Plant Communities, Species Diversity, Seedling Bank and Resprouting in Nandi Forests, Kenya

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von Adane Girma Gebreselasse

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Korreferent: Prof. Dr. Wilhelm Barthlott

This work is dedicated

To my father Ato Girma Gebreselass (1937-2004)

My mother Woizero Yeshi Kidanewold

My wife Enat Ashine

My brothers and sisters

and

To all Ethiopian peasants who did not enjoy formal education but toiled hard to send their children to school hoping that their offsprings will be better off.

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Abstract

Nandi forests (South and North Nandi forests) are situated in the Rift Valley Province of Kenya very close to Kakamega forest. From previous documents it has been seen that Kakamega and Nandi forests were connected to each other forming one big 'U' shaped forest block till the beginnings of 1900s. Due to human pressures, currently there are three different forests form the previous one block forest. Although they were one forest, information on Nandi forests is very scanty when it is compared to that of Kakamega forest. The species composition and diversity as well as plant communities and population structure of Nandi forests have not been studied. Information is not available about the similarity status of South and North Nandi forests. Furthermore the natural regeneration potential (seedling bank) of these forests is not well studied and documented. Hence this study aims to fill these gaps.

In this study totally 76 quadrates (49 from South Nandi and 27 from North Nandi) were used to collect data. In the South Nandi forests 27 of the quadrates were laid in the better side of the forest (at Kobujoi) and the remaining 22 were in the heavily disturbed part of this forest (Bonjoge). The quadrates were arranged on transects that have one to one and half km which were parallel to the slope. The distance between the quadrates was 100 meter and transects are 500 m apart. The size of the main quadrate was 400 m^2 (20 X 20 m) which also had five small plots (3 X 3 m) distributed on the four corners and in the center. Each woody plants (climbers, shrubs and trees) having more than one meter and greater than two centimeter diameter at breast height (dbh) were measured and recorded. Seedlings and herbaceous plants were sampled in the smaller plots. Individual plants were identified at species level and when it was not possible to identify in the field voucher specimen were prepared and latter identified at the East African Herbarium, National Museum of Kenya, and Nairobi. Clustering and ordination were performed using PC-ORD and CANOCO ecological softwares, respectively. For both clustering and ordination abundance data of the species was used. Shannon diversity index and evenness were computed using PC-ORD while similarity indices, Fisher alpha, rarefaction, species richness estimation (nonparametric species richness estimators) were conducted using EstimateS. Indicator species analysis was undertaken using PC-ORD. Basal area and height class distribution at forests level or site level (Bonjoge and Kobujoi) and diameter (dbh) class distribution for selected trees species were performed to evaluate population structure. Furthermore importance value (IV) of woody plant species was calculated. SPSS version 16 was used to undertake both parametric (when data assume normal distribution) and nonparametric

(when data are not assuming normal distribution) comparison of means, correlation and regression analysis.

In this study totally 321 vascular plant species comprising 92 families and 243 genera were identified in Nandi forests (both South and North Nandi forests). In South Nandi forest 253 plant species form 82 families and 201 genera were recorded while in North Nandi 181 species comprising 67 families and 155 genera were recorded. Jackknife second order estimators gave the highest species richness estimate for both South and North Nandi forests i.e. 284 and 209, respectively. In the case of highly disturbed and less disturbed parts of South Nandi forest 138 and 172 vascular plant species were recorded, respectively. Asteraceae, Rubiaceae and Euphorbiaceae are the top three species rich families of Nandi forests. In terms of different diversity measures (i.e. alpha and beta diversity, Fisher alpha, Shannon diversity and evenness indices) South Nandi is more diverse than North Nandi forest. Sørensen and Jaccard (classic) as well as their respective abundance based similarities showed that there is a low species similarity between South and Nandi forests. The cluster analysis resulted in three different plant communities and this result is supported by the ordination result.

South and North Nandi forest has inverted 'J' height class distribution showing that larger proportion of woody plant individuals are found in the lower height classes. Similar pattern is observed when the diameters of all woody plants were considered together. However, different diameter class distributions (seven types) were identified when selected tree species were analyzed separately. It has been observed that the basal area of South Nandi forest is significantly lower than that of North Nandi forest (Mann-Whitney U =358, $p < 0.001$). Similarly Bonjoge has significantly lower basal area (t-value=3.77, $p<0.01$) than that of Kobujoi.

Number of woody plat seedlings in South Nandi forest is significantly higher than that of North Nandi (Mann-Whitney U = 362.5, $p<0.001$). In the same way Bonjoge has significantly smaller number of ssedlings than Kobujoi (t-value 4.24, $p<0.001$). Most of species in both forests are able to resprout from stumps after physical damage; hence this helps the regeneration of the forests in addition to seedling banks. This study enables to fill some of the information gaps about Nandi forests especially of floristic composition, population structure, natural regeneration and human impacts on this ecosystem.

1. General Introduction

1.1 Tropical Rain Forest

Tropischer Regenwald was the first term used by a German naturalist, A. F. W. Schimper to describe tropical rain forest (Richards, 1996; Whitemore, 1998), however, it is also described as ever green forest in other scientific literature (Richards, 1996). In terms of structure and species diversity, tropical rain forests are Earth's most complex ecosystems. However, tropical rain forest species appear to have a highly patchy spatial distribution and often have restricted ranges and the ecology of the majority of tropical forest species is poorly known (Sayer *et al*, 1995). Tropical rainforests are composed of evergreen broadleaved trees which flourish in high temperature and humidity of the low altitudes between 10° north and 10° south of the equator (Park, 1992). It has been well reported that tropical rainforests of the world have rich and varied plant and animal species diversity, and provide habitat for half or more of the world's known terrestrial plant and animal species (Wilson, 1988; Osborne, 2000; MEA, 2005a), making them the world's most diverse ecosystems. Since tropical rainforests are having the highest tree diversity of our planet (Gentry and Dodson, 1987; Richards, 1996; Clark *et al*. 1999), they hold almost 50% of the terrestrial carbon pool (Gorte and Sheikh, 2010; Köhler *et al*. 2003). But, this important ecosystem occupies only about seven per cent of the total land area (Whitemore, 1998) of our planet. As cited by Richards (1996), Schimper defined tropical rain forest as evergreen, hygrophilous in character, at least 30 meter high, but usually much taller, rich in thick-stemmed lianas and in woody as well as herbaceous epiphytes.

Geographically, tropical rain forests are currently found in Central and South America, Southeast Asia, and Central and Western Africa (Richards, 1996; Whitemore, 1998). The Latin America or neotropical rain forests are the most extensive, covering four million km^2 area which is about 48.2 % of the world total. The second largest block of tropical rain forest occurs in Southeast Asia covering about 2.5 million km^2 (Whitmore, 1998).

It is reported that African tropical rain forest is less extensive than both of the Latin America and Southeast Asia (Richards, 1996; Whitemore, 1998) contributing about 21.7% of world total, covering an estimated area of 1.8 million km^2 (Whitemore, 1998). The Congo basin contains the large mass of rain forest in Africa from where it continues westwards into Gabon and Cameroon (Richards, 1996). From there a narrow belt follows the coast of the Gulf of Guinea through Nigeria to Ghana and beyond, finally ending in Guinea at about 10°N. This western extension of the rainforest is interrupted from western Nigeria to a little west of the Volta River in Ghana by a stretch mainly of savanna about 300 km wide, the Dahomey Gap, where savannas reach the sea and divide the forest into an eastern and a western block. South of Zaire (Democratic Republic of Congo) the African rain forest extends into Angola to about 9°S. In East Africa the area of continuous forest reaches its eastern limit at Bwamba in western Uganda (about 30°E). East of the Western Rift Valley, forest similar to tropical rain forest is absent except for outliers of various sizes, e.g. Budongo Forest and fragments near Lake Victoria in Uganda, a relic near Kakamega in western Kenya and some small areas in northwestern Tanzania. There are also tiny patches of tropical rain forest on the east coast of Madagascar and in the Mascarenes (White, 1998); outside the Congo core, the African rain forests have been extensively destroyed.

The total African forest coverage is estimated to be 635,412,000 ha which is equivalent to 21 % of total land area of Africa and accounts for 16% of global forest cover (FAO, 2006). Among all African ecosystems, its tropical rain forest is the most species-riche ecosystem housing more than half of Africa's biota (Sayer *et al*. 1992). It has been estimated that over 8000 plant species, some 80 % of which are endemic (White, 1983) are found in tropical rain forest of Africa.

In addition to their provision of row materials for plant improvement programs and modern pharmaceutical industries, tropical forest play important role in regulating local and global climate (Yeshitela, 2008). Tropical forests sequestrate large amount (half of) terrestrial carbon dioxide (Gorte and Sheikh, 2010; Köhler *et al*. 2003) and maintain atmospheric humidity (Lalfakawma, 2010). Environmentally, they are crucial in reducing soil erosion, maintaining soil moisture and regulating stream flow as well as budgeting heat of the area and provide shalter to diverse varity of flora and fauna (Lalfakawma, 2010). Millions of people who are living in or around tropical forests (Naughton-Treves and Weber, 2001) depend on the forests for many forest products and environmental services. Tropical forests are the main source of energy in the form of fuel wood; they provide timber and non-timber forest products; they are sources of food, particularly in times of drought and famine; and they are sources of traditional medicines. Hence, these tropical ecosystems are very important socially, economicaly and environmentaly for the wellbeing of mankind. Therefore, it is very crucial to understand the componts, the function and the ecological processes of tropical rainfores to understand how to maintain, protect and develop these ecosystems.

1.2 Biodiversity

Biodiversity is a short form for biological diversity which is to describe the total number, variety and variability of living organisms as well as the diversity of the ecosystem they are living in (Krebs, 1999; CBD, 2009). Nevertheless, it is still defined differently by different authors, and currently there are many definitions (DeLong, 1996; Müller, 2002; Hamilton, 2005) and most of them are vague (DeLong, 1996; Sarkar, 2002; Hamilton, 2005), which probably reflects the uncertainty of the concept (Hamilton, 2005). Adams (1994) characterized biodiversity as being a widely used term having no unified definition. Although there have been many different interpretations of diversity (MacArthur and Wilson, 1967; Whittaker, 1975), the concept of biodiversity is considered to be the integration of biological variability across all scales, from genetic level, through species and ecosystems, to the landscapes that they form, or are part of, and the ecological processes that support them (Walker, 1992; Purvis and Hector, 2000). The definitions of biodiversity are ‘‘as diverse as the biological resource’’ (Knopf, 1992). Some consider it to be synonymous with species richness (Marc and Canard, 1997; Heywood, 1998), still others see it as species diversity (Bond and Chase, 2002) where as many others suggest a much broader definition such as the full variety of life on earth (Takacs, 1996). In terms of scope its definitions ranges from "the number of different species occurring in some location ..." (Schwarz *et al*. 1976) to "... all of the diversity and variability in nature" (Spellerberg and Hardes, 1992) and "... the variety of life and its processes” (Noss and Cooperrider, 1994). According to Noss and Cooperrider, (1994) biodiversity includes the variety of living organisms, the genetic differences among them, the communities and ecosystems in which they occur, and the ecological and evolutionary processes that keep them functioning, yet ever changing and adapting. Kumaraswamy and Udayakumar (2011) explained that the world’s biodiversity includes all living organisms (animals, plants, fungi, and microbial groups inclusive of genetic diversity and ecosystem/landscape diversity) in their interactive state contributing to multitude of services of relevance to sustain the ecological integrity for the benefit of the humankind.

DeLong (1996) reviewed 85 different definitions of biodiversity. An important and widely used definition is that included within the Convention on Biological Diversity (CBD). This treaty is a document which was signed by over 150 nations at the United Nations Conference on Environment and Development, held in Rio de Janeiro, Brazil, in 1992. It defines biodiversity as “the variability among living organisms from all sources including, inter alia [among other things], terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems".

Biodiversity has recently emerged as an issue of both scientific and political concern primarily because of an increase in extinction rates caused by human activities (Ehrlich and Wilson 1991). Loss of biodiversity has been recognized as one of the main threats to the world's forests, and there is a general growing concern for developing new global, regional and national programs for conserving and managing forest biodiversity (Köhl *et al*, 1998). Köhl and his co-workers explained biodiversity as an irreplaceable value in itself since the diversity of the biosphere creates a genetic bank, crucial for functioning of ecosystems and to the recovery of ecosystems after disturbance and temporal changes in ecosystem functions as well as in environmental factors. Hence, apart from the immense economic, ethical and aesthetical benefits, biodiversity is essential for the ecosystem function and stability (Ehrlich and Wilson, 1991; Holdgate, 1996; Tilman, 2000).

1.2.1 Species diversity

Species are the fundamental units of biological organization, and any small changes in the species diversity may alter to some extent ecosystem functions and services (You *et al.*, 2009). Species diversity, species richness and biodiversity are widely used terms (sometimes interchangeably) in ecology and natural resource management. Species diversity is fundamentally multidimensional concept that includes species richness, abundance and evenness (Fisher *et al.*, 1943; Simpson, 1949; Purvis and Hector, 2000). It is an appropriate term for ecologists who are interested in understanding the mechanisms and effects of certain ecological phenomena, such as pollution, environmental disturbances, etc (Sanjit and Bhatt, 2005). It is also the most commonly used representation of ecological diversity, but it is not the only measure. Niche width and habitat diversity are also key components of ecological diversity (Hamilton, 2005). When considering the basic structure of biological systems such as communities or ecosystems, two fundamental parameters are the number of species and the number of individuals within each of these species (Hamilton, 2005). Ecologists have studied the inter-relationships between them (number of individuals within species and number of species) in considerable depth over many decades (e.g. Fisher *et al*, 1943; MacArthur, 1957; Hurlbert, 1971; May, 1975; Sugihara, 1980), and in doing so have primarily been concerned with what they call species diversity (Hamilton, 2005). Even if the concepts of species diversity and species richness have become key in conservation biology, there is lack of clear distinction between these two different concepts (Hamilton, 2005) hence in most cases they are used interchangebly.

Species diversity is a function of the number of species present (species richness or number of species) and the evenness with which the individuals are distributed among these species (species evenness, species equitability, or abundance of each species) (Margalef 1958; Lloyd and Ghelardi 1964; Pielou 1966; Spellerberg 1991). According to Hamilton (2005) this definition is may be the best one available at the moment. Hurlbert (1971) emphasized that the concept of species diversity concept should be restricted to this extent if it should have any useful meaning.

Ecologists have found species diversity difficult to define and measure, and this may in fact reflect the possibility that it is a ‘non-concept’ (Hurlbert, 1971). In general, there have been two approaches to measuring species diversity, both of which incorporate information on the number of species (species richness) and the relative abundances of individuals within each species (species abundance) (Hamilton, 2005). One method has been to construct mathematical indices broadly known as diversity indices and the other involves comparing observed patterns of species abundance to theoretical species abundance models. Species diversity indices take two aspects of a community into account, namely species richness and evenness or equitability (the distribution of abundance among the species) (Hamilton, 2005). In this study Shannon diversity index is computed to evaluate the species diversity of the study sites.

1.2.2 Species richness

In biological diversity, the concept of species richness is one of the oldest and most fundamental concepts (Peet, 1974); however it was first first coined by McIntosh (1967). Species richness can refer to the number of species present in a given area or in a given sample, without considering the number of individuals examined in each species (Hamilton, 2005). Species richness can be numerical (simply “species richness”; Hurlbert 1971) or be related to species density in an area (i.e. the number of species present in a given area) (Simpson 1964). Species richness is the simplest way to describe community and regional diversity (Magurran, 1988), and this variable i.e. number of species (species richness), forms the basis of many ecological models of community structure (MacArthur and Wilson, 1967; Connel, 1978; Stevens, 1989).

Quantifying species richness is important, not only for basic comparisons among sites, but also for addressing the saturation of local communities colonized from regional source pool (Cornnel, 1999). Maximizing species richness is often an explicit or implicit goal of conservation studies (May, 1988), and current and background rates of species extinction are calibrated against the patterns of species richness (Simberloff, 1986).

Generally, species diversity and species richness are related but different concepts. Sometimes ecologists use them interchangabily, however, species richness is not exactly the same as species diversity. But it is one of the components which describe species diversity of a given area.

Biodiversty measures (i.e. species diversity and species richness) have been widely used as indicators of ecosystem status, and play a critical role in studies dealing with the assessment of human impact on ecological sytems (Leitner and Turner, 2001). However, since the biodiversity of any ecosystem is far too complex to be comprehensively quantified, suitable indicsators (Duelli and Obrist, 2003) or surrogates (Sarkar, 2002) of biodiversity are needed. Conceptually, species richness appears as the most intuitive and straightforward parameter to measure biodiversity (Gotelli and Colwell, 2001). Nonetheles, for several reasons, to determine the true species richness of a community is not an easy task (Magurran, 2004). Hence, in this study different non-parameteric species richness estimators are used to estimate the true number of species found in Nandi forests based on the number of species observed in the study quadrates (samples).

1.3 Deforestation and Fragmentation of Tropical Forests

1.3.1 Deforestation

The clearing of tropical rain forests or other types of forest ecosystems across the earth has been occurring on a large scale basis for many centuries. This process, which is known as deforestation, involves the cutting down, burning, and damaging of forests. According to FAO (2006), the definition of deforestation refers to a change of land cover with depletion of tree crown cover to less than 10 percent. The depletion of tree crown could be resulted from land uses chage to agriculture, over grazing, new settlements, and infrastructure. One of the environmental challenges, that our world facing today is deforestation in the tropics. Tropical forests are being destroyed and fragmented at an ever-increasing rate with serious environmental and biological consequences including loss of biodiversity (Whitmore and Sayer 1992, Turner,

1996) and climate change at local, regional and global levels (Myers 1988). Laurance and Bierregaard (1997) explained that deforestation which is result of an increasing human population and a rush towards industrialisation of the developing countries resulted in a loss of much of the world's tropical rain forests. This activity in return resulted in the loss of biodiversity of our planet (Pimm and Raven, 2000). Biotic factors are rarely causes of species extinction, but habitat destruction, over exploitation and the impact of exotic species, which are all manmade problems, are the major causes of modern species extinction (Frankel and Soule, 1981).

FAO (2006) estimated that in the 1990s tropical countries have lost 111,350 km^2 of forests annually and 114,270 km^2 of tropical forests were lost between 2000 and 2005. Most of the forests of Africa have long been affected by human activities. African rainforests especially which are found outside the Congo core have been extensively destroyed (Whitmore, 1998). FAO (2003) reported that between 1990 and 2000 annually about 53,000 km^2 of forestland was deforested in Africa but this rate was reduced to 40,400 km^2 for 2000-2005 (FAO, 2006). In East Africa the forest resources are steadily disappearing and those that are left are being degraded. Kenya is one of the east African countries that has high deforestation rate. Between 1990 and 2000 the forest cover of Kenya was reduced from 180,270 km^2 to 170,960 km^2 (FAO, 2001).

Deforestation still continues at a very alarming rate around the world (Whitemore, 1997). This degradation of forest can result in fragmentation of forests and later the disappearance of that particular forest. Due to such kind of forest degradation and fragmentation a forest that was one block in early 1900s, resulted into three different forests i.e. Kakamega, South Nandi and North Nandi (Schaab *et al*, 2010). The factors responsible for this huge loss of world's forest are combination of agricultural expansion, commercial harvest (logging), free livestock grazing, unsustainable firewood collection and charcoal making, and inappropriate land and tree tenure regimes (GEO-2000, 1999; MEA, 2005b; Alemayehu, 2007). This high rate of deforestation will result in loss of species, habitat and resource which is a threat of forest health (Battles and Fahey, 2000). Yet forestry has immense potential to alter landscapes, and biodiversity conservation within forested landscapes has become a priority (Boutin and Herbert, 2002).

1.3.2 Fragmentation

Serious forest disturbance leads to deforestation, forest fragmentation and degradation, and subsequent exotic species invasion, all of which adversely affect plant diversity (Raghubanshi and Tripath, 2009). Habitat fragmentation or subdivision is defined as a process in which a wide area of habitat for example, natural forest is changed into a number of smaller patches of smaller total area, isolated from each other by a matrix of different land uses distinct from the previous land use type (Wilcove *et al.*, 1986; Andrén 1994; Fahrig 2003; Lindenmyer and Fischer, 2006). Habitat fragmentation could be caused either by natural disturbance (e.g. fire, wind throw) or due to anthropogenic disturbance (human caused) which includes clearing of forest for agriculture, settlements, road and dam construction, and logging (Attiwill 1994, Wade *et al*. 2006). However, fragmentation due to anthropogenic disturbance is more serious than that caused by natural disturbance (Laurance and Bierregaard, 1997) especially from species extinction point of view (Frankel and Soule, 1981; Pimm and Raven, 2000). The rapidly growing world population increased human activity which exacerbets deforestation and fragmentation, threatening many of our plants species (Pimentel *et al*., 1997) and humanity is rapidly destroying habitats that are most species-rich (Pimm and Raven, 2000), by doing so human activities have dramatically accelerated the global rate of species extinction.

Fahrig (2003) distinguished four different effects of habitat fragmentation on habitat pattern. These include; (a) reduction in habitat amount, (b) increase in number of habitat patches, (c) decrease in sizes of habitat patches, and (d) increase in isolation of patches. As explained by van den Berg and co-workrs (2001) fragmentation is more than habitat removal since it causes not only habitat loss but also changes the properties of the remaining habitat. It changes the physical environment and biogeographic entities (Saunders *et al.,* 1991). Hence, habitat connectivity is is considered to be very important to dispersal success, persistence, and genetic diversity of species in fragmented landscapes (Schooley and Branch, 2011).

In most cases fragmentation is strongly associated to human induced disturbances and it influences plant community structure and maintenance of biological diversity (Connell, 1978; Huston, 1979; Petraitis *et al*., 1989; Soule *et al*., 1992; Norton *et al*., 1995; Yates *et al*., 2000). In this regard, loss and fragmentation of natural habitat are considered as major threats to global biodiversity (Lovett and Wasser, 1993; Laurance and Bierregaard, 1997; Pimm and Raven, 2000).

The current extinction rate of species ranges from approximately 1000 to 10,000 times higher than natural extinction rates (Kellert and Wilson, 1993), and if this trend continues, as many as two million species of plants and animals will be exterminated worldwide by the middle of the next century (Pimm and Askins, 1995). Since biodiversity is essential for the sustainable functioning of agriculture, forest, and natural ecosystems on which human depend (Raven and Johnson, 1992; Myers, 1994; Wilson, 1994; Pimentel *et al.*, 1997), this forecast is alarming. Biotic factors are rarely causes of species extinction, but habitat destruction, over exploitation and the impact of exotic species, which are all manmade problems, are the major causes of modern species extinction (Frankel and Soule, 1981). The effect of fragmentation is more severe in tropical forests where diversity is high and forests are being removed and fragmented at an alarming rate (Pineda and Halffter, 2004).

Forest fragmentation has impact on biodiversity (Turner, 1996), increasing isolation of habitats, endangering species of plants, mammals and birds (Skole and Tucker, 1993; Scariot, 1999; Laurance *et al.* 2000) and on a variety of population and community dynamic processes (Saunders *et al.*, 1991; Valladares *et al.* 2006). However, the effects of habitat fragmentation on species diversity vary among different habitats and taxa. These effects could be both positive and negative (Fahrig, 2003). Positive effects include the creation of edge habitat increasing the abundances of edge or gap species (Yahner, 1988; Malcom 1994) and negative impacts include increasing the local rate of extinction by reducing population sizes (Leach and Givnish, 1996) through reducing habitat size and/or making patches of habitat (Fahring, 2003), creating forest edges and altering microclimate at forest edges (Matlack, 1993), changing forest dynamics (Wade *et al.*, 2006), and increasing predation at forest edges (Chalfoun *et al.*, 2002). As a result fragmentation has been described as one of threats to global biological diversity (Hill and Curran, 2005).

These impacts of fragmentation on biodiversity may be resulted from one or a combination of four separate effects: forest fragmentation *per se*, the loss of habitat during fragmentation, habitat degradation following the isolation of fragments, and the effect of isolation *per se* (Harrison and Bruna, 1999). Some reports (Fahrig, 1997; Caley *et al.*, 2001; Fahrig, 2003) argue to separate habitat loss from habitat fragmentation *per se* and claim that species loss and decline in species abundance following fragmentation is associated with habitat loss than with fragmentation *per se* (Caley *et al.*, 2001).

Actually, the effect of fragmentation can differ strongly among different species (Lindenmyer and Fischer, 2006). Some species have naturally a patchy distribution. For instance, plants and animals that are largely confined to rocky outcrops (Hopper, 2000; Schilthuizen *et al*., 2005) or those that live on mountain tops (Mansergh and Scotts, 1989) and in freshwater ponds (Sjorgen-Gulve, 1994) might not be affected by fragmentation. However, many other species which have more continuous natural distribution are negatively affected by habitat fragmentation (Lindenmyer and Fischer, 2006). In this study we investigate species similarity between South and North Nandi forest which were connected till the beginning of 20th century.

1.4 Natural regeneration

Regeneration of woody plants refers to the recruitment, survival and growth of seedlings and/or sprouts these plants in a given area (Lalfakawma, 2010). When the source of this process is occurring in nature from seeds or other vegetative propagules, the regeneration is known as natural regeneration. Harmer (2001) defined ‘Natural Regeneration’ as the establishment of trees from seeds that fall and germinate *in situ*. Seedlings represent the final stage in the process of regeneration from seed (Kitajima and Fenner, 2000). However, plants regenerate not only from seeds. Woody plants can also regenerate from vegetative part too, i.e. stumps (stools) (Evans, 1992) or rootstocks (Whitmore, 1982). In freshly cleared rain forest, the primary forest species are merely present as sprouts (coppice), contrary to secondary species and weeds which commonly develop from seed (Riswan, 1979; Uhl *et al*., 1982). This vegetative regeneration makes rain forest trees and lianas not solely dependent upon seed for their reappearance after destruction of the pre-existing vegetation (Rouw, 1993).

Generally, regeneration involves both the physiological and developmental (autecological) mechanisms inherent in plant biology as well as external ecological factors, including interactions with other biota, climate and disturbances (Price *et al*, 2001). Thus, success of woody plant regeneration in a forest is determined by successful completion of several events in the plant life cycle such as coppicing (sprouting) ability (Garwood, 1989; Evans, 1992; Bellingham and Sparrow, 2000), seed production, dispersal to safe sites, germination and seedling emergence, seedling establishment and onward growth (Barik *et al*, 1996). However, all these events can be affected negatively or positively by ecological factors. Therefore, understanding the patterns of regeneration enables to undertake proper forest management plan and this management plan in return helps to utilize a given forest ecosystem wisely and sustainably.

1.4.1 Factors affecting seedling regeneration

There are different ecological factors that affect regeneration potential of a given forest in general and a species in particular. For instance, disturbances such as gap formation, herbivory, landslides and logging affect the abundance and composition of the seedlings in the forest understorey (Benitez-Malvido, 1998) and therefore, play an important role in tree regeneration processes. In many ecosystems, either increasing or decreasing disturbance, changes overall community structure (Shafroth *et al*, 2002). Disturbances, whether natural or man-made have much influence on community composition, tree population structure and regeneration ability of forest ecosystems (Lalfakawma, 2010).

Seedling establishment: It is an ecological process that encompasses seed germination and emergence of seedling (Alemayehu, 2007). Seedling recruitment is a critical bottleneck in the population dynamics of many plant species (Horvitz and Schemske, 1994; Wenny, 2000). The successful seedling regeneration is determined by the presence of sufficient number of seedlings, saplings and young trees in a given population. However, this process is affected by the availability of seed for germination and favorable site condition (safe site).

Seedling establishment is mainly affected by the avilabily of seed (both in quality and quantity) as well as favorable environmental conditions (‘safe site’). Since seed limitation is strong for many plant species (Flinn and Vellend, 2005; Svenning and Wright, 2005), this factor mainly affects the number of seedlings to establish. Seeds are availabile for germination from seed rain (Bonvissuto and Busso, 2007; Du *et al*., 2007; Carrier *et al*, 2007) (current seed production), soil seed bank (Demel, 2005; Alemayehu, 2007) and seed desperised from outside (Bonvissuto and Busso, 2007; Carrier *et al*, 2007; Du *et al*., 2007). Seed rain is a function of seed production which is affected by several factors like resources availability, pollination failure, predation on flowers, fruits and leaves, climatic conditions, age and size of the plant and its genetic constitution (Winn and Warener, 1987). Reduced seed rain may also be attributed to fragmentation due to changes in tree phenology as a result of increased mortality of reproductive individuals and/or genetic drift that might lead to a reduction of flowering (Alemayehu, 2007). Even if there is enough quality seed, unless it is coulpled with appropriate dispersal mechanism (agent) still there could be shortage for seedling establishment. The availability of viable seed in the soil seed bank is highly dependant on the species at hand. Some species lose their viability immediately and others may persit to have their viability for longer periode (Demel, 2005). Seed predators are also other factors that affect the availability of seed either by reducing or eliminating seeds to germinat (Schupp, 1988; Demel 1996, 1997; Demel and Granström, 1995).

In addition to the availability of seed, existence of favorable environmental condition (‘safe site’) play an important role for succeful seedling establishment. The regeneration of plant communities from seed depends on seeds being in right physiological state to right place at the right time (Murdoch and Ellis, 2000). Unless seeds get the optimum environmental condition i.e. moisture, light and temperature, they will not germinate. When these environmental factors are not met seeds stay dormant and wait for favorable condition to come (Demel, 2005). The germination and dormancy mechanisms are of great adaptive importance to plants in ensuring that seedling emergence occurs at the most advantageous time and place (Bewley and Black 1994; Fenner 1985). In fact, there are species that lose their longevity in short period of time after they are released from the mother plants. Since each species has its own characteristic requirement, a site, which may be safe for one species, may not be safe for another. Even if several species share much the same life form, phenology and habitat range, they might have different seedling requirements (Grubb, 1977). The heterogeneity in edaphic, biotic and abiotic factors in an ecosystem can therefore play a vital role in both species as well as genetic diversity (Ramakrishnan, 1992) through their impact on seed germination. Due to this heterogeneity, the same site may not be safe or favourable for other species or individual of the same species. For instance, tree species exhibited great differences in emergence in response to the different layer of litter (Vazquez-Yanes, and Orozco- Segovia, 1992; Kostel-Hughes *et al*., 2005). Thick litter may affect the availability and/or quality of light that can enhance germination (photoblastic germination) in some palnt species. Photoblastic germination may act to initiate germination when a seed is close to the soil surface in a litter-free microsite (Pearson *et al*, 2002). Litter and soil decrease the quantity and the red/far red ratio of irradiance (Tester and Morris, 1987; Va´zquez-Yanes *et al*., 1990) and are barriers to the establishment of especially small-seeded species (Molofsky and Augspurger, 1992; Vazquez-Yanes and Orozco-Segovia, 1992; Metcalfe and Grubb, 1997; Kostel-Hughes, 2005). Thick forest litter layer decreases germination and seedling emergence through shading, biochemical effects and physical obstruction to the emergence of a seed’s cotyledons and radical (Alemayehu, 2007). Physical obstruction may either prevent seedling emergence or force seedlings to allocate more stored energy to hypocotyl growth in order to penetrate the litter layer, leaving less energy for allocation to the radicle and cotyledons. Even though litter cover may have both negative and positive effects, review made on published studies showed that the overall effects of litter are negative on both seed germination and seedling establishment (Kitajima and Fenner,2000; Ellsworth *et al.*, 2004).

