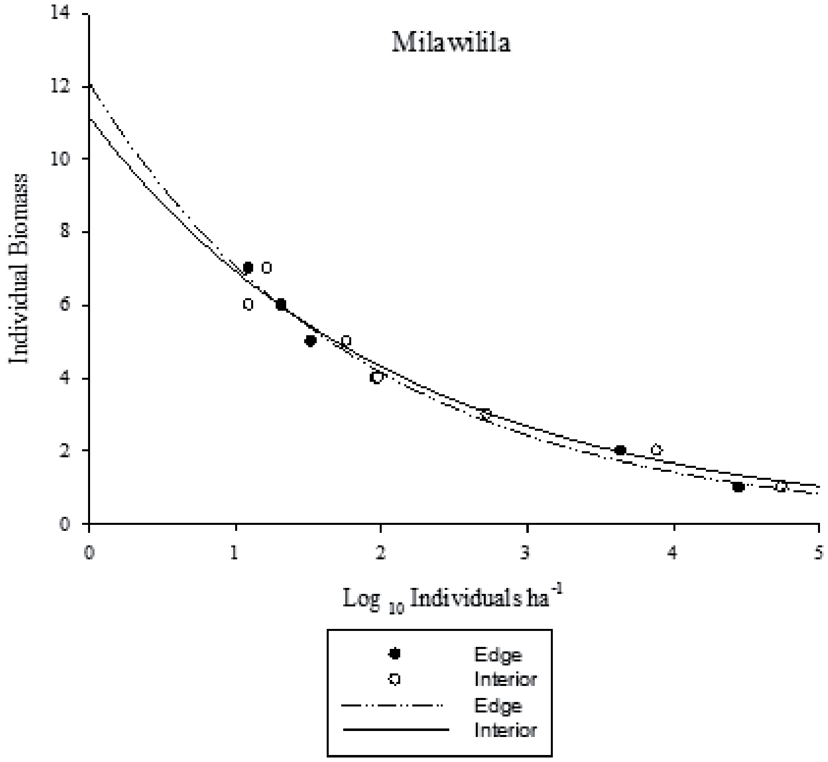
Appendix 4

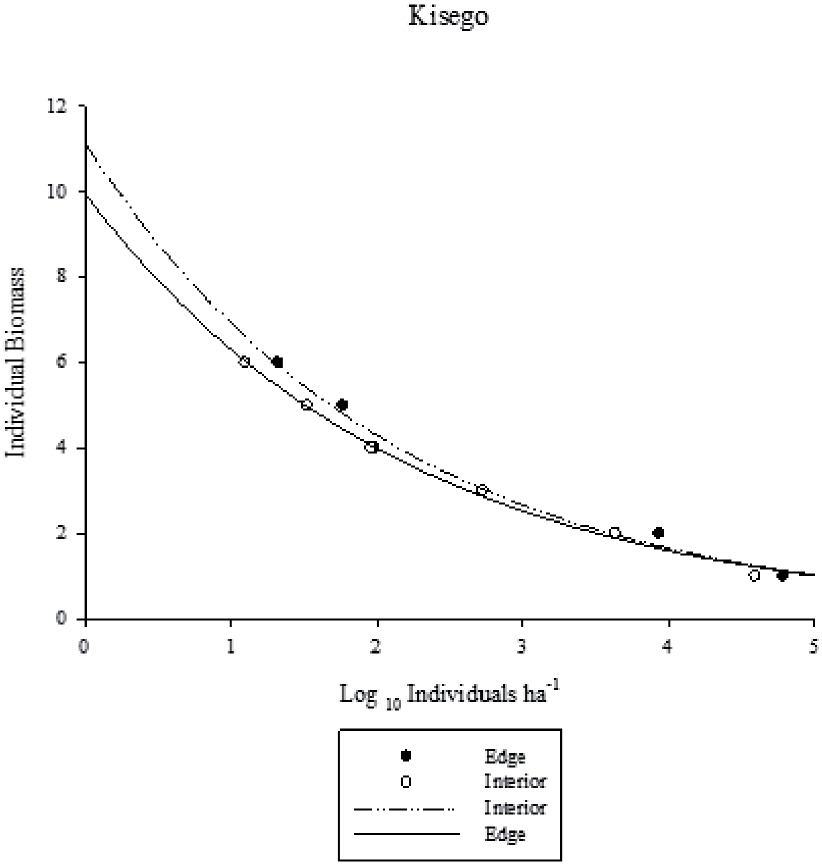
Relationship between number of trees per unit area and individual biomass (1 = seedling, 2 = small sapling, 3 = 3-10 cm DBH, 4 = 10-20 cm, 5 = 20-30 cm, 6 = 30-40 cm and 7 => 40 cm).






Ngambaula
Individual Biomass
10
8
6
4
2
0
0
1
2
3
4
5
Log $_{10}$ Individuals ha^{-1}
● Edge
○ Interior
Edge
Interior


Milawilila
Individual Biomass
14
12
10
8
6
4
2
0
0
1
2
3
4
5
Log $_{10}$ Individuals ha^{-1}
● Edge
○ Interior
Edge
Interior


Kisego
Individual Biomass
12
10
8
6
4
2
0
0
1
2
3
4
5
Log $_{10}$ Individuals ha^{-1}
● Edge
○ Interior
Interior
Edge

Curriculum Vitae

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2001-2004: B.Sc. *(Environmental Sciences and Management)*, Sokoine University of Agriculture, Morogoro, Tanzania.

Professional Experience

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Publication/Abstracts

Kacholi, D.S., Whitbread, A., Worbes, M. 2012. Floristic composition, diversity and structure of Uluguru forests in Morogoro, Tanzania. Abstract in Islands in land- and seascape: the challenges of fragmentation. Conference of the society for tropical ecology Erlangen, February 22-25, 2012.