Seedling growth: after the seed germinated, it needs to grow and pass the environmental (biotic and abiotic) challenges to rich sapling as well as tree stage. Like that of seed germination the environmental factors should favour the seedling development and growth. If the site is not well endowed with the optimum level of moisture and light it is difficult for the seedling to survive. The species requirements are also differe. For instance, seedlings of poineer species need more light than that of climax (shade loving) species. Demel (2005) reported that seedling of some species e.g. *Ekebergia capensis* and *Podocarpus falcatus* survived better under shade while that of *Junipers procera* and *Bersama abyssinica* did not show any difference. In addition, to light requirement, seedlings face physical damages and destruction due to trampling and grazing (Demel, 2005; Alemayehu, 2007), competition by weeds and herbs, which deprives the young seedlings of light and soil resources and raises seedling mortality (Kitajima and Fenner, 2000), and diseases and pests could be another factor increasing mortality. Therefore, in this study the effect of disturbance and type of disturbance (charcoal burning or tree cutting and graizing) on seedling bank of Nandi forests is investigated.

1.4.2 Factors affecting regeneration from stump

As new individuals start from seeds through seedling, there is also other possibility of regeneration mechanism from vegetative parts after experiencing physical damege. This process is known as resprouting or coppicing. Resprouting is usually used to refer to vegetative growth of rooted plants after loss of biomass (Bellingham and Sparrow, 2000). It is an important life history characteristic of woody species in moist tropical forests, and those subjected to serious disturbances such as fire and logging (Bellingham *et al*., 1995; Guariguata, 1998; Kammesheidt, 1999; Bond and Midgley 2001). Coppice or resprout management has its own contribution to maintain and conserve woodland flora and fauna (Evans, 1992). Therefore, knowledge about the responses' of plants to disturbance is very important to understand and manage a given vegetation as well as for understanding long-term vegetation dynamics, extinction risks and carbon balance (Vesk *et al*, 2004; Clarke *et al*., 2010).

Nonetheless, species differ in their sprouting ability, and thus both strong and weakly sprouting species occur in diverse ecosystems (Bond and Van Wilgen, 1996; Everham and Brokaw, 1996). Some species never sprout; in some species, sprouting ability increases with size to reach a maximum in adult stages, although in other species sprouting is common in juveniles but adults are unable to sprout (Bond and Midgley, 2001). Most broadleaved tree species have the ability to coppice (resprout), but most confers do not have this ability with the main exceptions of *Araucaria araucana* and *Sequoia sempervirens* (Evans, 1992) and some species of *Pinus* in the north and *Podocarpus* in the southern hemisphere (Everham and Brokaw, 1996). A few broadleaved species also do not coppice vigorously or only have the capacity to do so when the stump is fairly small; *Alnus cordata*, *Fagus sylvatica*, *Betula* spp., *Prunus avium* and some *Populus* species are such examples (Evans, 1992).

Sprouting ability of a species differ amonge life history stages and disturbance severity (Bond and Midgley, 2001), for inctance, frequent low intensity of disturbance favors sprouters and juvenile but adult individuals sprouting capacity is often not the same. Forest trees show similar diversity in sprouting behavior with many species sprouting as juveniles and losing the ability to sprout as adults (Everham and Brokaw, 1996; Bellingham and Sparrow, 2000). Starch accumulation in the root could also affect sprouting ability, as it was observed that sprouters have higher root starch concentration than non sprouters (Pate *et al*., 1990; Bowen, and Pate, 1993; Canadell and Lopez-Soria, 1998; Bell and Ojeda, 1999). In this study stumps of all species of woody plants with different size (both diameter and height of stumps) were investigated for resprouting ability.

1.5. Objective of the study

Generally, information about Nandi forests is very scanty. Among others, the floristic compositions, plant community types, natural regeneration potential of the forests as well as population structure are not well studied and documented. In addition, the effect of human activity on floristic composition, regeneration potential and forest structure of the Nandi forests are not well studied. Hence, the main purpose of this research work is to contribute filling these gaps. The following are the specific objectives:

- To describe the floristic composition and plant community types of Nandi forests
- To study the species diversity of Nandi forests along disturbance gradient

- To study the species similarities between South and North Nandi forests
- To study the population structure of South and North Nandi forests
- To estimate the total number of vascular plant species of Nandi forests
- To assess the natural regeneration potential (both seedling banks and coppicing) of Nandi forests
- To investigate the effect of human impact (disturbance) on floristic composition, population structure and natural regeneration potential (seedling bank) of South Nandi Forest

2. Materials and Methods

2.1 Study Area

2.1.1 Location and physiography

Nandi Forests are situated on the top of Nandi escarpment in the Rift Valley Provincce of Kenya to the east of Kakamega forest (KIFCON, 1994a and KIFCON 1994b). North Nandi is found to the north of Kapsabet town, while South Nandi forest is located to south and west of this town. North Nandi Forest, together with the Kakamega Forest and South Nandi Forest, is one of the three forests in western Kenya, southeast of Mount Elgon (Schifter and Cunningham-van Someren, 1998). North Nandi forest is found in Nandi North district between 00°12´23´´- 00°25´06´´ N latitude and 34°57´35´´- 35°01´30´´ E longitude. South Nandi forest is situated in Nandi South district between 00°03´18´´- 00°11´44´´ N latitude and 34°53´47´´- 35°05´05´´ E longitude (reading from Google Earth).

North Nandi Forest stretches for more than 30 km from north to south, and seldom more than five km wide or less than three km wide for a considerable parts of its length (KIFCON, 1994b) (Fig. 1) while that of South Nandi Forest is situated to the south of North Nandi Forest covering wider area.

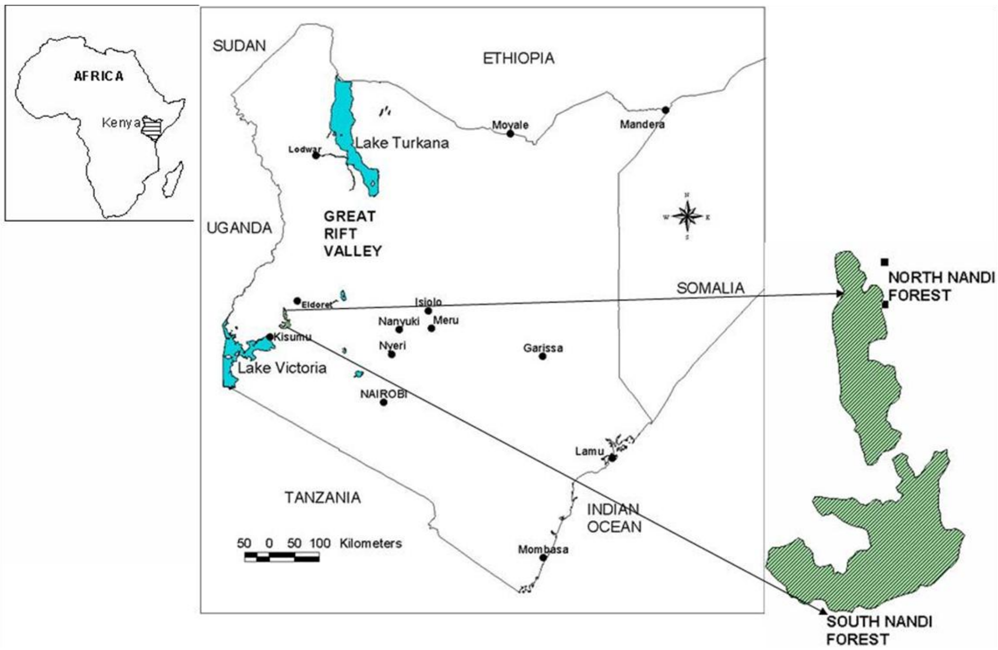


Figure 1 Location of North and South Nandi forests of Kenya

In different literature it was reported that the altitude of both North and South Nandi Forests is higher than that of Kakamega Forest (Kigomo, 1987; KIFCON, 1994b; Mitchell *et al*. 2006; Lung and Schaab, 2010) which is found to west of North and South Nandi Forests. KIFCON (1994b) reported that the mean altitude of North Nandi Forest is 2000 meter above sea level (masl) and the highest point of North Nandi Forest to be 2,140 m (Mitchell *et al*. 2006). Kigomo (1987) reported that the average altitude of South Nandi Forest is 1980 masl. KIFCON (1994a) described the altitudinal range of South Nandi Forest in between 1700 and 2000 m. More recently, Lung and Schaab (2010) describe the altitudinal range of Nandi forests in general is between 1695 and 2145 masl.

The drainage of North Nandi Forest is mainly to the east into the Kingwal/Kimondi River systems, which flow through South Nandi Forest and thence westwards into Yala river and Lake Victoria (KIFCON 1994b). Kimondi and Sirua are the two major rivers that merged within South Nandi forest to form the Yala River, which subsequently flows through Kakamega Forest and finanaly drains into Lake Victoria (KIFCON 1994a). Therefore, these forests are very important catchment area to Lake Victoria.

2.1.2 Geology and soil

Both North and South Nandi forests are located in the great east African Rift valley. The soils of North Nandi forest are derived from undifferentated basement sytem rocks and are well drained, deep, red to yellowish red friable sandy clays (KIFCON, 1994b). They are defined as ferralo-chromic Acrisols and have moderate to low inherent fertility.

The topography of South Nandi forest is gently undulating upland terrain underlain by garanitic and basement complex rock (KIFCON, 1994a). The soils are derived from these granitic and basement complex, and composed of well-drained, extremely deep and dark to reddish brown soils with friable clay and thick humic top layer principally developed on biotitegneiss parent material (KIFCON, 1994a, Dawit, *et al*. 2007; Lehmann, *et al*., 2007; Dawit *et al*., 2009). The soils are classified as humic Nitosols and have moderate to high natural fertility (KIFCON, 1994a).

2.1.3 Climate

The mean annual rainfall of Nandi North is in the range of 1800 to 2000 mm, with peaks in April/May and August/September. The mean annual temperatures range from 17°C to 18°C, with the mean maximum and minimum temperature oscillating around 24°C and 10°C (KIFCON, 1994b).

The rainfall distribution and the temperature of Nandi South are similar except slite difference in amount. The mean annual range of rainfall is between 1600 and 1900 mm, with the same peaks (Fig. 2) with that of Nandi North. The mean annual temperature ranges between 17°C and 20°C, with the mean maximum and minimum of 25°C and 11°C respectively.

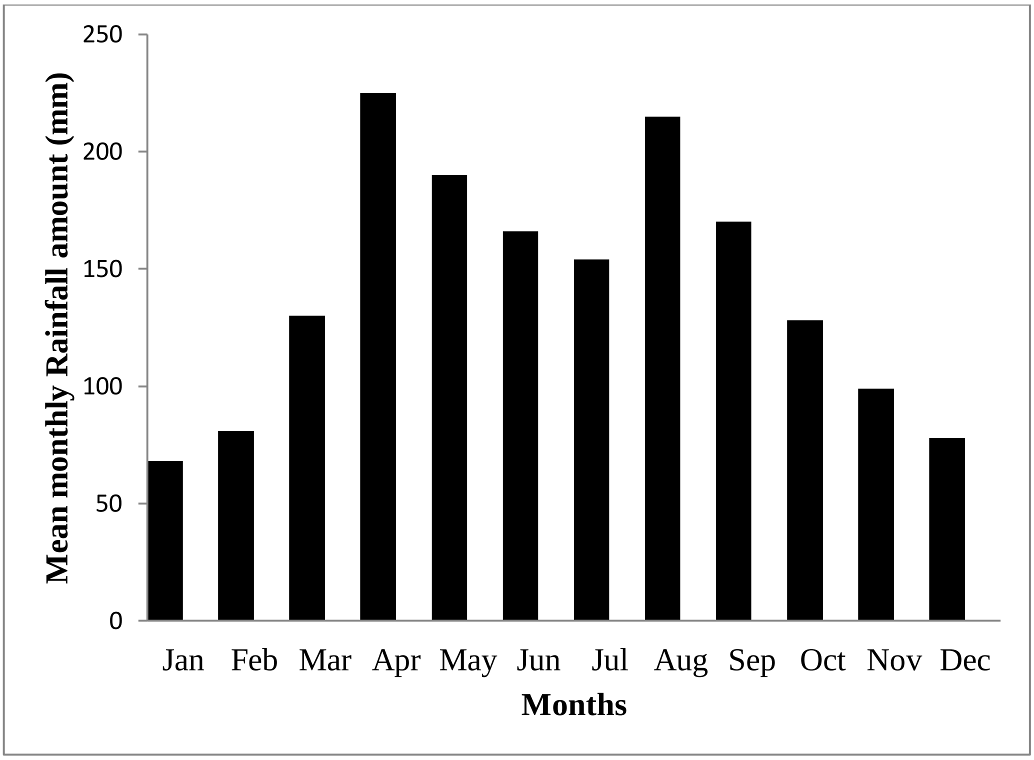


Figure 2. The mean monthly rainfall distribution of Nandi South (adapted from Kigomo, 1987)

2.1.4 Vegetation and fauna

Different authors were reporting the connection of the two Nandi forests together and Nandi forests with Kakamega forests. According to Schifter and Cunningham-van Someren (1998), in the past North Nandi forest apparently was contiguous with the South Nandi forest in the Kaptarop area and perhaps also with the Kakamega Forest. Mitchel (2004) and Brooks *et al*, (1999) underscored that South Nandi and Kakamega forests were connected.

More recently, Schaab *et al*, (2010) explained in detaile how Kakamega and Nandi forests were fragmented over years proving that these forests were one block. According to Schaab and here group, Kakamega and Nandi forests were one big U-shaped forest block in early 1900's based on 1912/13 topographic map (Fig. 4). During the last hundred years time this one single forest covered a total 78,124 ha of land according to Schaab *et al*. (2010). However, this block was disintegrated into three different forests starting in 1960s. Around 1965/67 there was just a tiny connection between Kakamega and South Nandi along the Yala River (Schaab *et al*, 2010), but it seems that earlier than this time that South and North Nanid were detached from one another. From these historic accounts one can conclude that anthropogenic impact in these areas started some decades ago.

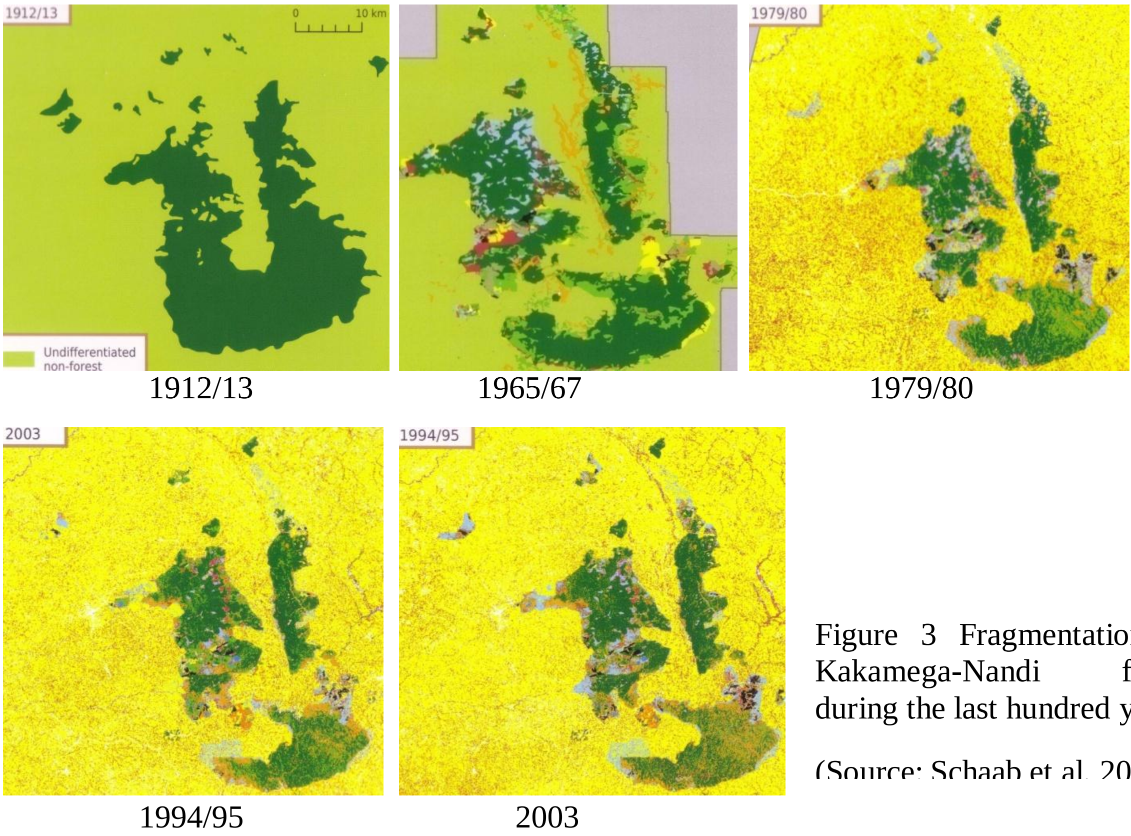


Figure 3 Fragmentation of Kakamega-Nandi forest during the last hundred years

(Source: Schaab et al. 2010)

Different authors classified Nandi forests differently. According to Beentje (1990) the vegetation of Nandi forests (both North and South Nandi Forest) classified as Tropical rainforest together with Kakamega forest. Beentje noted that Nandi forests are less diverse than Kakamega forest because of their higher altitude than that of Kakamega. In another account South Nandi forest is described as sub-montane tropical high forest (Kigomo, 1987). Nandi forests are also described as occupying transitional position between the lowland forests that stretch across Africa from the Zaire basin to western Kenya and the afro-montane forests of Kenyan highlands (KFICON, 1994a and KIFCON, 1994b). Young (1984) and Lehmann *et al*. (2007) describe Nandi forests as the easternmost relic of the tropical rainforests or the Guinea-Congolean region forests that extends from West Africa flora. Dawit *et al* (2009) also described Nandi forests together with Kakamega forest as one of the last remnants of pristine sub humid tropical rainforests currently existing in this intensely cultivated region.

Plant species of Nandi forests are not well documented and if there is any, it focuses on tree species. The most common tree species of North Nandi forests are *Diospyros abyssinica, Croton macrostachyus, Celtis africana, Strombosia scheffleri, Heinsenia diervilleoides, Cassipourea malasoma, Syzygium guineense, Tabernaemontana stapfiana, Casearia battiscombei, Croton magalocarpus, Macaranga capensis, Neoboutonia macrocalyx, Ehretia cymosa, Albizia gummifera,* etc. (KIFCON, 1994b). Schifter and Cunningham-van Someren (1998) described the most dominant tree species of North Nandi forest based on their height. *Antiaris toxicaria, Aningeria altissima, Diospyros abyssinica, Manilkaria butugi and Chrysophyllum albidum* are the dominant higher canopy tree species having more than 27 m and some are as tall as 45 m. Then intermediate canopy tree species include *Maesopsis emini, Macaranga* sp., *Polyscias fulva,* and *Premna angolensis* which are having up to 27 m height. Smaller trees such as *Hurungarna madagascariensis, Cussonia* sp., *Tabemaemontana* sp., *Cordia abyssinica, Albizzia* sp., *Vitex doniana, Celtis gomphophylla, Trichilia dregeana, Trema orientalis, Bersama* sp., *Fagaropsis angolensis* and *Ficus* sp., *Teclea* sp. were observed during their avifauna field work in 1978 and 1979.

According to KIFCON (1994a) the most common tree species of South Nandi forest are *Tabernaemontana stapfiana, Macaranga capensis, Croton megalocapus, Dracaena steudneri, Drypetes gerrardii, Neoboutonia macrocalyx, Strombosia scheffleri, Casearia battiscombei, Diospyros abyssinica, Cassipourea ruwensorensis, Heinsenia diervilleoides, Bersama abyssinica, Vernonia auriculifera, Ehretia cymosa,* etc.

There has been no recent study of the fauna of North Nandi Forest, and given its high perimeter to area ratio and the consequent high degree of human disturbance, it is unlikely to support many rare species and certainly nothing that will not occur in the less disturbed South Nandi Forest (KIFCON, 1994b).

A mammal survey carried out in November 1993 (Gathua, 1993 cited by KIFCON, 1994a), revealed that there were two “Read Data Book” species (i.e. considered rare) in South Nandi Forest. These are leopard and giant forest hog, both at very low population densities. Blue monkey, black and white colobus and olive baboon are the three diurnal primates recorded. A fourth, the red-tailed monkey is also believed to occur. The bushbuck is the largest of the antelopes to be found in South Nandi; others are the blue and red duikers, Bush pig, genet, African civet and red-legged sun squirrels were also recorded.

Generally in Kakamega and Nandi forests (both North and South) a total of 226 species of birds including 75 forest specialist bird species were recorded (Lewis and Pomeroy, 1989 cited in Kosgey, 1998). This represents the highest numbers for both these categories in any forest area of Kenya (Kosgey, 1998).

2.1.5 Gazettment detail and administration

Both North and South Nandi forests were originally gazetted in 1936 as a Trust Forest (KIFCON, 1994a and KIFCON, 1994b). The details of all the original areas of the forests and consecutive excisions are presented below in Table 1 and Table 2. As indicated in Table 1 and 2 since the original gazettment of these forests a total of 2028 ha (684 ha from South Nandi and 1344 ha from North Nandi) have been excised. Furthermore additional excision amounting 2150 ha was allocated for the settlement of people displaced because of the proposed establishment of Bonjoge Forest Reserve (KIFCON, 1994a). Currently the people form Bonjoge (they call it old Bonjoge) seetteled on the western side of South Nandi forest (see Fig. 4) and the settellers give the same previous village name (Bonjoge) to their new village. According to chief of the vilallege Mr. Devid Naskati, all the area occupied by the village was covered by dense forest when they settled in the area in 1985.

Table 1 Area and gazettment details of North Nandi Forest

Details	Legal Notice	Date	Area
Original gazettement as Trust Forest	76	1936	11845
Declared Central Forest	174	1964	11845
Excision for settlement	259	1967	61
Excision for settlement	260	1967	324
Sub-total			11460
Excision for settlement	142	1981	16
Excision for settlement	15	1985	943
Gazetted Forest Reserve Area			**10,501**

Source: KIFCON (1994b)

Table 2 Area and gazettment details of South Nandi Forest

Details	Legal Notice	Date	Area
Original gazettement as Trust Forest	76	1936	20186
Excision for settlement	15	1951	405
Declared Central Forest	174	1964	19781
Excision for settlement	39	1968	279
Sub-total			19502
Gazetted Forest Reserve Area			**19502**

Source: KIFCON (1994a)

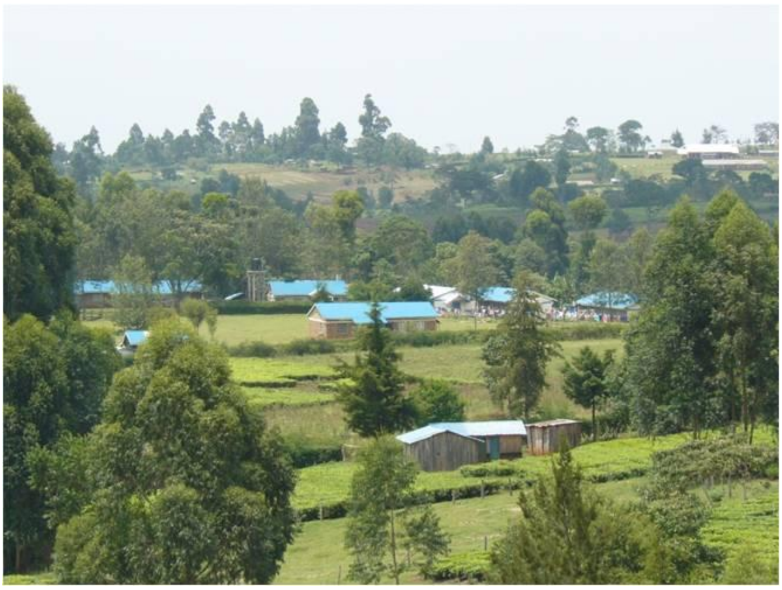


Figure 4 The result of excision in South Nandi Forest. Photo showing the established settlement (village and school) at Bonjoge

Both North and South Nandi forests are under the administration of Forest Department in the Ministry of Natural Resources and Wildlife, administered from respective district forest department. South Nandi Forest together with Mount Elgon and Kikuyu Escarpment Forests was declared a “Protected Catchment Area” under the Water Act (Cap 372) in Gazette Notice 83 of 12/1/65.

2.2 Data Collection

2.2.1 Vegetation data

A systematic sampling design was used to collect data on vegetation of different growth forms (Kent and Coker 1992; McCune and Grace, 2002; Mueller-Dombois and Ellenberg, 2002). Vegetation information was collected in quadrates of 20 x 20 meters. The quadrates were distributed along transects that ranges from 1 km to 1.6 km which were laid parallel to the slope. The distance between adjacent transects was 500 m while 100 m between consecutive plots. In total 76 quadrates, 49 from South Nandi and 27 from North Nandi forest were set up. Within each main quadrates five small plots of size 3 m X 3 m were laid; four at the corners and one at the center (Fig. 5).

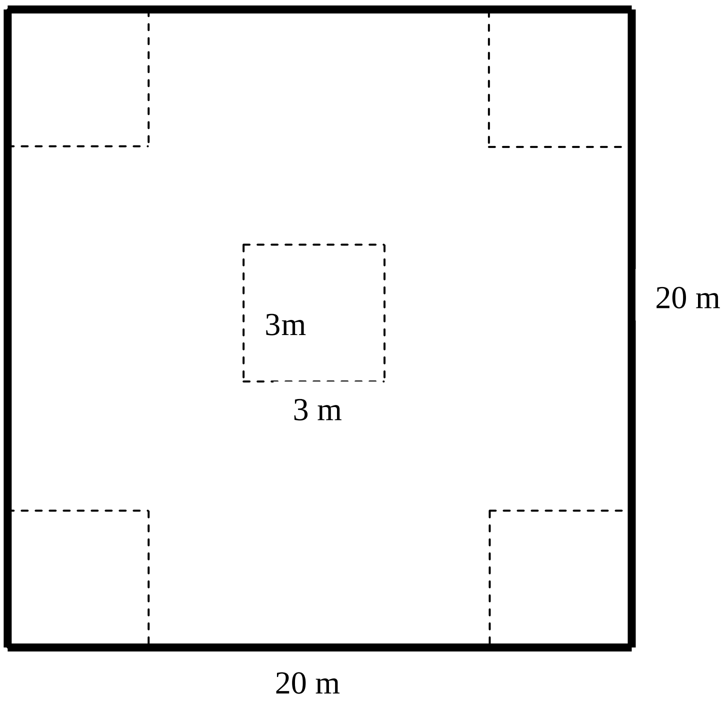


Figure 5 Layout of the quadrates

In each major quadrate all woody plants which are ≥ 2 cm diameter at breast height (dbh at 1.3m above ground) and height > 1m were identified, measured and recorded. The diameter was measured using diameter tape while total height of individual trees was measured using hypsometer and marked stick (for smaller individuals). All lianas encountered in the major plot were recorded and the diameter of the lianas was measured according to Gerwing *et al*, (2006). If the height of lianas was difficult to measure, estimation was used in comparison to the height of supporting trees. Plants with multiple stems below 1.3 m height were treated as a single individual and the dbh of all the stems were taken and then the average of the diameter was used for basal area calculation. If a tree was buttressed and abnormal at 1.3 m, the diameter was measured just above the buttress where the stem assumes near cylindrical shape. When epiphytes and ferns were found they were identified and recorded.

The diameter and height of stumps in the main plot were measured using diameter tape and measuring tape respectively. The stumps were identified to the species level. When it was difficult to identify the species local people were asked for the local name of the species then that name is checked in botanical books. If there were shoots on the stump and their diameter and height were greater than 2 cm and 50 cm respectively measurements were taken. Otherwise only the number of shouts per stump was recorded.

Herbaceous plants and seedlings of all woody plants (shrub, liana and trees) were recorded in the 3 X 3 m sub plots. Herbaceous plants were identified and their abundance (number of individuals) was recorded.

To produce species check list of the Nandi forests, species occurring outside of the plots including those encountered any where in the forest during data collection were also recorded. Plants were identified at species level in the field. For species that proved difficult to identify in the field, herbarium specimens were collected, dried properly and transported to the East African (EA) herbarium, National Museums of Kenya, in Nairobi for identification. Plant nomenclature is followed Letouzey (1982), Troupin (1988), Agnew and Agnew (1994), Beentje (1994), and Fischer and Killman (2008). Family names are followed Angiosperm Phylogeny Group (APG III) naming from an open acces website.

2.2.2 Environmental data

Altitude and geographical coordinates were measured using Gramin GPS in the middle of the main plots. Engineering compass was used to measure direction and aspect of plots. The canopy cover was visually assessed and recorded on 1 to 3 scale bases. When the canopy cover was estimated to be $\leq$ 33% (open canopy) 1 was given, 2 was given when it was estimated between 33 and 66 per cent (medium shade) and 3 when the canopy cover was estimated to be > 66% (high shade canopy).

The type and state of disturbance were also visually evaluated and recorded for each plot on ordinal scale ranging from 0 to 3, where 0 represent absence of disturbance and 3 represents the highest disturbance rate. Disturbance could be grazing, fire wood collection, charcoal making or pit sawing or the combination of any of these.

3. Floristic Composition of Nandi Forest

3.1 Introduction

Kenya is one of the sub-Saharan African countries with low natural forest cover. Several reports stated that the total closed canopy forest cover of Kenya is less than three per cent of the total land area of the country (Wass, 1995; FAO, 2003 and Akotsi *et al*, 2006). Total closed cannopy forest coverage is estimated to be 1.40 million hectares among which plantation forests cover only 0.16 million hectares of land (FAO, 2003). In Kenya, there are tropical rain forests in western parts, montane forest in the central and western highlands and on higher hills and mountains along the southern border as well as some coastal mosaic forests (Peltorinne, 2004). However, most of the forests are situated in the central highlands along the equator (Allaway and Cox, 1989, FAO 2003). These central highlands of Kenya are endowed with fertile soil and ample rainfall (FAO, 2003). About 15% of high potential land for agriculture of Kenya is covered by forests (Peltorinne, 2004). Due to this fact most of the natural forests are suffering from heavy human impacts (Allaway and Cox, 1989; FAO, 2003; Peltorinne, 2004) which include agriculture and other land uses. Though forests are shringing from time to time due to very high pressure, Kenya's forests still are biologically rich and harbour high concentrations of endemic species (Peltorinne, 2004).

Nandi hills are found in the Rift valley province of Kenya, where North and South Nandi forests are situated. Both North and South Nandi forests are found to east of Kakamega forest (Brooks, 1999; Althof, 2005), stretching from North-South direction. Once, this Kakamega-Nandi area was covered by one single block of forest (Brooks *et al*, 1999; Mitchel, 2004; Dawit *et al*, 2009; Lung and Schaab, 2010). However, currently this large forest block is divided into three different forests namely Kakamega, North Nandi and South Nandi forest. This shows how the Nandi forests and the environs are suffering from deforestation and fragmentation. As Kenya's indigenous forests are under huge pressure from competing land uses and from unsustainable exploitation (Allaway and Cox, 1989), there is no exception for both North and South Nandi forests which are under the main threats of agriculture, settlements and encroachments, charcoal production and logging (Lambrechts *et al.*, 2007).

Nandi forests are in close proximity to the Kakamega forest and they can play important roles in the endeavour of conserving the Kakamega forest. In addition, Nandi forests are enviromentaly very important as they protect the catchment of Nandi escarpment and the Lake Victoria basen.

However, information about floristic composition, plant community types, similarities between North and South Nandi forests as well as plant species diversity is not easily accessible or it is very scanty if it is available at all. Hence this work aims to fill the existing gap in such information of this very important forest of Kenya.

3.2 Material and Methods

3.2.1 Study sites

This study was conducted in the North Nandi and South Nandi forests which are located in Rift Valley Province of Kenya (Fig. 1). The forests are considered as the eastern remnants of African tropical rain forest. The detail description of each study site is given in chapter two (section 2.1).

3.2.2 Vegetation sampling

A total of 76 plots from both North Nandi and South Nandi forests were used for the following analysis. Twenty seven of these plots are from North Nandi forest and the rest are from South Nandi forest. The detailed sampling methods are described in chapter two.

3.2.3 Diversity analysis

Diversity measures

Species richness is a biologically appropriate measure of alpha (α) diversity and is usually expressed as number of species per sample unit (Whittaker 1972). The Shannon diversity (H ') and evenness (E') indices are calculated as a measure to incorporate both species richness and species evenness (Magurran, 1988). The Shannon diversity index (H') was calculated using the following equation.

$$H' = -\sum_{i=1}^{s} Pi \ln Pi$$

where pi, is the proportion of individuals found in the ith species

The values of Shannon diversity index is usually found to fall between 1.5 and 3.5 and only rarely surpasses 4.5 (Magurran, 1988).

To test whether Shannon indices of North and South Nandi forests are statistically significant independent t test was used. Since Shannon index is approximately normaly distributed, making comparison with paramrtric tests is feasible (Magurran, 2004).

To calculate the variance of the Shannon diversity index, the following formula, this is given by Magurran (1988) was used.

$$VarH' = \frac{\sum p_i (\ln p_i)^2 - \sum (p_i \ln p_i)^2}{N} - \frac{S-1}{SN^2}$$

The t statstic to test for significant difference was made using the following formula

$$t = \frac{H'_1 - H'_2}{\sqrt{VarH'_1 + VarH'_2}}$$

Where VarH' = variance of Shannon index

N = sample size

S = number of species

A probability level less than 5% ($P < 0.05$) was used for the significant different test between the means. The independent t test was performed using SPSS version 16 statistical software.

Evenness (E') was calculated from the ratio of observed diversity to maximum diversity (Magurran, 1988) using the following equation.

$$E' = \frac{H}{H \max} = \frac{H}{\ln s}$$

where H_{max} is the maximum level of diversity possible within a given population, which equals ln(number of species). Magurran (1988) explained that E' ranges normally between 0 and 1, where 1 representing a situation in which all the species are equally abundant.

To describe the relationship between the number of species and total number of individuals, Fischer's α, which is often known as log-series distribution (Magurran, 1988) was used. Unlike to other indices, Fischer's α is not influenced by sample size (Rosenzweig, 1995). If the abundances fit log-series distribution, the number of observed species follows the following equation (Magurran, 1988; Rosenzweig, 1995):

$$S = -\alpha \ln(1 - x)$$

Where S is the total number of species, α is a constant that depends on diversity alone and x is a variable that depends on sample size and estimated from the iterative solution of:

$$\frac{S}{N} = (1 - x)/x[-\ln(1 - x)]$$

Where N is the total number of individuals

The diversity index α can be obtained from the equation:

$$\alpha = \frac{N(1 - x)}{x}$$

Beta diversity can be defined as the 'extent of species replacement or biotic change along environmental gradients' (Whittaker, 1972). Accurate measurement of beta diversity is important in at least three ways (Wilson and Shmida, 1984): 1) it indicates the degree to which habitats have been partitioned by species; 2) values of beta diversity can be used to compare the habitat diversity of different study systems; 3) beta diversity and alpha diversity together measure the overall diversity of or biotic heterogeneity of an area.

To evaluate the species diversity and species richness due to gradient change, Beta diversity (Whittaker, 1972) was computed using the following formula:

$$\beta_w = \frac{S_c}{S} - 1$$

where β_w is Whittaker beta diversity, S_c is the number of species in the composite sample (number of species in the whole data set), and S is the average species richness in the sample units. The one is subtracted to make zero beta diversity correspond to zero variation in species presence (McCunne and Grace, 2002).

If β_w is equal to zero then all sample units have all the species. β_w less than one are rather low and β_w greater than five can be considered high. The maximum value of β_w is obtained when species are not shared among the sample units (McCunne and Grace, 2002). Hence, β_w does not have a fixed maximum value.

Similarity indeces

To evaluate the similarity of plant communities of the study sites, the widely used and classical similarity indices; Sørensen and Jaccard similarity index (Magurran, 1988) was used. The following equations wer used to calculate the Sørensen and Jaccard similarity indices respectively.

$$S = \frac{2C}{A+B} \quad \text{and} \quad J = \frac{C}{A+B-C}$$

where S is Sørensen's similarity index

J is Jaccard's similarity index

C is the number of species common to both sites,

A is the number of species present in one of the sites to be compared

B is the number of species present in the other site.

Despite their simplicity and wide application in ecological studies, the incidence-based (presence/absence) indices (i.e. Jaccard and Sørensen similarity indices) do not take species abundance into account, thus abundant and rare species are treated equally (Magurran, 2004; Chao *et al.* 2005; Chao *et al.* 2006). These indices, when estimated from samples, do not perform well (Wolda, 1981, 1983; Colwell and Coddington, 1994; Fisher, 1999; Plotkin and Muller-Landau, 2002). Based on incidence data, bias correction and measurements of variances are not possible (Chao *et al*, 2006). Hence in this study abundance based similarity indices estimators (Chao *et al*, 2005) were also applied using the following formulae:

$$\hat{L}_{abd} = \frac{2\hat{U}\hat{V}}{\hat{U}\hat{V}} \quad \text{and} \quad \hat{J}_{abd} = \frac{\hat{U}\hat{V}}{\hat{U}+\hat{V}-\hat{U}\hat{V}}$$

Where $\hat{L}_{abd}$ and $\hat{J}_{abd}$ abundance based Sørensen and Jaccard index estimators respectively,

$\hat{U}$ is adjusted total relative abundances (adjusted for unseen species) of individuals belonging to the shared species of assemblage 1

$\hat{V}$ is adjusted total relative abundances (adjusted for unseen species) of individuals belonging to the shared species of assemblage 2 (for the detail see Chao *et al*, 2005 equation 10 and 9 respectively) .

Rarefaction and species accumulation curves

Since number of species is highly dependent on sample size, comparing communities having different sample size is problematic (Peet, 1974; Magurran, 1988). Hence to overcome this problem, all samples from different communities should be standardized to a common sample size of the same number of individuals (Krebs, 1999). Sanders (1968) proposed rarefaction method for achieving this goal. Rarefaction is a statistical method for estimation the number of species expected in a random sample of individuals taken from a collection (Krebs, 1999).

The species accumulation curve, which is, the plot of the expected number of detected species as a function of sampling effort, arises as a graphical representation of the sampling process (Sanders, 1968; Palmer, 1990). The sampling effort can be the number of plot or the number of individuals to be sampled. Species accumulation curves have also been used by ecologists to perform quantitative comparison among species assemblages (Sanders, 1968; Colwell and Coddington, 1994; Gotelli and Colwell, 2001), and used to estimate the expected number of new species to be detected given a level of additional sampling effort, which can lead to efficient planning and sampling protocols (Soberon and Llorente, 1993; Colwell and Coddington, 1994; Moreno and Halffter, 2000; Shen *et al*., 2003).

In this study sample based rarefaction curves (Gotelli and Colwell, 2001) are computed to compare the species richness of North and South Nandi forests. To evaluate the effectiveness of the species estimators and to examine the degree of species collection (sampling) species accumulation curve was also ploted.

Species richnes (number of species) estimation

The number of species or species richness in a species assemblage is a significant measure of biodiversity at the habitat level (Bunge and Fitzpatrick, 1993; Colwell and Coddington, 1994; Mao and Colwell, 2005). However, it is virtully impossible to detect all species and their relative abundance with a limited number and intensity of samples (Chao *et al*., 2005; Mao *et al*, 2005). To meet this challenge, several methods have been developed for estimating species richness from sample data, either through extrapolation of species accumulation curves or through application of non-parametric methods (Bunge and Fitzpatrick, 1993; Colwell and Coddington, 1994; Magurran, 2004). The latter approach involeves the estimation of unseen species (species that is likely to be present in a larger homogenous sample of the assemblage, but that are missing from actuall sample data (Chao *et al*., 2005). In this study, non-parametric species richnses estimators including ACE, Chao1, Cho 2, Jackknife 1, Jackknife 2 and Bootstrap were used to estimate the number of species in Nandi forests. These non-parametrice species richness estimators are applicable to quadrate-based data sets that can be treated as either the random samples of space or as fixed samples of individuals (Heltshe and Forrester, 1983). Moreover these estimators are free of parametric (normal) species abundance distribution model (Magurran, 2004). They are also applicable for estimation using abundance data and incidence-based (presenc/absence) data (Wei *et al*., 2010).

To compute species accumulation curves and estimate species richness, EstimateS version 8.2 (Colwell, 2009) which is a public domain software was used. In order to to calculate the mean estimator and expected number of species for each sample accumulation level, the sample order was randomized 100 times.

The equations which were used in EtimateS (Colwell, 2009) to estimate species richness are given below

1. **Abundance-based Coverage Estimator (ACE):** It is based on species found in 10 or fewer samples (quadrats).

$$S_{ace} = S_{abund} + \frac{S_{rare}}{C_{ace}} + \frac{F_1}{C_{ace}} \gamma^2_{ace}$$

$$C_{ace} = 1 - \frac{F_1}{N_{rare}} \quad \text{and} \quad N_{rare} = \sum_{i=1}^{10} iF_j \ ,$$

$$\gamma^2_{ace} = \max\left[\frac{S_{rare}}{C_{ace}} \frac{\sum_{i=1}^{10} i(i-1)F_i}{(N_{rare})(N_{rare}-1)} - 1, 0 \right]$$

Where S_{ace} = expected species number based on abundance-based coverage estimator

S_{abund} = number of abundant species (each with more than 10 individuals) when all samples are pooled

S_{rare} = number of rare species (each with 10 or fewer individuals) when all when all samples are pooled

C_{ace} = sample abunce coverage estimator

N_{rare} = total number of individuals in rare species

F_1 = the number of singltones

γ^2_{ace} = estimated coefficient of variation of the Fi for rare species

2. **Chao 1 estimator:** is based on the number of rare species. It is computed using the following formula

$$S_{Chao1} = S_{obs} + \frac{F_1^2}{2F_2}$$

and the bias-corrected formula is

$$S_{Chao1} = S_{obs} + \frac{F_1(F_1 - 1)}{2(F_2 + 1)}$$

where S_{chao1} = the expected species number based on Chao 1 estimator

S_{obs} = the number of species observed in the all pooled samples

F_1 = the frequency of singletons (species represented by a single individual)

F_2 = the frequency of doubletons (species represented by two individuals)

3. **Chao 2:** is an incidence-based species richness estimator based on the number of uniques (species found in only one sample), and the number of duplicates (species found in exactly two samples). The classic formula is

$$S_{Chao2} = S_{obs} + \frac{Q_1^2}{2Q_2},$$

and the bias-corrected formula is

$$S_{Chao2} = S_{obs} + \left(\frac{m-1}{m}\right)\left(\frac{Q_1(Q_1 - 1)}{2(Q_2 + 1)}\right)$$

where S_{chao2} = the expected species number based on Chao 2 estimator

S_{obs} = the number of species observed in the all pooled samples

Q_1 = the frequency of uniques (species that occur in one sample only)

Q_2 = the frequency of duplicates (species that occur only in two samples)

m = total number of samples

4. **The first order Jackknife estimator (Jack 1):** is an estimator based both on the number of species occurring in only one sample (quadrate) and on the total number of quadrats.

$$S_{jack1} = S_{obs} + Q_1\left(\frac{m-1}{m}\right)$$

where S_{jack1} = the expected species number based on Jack 1 estimator

S_{obs} = the number of species observed in the all pooled samples

Q_1 = the frequency of unique (species that occur in one sample only)

m = total number of samples (quadrates)

5. **The second order Jackknife estimator (Jack 2):** is based on the number of species occurring in only 1 sample and the number of species occurring in exactly 2 samples.

$$S_{jack2} = S_{obs} + \left[\frac{Q_1(2m-3)}{m} - \frac{Q_2(m-2)^2}{m(m-1)}\right]$$

where S_{jack2} = the expected species number based on Jack 2 estimator

S_{obs} = the number of species observed in the all pooled samples

Q_1 = the frequency of uniques

Q_2 = the frequency of duplicates

m = total number of species

6. **The Bootstrap estimator:** is based on the proportion of samples containing each species.

$$S_{boot} = S_{obs} + \sum_{k=1}^{S_{obs}}(1 - p_k)^m$$

where Sboot = the expected species number based on Bootstrap estimator

S_{obs} = the number of species observed

pk = proportion of samples that contain species k

m = total number of species

3.2.4 Cluster analysis

Cluster analysis is a multivariate analysis which is widely used in ecological works. It is an operation of multidimensional analysis which consists in partitioning the collection of objects (or descriptors) in the study (Legendre and Legendre, 1998). Clustering is an operation by which the set of objects (sites) or descriptors (species) is partitioned in to two or more subsets or clusters, using pre-established rules of agglomeration or division. It helps to group (cluster) observations (plot or vegetation samples) based on their attributes or their similarities (Kent and Coker, 1992; McCunne and Grace, 2002). In this study, a hierarchical (agglomerative) cluster analysis was performed using PC-ORD version 5.22 (McCunne and Grace, 2006) to identify plant communities. The abundance data of the species was used in this analysis. Relative Euclidean Distance (RED) with Ward's method was used. Since it eliminates the difference in total abundance among sample units, RED was used, while Ward's method was used since it is useful to minimize the total with-in mean of squares or residual sum of squares (van Tongeren, 1995; McCunne and Grace, 2002).

To test the hypothesis of no difference between the identified groups, multi-response permutation procedure (MRPP) (Biondini *et al*., 1985; Mielke and Berry, 2001; McCunne and Grace, 2002) was used. Multivariate normality or homogeneity is not required to perform MRPP. According to McCune and Grace (2002), MRPP is a nonparametric procedure for testing the hypothesis of no difference between two or more groups of entities. PC-ORD version 5.22 (McCunne and Grace, 2006) was also used to perform MRPP.

In community analysis, detecting and describing the value of different species to indicate the environmental conditions is a common practice (McCunne and Grace, 2002). In this study the new method which is proposed by Dufrene and Legendre (1997) was used. This method combines information on the concentration of species abundance in a particular group and the faithfulness of occurrence of a given species in specific group (McCunne and Grace, 2002). It produces indicator values for each species in each group, based on these standards of perfect indicator. Indicator values are tested for statistical significance using a randomization (Monte Carlo) technique. The indicator values ranges from zero (no indication) to 100 (perfect indication). Perfect indication means that the presence of a species points to a particular group without error, at least with the data set in hand. In this analysis, only 73 plots were used since three of the plots were considered as outliers. Three of the plots i.e. plot three and seven due to high number (especially seedlings) of *Diospyros abyssinica* and *Prunus africana*, respectively and plot four was totally dominated by *Alchornea hirtella* hence all of them were not included in this analysis.

3.2.5 Ordination

Ordination is most often used in ecology to seek and describe pattern, hence in community ecology its most common use is to describe the strongest patterns in species composition (McCune and Grace, 2002). Thus it is known as gradient analysis, as the underlying factors are thought to vary continuously (Palmer, 1993; McCune and Grace, 2002). Ordination in a reduced space is an operation by which the objects or descriptors are positioned in a space that contains fewer dimensions than in the original data set; the position of the objects or descriptors with respect to one another may also be used to cluster them (Legendre and Legendre, 1998). It is the collective term for multivariate techniques that arranges sites along axes on the basis of data on species composition (ter Braak, 1995). The result of ordination in two dimensions (two axes) is a diagram in which sites are represented by points such that points in two-dimensional space. The aim of ordination is to arrange the points (sites or species) such that points that are close together correspond to sites that are similar in species composition, and points that are far apart correspond to site that are dissimilar in species composition. Similarly, if the ordination is on species space, points close together represent that those species have similar occurrences in their distribution.

Indirect gradient analysis has the following advantages over direct gradient analysis (ter Braak, 1995). Firstly, species compositions are easy to determine, because species are usually clearly distinguishable entities. By contrast, environmental conditions are difficult to characterize exhaustively. There are many environmental variables and even more ways of measuring them, and one is often uncertain of which variables the species react to. Species composition may therefore be a more informative indicator of environment than any given set of measured environmental variables. Ordination can help to show whether important environmental variables have been overlooked: an important variable has definitely been missed if there is no relation between the mutual positions of the sites in the ordination diagram and the measured environmental variables.

Secondly, the actual occurrence of any individual species may be too unpredictable to discover the relation of its occurrence to environmental conditions by direct means and therefore more general patterns of coincidence of several species are greater use in detecting species-environment relations.

Thirdly, for example in landscape planning, interest may from the onset be focused more on the question of which combinations of species can occur, and less on the behaviour of particular species. Regression analysis of single species then provides too detailed an account of the relations between species and environment. The ordination approach is less elaborate and gives global picture, but-one hopes- with sufficient detail for the purpose in hand.

In this study the indirect unimodal ordination method, Detrended Correspondence Analysis (DCA) (ter Braak, 1995; McCune and Grace, 2002) was used. CANOCO version 4.53 (ter Braak and Smilauer, 2004) was used to undertake DCA in this study. In the present analysis, 73 sample pots and 264 species were used. Since three of the total 76 plots were considered as outliers they were excluded from this analysis. Plot number three and seven due to high number (especially seedlings) of *Diospyros abyssinica* and *Prunus africana*, respectively and plot number four was totally dominated by *Alchornea hirtella* hence all of them were not included in this analysis.

3.3 Results

3.3.1 Floristic composition

Including those plants that were found out of the study plots (quadrates), totally 321 species from 92 families and 243 genera were identified in this study (Fig. 6). When the number of species, families and genera from the two forests analysed separately, South Nandi Forest has higher share in all aspect. As shown in Figure 6 the number of families, species and genera which were recorded in South Nandi forest are higher than that of North Nandi forest. In South Nandi totally 253 species (including those found out of the study quadrates) were recorded while in North Nandi the number of species was declined to 181. Eighty two and 67 families were identified in South Nandi and North Nandi, respectively. The number of genera decreased from 201 to 155 when we go from South Nandi to North Nandi forest (Fig. 6).

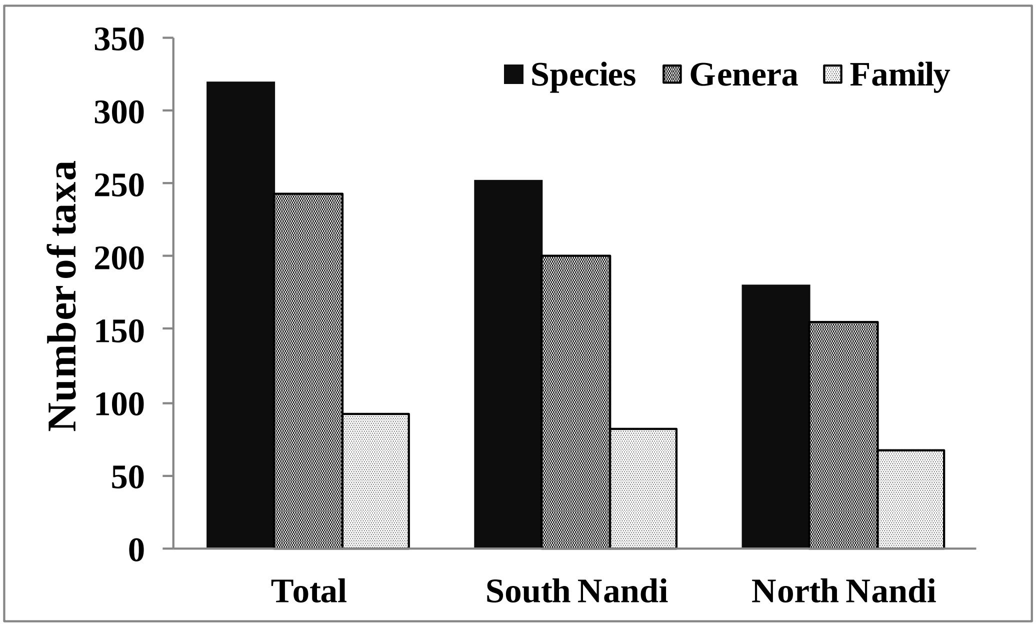


Figure 6. Total number of families, species and genera recorded in the Nandi Forests

Out of the total 321, only 271 of the species were recorded in the study quadrates. From these 271 species only 211 of them comprising 77 families and 171 genera were recorded in South Nandi forest while in North Nandi forest only 161 species from 61 families and 121 genera were recorded in the quadrates. Out of the 92 families recorded, 63% of them (58 families) occurred in both forests. Twenty four families (26.1% of the total families) were recorded only in South Nandi while the rest 10.9% (10 families) were recorded only in North Nandi forest.

When the whole data set is considered together, the species richest family of Nandi forests is Asteraceae, represented by 24 species and 19 genera, followed by Rubiaceae which is represented by 21 species and 16 genera (Table 3). The third species rich family is Euphorbiaceae which is represented by 15 species and 12 genera. Orchidaceae and Malvaceae are represented by 12 species each while Acanthaceae consists of 11 species. Fabaceae, Aspleniaceae and Moraceae are represented by 10 species each (Table 3).

Table 3 Top ten species rich families recorded in Nandi Forests

Families	**Number of species**	**Number of genera**
Asteraceae	24	19
Rubiaceae	21	17
Euphorbiaceae	15	12
Orchidaceae	12	8
Malvaceae	12	7
Acanthaceae	11	8
Fabaceae	10	8
Aspleniaceae	10	1
Moraceae	10	4
Solanaceae	9	3

The order of richest families is a bit different when the data is analysed separately (Table 4) even if the order in Table 3 is maintained in South Nandi forest at least for the first three rich families. In South Nandi Forest, as indicated in Table 4, Asteraceae is the richest family being represented by 21 species and 16 genera. The second richest family is Rubiaceae which has 20 species and 16 genera followed by Euphorbiaceae and Acanthaceae consisting of 11 species each. Moraceae, Solanaceae, Asplenaceae, Fabaceae, Malvaceae and Orchidaceae are families represented by six or more species in South Nandi Forest (Table 4).

Table 4 Families with five or more species in North and South Nandi Forest

Nothr Nandi forest			**South Nandi forest**		
Families	**Number of species**	**Number of genera**	**Families**	**Number of species**	**Number of genera**
Rubiaceae	12	11	Asteraceae	21	16
Asteraceae	11	11	Rubiaceae	20	16
Euphorbiaceae	10	9	Euphorbiaceae	11	10
Orchidaceae	8	7	Acanthaceae	11	8
Malvaceae	8	7	Moraceae	9	4
Fabaceae	7	7	Solanaceae	8	3
Solanaceae	6	1	Aspleniaceae	8	1
Acanthaceae	5	5	Fabaceae	7	6
Asparagaceae	5	3	Malvaceae	7	5
Aspleniaceae	5	1	Orchidaceae	6	6

In North Nandi, Rubiaceae is the richest family being represented by 12 species and 11 genera. The second richest family is Asteraceae with 11 species and 11 genera followed by Euphorbiaceae consisting of 10 families and nine genera. Orchidaceae, Malvaceae, Fabaceae, Solanaceae, Acanthaceae, Asparagaceae and Aspleniaceae are other species rich families in North Nandi which are represented by 5 or more species (Table 4).

In both forests the first ten species rich families comprises considerable number of species. In South Nandi, 42.7 % (108 species) of the recorded species belongs to the top ten families. However, 37 of the families recorded (45.1 %) in this forest were represented only by one specie. The same is true for North Nandi, where, 42.5 % (77 species) of the total species were from top ten species rich families and 44.8 % (30 families) of the families were represented only by a single species.

3.3.2 Alpha and beta diversity

This study showed that there were more species per plot (400 m^2) in South Nandi Forest than that of North Nandi. In South Nandi forest a mean number of 59.6 species per plot was recorded and in North Nandi Forest this number was decreased to 49.6 (Fig. 7). The resulting nonparametric mean comparison showed the difference is statistically significant (Mann-Whitney $U = 313.5$ and $p < 0.001$). This result is also supported by the rarefaction curve with 95% confidence interval (see section 3.3.3 Fig. 8).

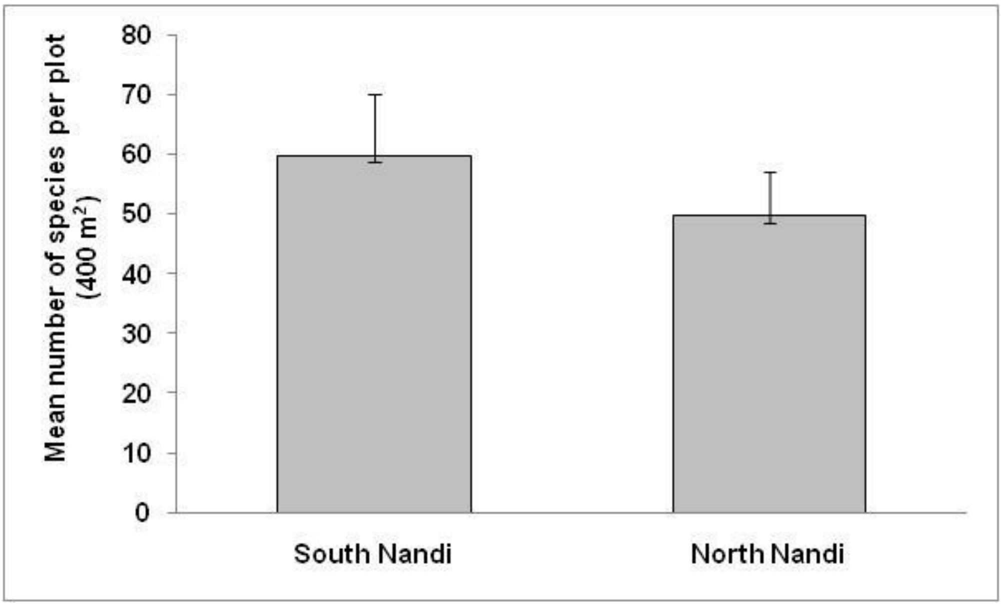


Figure 7 Number of species per plot in South and North Nandi Forests (values are mean and ± SD)

As indicated in Table 5 all Fisher *α*, Whittaker beta diversity, Shannon diversity index and evenness index were higher in South Nandi than that of North Nandi Forest. Shannon diversity index for South Nandi was 2.74 and 1.63 for that of North Nandi forest. These values were compared statistically to see if the difference is significant. The t-test showed that the difference is highly significant (t-value =16.6, $p<0.001$). This shows that South Nandi forest has relatively higher species diversity than that of North Nandi. Moreover, the evenness of species distribution and species turn over is relatively higher in South Nandi (Table 5).

Table 5 Various diversity parameters calculated in North and South Nandi Forests

Diversity measurment	**North Nandi Forest**	**South Nandi Forest**
Fisher's α	19.14	27.4
Shanon diversity (H')	1.63	2.74
Evenness index (E')	0.42	0.67
Whittaker beta diversity (β_w)	2.22	2.54

3.3.3 Species accumulation curve

As indicated in Figure 8, species accumulation curves (rarefaction) were plotted for the vascular plants recorded in South and North Nandi forests. This graph was plotted for the cumulative number of species recoded as a function of sampling effort i.e. the number of samples pooled.

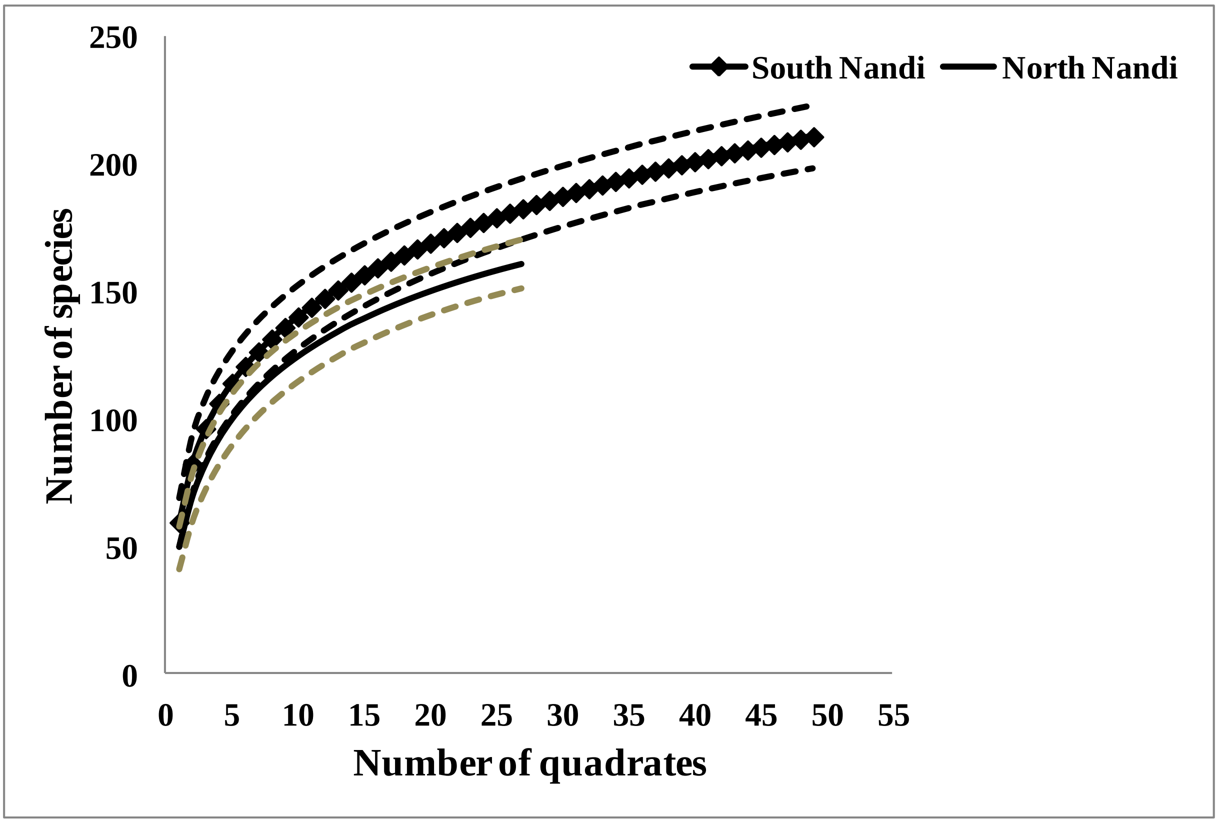


Figure 8 Species accumulation (rarefaction) curves (solid lines) and 95% confidence intervals (dashed lines) for South and North Nandi Forests.

Species accumulation curve helps to illustrate the rate at which new species are included as the sampling effort proceed. From Figure 8 it is observed that there are still new species to be recorded in both forests though at decreasing rate. The rate is still higher for South Nandi Forest. The rarefied number of species based on 27 plots (plots of North Nandi forest) resulted in 182.7 species in South Nandi forest however, 161 species were recorded at North Nandi forest at this sampling effort.

Rarefaction curve is also useful to test whether there is significance difference in species richness between different sites or not. As it is depicted from Figure 8 the observed species accumulation curve of North Nandi forest is outside of the 95% confidence interval of South Nandi forest revealing that South Nandi forest has significantly higher species richness than that of North Nandi.

3.3.4 Species richness estimation

As it was described in section 3.3.1 totaly 321 vascular plant species (including those found out side of the study plots) were recorded in Nandi forests. However, these are not the only species that are found in this ecosystem. For various reasons especially those which are rare might not be included in sampling process. Hence, it is valid to estimate the total number of species. Based on different species richness estimators, the total number of species in Nandi forests was estimated to be between the range of 286.54 and 358.85 (Table 6). The lowest estimate (i.e. 286.54) was given by Chao1, while the highest estimate was obtained using Jackknife 2 (i.e. 358.85) (Table 6). Based on these different estimations, in this study 75.25 to 94.56 % of the estimated species were recorded.

Table 6 Number of samples, individuals, observed species and estimated species richness (based on different methods) of Nandi Forests in general

Charachterstics	Nandi Forests
Number of samples	76
Number of individuals	142055
S_{obs}	271
ACE	291.25
Chao 1	286.54 ±7.56
Chao 2	325.58 ±18.62
Jackknife 1	330.21 ±7.86
Jackknife 2	358.85
Bootstrap	298.32
Species collection degree	75.52-94.57 %

As indicated in table 7 using different methods, species richness (number of species) of both North and South Nandi forests was separately estimated. All the species richness estimators used in this study resulted in a higher species richness than the observed number of species (S_{obs}). In both forests the highest species richness estimation (283.45 for South Nandi and 208.52 for North Nandi) was obtained by second order Jackknife estimator (Table 7). Abundance coverage estimate (ACE) gave the lowest species richness estimate (174.53) for North Nandi. While the smallest estimate for South Nandi (219.55) was given by Chao 1 estimator. In this study 76.76-92% of the species estimated by various estimators for North Nandi as well as 74.4-96% for that of South Nandi were recorded (Table 7).

Table 7 Number of samples, individuals, observed species and estimated species richness (based on different methods) of North and South Nandi Forest

	North Nandi	**South Nandi**
Number of samples	27	49
Number of individuals	81584	60463
S_{obs}	161	211
ACE	174.53	226.27
Chao 1	178.5±10.1	219.55 ±5.01
Chao 2	186.27±11.12	257.08 ±17.45
Jackknife 1	195.56 ±5.88	259±7.67
Jackknife 2	208.52	283.45
Bootstrap	177.51	232.74
Species collection degree	77.21-92.25%	74.44-96.1%

3.3.5 Floristic similarities

As indicated in Table 8 both incidence and abundance based similarity indices resulted in very low similarty indices for North Nandi and South Nandi forests. Incidence based Sørensen similarity index was 0.39 and that of incidence based Jaccard was 0.25. Almost identical values were obtained for the corresponding abundance based similarty indices (Table 8). Chao-Sørensen similarty index resulted in 0.38 and that of Chao-Jaccard index gave 0.25, which is very low in both cases.

Table 8 Incidence and abundance based similarity indices of North and South Nandi Forests

Incidence based similarity indices		**Abundance based similarity indices**	
Sørensen	0.39	Chao-Sørensen estimate	0.38
Jaccard	0.25	Chao-Jaccard estimate	0.25

3.3.6 Plant communities

Cluster analysis in combination with Multi-response Permutation Procedures (MRPP) of the whole data set resulted in three different plant communities of Nandi Forests (Figure 6). The analysis was based on the abundance data of 264 vascular plant species in 73 plots. Three of the plots (plot 3, 4 and 7) were excluded since they were outliers. Plot three is outlier because of huge number of *Diospyros abyssinica* especially seedlings, Plot four is extremely dominated by *Alchornea hirtella* and Plot seven has very high number of *Prunus africana* seedlings.

Accordingly, the test statistic **T** value from this analysis for the three groups was -37.85 ($P < 0.001$) showing that the three groups are different. The agreement statistic A was 0.32. The test statistic, **T**, describes the separation between the groups (McCune and Grace, 2002). The more negative is **T**, the stronger the separation. The P-value associated with **T** is determined by numerical integration of the Pearson type III distribution. The P-value is useful for evaluating how likely an observed difference is due to chance (McCune and Grace, 2002).

The agreement statistic **A** describes within-group homogeneity, compared to the random expectation and **A** ranges between 0 and 1. When the items are identical **A**=1 and if heterogeneity within groups equals with expectation by chance **A**=0. In community ecology, values for **A** are commonly below 0.1 An **A** value greater than 0.3 is fairly high (McCune and Grace, 2002).

The identified plant communities of this study varied in size ranging from 16 to 30 plots (Fig. 9). The indicator species (those having indicator value ≥ 40%) of each community is presented in Table 4. The community is named after the dominant tree or shrub species in that specific community based on their indicator values (Table 9). These identified communities of Nandi forest are described on the ongoing paragraphs.

A. *Diospyros abyssinica-Heinsenia diervilleoides* community

This community consists 30 plots, which are all from South Nandi forest. The altitudinal range of this community is from 1820 to 2057 meter above sea level. About 76.7 % of the plots (23 plots) of this community lie in altitude which is above 2000 meter (i.e. with mean altitude of 2031 meter and ranging from 2007 to 2057 masl). This community has steeper slope than the other two communities identified in Nandi forests. Totally, 96 species are associated with this community and has many indicator species with significant indicator values (Table 9). The common tree species of this community are *Diospyros abyssinica, Heinsenia diervilleoides, Cassipourea ruwensorensis, Prunus africana, Drypetes gerrardii, Strombosia scheffleri, Oxyanthus speciosus, Deinbollia kilimandscharica, Xymalos monospora, Chionanthus mildbraedii*. *Dracaena laxissima, Acanthopale pubescens, Piper capense, Coffea eugenioides,* and *Acanthus eminens* are the common shrub species in this community. The herb layer is dominated by *Oplismenus hirtellus, Dorstenia brownii, Achyranthes aspera, Impatiens cf niamniamensis* and *Laportea alatipes*. There are also different climbers in this community.

Cissus rotundifolia, Salacia cerasifera, Rutidea orientalis, Tiliacora funifera, Culcasia falcifolia, Keetia gueinzii, and *Artabotrys likimensis* are the most common ones.

B. *Trilepisium madagascariense-Solanum mauritianum* community

This community occurs in altitudinal range of 1821 to 1874 m. All the plots belonging to this community are drawn from the heavily disturbed part of South Nandi forest. It is comprised of 16 plots and 61 species have association with this community. There are also several indicator species with significant indicator values in this group and the major ones are *Trilepisium madagascariense, Solanum mauritianum, Mimulopsis arborescens, Lepidotrichilia volkensii, Polyscias fulva* etc (Table 9). Topographically this community is situated in gentler slope than that of *Diospyros abyssinica-Heinsenia diervilleoides community*. The common tree species of this community are *Trilepisium madagascariense, Celtis durandii, Lepidotrichilia volkensii, Polyscias fulva, Trema orientalis, Ficus sur, Alangium chinensee, Tabernaemontana stapfiana* and *Croton megalocarpus*. The shrub layer is dominated by *Solanum mauritianum, Mimulopsis arborescens, Piper umbellatum* and *Macrorungia pubinervia. Chlorophytum zavattarii* and *Adenostemma caffrum* are the common herb species. *Sericostachys scandens, Connarus longistipitatus* and *Gouania longispicata* are the most common climbers found in this community.

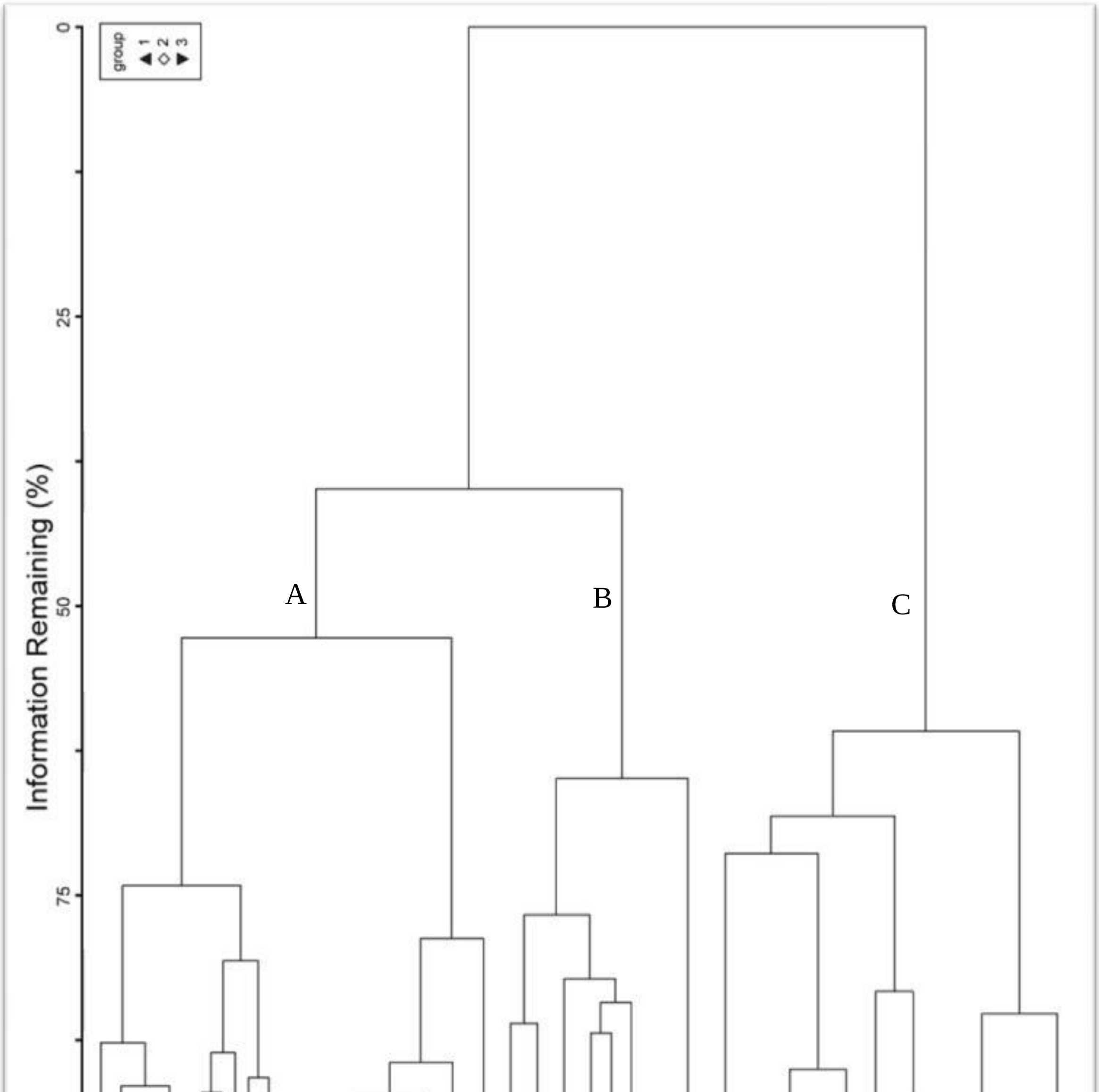


Figure 9 Dendrogram of the cluster analysis result of species abundance data of Nandi Forests. The level of grouping was based on 50% information remaining. Plots forming the same cluster group (plant community) have the same symbols.

Table 9 Indicator values of species for the identified plant community of Nandi Forests. The probability value refers to Monte Carlo tests, while values under each group are indicator values (only those with ≥ 40%), which indicate the faithfulness of occurrence of species within a particular group or community (Dufrêne and Legendre, 1997).

Species name	**1**	**2**	**3**	**Probability**
Oplismenus hirtellus	87	8	0	0.001
Diospyros abyssinica	**80**	5	12	0.001
Heinsenia diervilleoides	**80**	2	4	0.001
Cissus rotundifolia	80	7	0	0.001
Cassipourea ruwensorensis	78	3	12	0.001
Salacia cerasifera	72	18	0	0.001
Rutidea orientalis	72	0	0	0.001
Prunus Africana	70	3	10	0.001
Tiliacora funifera	67	25	0	0.001
Dracaena laxissima	65	27	2	0.001
Culcasia falcifolia	63	10	11	0.002
Drypetes gerrardii	63	34	0	0.001
Peperomia abyssinica	63	4	0	0.001
Dorstenia brownii	52	31	0	0.002
Piper capense	52	42	1	0.002
Acanthopale pubescens	52	7	31	0.008
Achyranthes aspera	51	12	27	0.001
Keetia gueinzii	51	5	10	0.002
Strombosia scheffleri	51	49	0	0.003
Oxyanthus speciosus	51	5	5	0.01
Allophylus abyssinicus	50	20	29	0.002
Deinbollia kilimandscharica	49	26	4	0.007
Cribbia brachyceras	48	2	2	0.003
Artabotrys likimensis	48	3	0	0.001
Xymalos monospora	47	22	0	0.001
Chionanthus mildbraedii	44	1	1	0.002
Coffea eugenioides	43	9	11	0.061
Impatiens cf niamniamensis	42	3	0	0.002
Asplenuim elliottii	40	0	0	0.001
Trilepisium madagascariense	6	**90**	0	0.001
Solanum mauritianum	8	**78**	9	0.001
Mimulopsis arborescens	15	69	0	0.001
Lepidotrichilia volkensii	18	68	0	0.001
Polyscias fulva	17	60	2	0.001
Trema orientalis	4	56	0	0.001
Ficus sur	7	59	0	0.001

Table 9 continued

Species name	**1**	**2**	**3**	**Probability**
Piper umbellatum	0	54	0	0.001
Celtis durandii	0	59	0	0.001
Alangium chinensee	18	51	0	0.001
Macrorungia pubinervia	33	51	4	0.005
Chlorophytum zavattarii	21	45	1	0.006
Croton megalocarpus	28	49	0	0.003
Sericostachys scandens	14	44	0	0.003
Tabernaemontana stapfiana	30	48	4	0.004
Gouania longispicata	21	45	5	0.005
Macaranga kilimandscharica	28	44	7	0.018
Adenostemma caffrum	19	41	2	0.006
Pseudechinolaena polystachya	0	0	100	0.001
Justicia striata	1	0	99	0.001
Turraea holstii	11	0	**82**	0.001
Ehretia cymosa	1	0	**78**	0.001
Syzygium guineense	4	0	76	0.001
Lippia kituiensis	0	0	74	0.001
Vangueria madagascariensis	12	4	68	0.001
Erythrococca trichogyne	14	6	66	0.001
Ouratea hiernii	0	0	67	0.001
Erythrococca fischeri	25	3	64	0.001
Dovyalis macrocalyx	27	1	61	0.001
Asplenium aethiopicum	10	0	56	0.001
Loxogramme abyssinica	27	0	55	0.001
Asplenium theciferum	11	0	54	0.001
Croton macrostachyus	1	0	54	0.001
Landolphia buchananii	35	3	51	0.003
Ekebergia capensis	17	1	51	0.001
Celtis Africana	18	20	51	0.003
Gloriosa superb	0	1	49	0.001
Albizia gummifera	7	13	48	0.005
Solanum mauense	0	0	48	0.001
Desmodium repandum	40	5	45	0.010
Maytenus heterophylla	0	0	44	0.001
Solanum terminale	2	1	43	0.002
Casearia battiscombei	23	3	41	0.019
Stephania abyssinica	2	0	41	0.004
Clerodendrum johnstonii	2	0	40	0.001
Hippocratea Africana	28	29	40	0.139

C. *Turraea holstii - Ehretia cymosa* community (North Nandi Forest)

This community comprises 27 plots which are all from North Nandi forest. There are 60 species that are associatee with this community. It occurs in the altitudinal range of 2020 to 2089 m (having 2059 m mean altitude) on gentle slope of topography. There are many indicator species with significant indicator value (Table 9) and this include *Pseudechinolaena polystachya, Justicia striata, Turraea holstii, Ehretia cymosa, Syzygium guineense, Lippia kituiensis, Vangueria madagascariensis, etc. Syzygium guineense, Ehretia cymosa, Turraea holstii, Vangueria madagascariensis, Ouratea hiernii, Croton macrostachyus* and *Maytenus heterophylla* are the most common tree species of this community. *Lippia kituiensis, Erythrococca trichogyne, Erythrococca fischeri, Dovyalis macrocalyx, Solanum mauense, Vernonia auriculifera, Acalypha ornata* and *Rubus steudneri* are the most common shrub species. This community has very sparse shrub layer when compared to the other two communites of Nandi forests. The herb layer of this community is dominated by *Pseudechinolaena polystachya, Justicia striata* and *Spermacoce princeae.* The most common climbers of this community are *Clerodendrum johnstonii, Landolphia buchananii, Stephania abyssinica, Scutia myrtina, Jasminum floribundum* and *Scleria distans.*

3.3.7 Ordination

The distribution of the study plots in Nandi forests over environmental gradient was well explained using Deterended Coresponance Analysis (DCA) which is an indirect gradient analysis. The result of the ordination is complementing to the cluster analysis which was resulted in there plant communities. The eigenvalue of the first axis of the DCA is 0.74 which is much higher than the eigenvalues of the rest of the axes (Table 10). This shows that the first axis has the strongest influence for the variation. Hence, it is the most important environmental variable contributing about 27.4% of the total variation. The second axis having the eigenvalue of 0.248 explains 9.2% of the variation. Generally, the first four axes accounted for 45.2% of the variation (Table 10).

Table 10 Eigenvalues of the first four axes of DCA and the amount of variance explained by each axes in two Nandi Forests

Axes	I	II	III	IV	Total inertia
Eigenvalues	0.740	0.248	0.149	0.083	2.699
Lengths of gradient	3.712	2.787	1.736	1.692	
Cumulative % variance of species data	27.4	36.6	42.1	45.2	

The plots which are found on the left side (the circles) of the first DCA axis are those sampled from South Nandi Forest (Fig. 10) and those from North Nandi (the triangles) are situated on the right side of first axis.

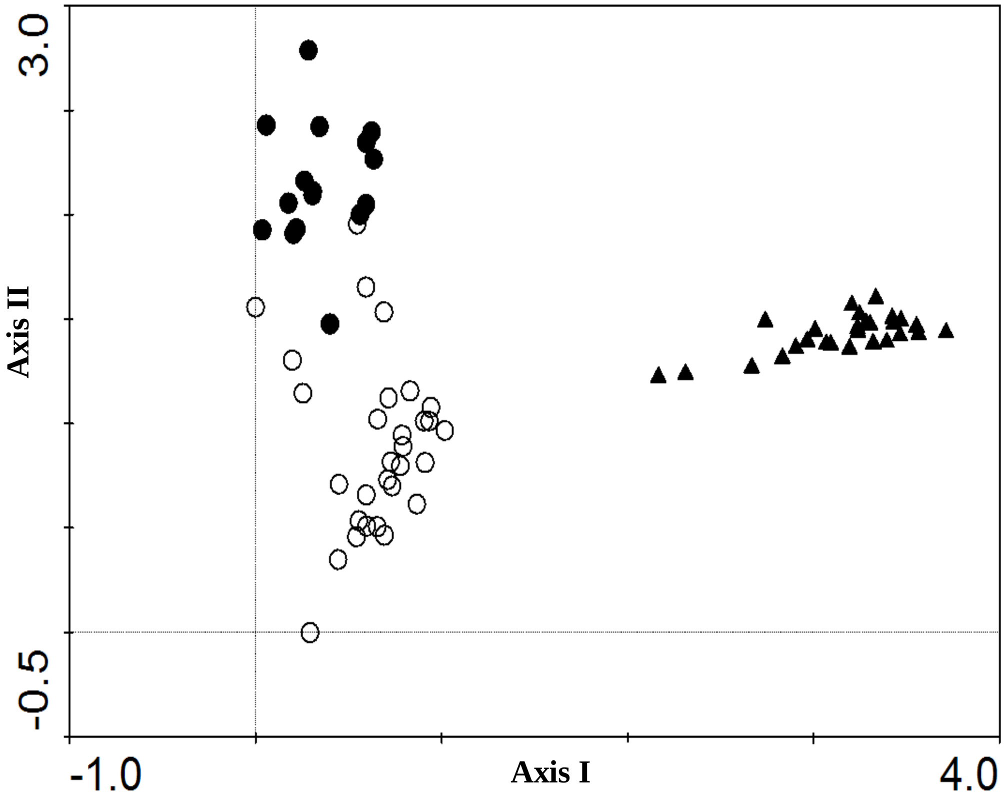


Figure 10 Ordination based on Detrended Correspondence Analysis (DCA) with abundance of species from Nandi Forests. One symbol represents one plot, circles (● and○) are samples from south Nandi and Triangles (▲) are from North Nandi

The first axis reflects the altitudinal difference between the two forests (North and South Nandi forest), the plots which are sampled from the North Nandi forest have higher altitude than those of South Nandi. However, this altitudinal difference might also be coupled with other environmental factors such soil, rainfall, temperature, disturbance etc or by the combination of all these factors. Hence, this first axis can be a single factor or it could be a combination of two or more factors.

The second axis reflects disturbance (anthropogenic) gradient. The plots that are situated on the top of this axis (filled circles) are those found in highly disturbed part of South Nandi forest (Fig. 10). Those found at the lower part of this axis (open circles) are plots from relatively better part of South Nandi forest. Form the disturbance point of view the plots from North Nandi are situated in the middle of the second axis which shows that the disturbance rate in this forest is between relatively highly disturbed and less disturbed sites of South Nandi forest. The sources of disturbances are also different in North and South Nandi forests. In South Nandi, the major factors are charcoal burning and illegal logging. But in North Nandi, the main disturbance factor is graizing.

3.4 Discussion

3.4.1. Floristic composition

Generally tropical forests are among ecosystems that have high specie diversity of the world (Wilson, 1988; Gentry, 1992). East African forests are also considered as center of botanical endemisim (Lovett, 1998). Reports by Coetzee (1978) and Tamrat (1993) revealed that east African montane forests are among the most diverse and richest African regions with regard to flora composition. In fact it is difficult to compare the species richness of one area with others directly as there might be difference in forest size, data collection methodology and objectives of the studies. However, species richness can show the overall diversity of a given forest. In this regard Nandi forests are not poor in species richness though the number of species is less when compared to other Kenyan and neighboring countries forests.

In total 321 species were recorded in Nandi forests. These forests were connected with Kakamega forest (Lug and Schaab, 2010; Schaab *et al.*, 2010) which is found to the west of Nandi forests. Althof (2005) has reported that Kakamega forest has 400 species of vascular plants. More recently the number of vascular plant species of Kakamega forest is reported to be 986 (Fischer *et al.*, 2010). Higher number of vascular plant species were also recorded in Shimba Hills (1396) (Luke, 2005) and Aberdare Natioanl Park (778) (Schmitt, 1991); implying that Nandi forests are florstically poorer than these forests. In the eastern ridge of Lake Kivu (Rwanda) totally 722 vascular plant species were recoded (Habiyaremye, 1997). In Budongo forest which is found in neighboring Uganda, 269 tree species were identified (Mwavu, 2007) and this number could be higher if the number of all vascular plants with other growth form (i.e. herbs, climbers, etc) were included. In Brihane-Kontir forest which is an Afromontane rainforest in Ethiopia, 374 plant species were recorded (Feyera, 2006). This difference in number of species between Nandi forests and the others might be resulted from relative location of the frorests as well as their altitude. All these forests have lower altitude than that of Nandi forests. On the otherhand, in Nandi forests relatively higher number of species were recorded than other afromontane forests of Ethiopia such as Bonga (285), Maji (146), Harenna (289) (Feyera, 2006) and Yayu (220) (Tadesse, 2003). All these differences in species richness among these sites could mainly attributed to the dismilarities of the sites in terms of location, altitude, human impact, rainfall, and other biotic and abiotic favtors.

The other difference between Nandi forests and Kakamega is their administrative arrangement, which might have something to do with florstic composition. Kakamega forest is administered by both Kenyan Wildlife Service (KWS) and Kenyan Forest Service (KFS) while Nandi forests are managed only by KFS. Forests managed by KWS are kept for conservation and tourism and people are not allowed to collect any forest products (Glenday, 2006; Yeshitela, 2008). However, in KFS managed forests, grazing, collection of dead fuelwoods, medicinal plants and thatching grass are permited but logging and charcoal burning are not allowed (Glenday, 2006). This strict conservation based management by KWS might also be contributed to maintain more species in Kakamega forest. Surveyes showed that people, who are living adjacent to forests that are managed by KFS, are reliant on forest recources, with approximately 60% of average household income directly tied to forest uses (Sharp, 1993; Emerton, 1994; Nambiro, 2000). Cattel garazing, illegal logging (pit sawing) and charcoal burning are common in Nandi forests. Therefore, this kind of excessive reliance on forest could affect the abudance as well as the existence of some species in Nandi forests.

In this study it has been observed that about 64% of the recorded species are rare. For instance, rare species like *Eulophia galeoloides, Canarina abyssinica* and others are recorded. Rare taxa are those having low abundance or small ranges (Gaston, 1994). Any combination of biological or physical factors or both could restrict either species abundance or geographical range (Cowling, 1990). It has been also seen that only 51 species, which are 18.8% of the recorded species of Nandi forests have absolute frequency of 50% or more. Althof (2005) reported that there are twenty-seven woody species in Kakamega forest but not recorded in other parts of

Kenya. These include *Acacia montigena, Achyrospermum parviflorum, Aningeria altissima, Bequaertiodendron oblanceolatum, Cassipourea ruwensorensis, Chionanthus mildbraedii, Chrysophyllum albidum, Clerodendrum buchholzii, Craterispermum schweinfurthii, Dracaena fragrans, Entandrophragma angolense, Illigera pentaphylla, Leea guineense, Maesopsis eminii, Monodora myristica, Oreobambus buchwaldii, Ouratea densiflora, Ouratea hiernii, Piper guineense, Premna angolensis, Pseuderanthenum ludovicianum, Rothmannia longiflora, Rothmannia sp., Uncaria africana, Uvariopsis congensis*, and *Vernonia conferta*. However, in this 11 of these species were also recoded in Nandi forests. These species are *Acacia montigena, Aningeria altissima, Bequaertiodendron oblanceolatum, Cassipourea ruwensorensis, Chionanthus mildbraedii, Chrysophyllum albidum, Dracaena fragrans, Illigera pentaphylla, Ouratea hiernii, Pseuderanthenum ludovicianum* and *Uncaria africana*. Further more, Althof (2005) recorded 15 woody species for the first time in Kakamega forest including *Artabotrys likimensis, Basella alba, Connarus longistipitatus,* and *Meyna tetraphylla,* which were also recorded in Nandi forests during this study.

3.4.2 Alpha and beta diversity

When the two Nandi forests compared separately higher mean number of species per plot as well as total species richness were recorded in South Nandi forest. In fact it is difficult to conclude South Nandi forest has higher number of species than that of North Nandi based on this alpha diversity or total species richness as the number of quadrate from the two forests differ. Using rarefaction curve this difference was proven to be statistically significant. Relatively higher beta diversity is observed in South Nandi forest and this means that South Nandi has relatively higher species turnover than that of North Nandi. The difference in species richness of these forests might be attributed to the difference in geographical location, elevation and disturbance (rate and type). North Nandi forest is situated on higher altitude than that of the South Nandi forest and this could affect the number of species that can exist in North Nandi forest. Many types of environmental changes influence the processes that can both augment or erode diversity (Sagar *et al*., 2003). Ellu and Obua (2005) have suggested that different altitude and slopes influence species richness and dispersion behavior of tree species. Altitude and climatic variables like temperature and rainfall are also other determinant factors that affect species richness (Kharkwal *et al*., 2005). Sharma *et al*. (2009) also reported that as altitude increases the species richness and species diversity decrease in temperate forest of Garhwal Himalya.

Both of the forests are not intact but the intensity and main causes for disturbance are not the same. In South Nandi forest major cause of disturbance are charcoal burning and pit sawing (illegal logging). Free grazing is the main disturbance cause in North Nandi but charcoal burning and illegal logging is not as intense as that of South Nandi forest.

Charcoal making is an important economic sector in Kenya and it was reported that it gives an employment opportunity for about 200,000 Kenyans in the production sector alone (Mugo and Ong, 2006). It is also reported that about 20% charcoal come from government forests (Anonymous, 2002). Therefore, one can imagine that how this activity can affect species diversity when it is undertaken unsustainably. In South Nandi forest high rate of charcoal burning especially in Bonjoge area was witnessed and this gives way to the invasion of the forest site by *Solanum mauritianum*. On the other hand uncontrolled grazing also has its own effect on plant species diversity as some well palatable species are expected to be more severely affected by cattle than others, perhaps in the long run resulting in dominance of grazing resistant species (McNaughton, 1983, 1985; Pueyo *et al*., 2006). Hence lower diversity of North Nandi forest could also be attributed to the heavy grazing which was observed during the field work. Furthermore, removing (cutting) bigger trees for charcoal or pit sawing my open up space and encourage seedling regeneration as far as there is enough mature tree to produce seed. In some part of the South Nandi forest (southern part of the forest) charcoal burning is not as heavy as in the western part and this might help the southern part in having better seedlings of woody plants than that of North Nandi forest as well as the western part of South Nandi. However, both charcoal burning and illegal logging could damage seedlings and create shortage of viable seeds for proper regeneration if the harvesting is heavy. Therefore, charcoal making and/or illegal logging and uncontrolled grazing can result in less species diversity.

Both incidence based and abundance based similarity indices resulted in very low similarity indices i.e. 0.39 (Sørensen) and 0.38 (Jaccard) (for incidence based) and 0.38 (Chao-Sørensen estimator) and 0.25 (Chao-Jaccard estimator) (for abundance based). This means the similarity of the species composition of the two forests ranges between 25 to 39%. This law similarity index may result of fragmentation, geographic location and/or altitudinal difference as well as difference in intensity and type of disturbance between the two forests or combination of these factors. Furthermore, in both similarity indices (Jaccard and Sørensen) incidence based similarity indices have relatively higher index than their respective abundance based indices. As the abundance based indices take unseen but shared species into consiederation (Chao *et al*.,

2005) normally values of abundance based indices must be greater than the respective incidence based indices. However, the revers can be happen when the two communities shared only the common species as the contribution of the unseen species is becoming not substantial (Robin Chazdon 19/03/2011 personal communication).

In both forests the top species rich families are more or less the same even if there is difference in their order. Some of these families for instance Asteraceae, Rubiaceae, Euphorbiaceae, and Moraceae are said to be always among the top 10 species-rich families in many neotropical forests (Gentry, 1988; 1992). Hence, the dominance of these families in this study is in agreement to their general dominance in tropical forests.

3.4.3 Species accumulation curve and species richness estimation

Species accumulation curve is useful to show how much of the species in a given ecosystem are sampled given the sampling effort (number of samples) and the rate of including new species if the sampling effort proceed. As it is shown in Figure 8 the accumulation curves of both forests did not attain its asymptote revealing that there are new species to be recorded if sampling continues though in a decreased rate than at the beginning of the sampling stage. But the rate of recording new species is lowern in North Nandi than that of South Nandi forest. Comparing mean number of species per plot is not possible for different number of sample as number of species is highly affected by sample size (Magurran, 2004). However, one can use rarefaction for this purpose. As indicated in section 3.3.3 rarefaction curve of North Nandi forest is outside of the 95% confidence interval of that of South Nandi forest indicating that South Nandi has higher species richness than that of North Nandi. Magurran (2004) explained that if the observed diversity of smaller community lies within the 95% confidence limits of the rarefaction of the larger community then there is no significant difference between the two communities. Similarly Colwell *et al* (2004) compared tropical rainforest by sampling old and secondary growth forests and concluded that when confidence intervals overlap, the difference in species richness is not significant and when the confidence intervals do not overlap species richness is significantly different. In this study, the number of species that are observed in North Nandi, which has smaller species richness, is out of the 95% confidence limits of South Nandi. This confirms that North Nandi forest has significantly less number of species than South Nandi forest.

One of the most commonly used measures of species diversity, or biodiversity, is species richness (Colwell and Coddington, 1994; Chiarucci *et al*., 2003). Species richness as a measure of diversity is very attractive to ecologists because it is simple, easily calculated, readily appreciated, and easy to communicate to policy makers and other lay people (Purvis and Hector, 2000). It provides a fundamental measure of community status in quantitative assessments of biological diversity (Dorazio *et al.*, 2006). However, complete enumeration of species richness (total number of species) for large-scale study of community is difficult, especially for sampling units exceeding a few hundreds of square meters (Palmer, 1995, Palmer *et al.*, 2002; Chiarucci *et al.*, 2003). But, estimating species richness is a central activity in studies of biodiversity (Magurran 2004). Species richness has been suggested as a useful indicator to monitor changes in ecological integrity (Dale and Beyeler, 2001), and as necessary tool to make informed decisions in conservation biology (Hellmann and Fowler, 1999; Walther and Martin, 2001). Thus, there are various numerical methods that are developed to estimate species richness reliably (Heltshe and Forrester, 1983; Chao, 1984, 1987; Colwell and Coddington, 1994; Walther and Morands, 1998).

In this study total number of species is estimated using different non-parametric species estimators which are applicable to quadrate-based data sets (Heltshe and Forrester, 1983). Based on these estimators the number of species in North Nandi forest was estimated in the range of 175 to 209 while that of South Nandi forest is estimated to be between 220 and 284. This estimation revealed that in our work 77 to 92% of North Nandi forest species as well as 74 to 96% of South Nandi forest species were recorded. Generally, the species richness of Nandi forests estimated to be in the range of 287 to 359 and this study covered 75-94% of the estimated number of species. It has been reported that collecting 50-75% of the total number species of a given area might be satisfactory (Heck *et al.*, 1975). Therefore, in our study sufficient species of both South and North Nandi forests were recorded.

It has been observed that in our study all species richness estimators gave higher number of species than that of recorded in the study quadrats. In both forests the highest species richness estimation (283.45 for South Nandi and 208.52 for North Nandi) was obtained by second order Jackknife estimator. Abundance coverage estimate (ACE) gave the lowest species richness estimate (174.53) for North Nandi. While the smallest estimate for South Nandi (219.6) was obtained by Chao 1 estimator.

3.4.4 Plant communities

Plant community is the collection of plant species growing together in a particular location that shows a definite association or affinity with each other (Kent and Coker, 1992). Mulller-Dombois and Ellenberg (2002), expressed plant community formation as a function of the flora of a given area (or simply a species), the ability of a given species to reach the habitat in question (accessibility factor), ecological plant properties (life forms, their physiological requirements and other characteristics of the species), the habitat and the time (that has passed following a major historical event that initiated vegetation invasion or a change of one or another habitat factor). In this study it has been tried to look into the palnt communities that were formed in Nandi forests and three different communities were identified. The altitudinal difference coupled with other environmental variation such as soil, slope, etc. as well as the type and intensity of disturbance and species ecological requirements might be contributed to the formation of these communities.

In this study, cluster analysis coupled with indicator species analysis and ordination was used to identify the plant communities. The two multivarate (cluster analysis and ordination) techniques result complement to each othere. The plant communities from North and South Nandi forests were formed separetly based on these multivariate analysis techniques. These communities have their own distinict characterstics species. For instance, several species were confined only to South Nandi forest. These include *Oplismenus hirtellus, Cissus rotundifolia, Salacia cerasifera, Rutidea orientalis, Tiliacora funifera, Drypetes gerrardii, Peperomia abyssinica, Strombosia scheffleri, Artabotrys likimensis, Xymalos monospora, Impatiens cf. niamniamensis, Ochna inscuplta, Ficus sur, Piper umbellatum, Celtis durandi, Alangium chinensee, Croton megalocarpus, Sericostachys scandens, Crassocephalum montuosum, Aningeria altissima, Mondia whytei*, etc (Table 9). Similarly there are charachteristic species of North Nandi which include *Pseudechinolaena polystachya, Lippia kituiensis, Ouratea hiernii, Solanum mauense, Maytenus heterophylla, Doryopteris kirkii, Scleria distans, Thalictrum rhynchocarpum, Laggera elatior, Acalypha ornata, Cynoglossum lanceolatum, Jasminum floribundum, Solanum hastifolium, Spermacoce princeae* etc that were recorded only in North Nandi (Table 9). Further more, other characteristic species of Afromontane distribution were identified. This species include *Diospyros abyssinica, Croton megalocarpus, Deinbollia kilimandscharica, Olea capensis, Neoboutonia macrocalyx, Acanthopale pubescens, Allophylus abyssinicus* and *Strombosia scheffleri.* There are also transitional species which have both Afromontane and

Guino-Congolia nature these include, *Heinsenia diervilleoides, Trilepisium madagascariense, Solanum mauritianum, Trema orientalis, Alangium chinensee, Ficus sur* and *Kigelia africana*.

South Nandi forest has two different plant communities (i.e. community A and community B). These communities might be the result of difference in disturbance rate and other biotic and abiotic factors or combination of these factors. In community A (*Diospyros abyssinica-Heinsenia diervilleoides* community), the majority of the plots (24 plots) are from relatively less disturbed part of South Nandi forest and the rest (4 plots) are from heavily disturbed part of this forest. In this community some of the characteristic species are those of Guineo-Congolian, such examples are *Aningeria altissima, Artabotrys likimensis, Culcasia falcifolia, Dracaena laxissima,* and *Mondia whytei*. In addition to these Guineo-Congolian species, there also afromontane species like *Diospyros abyssinica, Heinsenia diervilleoides, Cassipourea ruwensorensis, Prunus africana, Drypetes gerrardii,* and *Strombosia scheffleri* in this community. Community B (*Trilepisium madagascariense-Solanum mauritianum* community) is comprised of 16 plots which are from heavily disturbed part of South Nandi forest. The characteristic species of this community are *Trilepisium madagascariense, Solanum mauritianum, Lepidotrichilia volkensii, Polyscias fulva, Trema orientalis, Ficus sur, Piper umbellatum, Celtis durandi, Alangium chinensee, Croton megalocarpus, Tabernaemontana stapfiana* etc (see Table 9). Most of these species are either transitional or afromontane species. In this community pioneer species like *Solanum mauritianum, Polyscias fulva, Trema orientalis, Piper umbellatum and Croton megalocarpus* become dominant because of the open space created by harvesting trees for charcoal production.

Community C (*Turraea holstii - Ehretia cymosa* community) is comprised of 27 plots which are all from North Nandi forest. The characteristics species of this community is dominated by Afromontane species and these include *Syzygium guineense, Vangueria madagascariensis, Croton macrostachyus, Ekebergia capensis, Celtis africana, Albizia gummifera* and *Casearia battiscombei*. There are also transitional species like *Ehretia cymosa, Erythrococca fischeri, Erythrococca trichogyne, Maytenus heterophylla* and *Stephania abyssinica* as characteristics species of this community. The Guineo-Congolian species in this community include *Ouratea hiernii* and *Clerodendrum johnstonii* as indicator species.

In both forests, there are all Afromontane, Guineo-Congolian and transitional species as characterstics or indicator species. This might be due to the geographical location of these forests. White (1983) described Nandi forests together with Kakamega forest as the Lake Victoria regional mosaic. He explained this Lake Vectoria regional mosaic as the meeting-place of five distinct floras: Guineo-Congolian, Sudanian, Zambezian, Somalia-Masai and Afromontane. Thus, this specific geographical position of Nandi forests resulted in having Guino-Congolian, transitional (both Guineo-Congolian and Afromontane) and Afromontane species.

Nandi forests have smaller number of plant communities when compared to the neighboring Kakamega forest. As it was described by Althof (2005) there are thirteen plant communities and two subcommunities in Kakamega forests. This huge difference might be directly related to the superiority of Kakamega forest interms of species richness and diversity which is the result of altitudinal difference of the forests.

When we compare the plant community of Nandi forests with that of Mount Kenya and that of Aberdare National Park the difference is wider than Nandi vs Kakamega. Even if the methodology used to describe plant communities of Nandi and these forests is different, it is possible to highlight the commonuities of Mount Kenya and Aberdare to see how different the vegetations are.

According to Bussmann (1994), the six forest formations were identified in Mount Kenya vegetation. These include evergreen submountane forests, evergreen deciduous submontane forests, evergreen broadleaved montane forests, evergreen xeromorphic montane forests, evergreen montane bamboo and evergreen subalpine forests. The vegetation is further devided into four vegetation classes, comprising five orders, 10 alliances, 41 associations and 48 subassociations, and two fazies.

In Aberdare National Park four vegetation formation classes (i. e. grass land and secondary bushland (submontane to subalpine), forest, bush-and shrubland, and grassland (edaphic, subalpine and alpine) were identified by Schmitt (1991). These four formations incorporated totally 42 plant communities.

Forest formation of Aberdare National Park mainly classified into three groups (i.e. submontane, montane and subalpine) based on altitudinal zonation using floristic criterions (Schmitt, 1991). Moreover, Schmitt used easily recognizable physiognomic features to subdivide the four fourst classes (i. e. submontane (evergreen seasonal forest, evergreen forest and evergreen xeromorphic forest), montane (evergreen xeromorphic forest, evergreen montsane and evergreen montane bamboo forest), and subalpine (Evergreen *Hagenia abyssinica* forest and Evergreen *Hypericum revolutum* forest).

The huge difference in the number of plant communities or associations between Aberdare National Park and Mount Kenya vegetation might be attributed to the area coverage as well as the altitudinal range of these ecosystem covering. For example, in terms of area coverage Mount Kenya forest coverd about 2000 km^2 (200,000 ha) and the mountain reaches upto 5199 masl (Bussmann, 1994) while Aberdare National Park has an area of 760 km^2 (76, 600 ha) with highest peak 4001 masl (Schmitt, 1991).

The characteristic species recognized in Nandi forests were also used as differential species of Mount Kenya forest and vegetation of Aberdare National Park. For instance, *Diospyros abyssinica*, *Tiliacora funifera* and *Drypetes gerrardii* are characteristic species of *Diospyros abyssinica-Heinsenia diervilleoides* community. Bussmann (1994), also described these species as differential species of different associations of Mount Kenya vegetation. Similarly, *Piper umbellatum* is one of the character species in *Trilepisium madagascariense-Solanum mauritianum* community of this study and it also used to identify the *Myrianthetum holstii-Piperetosum umbellatae* sub-association from other associate/sub-association of Mount Kenya (Busmmann, 1994). *Ehretia cymosa, Syzygium guineense, Celtis africana* (Bussmann, 1994), *Ekebergia capensis* and *Albizia gummifera* (Schmitt, 1991; Busssmann, 1994) were used as differential species as it has been done for *Turraea holstii - Ehretia cymosa* community.

3.4.5 Description of east African mountain forests

Different authors described the forests of east Africa mountains differently. The main factors for these descriptions were altitude, physiognomic criteria, floristic criteria, species dominance and edaphic factors (Bussmann, 1994). Schmitt (1991) and Bussman (1994) reviewed most of these works which were conducted starting the 1920s till early 1990s. Table 11 shows some of the selected vegetation classification of east African mountains.

Table 11 Classification (zonation) of esat African mountain forests by different authors

Classification (zone)	**Altitude (masl)**	**Rainfall (mm)**	**Author**❖
Montane rain forest	Up to 2400		Engler, 1925
Bamboo region with			
Lower bamboo region	2400-2800		
Upper bamboo region	2800-3200		
High altitude forest and high mountain bush	3200-3300		
Montane rain forest with	Up to 2380		Fries and Fries, 1948
Drier rain forest			
Humid rain forest			
Bamboo zone with			
Lower bamboo zone	2380-2840		
Upper bamboo zone	2840-3200		
Hagenia-Hypericum zone	3200-3300		
Submontane forests	800-1500	2500-3000	Pócs, 1976
Mesophilous montane forest	1500-1800 partly 2000-2400	>3000	
Montane rain forest	1500-2400	<3000	
Montane mossy forest	1850-2400	>3000	
Riverine forest			
Subalpine elfin forest	>2400	>2100	
Afromontane rainforest	1500-2600	700-1500	Friis,1991
Undifferentiated forest			
Dry single dominant forest	(1600)-2200-3200	900-1500	
Submontane forest	800-1400	>1500	Lovett, 1993
Montane forest	1200-1800	>1200	
Upper montane forest	>1800	>1200	
Dry montane forest	>1800	1000-1200	

❖ Authors are cited in Bussmann, 1994

According to the above vegetation classification Nandi forest can be considered as Montane rain forest (Engler, 1925; Pócs, 1976) or Montane rain forest with Humid rain forest (Fries and Fries, 1948) or Afromontane rainforest (Friis,1991) or Upper montane forest (Lovett, 1993).

4. Population Structure of Nandi Forest

4.1 Introduction

Vegetation structure is defined by Dansereau (1957) as the organization in space of the individuals that form a stand (and by extension a vegetation type or a plant association) and he stated that the primary elements of structure are growth form, stratification, and coverage. This definition is still valid (Mueller-Dombois and Ellenbrg, 2002); however, the term vegetation structure is used with different meanings. According to Mueller-Dombois and Ellenbrg (2002), in vegetation ecology one may speak of vegetation stratification at least at five levels i.e. vegetation physiognomy, biomass structure, life form structure, floristic structure and stand structure. On the other hand, Kershaw (1964) summarzied vegetation structure into three components. These include: (a) vertical structure (i.e. stratification into layers); (b) horizontal structure (i.e. spatial distribution of species populations and individuals), and (c) quantitative structure (i.e. abundance of each species in the community).

Another ecological terminology but more or less with similar meaning with that of vegetation structure often in use is population structure. Population structure is a description of vegetation based on external morphology, life-form (growth form); stratification and size of the species present (Kent and Coker, 1992) in a given vegetation. Population structure carries a wealth of demographic information and is frequently the most unequivocal and accessible attribute available for a population (Souza, 2007). Population structure of a forest is influenced by both biotic and abiotic factors which have their own impact on ecological processes.

For instance, when it is described based on growth form i.e. trees, shrubs, climebers, herbs, etc it is genetically (biotic factor) inherited attributes. In another way it can be described by height or diameter class distribution (size class distribution) of individuals found in a given plant community or population. This kind of description is also named as stand structure (Mueller-Dombois and Ellenbrg, 2002). These individual characterstics (height and diameter) which are directly related to growth and development, are highly influenced by environmental factors such us temperature, rainfall, soil, disturbance, etc as well as the genetics of individuals. The size distribution of a population is a synthesis of the demographic events of recruitment, mortality and individual growth rates over time (Kelly *et al.*, 2001).

Population structure of a given forest or species can tell something what is/was going on in that forest. Population (age) structure of a species in a forest can convey its regeneration behavior (Saxena and Singh, 1984). Theoretical population models predict that the shape of population size distributions results from the interaction between size-specific survival, growth and fecundity (Condit *et al.*, 1998; Case, 2000; Caswell, 2001). Population structures, characterized by the presence of a sufficient population of seedlings, saplings and young trees, indicate a successful regeneration of forest species (Saxena and Singh, 1984).

In this study the emphasis is given to the meaning of growth form structure as well as stand sturacture (Mueller-Dombois and Ellenbrg, 2002) or vertical stratification focusing on height class distribution, quantitative structure (Kershaw, 1964) and diameter class distribution. It describes that how the population of Nandi forests distributes in size classes (height and diameter) as well as the proportion of each growth forms (trees, shrubs, climbers, herbs and epiphytes) in this ecosystem.

4.2 Material and Methods

4.2.1 Study sites

This study was under taken in Nandi Forests i.e. North and South Nandi Forests, in the Rift Valley Province of western Kenya. A detailed description of the study sites is given in chapter two (section 2.1)

4.2.2 Data collection and analysis

To collect vegetation data 76 plots (20 m by 20 m each) which were laid on transect were used. Out of the total 76 plots 49 of them were laid in South Nandi forest and the rest of the plots were used in North Nandi forest. All woody plants with height greater than or equal to one meter as well as with diameter at breast height (dbh) which is equal or more than two centimeter were measured and recoded. Diameter was measured using diameter tape and hypso meter was used to measure height for tall trees while height of saplings was measured by marked sticks. Frequency and abundance of all woody plant species (trees, shrubs and lianas) were recorded on a plot basis. To record seedlings of all woody plant species (which have height of 10 to 100 centimeters) five, three by three meter plots in the bigger plot was used. These subplots were situated on the four corners and one at the center of the main plots.

Based on the information from literature and field observation species were grouped to one of the five growth forms i.e. trees, shrubs, climbers, herbs and epiphytes. Size class distribution was carried out for height (100 cm and above) and diameter classes (2 cm and above).

Size class distribution for both height and diameter at breast height (dbh) was constructed. Basal area of each woody plant species that have dbh ≥ 2 cm was computed using the following formula.

$$BA = \frac{\pi D^2}{4}$$

Where BA is basal area, π is 3.14 and D is diameter at breast height (at 1.30 m)

To test stastical difference between the mean basal areas of the two forests non-parametric test was conducted using SPSS visrion 16.0 statistical software. As two of the plots have very high basal area due to very big *Prunus africana* and *Ekebergia capensis* they were considered as outliers and excluded from this analysis.

The Importance Value (IV) of species is useful to describe and compare the species dominance of the forests (Kent and Coker, 1992). The IV of a species is the sum of its relative dominance, relative density and relative frequency. The calculation of these components of IV was done using the following formulae (Kent and Coker, 1992).

$$\text{Relative density} = \frac{\text{Number of individuals of the species}}{\text{Number of individuals of all species}} \text{x}100$$

$$\text{Relative dominance} = \frac{\text{Total basal area of the species}}{\text{Total basal area of all species}} \text{x}100$$

$$\text{Relative frequency} = \frac{\text{The frequency of species}}{\text{Frequency of all species}} \text{x}100$$

4.3 Results

4.3.1 Growth forms

As compared to other classification of growth forms for example Raunkiaer (1934), in this study simple classification of growth forms are adapted. The information obtained from filed and literature were used for categorizing the recorded species into one of the five different growth forms, i.e. trees, shrubs, herbs, epiphytes and climbers.

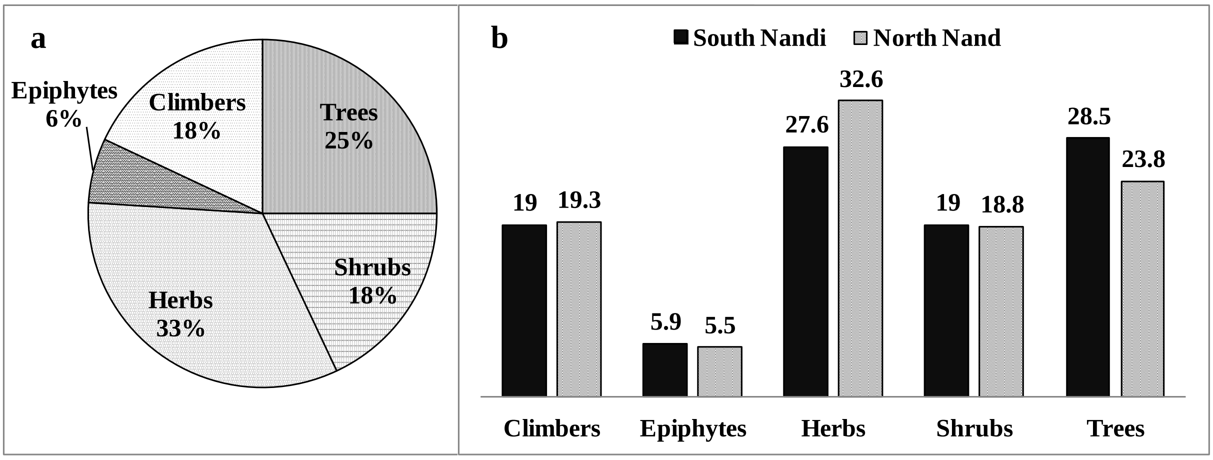


Figure 11 Species diversity according to growth form in Nandi Forests (a) and North and South Nandi Forests separately (b). Numbers on top of the bars are percentage proportion of species in respective growth forms.

As it is depected in Figure 11a, herbaceous species accounted for 33% of the total number of species observed in Nandi Forests. Trees and shrubs together comprised 43% (tree 25% and shrub 18%) of the total number of species. Climbers and epiphytes contributed 18 and six per cent of the total number of species, respectively.

When the whole data set is analyzed separately for the two forests of Nandi, in North Nandi forest still herbs accounted for the upper hand (32.6%). Trees, shrubs, climbers and epiphytes contributed 23.8, 18.8, 19.3 and 5.5 per cent, respectively (Fig. 11b). In the South Nandi forest, trees and herbs comprised together 56.2% (Trees (28.5 % and herbs 27.6%) of species recorded in this forest while climbers, shrubs and epiphytes accounted for 19, 19 and 5.9 %, respectively (Fig. 11b).

4.3.2 Height class distribution

Generally large proportion of woody plants that were identified in Nandi forest was found in the lower height class (Fig. 12a) resulted in inverted 'J' distribution pattern. For instance, 88.7% of the individuals were found in the first height class (1-5 m). The second height class (5-10 m) accounted for 8.7% of the woody plant individuals. The rest of the height classes (i.e. class 3 to class 7) contributed only 2.6% of the total individuals (Fig. 12a).

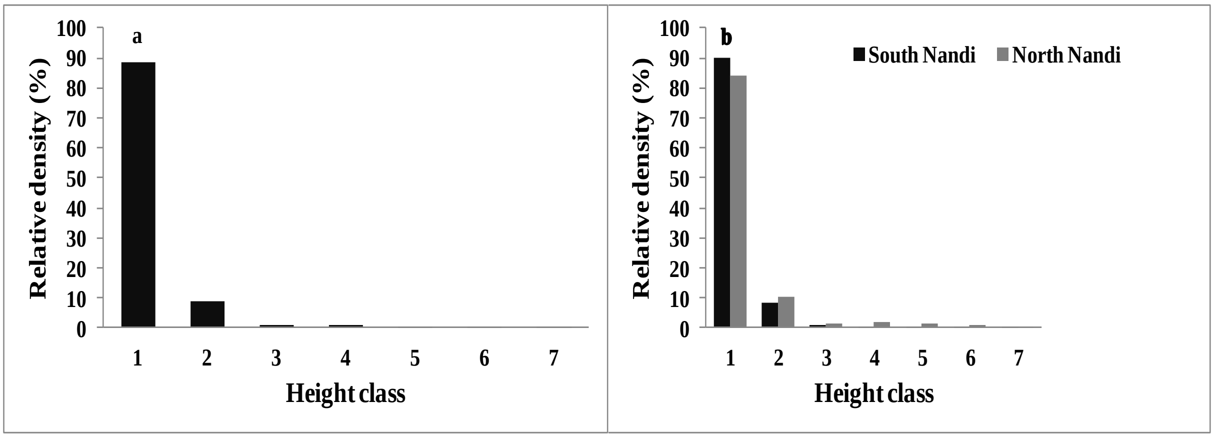


Figure 12 Height class distributions of woody plant species in Nandi Forests (a) and South and North Nandi forests (b). Height class: 1 = 1-5 m, 2 = 5-10 m, 3 = 10-15 m, 4 = 15-20 m, 5 = 20-25 m, 6 = 25-30 m and 7 > 30 m.

Similar to the general height class distribution of Nandi forest, in both South and North Nandi forests inverted 'J' height class distribution was observed (Fig. 12b). In both forests considerable proportion of individuals were found in the lower height class. As it is indicated in Figure 12b, the first height class (1-5 m) consisted 90% of the total individuals in South Nandi forest. However, individuals from the upper height class (taller than 30 m) contributed only less than 0.1%. The second height class (5-10 m) accounted for 8.3% and the rest (class 3-6) contributed only 1.7% of the individuals, i.e. each class contributed only less than one per cent.

The same inverted 'J' height class distribution was observed in North Nandi forest. Considerably higher proportion (84.1%) of the individuals was found in the lowest height calss (1-5m) (Fig. 12b). Like that of South Nandi forest individuals from the highest class (taller than 30m) contributed very small proportion of the total individuals (less than 0.1%). The second class accounted for 10.3% of the individuals while about 5.5% of them were found in the classes that range from three to six. Height class three, four, five and six accounted for 1.5, 2, 1.3 and 0.8 %, respectively.

4.3.3 Diameter class distribution

As it was revealed in height class distribution, the same inverted ‘J’ population distribution was observed in diameter class too (Fig. 13a and b). For the whole data set, 76.7% of the individuals were found in class one (2-5 cm) while class two (5-10 cm) accounted for 14.5% (Fig. 13a). The rest of the individuals (8.8%) were found in the higher classes (class 3-7). Diameter class three, four, five, six and seven contributed 4.6%, 1.5%, 0.9%, 0.6% and 1.1% of the individuals, respectively.

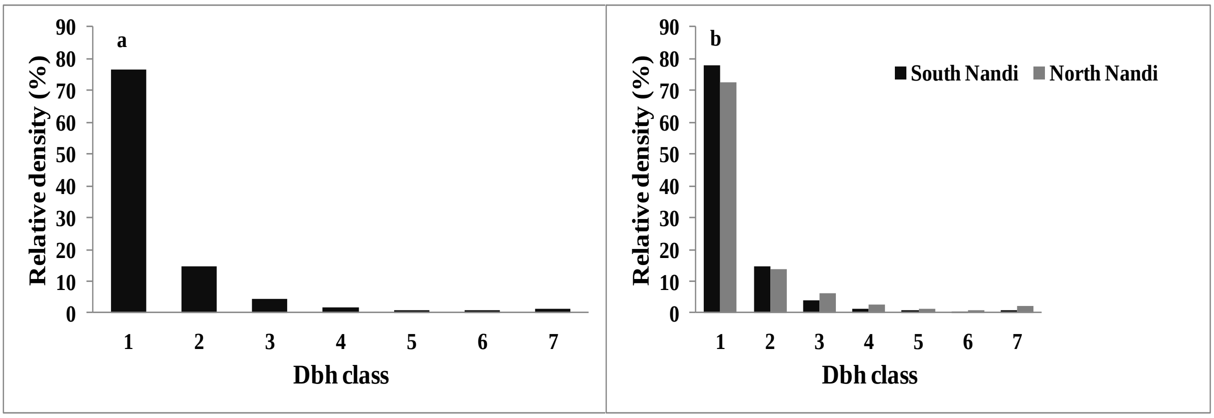


Figure 13 Diameter class frequency distribution of woody plants in Nandi forests (a) and in North and South Nandi forests (b). Diameter at breast height (Dbh) class: 1 = 2-5 cm, 2 = 5-10 cm, 3= 10-20 cm, 4 = 20-30 cm, 5 = 30-40 cm, 6 = 40-50 cm and 7 > 50 cm

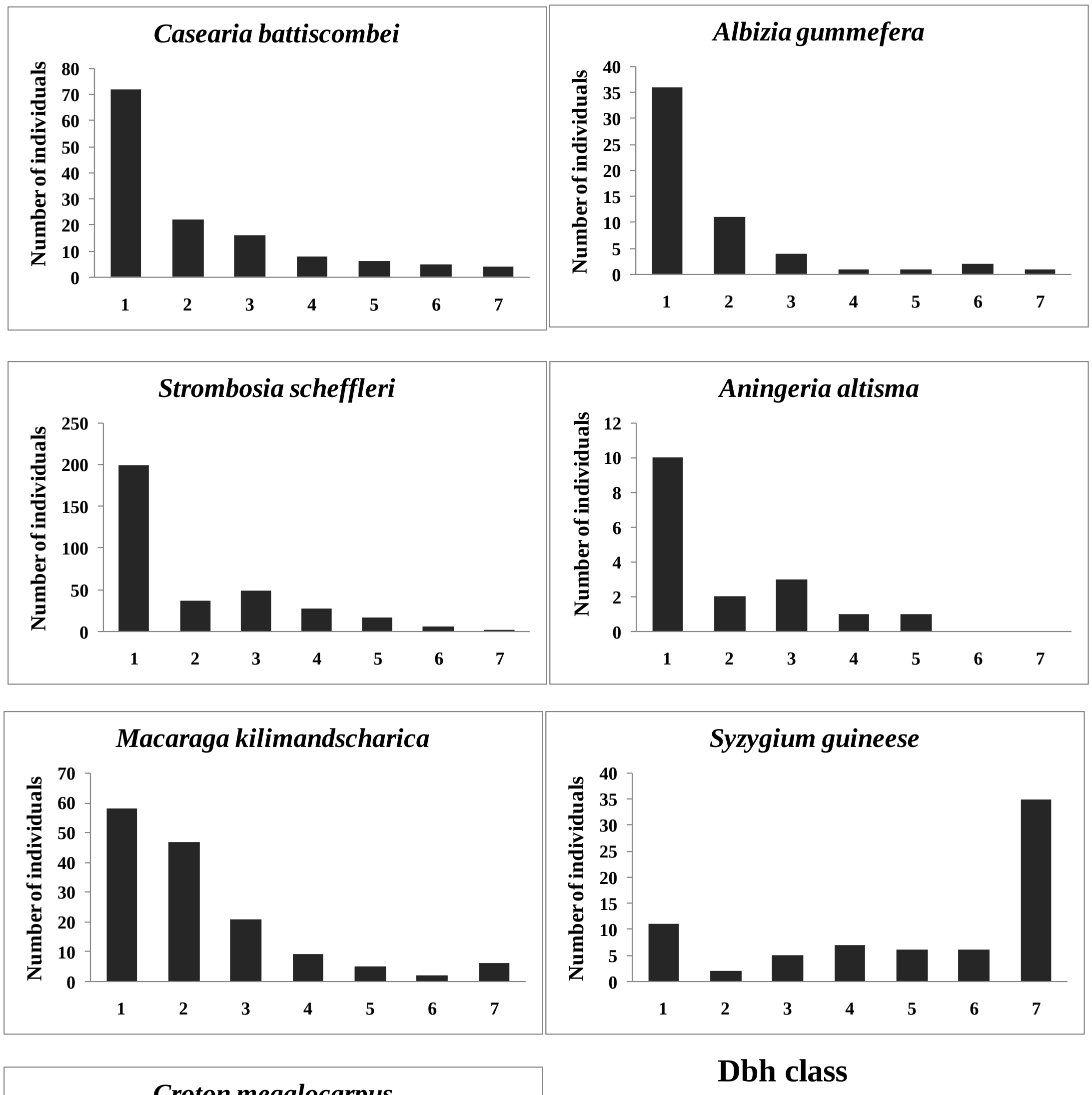
The largest diameter recoded in South Nandi forest was 208 cm for *Prunus africana* while in North Nandi it was 158 cm for *Ekebergia capensis*. When the diameter class distribution is looked into the two forests separately, both forests had an inverted ‘J’ distribution (Fig. 13b). As it is shown in Figure 13b in both South and North Nandi forests considerably higher number of individuals were found in the lower diameter classes (class 1 and 2). In class one, 78% and 72.7% of the individuals were found in South and North Nandi, respectively (Fig. 13b). In the second diameter class, 14.7 % and 13.9 % of individuals were found in South Nandi and North Nandi forest, in the same order (Fig. 12b). However, in the upper classes higher proportion is found in North Nandi than that of South Nandi forest (Fig. 13b). The third, fourth, fifth, sixth and seventh diameter classes contributed 4%, 1.2, 0.7, 0.6 and 0.7% of the individuals in South Nandi forest, respectively. While in North Nandi, 6.2, 2.6, 1.5, 0.9 and 2.3 per cent of the individuals were found in diameter class 3,4,5,6 and 7, respectively (Fig. 13b).

Diameter class distribution helps to understand the general trends in population dynamics and recruitment process of a given species. Based on the evaluation of diameter class distribution of selected tree species (commercial tree species) (KIFCO, 1994a) the following seven population distribution patterns were identified in this study.

Inverted 'J' shape: In this distribution pattern most of the individuals are in the lower diameter class and the number is subsequently decreasing so that the higher classes are having very few individuals. Examples for this distribution are *Casearia battiscombei, Albizia gummifera, Strombosia scheffleri, Macaranga kilimandascharica* (Fig. 13). As indicated in Figuger 14 the number of individuals in first diameter class is high in all these species then it decreases dramatically at the second class (e.g. *Casearia battiscombei, Albizia gummifera, Strombosia scheffleri)* and then after wards the number goes down sebsiquently. The trend is the same in *Macaranga kilimandascharica* except that the number at the second class does not decrease dramatically as it is observed in the other three species.

'U' shape: This pattern shows higher number of individuals in the lowest and highest diameter class and the intermediate class contains few number of individuals e.g. *Croton megalocarpus* (Fig. 14). The number of individuals of *Croton megalocarpus* is higher both at first and second class then it start to decrese in the third class upto being zero in the forth class and then the number start to increase from the fith class onwards.

'J' shape: The 'J' shaped distribution reveals that there is few numbers of individuals in the lower diameter class but the number gradually increases to the upper classes so that the higher diameter class has large number of individuals. In this study *Syzygium guineense* has such diameter class distribution (Fig. 14). This distribution pattern is opposite to that of inverted 'J'. This shows that the number of big tree of *Syzygium guineense* is higher than the saplings and small trees.



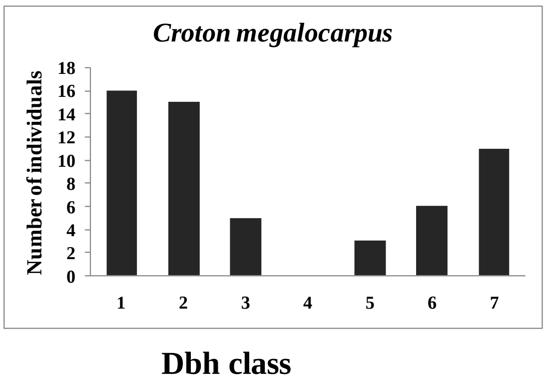


Figure 14 Different diameter class frequency distribution patterns for selected tree species in Nandi Forests. Diameter at breast height (Dbh) class: 1 = 2-5 cm, 2 = 5-10 cm, 3= 10-20 cm, 4 = 20-30 cm, 5 = 30-40 cm, 6 = 40-50 cm and 7 > 50 cm

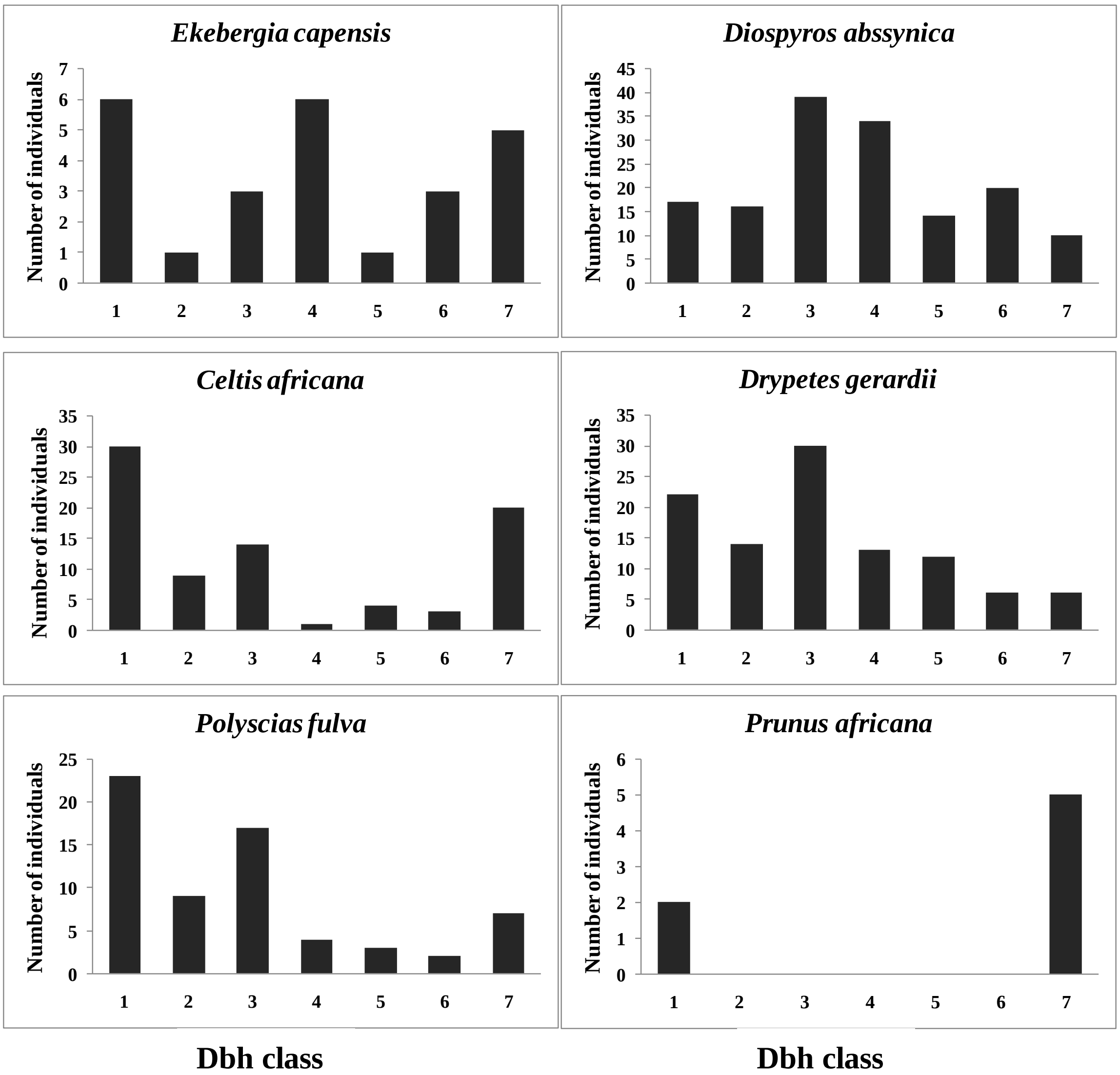


Figure 14 (continued) Different diameter class frequency distribution patterns in Nandi Forests. Diameter at breast height (Dbh) class: 1 = 2-5 cm, 2 = 5-10 cm, 3= 10-20 cm, 4 = 20-30 cm, 5 = 30-40 cm, 6 = 40-50 cm and 7 > 50 cm

'Bell' shape: This kind of frequency distribution is formed when higher number of individuals is concentrating in the intermediate diameter class. The either side of the intermediate diameter classes has few numbers of individuals e.g. *Diospyros abyssinica* (Fig. 14).

Upward 'E': This type of frequency distribution shows that there are relatively larger numbers of individuals in the lowest, intermediate and highest diameter class. For instance it has been observed that higher numbers of individuals were recorded in class one, four and seven for *Ekebergia capensis* distribution. Other example of such distribution pattern can be *Celtis africana* (Fig. 14).

Upward 'F': It is a type of frequency distribution pattern that individuals concentrate in the first (lower) and intermediate (third or fourth) diameter class. The rest of the classes have almost equally few numbers of individuals e.g. *Polyscias fulva* and *Drypetes gerardii* (Fig. 14).

Broken 'J': This frequency distribution is representing few individuals in the first diameter class and individuals were absent in the intermediate diameter class and relatively higher number of individuals in the highest diameter class. Example for such distribution is *Prunus africana* (Fig. 14)

4.3.4 Basal area and abundance

The mean basal area per hectare of South and North Nandi forest is shown in Figure 15. As it is indicated in the figure, North Nandi has higher basal area per hectare (46.01 m^2) than that of South Nandi (32.1 m^2). This difference is statistically very significant (non parametric Mann-Whitney U =358, $p < 0.001$).

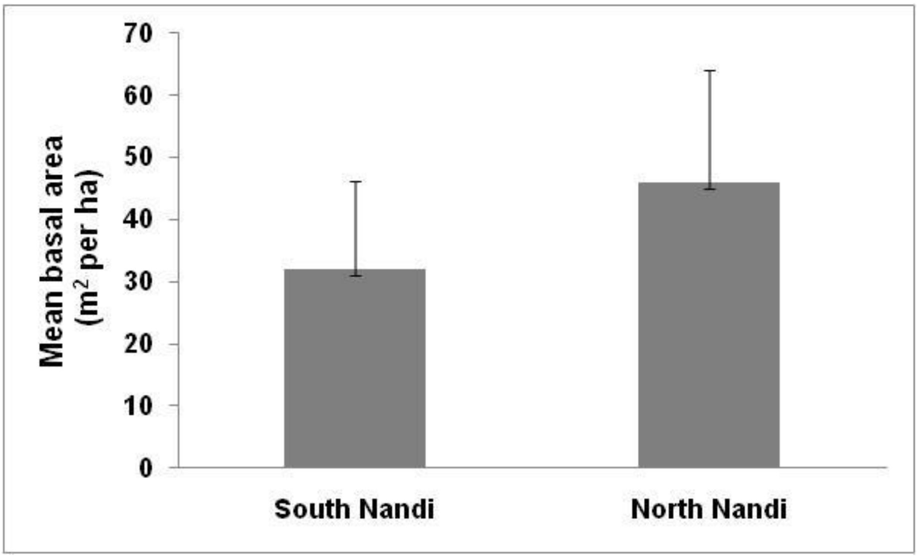


Figure 15 Mean basal area per ha of South and North Nandi forests (values are mean ±SD).

Density of woody plants of Nandi forests is presented in Table 12. Higher woody plant density per hectar (22646 individuals per ha) was recorded in South Nandi forest while in North Nandi, 21754 individual per ha was recorded (Table 12). However, maximum density per polt was observed in North Nandi which is 2466 individuals and that of South Nandi was 2281 individuals per plot. Minimum density per plot recorded in South Nandi forest was 302 individuals while in that of North Nandi it was 228 (Table 12).

Table 12 Density of woody plants in Nandi forests of Kenya

Characteristics	North Nandi	South Nandi
Total plots	27	49
Total Density	23494	44387
Minimum Density per plot	228	302
Maximum Density per plot	2466	2281
Density per hectare	21754	22880

Based on importance value (IV) index, the top fifteen dominant species in both forests are indicated in Table 13. In both forests *Culcasia falcifolia* was recorded as one of the top three dominant species. It has the highest IV in South Nandi forest and third in North Nandi. Tree species were dominant in both forests, for instance, *Tabernaemontana stapfiana, Strombosia scheffleri, Prunus africana, Croton megalocarpus, Drypetes gerrardii, Diospyros abyssinica* and *Cassipourea ruwensorensis* are from top ten dominant woody plant species in South Nandi forest. Out of the top 15 dominant species in South Nandi forest ten of them are tree species and the remaining five species are from shrub and climber growth form (two climbers i.e. *Culcasia falcifolia* and *Hippocratea africana, and* three shrubs i.e. *Solanum mauritianum*, *Alchornea hirtella* and *Macrorungia pubinervia*) (Table 13). This revealed that how trees are dominant in the South Nandi forest.

As indicated in Table 13, *Lippia kituiensis* has the highest IV in North Nandi forest followed by *Syzygium guineense, Culcasia falcifolia, Celtis africana, Diospyros abyssinica, Ekebergia capensis, Hippocratea africana, Acanthus eminens, Macaranga kilimandscharica and Cassipourea ruwensorensis*. From the top 15 dominant species of North Nandi forest nine of them are tree and the rest six are climbers (three species i.e. *Culcasia falcifolia, Hippocratea africana* and *Landolphia buchananii*) and shrubs (three species i.e. *Lippia kituiensis*, *Acanthus eminens* and *Solanum mauritianum*).

Table 13 Importance Value (IV) of the top 15 common woody plant species in Nandi Forests (Abu=abundance, RF=relative frequency, RDen= relative density, and RDom=relative dominance).

Forest	**Name**	**Growth Form**	**Abu (No. indiv. / ha)**	**RF (%)**	**RDen (%)**	**RDom (%)**	**IV (%)**
South Nandi	*Culcasia falcifolia*	Climber	7215	2.14	31.54	-	33.68
	Tabernaemontana stapfiana	Tree	117	2.05	0.51	13.04	15.60
	Strombosia scheffleri	Tree	980	2.18	4.29	8.51	14.98
	Solanum mauritianum	Shrub	1713	1.65	7.49	5.45	14.20
	Prunus africana	Tree	499	1.43	2.18	10.03	13.64
	Croton megalocarpus	Tree	72	1.65	0.32	10.67	12.63
	Drypetes gerrardii	Tree	144	2.14	0.63	9.83	12.59
	Diospyros abyssinica	Tree	1088	2.14	4.75	3.90	10.79
	Alchornea hirtella	Shrub	1042	1.20	4.56	2.86	8.62
	Cassipourea ruwensorensis	Tree	933	1.87	4.08	2.01	7.96
	Trilepisium madagascariense	Tree	528	1.56	2.31	3.63	7.50
	Polyscias fulva	Tree	78	1.60	0.34	5.31	7.25
	Heinsenia diervilleoides	Tree	643	1.74	2.81	2.49	7.04
	Macrorungia pubinervia	Shrub	1036	1.92	4.53	0.20	6.65
	Hippocratea africana	Climber	773	2.18	3.38	0.03	5.59
	Total other species (118)		6019	72.56	26.3	22.06	
	Total		22880	100	100	100	
North Nandi	*Lippia kituiensis*	Shrub	9098	1.50	41.82	-	43.32
	Syzygium guineense	Tree	163	1.72	0.75	38.04	40.51
	Culcasia falcifolia	Climber	4456	0.82	20.48	-	21.30
	Celtis africana	Tree	119	2.02	0.55	14.28	16.85
	Diospyros abyssinica	Tree	258	1.87	1.19	12.84	15.90
	Ekebergia capensis	Tree	62	1.64	0.29	8.47	10.40
	Hippocratea africana	Climber	1207	1.87	5.55	0.04	7.45
	Acanthus eminens	Shrub	1126	0.67	5.18	0.93	6.78
	Macaranga kilimandscharica	Tree	53	0.97	0.24	4.68	5.90
	Cassipourea ruwensorensis	Tree	219	1.94	1.00	2.63	5.58
	Solanum mauritianum	Shrub	488	1.87	2.24	1.00	5.11
	Landolphia buchananii	Climber	663	1.94	3.05	0.11	5.10
	Tabernaemontana stapfiana	Tree	49	0.45	0.23	3.53	4.20
	Ehretia cymosa	Tree	77	1.72	0.35	2.1	4.17
	Erythrococca fischeri	Tree	205	2.02	0.94	1.00	3.96
	Total other species (81)		3511	76.98	16.14	10.36	
	Total		21754	100	100	100	

4.4 Discussion

Analysis of population structure is an extremely useful tool for orienting management activities and, perhaps most importantly, for assessing the impact of resource extraction (Peters, 1996). Given the lack of well-defined growth rings and the difficulty of accurately determining tree age in the tropics (Bormann and Berlyn, 1981), population structure studies in tropics are almost defined in terms of the size-class or diameter distribution of individuals.

Generally the overall height and diameter class distribution of both South and North Nandi forests showed an inverted 'J' distribution pattern. This kind of distribution pattern displays a greater number of small trees than large trees, and an almost constant reduction in numbers from one size class to the next (Peters, 1996). This might show that the reproductive capacity of the forest must be sufficient to sustain the forest, and the population structure of most species must have an inverted 'J' distribution pattern. This pattern is an indicator of healthy regeneration of the forest and species, and shows a good reproduction and recruitment capacity (Feyera, 2006). However, the diameter distribution of some selected tree species have shown different distribution pattern.

The identified diameter class distributions of our study are in one of the three tropical tree species population distribution patterns summarized by Peters (1996). Peters has grouped tropical tree species population distribution in to type I, II and III distribution patterns. Those which have an inverted 'J' distribution pattern are considered as type I by Peters. This type of population structure is characteristic of shade-tolerant canopy trees that maintain a more or less constant rate of recruitment. There is a large probability that the death of an adult tree will be replaced by the growth of individuals from the smaller size classes. A type I structure is considered by many authors as the ideal, stable and self-maintaining plant population (Meyer 1952; Leak 1965).

The distribution patterns described in this study as 'U', upward 'E' and 'F', 'Bell' shaped and broken 'J' are considered as type II by Peters (1996) where as those which has 'J' shaped distribution as type III distribution. Type II distribution is characteristic of species that show discontinuous or periodic recruitment (Peter, 1996). The actual level of seedling establishment may be sufficient to maintain the population, but its infrequency causes notable discontinuities in the structure of the population as the newly established seedlings and saplings grow into the larger size classes. Anthropogenic disturbance can also cause such kind of distribution pattern.

For instance, Feyera (2006) explained the reason for a 'U'shaped pattern of *Olea welwitschii* in afromontane forests of Ethiopia is due to selective cutting of medium-sized trees. In this study similar selective cutting was observed in some species (e.g. *Croton megalocarpus, Celtis africana*) may be for charcoal production and pit sawing. This type of diameter distribution is quite common among late secondary species that depend on canopy gaps for regeneration (Peters, 1996). 'Bell' shaped which follows a Gauss distribution pattern might be a results of poor recruitment of saplings and removal of trees in the higher diameter classes (e.g. *Diospyros abyssinica*).

Broken 'J' distribution pattern of *Prunus africana* might be the result of poor seedling growth and development to saplings and saplings to small trees. *Prunus* is one of the species that have many seedlings in Nandi forest (see section 5.3.1 of chapter 5). However, there is almost no sapling or small tree of this species. There are a lot of seedlings of this species under mature tree but there are no saplings under these mature trees. This multipurpose tree species has local and international significance. It has been reported by different authors that the population of *Prunus africana* is decreasing due to unsustainable bark exploitation (Cunningham and Mbenkum, 1993; Sunderland and Tako, 1999; Hall *et al*., 2000) in different parts of Africa. This decreament started to happen following the discovery in 1966 that an extract from the bark of *P. africana* bark effectively treats prostate gland hypertrophy and benign prostatic hyperplasia; pharmaceutical campanies began hiring Africans to collect *P. africana* bark for export to Europe (Cunningham and Mbenkum, 1993; Ndibi and Kay, 1997). In addition to this international importance, Africans have long used this valuble tree as a source of timber and traditional medicines (Cunningham and Cunningham, 1999; Halle *et al*., 2000; Stewart, 2003). Similarly in Nandi forest this important tree species is decreasing. Our finding is in agreement with what was reported by (Nzilani, 2001). Similar decreasing trend of this importat species was also observed in Isecheno which is the fragment of Kakamega forest (Fashing, 2004). Fashing reported that the decline of this species at Isecheno is not due to bark harvesting unlike to western African case. Though there are bark explotation in Isecheno, the intensity is minimal to cause tree mortality according to Fashing (2004). In our study we did not encounter with bark explotation in Nandi forests. Hence we conclude that the declining of *P. africana* population is mainly caused due to poor recruitment of saplings and small trees. Fashing (2004) revealed that there is no recruitment occurring at Isecheno into the smallest dimater classes (10-19, 20-29, 30-39 cm). Nzilani (2001) and Tsingalia (1989) have also suggested that *P. africana* has extremely poor survival of seedlings to the sapling stage. There could be several reasons for this poor performance of seedlings to sampling as well as sapling to small tree recruitment. Factors like disease (Franklin *et al*., 1987; Waring, 1987), insect attack (Nair *et al*., 1996; Cunningham *et al*., 2002), nutrient deficiency (Hunter, 1993) and climatic fluctuation (Lwanga, 2003) or a combination of two or more of these factors could be responsible for the poor seedling performance. Moreover, the seedlings of *P. africana* require bigger light gaps in the canopy to survive to the pole stage (Tsingalia, 1989; Nzilani, 2001; Kiama and Kiyiapi, 2003). It has been also observed that in South Nandi forest there are dense shrub layer in addition to the canopy cover of the trees. Hence, this might also resulted in poor survival of the seedlings, thereby affecting the diameter distribution pattern of *P. africana.*

Type III distribution ('J' shaped) is resulted from either poor seedling regeneration or poor recruitment of saplings. This pattern of distribution shows that there is less number of individuals in the lower diameter classes and the number increases subsequently in the next classes so that there is higher number of individuals in the highest diameter class. Type III distributions are frequently encountered among light-demanding, early pioneer species that require large canopy gaps for regeneration (Peters, 1996). In the absence of such a disturbance, these species may temporarily disappear from the forest, the former population represented only by the seeds lying dormant in the soil. In this work *Syzygium guineense* has shown such kind of distribution pattern. Similar kind of dimeter distribution of this species was reported in the afromontane forests of Ethiopia (Feyera, 2006). He explained the reason for such distribution of *Syzygium guineense* could be due to poor reproduction and hampered regeneration as a result of either most trees are not producing seeds due to age or there is seed losses due to predators after reproduction. According to Feyera (2006), fruit of *Syzygium* is usually used as food by many animals and also human, which could also be a reason for this pattern. In Nandi Forests, it has been observed that *Syzygium guineense* is not among the seedling and/or sapling rich species (top ten species) of Nandi forests when the whole seedlings data is analysed together (see chapter 5 for deails). This could be either due to some or all the reasons mentioned by Feyera (2006) or due poor seedling establishment or seedling growth to sapling and then to small tree stage as a result of heavy grazing. According to Alemayehu (2007), livestock-induced disturbances might be among the major factors constraining regeneration and recruitment of woody species and contributing, ultimately, to the decline of woody species populations in forests. Pueyo *et al*. (2006) reported that community structure is proved to be more sensitive to grazing effects.

In this work it has also been seen that the basal area in North Nandi forest is higher than that of South Nandi forest. Basal area is influenced by site productivity, density and/or competition between individuals in the forest. In this regard the difference in basal area of Nandi forests is due to the existence of relatively higher number of trees with bigger diameter in North Nandi forest. Otherwise, as it is shown in Table 12, the number of individuals per ha (density per ha) is smaller in North Nandi than that of South Nandi forest. This difference could be mainly attributed to the disturbance difference in these two forests as well as geographical location. In South Nandi, since charcoal burning is the main disturbance factor, trees with intermediate diameter classes were heavily removed, which resulted in lower basal area. This situation is more explained by Figure 13 which shows that in North Nandi the relative density of individuals in diameter class three and beyond is higher than that of South Nandi. The difference in the number of individuals per hectare (density) could also be due to difference in site productivity or disturbance or combination of these factors. In South Nandi forest there is higher intensity of tree harvesting for charcoal and this can lead to the emerging of pioneer species to fill the gap created. During early successional development, many pioneer species may establish and grow together in high density until they reach the climax stage where many individuals are eliminated due to competition (Ewel, 1983). However, in North Nandi forest these pioneer species can not emerge due to the canopy cover of the bigger trees. On the other hand, in North Nandi the growth and development of climax species might be hampered due to the fact that there is heavy grazing in this forest. Hence, higher and lower densities of stems in Nandi forests are both dependent on human impact on the forests.

In both forests few species are dominant and this domination is explained through abundance, basal area and IV. As indicated in Table 13 the top 15 common species contributed to the 73.7% of density per ha in South Nandi and these species also accounted for about 78% of the basal area. Out of these 15 species, eight of them have IV greater than 10%. In North Nandi the top 15 common species accounted for 83.9% of the density per ha as well as 89.7% of the basal area. Six of these species have IV of greater than 10% (Table 13).

5. Seedling Bank and Resprouting in Nandi Forests

5.1 Introduction

The term regeneration is often used to refer to the processes by which juvenile trees (saplings) are produced and established within a forest stand that represented very simplistically in traditional forest gap models (Price *et al.,* 2001). These processes include the production, dispersal and germination of seeds and the subsequent establishment of seedlings, as well as vegetative regrowth (coppicing or resprouting) following mortality of aboveground portions of mature trees. Regeneration (both through seedling and coppicing) is one of the important ecological process to the maintenance and continuity of a given forest ecosystem. However, this process is amongst ecological processes which are vital to forest function that are potentially vulnerable to fragmentation (Grime and Hillier, 2000) and other human disturbance.

Patterns of regeneration are important because they will ultimately determine the floristic composition of the remnants (Laurance *et al.,* 1998) and structure as well. Successful management and conservation of natural forest requires reliable data on aspects such as the regeneration trends (Eilu and Obua, 2005). Generally, regeneration involves both the physiological and developmental (autecological) mechanisms inherent in plant biology as well as external ecological factors, including interactions with other biota, climate and disturbances (Price *et al.,* 2001).

Anthropogenic disturbance affects the composition and structure of forests. This impact in return affects natural regeneration i.e. seedling bank, soil seed bank and resprouting. For instance, logging which has immediate and direct effects on composition and structure (Parthasarathy, 2001) also creates canopy openings which may cause regeneration problems, especially in exposed conditions where soils dry out rapidly and nutrient loss through run-off becomes common. Canopy openings readily support the growth of invasive weeds and other herbaceous plants which usually interfere with regeneration and impede recovery of trees and shrubs (Epp, 1987; Hawthorne, 1993 and 1994; Madoffe *et al*., 2006). Invasive weeds threaten biodiversity by displacing native species and disrupting community structure (Parker *et al.*, 1999; Richardson *et al*., 2000; Sala *et al*., 2000; Stein *et al*., 2000). Soil water availability is also considered a key factor for the regeneration, survival and growth of seedlings (Lieberman and Lieberman, 1984; Ceccon *et al*., 2002) and this factor could be affected negatively by logging. Light conditions influence regeneration pathways strongly (Haugaasen *et al*., 2003) and ultimately affect the composition and structure of forest. It has been reported that light limitation alone may prevent seedling survival regardless of other resource levels (Tilman, 1982) especially those of light loving species. Hence, gaps which are caused naturally or anthropogenic might modify the availability of light and there by facilitate the regeneration of light demanding species.

Initial floristic composition in disturbed tropical forest is mainly determined by the soil seed bank, seedling bank (advance regeneration) and the resprouting capacity of stumps (Kammesheidt, 1998). Understanding the natural regeneration of a given forest helps to plan in advance the development and conservation strategies for that particular ecosystem. Knowing about the regeneration status paves way for predicting what kind of forest composition and structure we are going to have in foreseeable future. So far natural regeneration potential of Nandi forests (seedling bank and resprouting) is not yet studied. Hence this study aims at addressing this gap looking into the seedling bank and resprouting ability of woody species after suffering from physical damage either by cutting or tree and/or branch falls.

5.2 Material and Methods

5.2.1 Study sites

This study was under taken in Nandi Forests i.e. North and South Nandi Forests, in the Rift Valley Province of western Kenya. A detailed description of the study sites is given in chapter two (section 2.1)

5.2.2 Data collection and analysis

Data collection

Data was collected using quadrats. Five three by three meter plots were laid down within the bigger 20 by 20 m quadrats to gather information on seedling bank. The detail lay out of the plots is described in chapter two section 2.2.1. Seedlings were identified at sepecies level and their count was recoreded. The seedlings in the five plots summed up and considered as a value for a plot with an area of 45 m^2.

To assess the sprouting ability of woody species (i.e. tree, woody climber and shrubs) after physical damage, stumps were investigated for shoot growth (resprouting). All wood stumps within the bigger plot (20 X 20 m) was recorded and identified at species level. Diameter and height of the stumps were measured using diameter tape and meter, respectively. When stump coppices, number of shoots were counted and recorded. A stump was considered sprouting when it has at least one visible shoot.

Data analysis

Diversity measures such Shannon diversity index (H´), evenness (E´), Fisher alpha, alpha diversity and Whittaker beta diversity were calculated. Similarity indices were calculated to look into the similarities between seedling population of South and North Nandi forest as well as similarities between the seedlings and trees (includes sampling too) that were recorded in the bigger plot (at plot level). For this purpose both Sørensen and Jaccard incidence based similarity indices as well as their respective abundance based indices (Chao-Sørensen estimator and Chao-Jaccard estimator) were calculated. The formulae of all these measurements (Shannon diversity index, evenness index, Fisher alpha, Whittaker beta diversity and the similarity indices) are presented and described in chapter 3 section 3.2.3.

Shannon diversity index and evenness were calculated using PC-ORD version 5.22 (McCunne and Grace, 2006). Fisher alpha and all the similarity indices were computed using EstimateS 8.2 (Colwell, 2009) which is a public domain ecological software. To evaluate whether there is statistically significant difference between Shannon diversity indices of the two Nandi forests T-test was conducted using SPSS 16.0 version. To compare mean number of seedlings per plot non-parametric (Mann-Whitney U) test was also performed. Kruskal-Wallis test was also undertaken to test if there is significant differences in mean number of sprouts among species.

To look into the effect of environmental factors (especially disturbance) on the distribution of seedlings, gradient analysis was undertaken. For this purpose indirect gradient analysis was made using Detrended Correspondence Analysis (DCA) ordination method (ter Braak, 1995; McCune and Grace, 2002). CANOCO version 4.53 (ter Braak and Smilauer, 2004) was used to undertake DCA in this study. In this analysis totally 117 species and 76 plots were used.

5.3 Results

5.3.1 Seedling bank

5.3.1.1 Seedling species composition

Generally in Nandi forests seedlings of 117 woody plant species from 101 genera and 51 families were recorded. Totally 18,358 seedlings of different woody plant species were identified in the the sample plots with a total area of 3420 m^2, and this means there were a total of 53678 seedlings of woody plants per hectar. When the seedling population of the two forest analysed together Rubiaceae is the richest family reperesented by 14 species and followed by Euphorbiaceae consisting of 8 species, and Acanthaceae and Solanaceae each represented by five species.

When the seedling population of the two forests is analysed separately Rubiaceae and Euphorbiaceae are still the top two species rich families in both forests (Table 14). In South Nandi the third richest family is Acanthaceae having five species while in North Nandi Solanaceae takes the third place containing five species too (Table 14).

Table 14. Families represented by four or more species in the seedling population of South and North Nandi forests

South Nandi			**North Nandi**		
Family	**Number of species**	**Number of genera**	**Family**	**Number of species**	**Number of genera**
Rubiaceae	14	12	Rubiaceae	9	8
Euphorbiaceae	6	5	Euphorbiaceae	5	4
Acanthaceae	5	5	Solanaceae	5	1
Sapotaceae	4	3	Acanthaceae	4	4
Rutaceae	4	4			

When the number of seedlings is analysed separately, higher proportion of seedlings gose to South Nandi forest. Totally 13733 seedlings of woody plants composed of 97 species from 87 genera and 45 familes were identified in South Nandi forest in plots size of 2205 m^2 which resulted in a total of 62,281 seedling per ha. In the North Nandi, totally 4625 seedlings of 73 woody plant species from 65 genera and 41 families were recorded in 1215 m^2, which resulted in a total of 38,066 seedlings in a ha.

Similarly, higher number of seedlings per plot was observed in South Nandi forest (280.3 seedlings per plot or 45 m^2) than that of North Nandi (171.3 seedlings per plot) (Fig. 16). This difference is statistically very significant (Mann-Whitney U = 362.5, p<0.001).

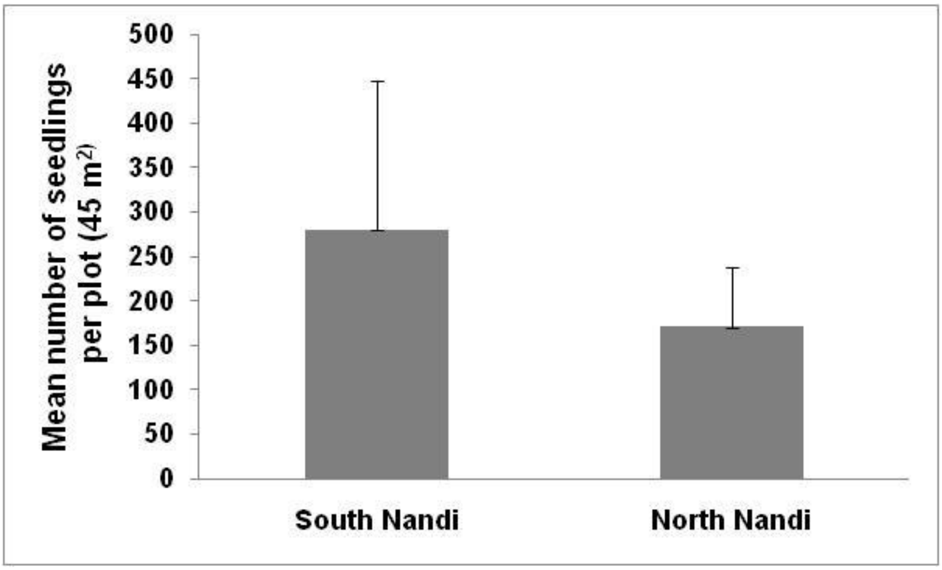


Figure 16 Mean number of seedlings per plot in South and North Nandi Forests (values are mean ± SD).

In terms of growth forms, the pooled data set from both forests showed that, seedlings from tree species contributed about 46 % of the seedling population in a ha while that of climbers and shrubs accounted for 24.9 and 29.1%, respectively (Fig. 17). But when the data is segregated into the two forests, these proportions become different. As indicated in Figure 17, even though smaller numbers of climber species (17 species) were recorded in North Nandi forest, 40.5% of the seedlings belonged to this growth form. Shrub species (26 species) contributed about 39.1% and tree species (30 species) accounted for only 20.4% of the seedlings population. In South Nandi, tree species (48 species) contributed bigger proportion of seedlings (54.6%) while that of shrubs (25 species) and climbers (24 species) accounted for 25.7 and 19.7% of seedling population, respectively (Fig. 17).

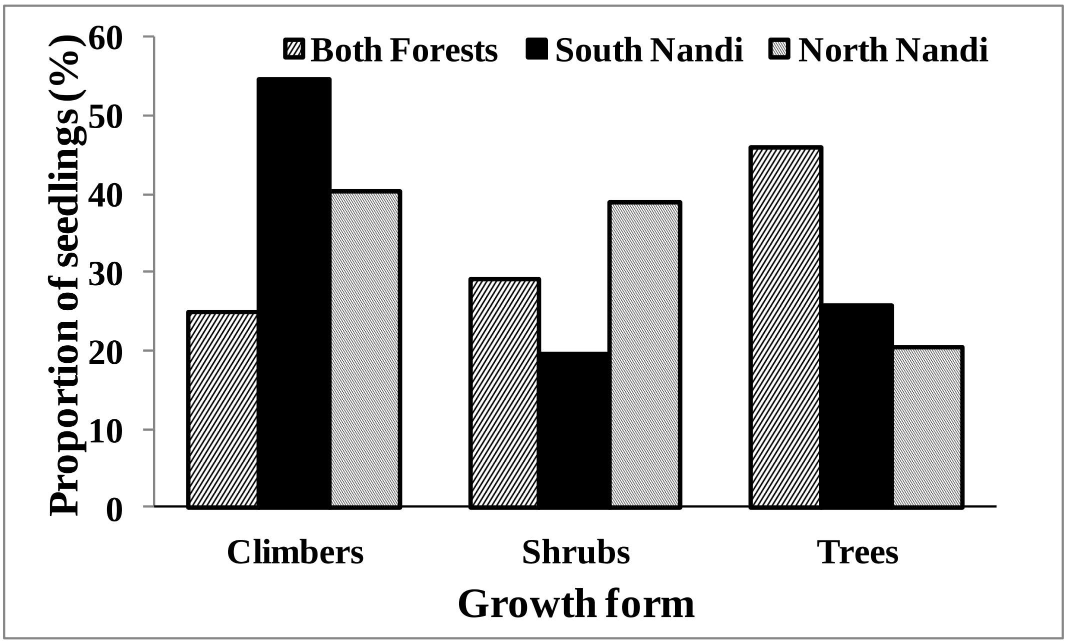


Figure 17 Relative propotion of seedlings in terms of species growth form in Nandi Forests

In both forests the seedling population is dominated by few species. For instance, in North Nandi the first 20 seedling rich species comprised 89% of the seedling population (Fig. 18). The remaining 53 species consisted only 11% of the seedlings. The first ten seedling rich species which include, *Hippocratea africana, Landolphia buchananii, Acanthopale pubescens, Acanthus eminens*, *Allophylus abyssinicus*, *Macrorungia pubinervia*, *Diospyros abyssinica, Cassipourea ruwensorensis*, *Syzygium guineense* and *Albizia gummifera* accounting for 77.2% of the total seedling population (Fig. 18). *Hippocratea africana* is the most dominat species having 10,461 (27.5%) seedlings per ha followed by *Landolphia buchananii* and *Acanthopale pubescens* wih 3588 (9.4%) and 3556 (9.3%) seedlings in a ha, respectively (Table 15 and Fig. 18).

Table 15 List of species with their seedling densities (No. of seedlings/ha) and frequency (percentage of quadrate in which the seedlings of the species was recorded) at the North and South Nandi forests

Species	Family	South Nandi		North Nandi	
		Density	Frequency	Density	Frequency
Hippocratea africana	Celastraceae	5696	100.0	10461	92.6
Diospyros abyssinica	Ebenaceae	9220	98.0	1300	77.8
Strombosia scheffleri	Strombosiaceae	5628	93.9	-	-
Trilepisium madagascariense	Moraceae	4426	44.9	-	-
Prunus africana	Rosaceae	4213	59.2	41	14.8
Macrorungia pubinervia	Acanthaceae	3084	79.6	2379	33.3
Acanthus eminens	Acanthaceae	2839	63.3	2848	33.3
Allophylus abyssinicus	Sapindaceae	2707	98.0	2486	92.6
Cassipourea ruwensorensis	Rhizophoraceae	3483	69.4	1111	88.9
Landolphia buchananii	Sapotaceae	2023	73.5	3588	88.9
Dracaena laxissima	Asparagaceae	2531	93.9	239	22.2
Acanthopale pubescens	Acanthaceae	385	30.6	3556	85.2
Salacia cerasifera	Celastraceae	2399	81.6	-	-
Solanum mauritianum	Solanaceae	1442	53.1	272	51.9
Heinsenia diervilleoides	Rubiaceae	1279	65.3	420	40.7
Piper capense	Piperaceae	1188	93.9	123	25.9
Lepidotrichilia volkensii	Meliaceae	907	44.9	0	0.0
Coffea eugenioides	Rubiaceae	649	53.1	272	51.9
Celtis africana	Ulmaceae	467	42.9	453	70.4
Macaranga kilimandscharica	Euphorbiaceae	540	42.9	148	18.5
Syzygium guineense	Myrtaceae	32	8.2	1045	55.6
Drypetes gerrardii	Euphorbiaceae	567	63.3	-	-
Erythrococca fischeri	Euphorbiaceae	249	53.1	601	81.5
Gouania lonispicata	Rhamnaceae	485	49.0	91	25.9
Deinbollia kilimandscharica	Sapindaceae	585	57.1	25	11.1
Alchornea hirtella	Euphorbiaceae	590	38.8	-	-
Rutidea orientalis	Rubiaceae	463	42.9	8	3.7
Albizia gummifera	Fabaceae	86	18.4	601	55.6
Erythrococca trichogyne	Euphorbiaceae	109	30.6	560	85.2
Polyscias fulva	Araliaceae	376	49.0	25	11.1
Ekebegria capensis	Meliaceae	132	30.6	395	59.3
Cissus rotundifolia	Vitaceae	331	61.2	-	-
Turraea holstii	Meliaceae	18	8.2	535	77.8
Dovyalis macrocalyx	Salicaceae	168	30.6	337	48.1
Solanum terminale	Solanaceae	54	12.2	436	51.9
Ouratea hiernii	Ochnaceae	-	-	494	66.7
Tabernaemontana stapfiana	Apocynaceae	195	32.7	115	14.8

Table 15 continued

Species	**Family**	**South Nandi**		**North Nandi**	
		Density	**Frequency**	**Density**	**Frequency**
Tiliacora funifera	Menispermaceae	263	59.2	-	-
Teclea nobilis	Rutaceae	240	46.9	8	3.7
Ficus sur	Moraceae	195	22.4	33	3.7
Vangueria madagascariensis	Rubiaceae	54	18.4	255	63.0
Keetia gueinzii	Rubiaceae	91	26.5	132	22.2
Croton megalocarpus	Euphorbiaceae	181	30.6	-	-
Solanum mauense	Solanaceae	18	2.0	247	37.0
Vernonia auriculifera	Asteraceae	14	6.1	239	25.9
Bersama abyssinica	Melianthaceae	100	30.6	99	33.3
Scutia myrtina	Rhamnaceae	32	14.3	198	40.7
Clerodendrum johnstonii	Verbenacea	18	8.2	198	29.6
Embelia schimperi	Myrsinaceae	27	4.1	173	14.8
Artabotrys likimensis	Annonaceae	118	26.5	-	-
Alangium chinense	Cornaceae	113	26.5	-	-
Casearia battiscombei	Salicaceae	63	20.4	49	14.8
Maytenus heterophylla	Celastraceae	-	-	156	29.6
Ochna insculpta	Ochnaceae	86	18.4	-	-
Dalbergia lactea	Fabaceae	50	22.4	74	22.2
Oxyanthus speciosus	Rubiaceae	36	8.2	74	18.5
Pavonia urens	Malvaceae	-	-	140	14.8
Rawnsonia lucida	Salicaceae	82	16.3	-	-
Ritchiea albersi	Capparaceae	77	22.4	16	7.4
Acalypha ornata	Euphorbiaceae	-	-	132	18.5
Piper umbellatum	Piperaceae	73	18.4	-	-
Rytigynia acuminatissima	Rubiaceae	73	10.2	-	-
Croton macrostachyus	Euphorbiaceae	-	-	123	29.6
Pavonia propinqua	Malvaceae	-	-	115	11.1
Jasminum floribundum	Oleaceae	-	-	107	14.8
Trema orientalis	Ulmaceae	59	12.2	-	-
Acacia montigena	Fabaceae	54	4.1	-	-
Pavetta abyssinica	Rubiaceae	23	8.2	58	14.8
Mimulopsis arborescens	Acanthaceae	45	6.1	-	-
Ehretia cymosa	Boraginaceae	5	2.0	66	18.5
Meyna tetraphylla	Rubiaceae	14	4.1	49	11.1
Aningeria altissima	Sapotaceae	36	8.2	-	-
Thunbergia alata	Acanthaceae	32	8.2	25	7.4
Mikaniopsis usambarensis	Asteraceae	32	12.2	-	-
Mondia whytei	Apocynaceae	27	8.2	8	3.7
Cyphostemma kilimandscharia	Vitaceae	27	12.2	-	-

Table 15 continued

Species	Family	South Nandi		North Nandi	
		Density	Frequency	Density	Frequency
Pavonia patens	Malvaceae	27	4.1	-	-
Psychotria peduncularis	Rubiaceae	27	8.2	-	-
Tarenna pavettoides	Rubiaceae	27	8.2	-	-
Toddalia asiastica	Rutaceae	18	6.1	16	7.4
Urera hypselodendron	Urticaceae	9	4.1	33	11.1
Clausena anisata	Rutaceae	23	10.2	-	-
Connarus longistipitatus	Connaraceae	23	4.1	-	-
Neoboutonia macrocalyx	Euphorbiaceae	23	6.1	-	-
Solanecio mannii	Asteraceae	-	-	41	3.7
Chionanthus mildbraedii	Oleaceae	18	6.1	-	-
Dracaena steudneri	Asparagaceae	18	8.2	-	-
Pterolobium stellatum	Fabaceae	-	-	33	11.1
Solanum hastifolium	Solanaceae	-	-	33	14.8
Markhamia lutea	Bignoniaceae	14	6.1	-	-
Olea capensis	Oleaceae	5	2.0	25	7.4
Sericostachys scandens	Chenopodiaceae	14	6.1	-	-
Trimeria grandifolia	Salicaceae	-	-	25	7.4
Xymalos monospora	Monimiaceae	18	6.1	-	-
Zanthoxylum gilletti	Rutaceae	14	4.1	-	-
Apodytes dimidiata	Icacinaceae	-	-	16	7.4
Asparagus africanus	Asparagaceae	-	-	16	7.4
Craibia brownii	Fabaceae	9	4.1	-	-
Crotalaria mauensis	Fabaceae	-	-	16	3.7
Dracaena fragrans	Asparagaceae	9	2.0	-	-
Ensete ventricosum	Musaceae	9	2.0	-	-
Rubus scheffleri	Rosaceae	5	2.0	8	3.7
Rubus steudneri	Rosaceae	-	-	16	7.4
Vangueria apiculata	Rubiaceae	5	2.0	8	3.7
Abutilon longicuspe	Malvaceae	-	-	8	3.7
Adenia bequaertii	Passifloraceae	5	2.0	-	-
Allophylus africanus	Sapindaceae	5	2.0	-	-
Chrysophyllum viridifolium	Sapotaceae	5	2.0	-	-
Dombeya rotundifolia	Malvaceae	-	-	8	3.7
Grewia similis	Malvaceae	-	-	8	3.7
Jasminum fluminense	Oleaceae	5	2.0	-	-
Psidium guajava	Myrtaceae	5	2.0	-	-
Psychotria mahonii	Rubiaceae	5	2.0	-	-
Solanum aculeastrum	Solanaceae		-	8	3.7
Tinospora caffra	Menispermaceae	-	-	8	3.7
Chrysophyllum albidum	Sapotaceae	32	2.0	-	-
Gardenia volkensii	Rubiaceae	5	2.0	-	-

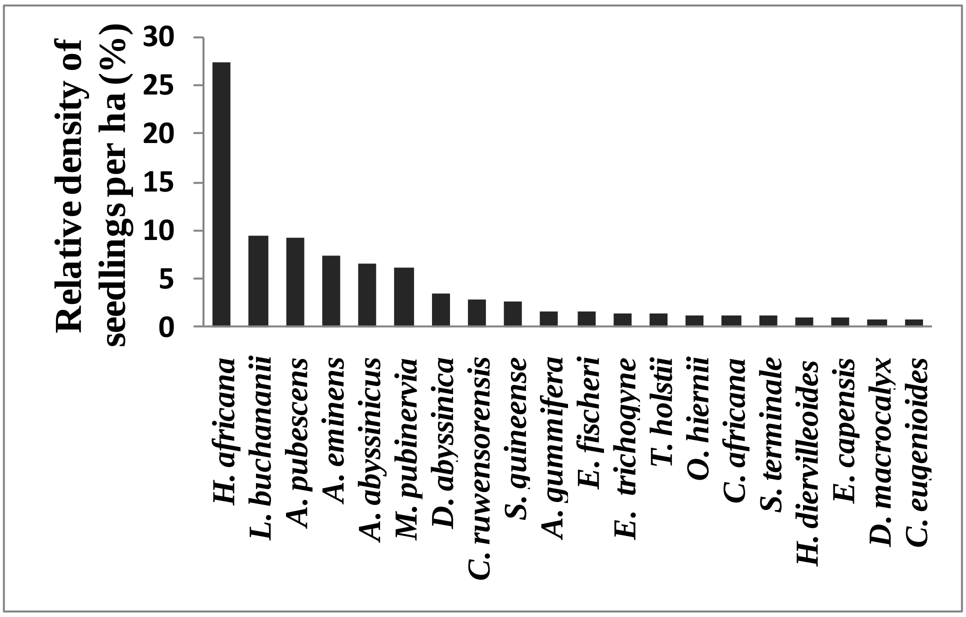


Figure 18 Relative density of top 20 seedling rich woody plant species of North Nandi forest.

As explained above seedlings from tree species of North Nandi forest contributed only 20.4% of seedlings in this forest (Fig. 17). Out of this 20.4% of seedlings 17.5% is contributed by the top ten seedling rich tree specie (Fig. 19). This includes *Diospyros abyssinica*, *Cassipourea ruwensorensis*, *Syzygium guineense*, *Albizia gummifera*, *Erythrococca fischeri*, *Ouratea hiernii*, *Celtis africana*, *Heinsenia diervilleoides*, *Ekebegria capensis* and *Vangueria madagascariensis* (Fig. 19). The remaining 20 tree species contributed only 2.9% of the total seedling population.

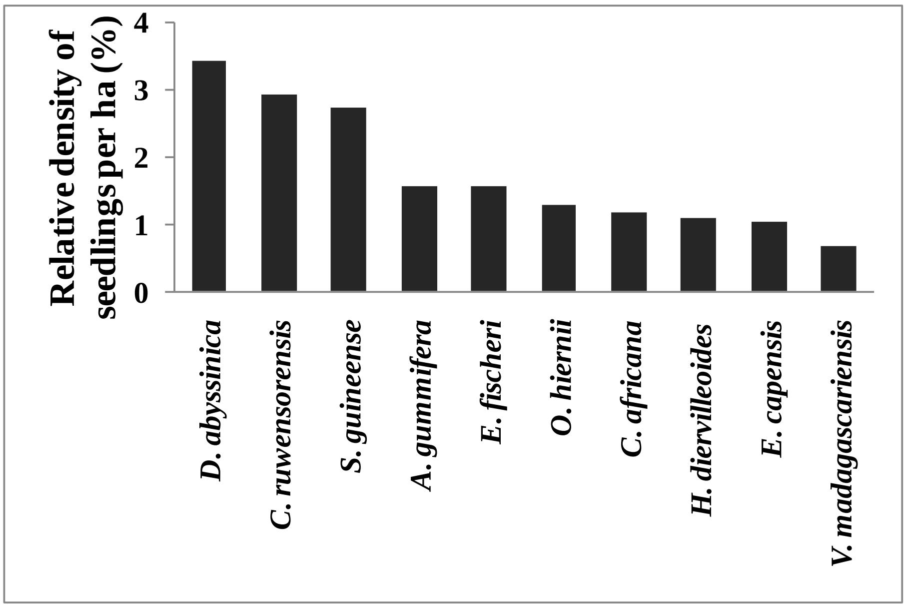


Figure 19 Relative density of top ten seedling rich tree species of North Nandi forest

The most seedling dominat tree species is *Diospyros abyssinica contributing* 3.4% of the seedlings followed by *Cassipourea ruwensorensis* and *Syzygium guineense*, having 2.9 and 2.8% of seedlings, respectively (Fig. 19).

Figue 20 shows the top 20 seedling rich species in South Nandi. Like that of North Nandi, seedling population is dominated by few species in South Nandi too. Similarly, 89% of the seedlings belonged to the top 20 seedling rich species and the remaining 77 species comprised only 11% of the seedling population. The top ten seedling rich sepecies comprised about 70.4% of seedling population.

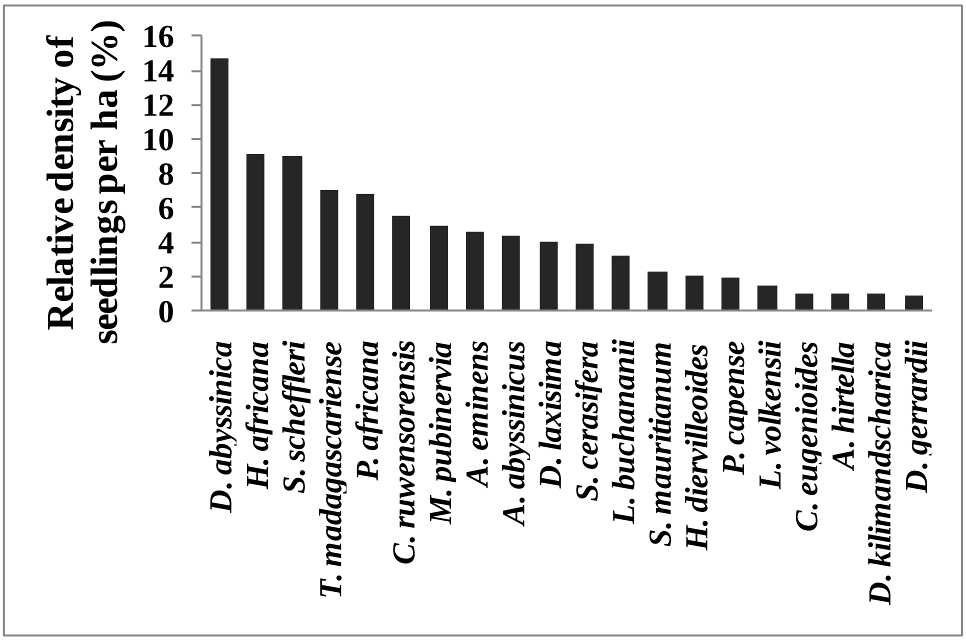


Figure 20 Top 20 seedling rich species in South Nandi forest.

In South Nandi forest *Diospyros abyssinica* has the most abundant seedlings (9220 seedlings per ha) followed by *Hippocratea africana* and *Strombosia scheffleri* with 5696 and 5628 seedlings per ha, respectively. Seedlings belonging to these species alone contributed about 33% of the total seeling population (Fig. 20). Generally, the first ten seedling rich tree species comprised almost half (i.e. 49.5 %) of the total seedlings per ha (Fig. 21). These include *Diospyros abyssinica, Strombosia scheffleri, Trilepisium madagascariense, Prunus africana, Cassipourea ruwensorensis, Heinsenia diervilleoides, Lepidotrichilia volkensii*, *Deinbollia kilimandscharica*, *Drypetes gerrardii* and *Macaranga kilimandscharica* (Fig. 21).

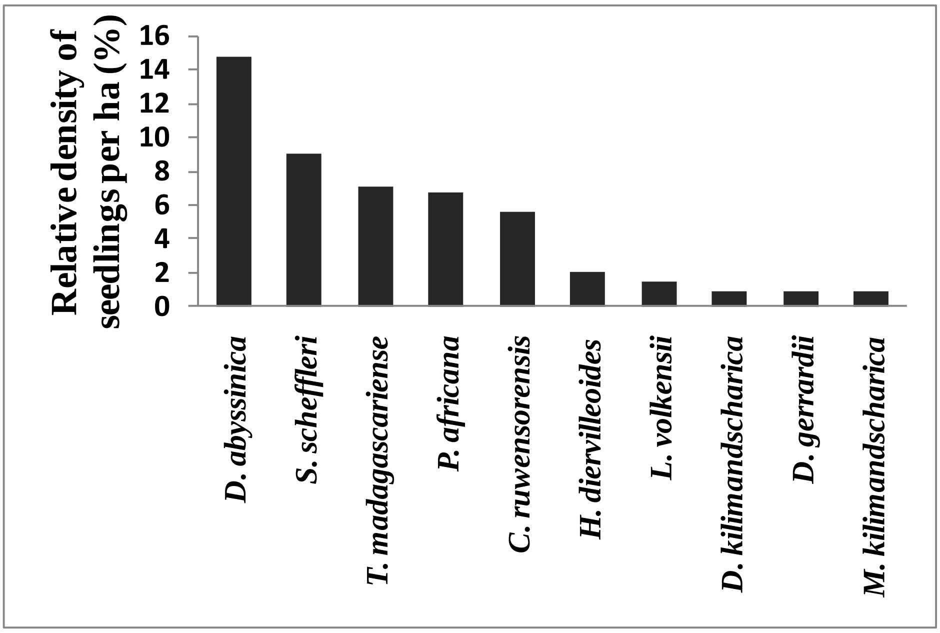


Figure 21 Relative densities of seedlings of top ten seedling rich tree species in South Nandi forest.

5.3.1.2 Diversty of seedlings

As it is presented in Table 16 the mean number of seedling species per plot is higher in South Nandi (26.3 species per plot) than that of the North Nandi forest (21.6 species per plot). The result of t-test showed that this difference is statistically very significant (t-value = 3.76, p<0.001). This is further strengthened by the rarefaction curve (Fig. 22). As it is shown in the rarefaction curve seedling species of the North Nandi forest is out side of the 95% confidence interval of the South Nandi forest. This means North Nandi seedling population has significantly lower species richness. Even if relatively higher Shannon diversity index was observed in South Nandi forest (2.38) than that of North Nandi (2.17) (Table 16), it is not statistically significant (t-value= 2.017, p=0.5). Evenness index, Fisher alpha and Whitaker beta diversity are relativel higher in South Nandi than North Nandi (Table 16).

Table 16 Different diversity characterstics of seedlings in North and South Nandi forests

Diversity measurment	North Nandi Forest	South Nandi Forest
Mean number of species per plot	21.6	26.3
Fisher's α	12.3	14.1
Shannon diversity (H')	2.17	2.38
Evenness index (E')	0.71	0.73
Whittaker beta diversity (β_w)	2.3	2.6

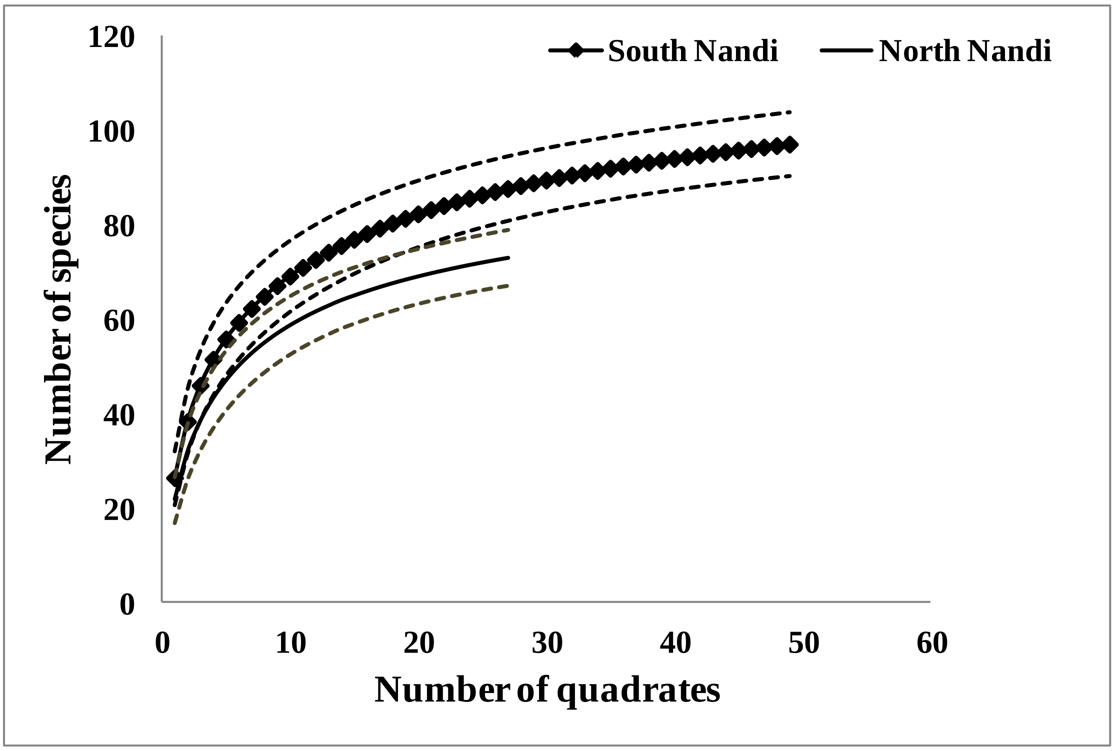


Figure 22 Seedling species accumulation (rarefaction) curves (solid lines) and 95% confidence intervals (dashed lines) for South and North Nandi forests

5.3.1.3 Similarity of seedlings between North and South Nandi Forests

In this study similarity indices for seedlings between North and South Nandi forests were calculated. As it is presented in Table 17 very low similarity is observed for both incidence and abundance based indices except for that of Chao-Sørensen estimator (0.52) which is medium. The lowest similarity (0.21) was calculated by Jaccard. Still low but relatively higher (0.34) and 0.38 similarity index was resulted by Sørensen (classic) and Chao-Jaccard estimator, respectively. The abundance based similarity, Chao-Sørensen estimator, resulted in medium similarity (0.52) (Table 17).

Table 17 Incidence and abundance based similarity indices of North and South Nandi Forests

Incidence based similarity indices		**Abundance based similarity indices**	
Sørensen	0.34	Chao-Sørensen estimator	0.52
Jaccard	0.21	Chao-Jaccard estimator	0.38

Similarities between tree (including saplings) species recorded in the biger plots and seedlings of tree species were also analysed using both incidence and abundance based indices. As indicated in Table 18 almost equal Sørensen similarities were observed in North (0.6) and South Nandi (0.55). Relatively higher Jaccard similarity index was recorded in North (0.44) than South Nandi forest (0.39). In both forests higher Chao-Sørensen estimator and Chao-Jaccard estimator was observed (i.e. 0.79 and 0.69 for South Nandi and 0.78 and 0.68 for North Nandi, respectively) (Table 18).

Table 18 Incidence and abundance based similarity indices of trees and tree species seedlings in North and South Nandi Forests

South Nandi				**North nandi**			
Incidence based		**Abundance based**		**Incidence based**		**Abundance based**	
Sørensen	0.55	Chao-Sørensen estimator	0.79	Sørensen	0.6	Chao-Sørensen estimator	0.78
Jaccard	0.39	Chao-Jaccard estimator	0.69	Jaccard	0.44	Chao-Jaccard estimator	0.68

5.3.1.4 Ordination

The DCA ordination of seedlings plots in Nandi forests is presented in Figure 23. The eigenvalues and the cumulative percentage variation of species data is presented in Table 19. The first four axes explain 34.9% of the variation of the seedling species data. The first axis has an eigenvalue of 0.507 explaining 14.9% of the variation. The second and the third axes explained 10 and 6.4% of the variation, respectively with the eigenvalues of 0.341 and 0.22 in the same order (Table 19). Plots are distributed over the two axes based on the disturbance type of the sites. The plots which are found on the upper side of the second axis are those sampled from North Nandi forest (Triangles▲). Those sampled from South Nandi forest (circles ● and○) are distributed along the first axis.

Table 19 Eigenvalues of the first four axes of DCA and the amount of variance explained by each axes in two Nandi Forests

Axes	I	II	III	IV	Total inertia
Eigenvalues	0.507	0.341	0.220	0.123	3.408
Lengths of gradient	3.287	3.044	2.306	2.389	
Cumulative % variance of species data	14.9	24.9	31.3	34.9	

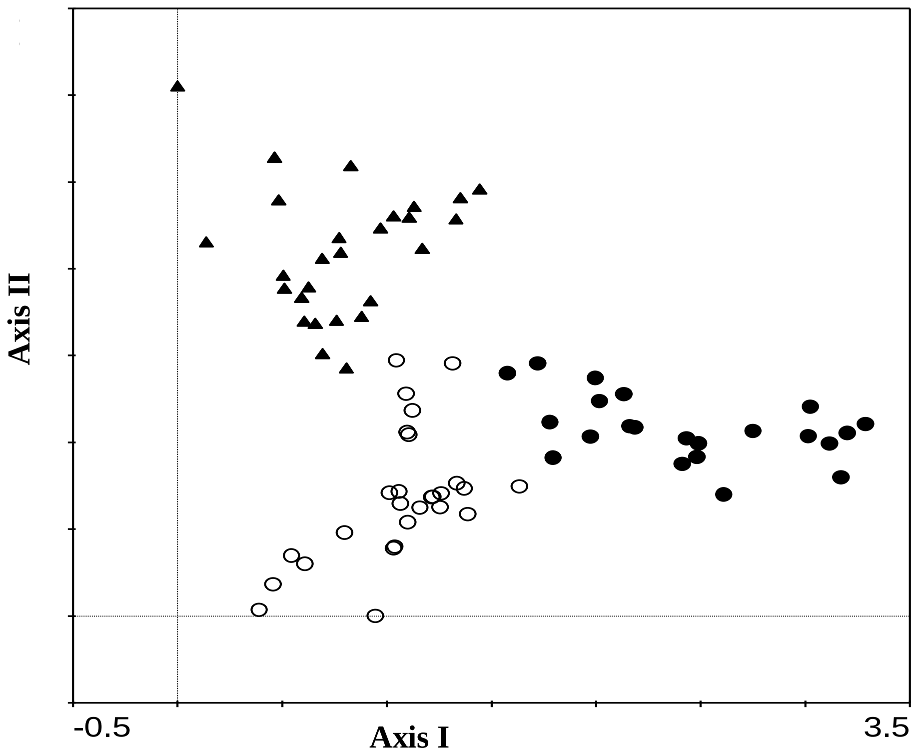


Figure 23 Ordination based on Detrended Correspondence Analysis (DCA) with abundance of woody plant species seedlings from Nandi Forests. One symbol represents one plot, circles (● and ○) are samples from south Nandi and Triangles (▲) are from North Nandi.

The first two axes of the DCA might be the type of disturbances which are observed in the two forests of Nandi (i.e. cutting of trees and grazing). For instance, plots form relatively better side of South Nandi forest (i.e. open circles) are situated on the lower side of the second axis and on the left side of the first axis. Those sampled from heavily disturbed side (i.e. filled circles) are found on the right side of the first axis and still on the lower side of the second axis though most of the plots are situated above those from the better side (Fig. 23). Hence, the first axis reflects the difference in the intensity of the removal or cuttings of matured trees. However, it could be coupled with other environmental factors. Plots from North Nandi forest (triangles) are situated at the left of the first axis but on the upper side of the second axis (Fig. 23). It has been observed that there is heavy grazing by domestic animals in North Nandi forest. Therefore, the second axis might reflect the rate of grazing in the forests. But it could also be combined with other biotic or abiotic factors.

5.3.2 Regeneration from stumps

5.3.2.1 Causes, level of stem damage and sprouting after damege

To look into the response of woody plants after physical damage, stumps, which are both cut and broken, were investigated. Totally, 676 stumps from both South and North Nandi forests, representing 56 species (from 51 genera and 28 families) including 24 stumps which were difficult to indentify (since they were rotten), were recorded. Out of these 676 stumps, 567 (83.9%) were resulted from cuttings and the remaining 109 (16.1%) were due to brakage from various reasons (i.e. mainly branch and tree fall). Among these identified stump species (56), 40 species were represented by less than ten stumps and the remaining 16 species were represented by ten or more stumps. Generally, most of the stumps belong to few tree species. For instance, stumps of *Drypetes gerrardii, Cassipourea ruwensorensis, Strombosia scheffleri, Heinsenia diervilleoides, Diospyros abyssinica, Macaranga kilimandscharica, Tabernaemontana stapfiana, Casearia battiscombei, Trilepisium madagascariense* and *Deinbollia kilimandscharica* made about 56.5% of the total stumps of Nandi forsts (Table 21). Except *Macaranga kilimandscharica* of which 38% of the stumps sprouted, the rest of these species have at least 50% of their stumps have resprouted (Table 21). It was observed that totally 453 stumps (67%) from 54 species sprouted but the remaining 223 (33 %) stumps did not give any shoot growth. The only two species which did not have shoot (sprout) on their stumps were *Croton megalogarpus* and *Syzygium guineense*. Among 14 woody species that have ten or more stumps and able to resprout, only two species have less than 50% stumps that sprouted (i.e. *Macaranga kilimandscharica* (38%) and *Mimulopsis arborescens* (17%)) (Table 21).

In South Nandi forest totally 523 stumps (13 stumps were not possible to identify) from 45 species comprising 43 genera and 24 families were recorded. The majority of the stumps (435 or 83.2%) are result of removal of stems by human beings (i.e. cuttings) but the remaining, 88 of them (16.8%) broken due to fall of branches and/or big trees. Out of the total stumps in South Nandi, 346 (66.2%) of them were able to sprout and the remaining 177 stumps (33.8%) did not give any shot. On the other hand totally 153 stumps (out of which 11 of them were not identified) comprising 28 species (27 genera and 17 families) were recorded in North Nandi.

Only 20 of these stumps were resulted from fall of branches and/or big trees (broken) on them. Form the total stumps of North Nandi forests, 107 (69.9%) of them resulted in resprouting and the remaining 46 stumps (30.1%) did not able to resprout. Stumps of *Croton megalogarpus* did not give any shoot growth and this was observed in South Nandi while in North Nandi all stumps of *Syzygium guineense* did not result in shooting.

Higher mean number of stump was observed in South Nandi forest (10.7 stumps per plot) than that of North Nandi (5. 7 stumps per plot) (Table 20). This difference is statistically very significant (t-value 4.92, p<0.001). This mean number of stump can be extarapolated to hectare bases resulting 268 and 142 stumps per ha in South Nandi and North Nandi forest, spectively (Table 20).

Table 20 Mean number of stumps per plot (400 m^2) and hectare in South Nandi and North Nandi forests (* values are mean ± SD)

Forest	Mean stumps per* plot	Stumps per ha
South Nandi	10.7 ±5.4	268
North Nandi	5.7 ±3.4	142

5.3.2.2 Sprouting ablity of species

It was observed that *Drypetes gerrardii* has the highest number of stumps (Table 21) among the woody plants which were damaged by human as well as naturally. Generaly, 74 stumps were recorded only in South Nandi forest (i.e. it is not recorded in North Nandi) among which only seven (9.5%) of them were resulted from brakage due to either branch or big tree fall. This tree species is highly sought for its timber value and charcoal production. Half (37) of the stumps were able to resprout. Stump diameter of this species ranges from two to 97 cm in which about 67% of them are greater or equal to 15 cm.

Cassipourea ruwensorensis has the second abundant stumps. Totally 70 stumps of this speces were identified in both forests (62 of them in South and the remaining in North Nandi forest). About 30% of the stumps (21) were resulted from fall of branches and/or trees and the remaining 49 stumps were due to cuttings. As most of the stumps (64) were having diameter of less than or equal to ten cm, this species may be removed either to ease movement in the forest or probally to be used as pegs when charcoal is produced. Almost 84% of the stumps of *Cassipourea ruwensorensis* were able to resprout.

Table 21 Stumps recorded in Nandi forests with their resprouting percentage

Species Name	Total stumps	South Nandi	North Nandi	Sprouted	Not sprouted	Percent of sprouted	Relative proportion of stumps
Drypetes gerrardii	74	74	0	37	37	50	10.9
Cassipourea ruwensorensis	70	62	8	59	11	84.3	10.4
Strombosia scheffleri	53	53	0	47	6	88.7	7.8
Heinsenia diervilleoides	48	47	1	35	13	72.9	7.1
Alchornea hirtella	46	46	0	39	7	84.8	6.8
Solanum mauritianum	43	32	11	26	17	60.5	6.4
Diospyros abyssinica	35	7	28	20	15	57.1	5.2
Macaranga kilimandscharica	32	24	8	12	20	37.7	4.7
Unidentified stumps	24	13	11	0	24	0	3.6
Tabernaemontana stapfiana	22	22	0	18	4	81.8	3.3
Casearia battiscombei	17	5	12	13	4	76.3	2.5
Trilepisium madagascariense	16	16	0	9	7	56.3	2.4
Deinbollia kilmandscharica	15	9	6	12	3	80	2.2
Dovyalis macrocalyx	12	4	8	12	0	100	1.8
Mimulopsis arborescens	12	12	0	2	10	16.7	1.8
Syzygium guineense	11	0	11	0	11	0	1.6
Croton megalocarpus	10	10	0	0	10	0	1.5
Alangium chinensee	9	9	0	8	1	88.9	1.3
Erythrococca fischeri	9	5	4	8	1	88.9	1.3
Xymalos monospora	9	9	0	4	5	44.4	1.3
Oxyanthus speciosus	8	6	2	8	0	100	1.2
Turraea holstii	8	1	7	7	1	87.5	1.2
Vangueria madagascariensis	7	1	6	7	0	100	1.0
Albizia gummifera	6	2	4	6	0	100	0.9
Celtis africana	6	5	1	3	3	50	0.9
Ehretia cymosa	6	0	6	5	1	83.3	0.9
Polyscias fulva	6	6	0	5	1	83.3	0.9
Bersama abyssinica	4	0	3	3	1	75	0.6

Craibia brownii	4	4	0	3	1	75	0.6
Lepidotrichilia volkensii	4	4	0	4	0	100	0.6
Olea capensis	4	2	2	2	2	50	0.6
Chrysophyllum viridifolium	3	3	0	3	0	100	0.4
Coffea eugenioides	3	3	0	3	0	100	0.4
Ficus sur	3	3	0	2	1	66.7	0.4
Rawsonia lucida	3	3	0	1	2	33.3	0.4
Zanthoxylum gillettii	3	3	0	2	1	66.7	0.4
Allophylus abyssinicus	2	0	2	2	0	100	0.3
Allophylus africanus	2	2	0	1	1	50	0.3
Celtis durandii	2	2	0	1	1	50	0.3
Croton macrostachyus	2	0	2	1	1	50	0.3
Erythrococca trichogyne	2	1	1	2	0	100	0.3
Markhamia lutea	2	2	0	2	0	100	0.3
Neoboutonia macrocalyx	2	1	1	2	0	100	0.3
Pavetta abyssinica	2	0	2	2	0	100	0.3
Teclea nobilis	2	2	0	2	0	100	0.3
Vernonia auriculifera	2	1	1	1	1	50	0.3
Aningeria altissima	1	1	0	1	0	100	0.1
Chionanthus mildbraedii	1	0	1	1	0	100	0.1
Dalbargia lactea	1	0	1	1	0	100	0.1
Ekebergia capensis	1	1	0	1	0	100	0.1
Keetia gueinzii	1	1	0	1	0	100	0.1
Kigelia africana	1	1	0	1	0	100	0.1
Maytenus heterophylla	1	0	1	1	0	100	0.1
Meyna tetraphylla	1	1	0	1	0	100	0.1
Ritchiea albersii	1	1	0	1	0	100	0.1
Rytigynia acuminatissima	1	0	1	1	0	100	0.1
Solanum hastifolium	1	0	1	1	0	100	0.1

The other tree species with higher stump number were *Strombosia scheffleri*, *Heinsenia diervilleoides*, *Diospyros abyssinica* and *Macaranga kilimandscharica* with stump number of 53, 48, 35 and 32, respectively. It was observed that 89, 73, 57 and 38% of the stumps of these species were able to resprout, in the same order.

In North Nandi forest, *Diospyros abyssinica* has the highest stump number (28) followed by *Casearia battiscombei*, and *Syzygium guineense* with 12 and 11 stumps, respectively. Half of *D. abyssinica* and 83.3 % *C. battiscombei* stumps were able to resprout but none of *S. guineense* stumps were able to shoot. These tree species are cut mainly for their timebr value.

Mean number of sprout per stump ranges from zero for *Croton megalogarpus* and *Syzygium guineense* (10 and 11 stumps, respectively) to 11.5 for *Allophylus abyssinicus* (with only two stumps). Mean number of sprout per stump for species with 10 or more stumps was subjected to Kruskal-Wallis test and it was reaveled that there is statistically significant difference (Chi-square= 114.14, P<0.0001). *Strombosia scheffleri* has the highest mean number of sprout per stump (8.19±7.9) (Table 22). It is significantly different from *Cassipourea ruwensorensis, Croton megalocarpus, Drypetes gerrardii, Heinsenia diervilleoides, Macaranga kilimandscharia, Mimulopsis arborescens, Solanum mauritianum* and *Syzygium guineense.* However, no significant difference was observed between *Strombosia scheffleri* and the rest of species as well as among other species. *Dovyalis macrocalyx* and *Tabernaemontana stapfiana* are the second and third species having 6.8±2.78 and 6.23±5.9 shoots per stump, respectively among species that have ten or more stumps (Table 22).

Wider range of number of shoots per stump was recorded in general. For example as high as 65 and 64 shoots per stump were recorded for *Cassipourea ruwensorensis* and *Drypetes gerrardii*, respectively. As high as 35, 33 and 28 sprouts per stump were counted for *Solanum mauritianum, Strombosia scheffleri* and *Trilepisium madagascariense* in the same order. This shows that there is huge gap in number of shoots per stump between species as well as with in different stumps of the same species.

Table 22 Mean number of sprout (shoot) per stump for species that have ten or more stumps in Nandi forests

Species name	Mean number of sprout per stump	Number of stumps investigated
Drypetes gerrardii	3.9±8.43	74
Cassipourea ruwensorensis	4.13±8.6	70
Strombosia scheffleri	8.19±7.9	53
Heinsenia diervilleoides	2.67±2.59	48
Alchornea hirtella	3.91±4.8	46
Solanum mauritianum	2.53±5.5	43
Diospyros abyssinica	3.8±5.2	35
Macaranga kilimandscharia	2.03±4.67	32
Tabernaemontana stapfiana	6.23±5.9	22
Casearia battiscombei	2.18±1.94	17
Trilepisium madagascariense	6±9	16
Deinbollia kilimandscharica	1.8±1.26	15
Dovyalis macrocalyx	6.8±2.78	12
Mimulopsis arborescens	0.33±0.88	12
Syzygium guineense	0	11
Croton megalocarpus	0	10

5.3.2.3 Relationship between stump characterstics and sprouting ability

Stump diameter

Generally, higher number of stumps was found in the range of two to ten cm stump diameter (the frst two diameter classes) and the number is subsequently decreasing towards the bigger size (Table 23). For instance, 248 and 158 stumps were found in the first and second stump diameter class (2-5 and 5-10 cm) in Nandi forests in general (Table 23). The third stump diameter size class (10-20 cm) contained totally 110 stumps, where as stump dimeter class 20-30 cm has a total of 41 stumps. The number of stumps in the largest dimeter class (>60 cm) is only 29 while those in classes 30-40, 40-50, 50-60 cm are 37, 32 and 21 stumps, respectively (Table 23).

Table 23 Toal number of stumps and number of sprouted stumps in Nandi Forests in each stump diameter class

Stump dimeter size class (cm)		2-5	5-10	10-20	20-30	30-40	40-50	50-60	>60
South Nandi▲	**Stumps**	194	117	86	36	31	27	14	18
	Sprouted	167	86	40	23	10	11	4	5
	% sprouted	86.1	73.5	46.5	63.9	32.3	64.7	28.6	27.8
North Nandi★	**Stumps**	54	41	24	5	6	5	7	11
	Sprouted	50	35	16	3	1	0	1	0
	% sprouted	92.6	86.4	66.7	60	16.7	0	14.3	0
Total ❖	**Stumps**	248	158	110	41	37	32	21	29
	Sprouted	217	121	56	26	11	11	5	5
	% sprouted	87.5	76.6	50.9	63.4	29.7	34.4	23.8	17.2

Total stumps recorded in ▲=1.96 ha, ★=1.08 ha and ❖=3.04 ha

In South Nandi 311 (59.5%) of the stumps are found in the first two lowest stumps diameter class (194 and 117 stumps in 2-5 and 5-10 cm, respectively) while in North Nandi totally 95 stumps (62.1%) (i.e. 54 and 41 stumps in 2-5 and 5-10 cm, respectively) fell in these stump diameter classes (Table 23). In 10-20 cm class 86 and 24 stumps were found in South and North Nandi, respectively. The stump size class 20-30 cm comprised 36 stumps in South Nandi where as in the North only 5 stumps were recorded in this range. In the range of 30-40 cm stump diameter 31 stumps were counted in South Nandi but in the same range only six stumps were recorded in North Nandi forest. In the bigger stump size classes (i.e.40-50, 50-60 and >60 cm) totally 59 and 23 stumps were recorded in South and North North Nandi, respectively (Table 23).

As it is shown in Table 23 resprouted stumps were higher in the first two stump diameter classes. In South Nandi 86.1% of the stumps in the range of 2-5 cm diameter were able to resprout while in the North Nandi in this same diameter class 92.6% of the stumps gave shoot (Table 23). The lowest sprouting ability were observed in the largest diameter class (>60 cm) in which only 27.8% of the stumps were able to resprout in South Nandi where as in the North none of the stumps in the range of 40-50 cm and those above 60 cm able to shoot.

The highest number of sprout per stump (6.3) was recorded in diameter class four (20-30 cm) and the lowest number (0.95) was found in stump diameter range of 50-60 cm (stump diameter class 7) (Fig. 24). Kruskal Wallis test of analysis of variance reaveled that there is significant difference (Chi-square=76.9, $p<0.05$) of medians of number of sprout per stump among the diameter classes. The multiple comparison showed that there is significant difference between stump diameter class four (20-30 cm) and seven (50-60 cm) while there is no significant difference among the other diameter classes (Fig. 24).

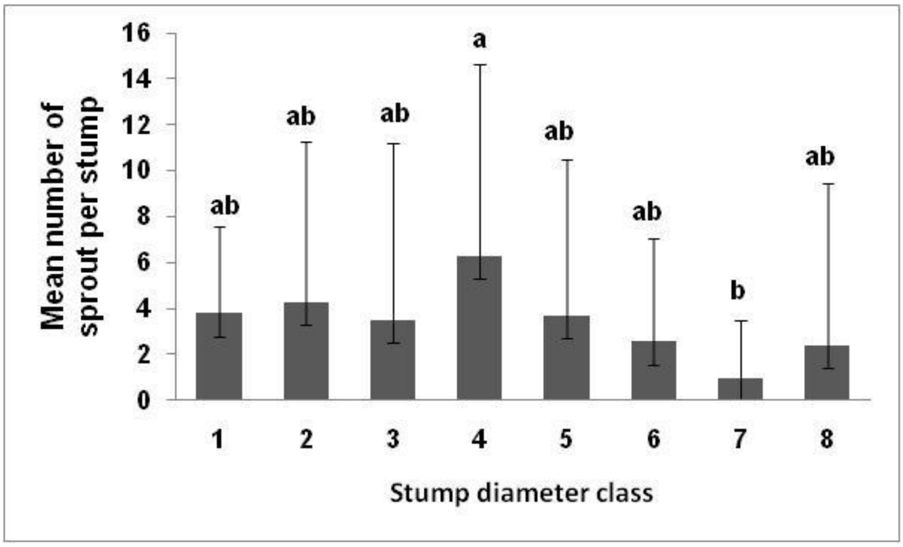


Figure 24 Mean number of sprout (shoot) per stump in stump diameter classes 1=2-5 cm, 2=5-10 cm, 3=10-20, 4=20-30, 5=30-40, 6=40-50, 7=50-60 and 8=>60 (means with the same alphabets are not significantly different).

In this study, analysis was made to see if there is any correlation between number of sprout per stump and stump diameter as well as between number of sprout per stump and stump height. The resulting correlation analysis for the whole data set revealed that there is significant correlation between number of sprout and the two stump charachteristics (stamp diameter and stump height) with Perason correlation coefficient (r)=0.078, $p<0.05$ for stump diameter and r=0.083, $p<0.05$ for stump height. However, when this analysis is made on species basis only stump diameter of three species showed significant correlation with number of sprout. Significant relationship was observed in *Strombosia scheffleri* (r=0.33, $p<0.05$), *Diospyros abyssinica* (r=-0.39, $p<0.05$) and *Heinsenia diervilleoides* (r=-0.45, $p<0.01$). The resulting regression analysis of these species is presented in Figure 25 showing that there is negative relationship between stump diameter and number of sprout per stump of *Diospyros abyssinica* and *Heinsenia diervilleoides*. However, this relationship is positive in the case of *Strombosia scheffleri*.

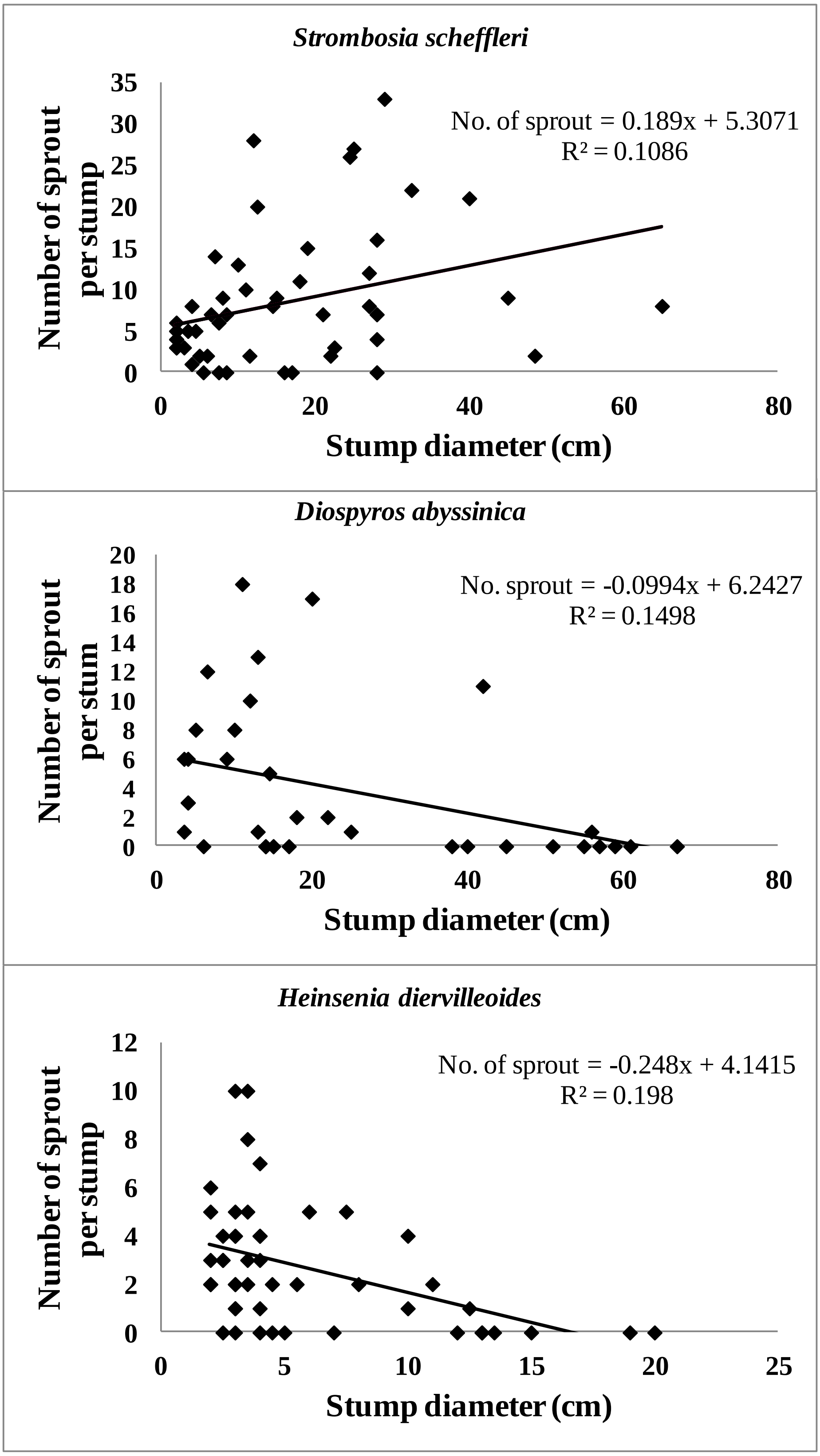


Figure 25 Regression analyses of stump diameter on the number of sprouts/stump of three species (which showed significant relationships) following cutting, and tree and/or branch fall disturbances in Nandi Forests, Kenya

Stump height

Generally, the majority (37.6% or 254 stumps) of the stumps (stumps of all species together) were found in the second stump height class that ranges from 50-90 cm (Fig. 26). The second majority, 158 stumps (23.4%) fell in the range of 10-50 cm stump height class (i.e. first stump height class) followed by third, fifth and fourth height class (i.e. 122, 86 and 56 stumps, respectively). The number of sprouted stumps have almost similar pattern like that of the total number of stumps in each stump height class (Fig. 26). The largest number of stumps (153 stumps) sprouted in the second height class followed by third (93 stumps), first (85 stumps) and fifth (80 stumps) height classes. The smallest number of stumps (44 stumps) sprouted was found in the fourth height class (Fig. 26).

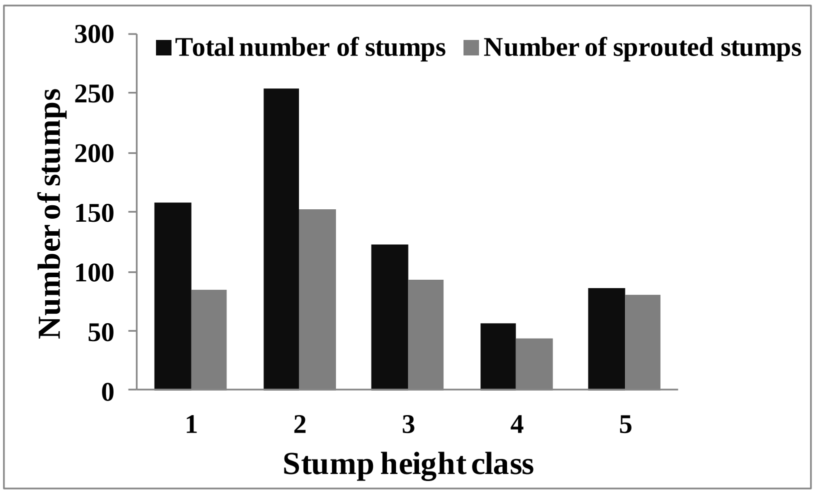


Figure 26 Total number of stumps and number of sprouted stumps vs stump height class (1= 0.1-0.5 m, 2=0.5-0.9 m, 3=0.9-1.3 m, 4=1.3-1.7 m and 5=>1.7 m)

As presented in Table 24 in most species the majority of the stumps were found in in the second stump height class (i.e. 50-90 cm). For example, 45.9% (34) of *Drypetes gerrardii* stumps range between 50 to 90 cm heigh. Similar pattern is also observed in *Strombosia scheffleri* where 37.7% of the stumps are found in the second stump height class. In the case of *Cassipourea ruwensorensis* the largest proportion of the stumps (34.3%) are found in class 5 (i.e. >1.7 m). *Heinsenia diervilleoides* has also such type of pattern with about 29.2% of stumps are having stump height taller than 1.7 m.

Stump height class did not show any significant difference in number of sprout per stumps for species that have more than 30 stumps. *Drypetes gerrardii* has the highest mean number of sprout per stump (6.7) in the height class three (90-130 cm) and the lowest (0.67) in stump height class five (more than 1.7 m) (Table 24).

Table 24 Number of stumps in each stump height class with their sprouting ability and mean number of sprouts per stumps for woody species that have more than 30 stumps (stmp height class 1= 0.1-0.5 m, 2=0.5-0.9 m, 3=0.9-1.3 m, 4=1.3-1.7 m and 5=>1.7 m)

Species name/Stump heigh class		**1**	**2**	**3**	**4**	**5**
D. gerrardii	Stumps	18	34	10	6	6
	Sprouted	5	16	7	6	3
	Mean number of sprout per stump	1.6±3.7	4.5±11.4	6.7±6.3	5.3±3.7	0.7±0.8
C. ruwensorensis	Stumps	14	10	16	6	24
	Sprouted	7	8	14	6	24
	Mean number of sprout per stump	3±4.1	10±19.5	5±6.3	4.2±5	1.8±2.6
S. scheffleri	Stumps	15	20	8	3	7
	Sprouted	14	16	8	3	6
	Mean number of sprout per stump	9±9.4	9.1±8.2	6.6±4.1	6.3±3.1	6.2±9.7
H. diervilleoides	Stumps	11	10	9	4	14
	Sprouted	4	7	7	4	13
	Mean number of sprout per stump	1.5±2.3	2.6±2.2	3.8±3.7	4.3±3.9	2.5±1.4
D. abyssinica	Stumps	4	15	5	6	5
	Sprouted	2	8	2	4	4
	Mean number of sprout per stump	3±5.4	3.7±5.1	3.6±5.7	7±7	1.2±0.84
M. kilimandscharica	Stumps	9	15	4	1	3
	Sprouted	0	6	2	1	3
	Mean number of sprout per stump	0	3.7±6.4	0.8±0.9	2	1.3±0.57
A. hirtella	Stumps	10	19	5	5	7
	Sprouted	10	14	4	4	7
	Mean number of sprout per stump	3.5±1.6	3.5±4.5	2.4±2.1	7.4±8.9	4.1±6.3
S. mauritianum	Stumps	9	16	10	4	4
	Sprouted	3	14	6	0	3
	Mean number of sprout per stump	0.7±1.1	2.9±2.6	5.1±10.7	0	1.3±0.9

5.4. Discussion

5.4.1 Seedling bank

Generally, it is observed that the seedling population of Nandi Forests is dominated by few species. In addition, the distribution pattern of some species is restricted to a particular site or habitat. In both South and North Nandi forests the top two species rich families in the seedling population were Rubiaceae and Euphorbiaceae followed by Acanthaceae and Sapotaceae (in South Nandi) as well as Solanaceae and Acanthaceae (in North Nandi). In Kakamega forest it was reported that Euphorbiaceae is the richest family of tree seedlings followed by Sapotaceae, Flacourtiaceae (the new name of this family is Salicaceae), Moraceae and Rubiaceae (Gliniars, 2010). Gliniars also reported that in Budongo forest (a tropical rainforest found in Uganda) the most abundant tree seedlings belong mainly to families of Sapotaceae, Meliaceae, Sapindaceae and Violaceae.

Totally seedlings of 117 woody plant species were recorded in both North and South Nandi forests, however few species (eight species) have wider distribution in both forest with frequency of more than 50% (Table 15). These include *Hippocratea africana, Diospyros abyssinica, Allophylus abyssinicus, Cassipourea ruwensorensis, Landolphia buchananii, Solanum mauritianum, Coffea eugenioides* and *Erythrococca fischeri*. This shows that most of the species have restricted distribution in Nandi forests which can change the future population structure of these forests. For instance, seedlings of *Strombosia scheffleri* and *Drypetes gerrardii* were not recorded in North Nandi forest; this is mainly due to the absence of matured trees of these species (i.e. no seed source) in this forest. Both species are absent in North Nandi forest, at least they are not recorded in our study quadrat that could be either they are very rare or totally absent in this forest.

Tree seedlings of South Nandi forest were dominated by *Diospyros abyssinica, Strombosia scheffleri, Trilepisium madagascariense* and *Prunus africana* (Fig. 21). Seedlings of these tree species were also the most dominant in the same order even when both South and North Nandi forests were analyzed together (Table 15). In Kakamega forest which was connected to the Nandi forests at the beginning of the 20th century, *Trilepisium madagascariense, Prunus africana* and *Diospyros abyssinica* were the top three abundant tree seedlings (Gliniars, 2010). Seedlings of North Nandi forest were dominated by shrub and climber species. As indicated in Figure 19 the first six seedling rich species of this forest are either climbers or shrubs.

Hippocratea africana is the most dominant species contributing more than 27% of the seedlings followed by *Landolphia buchananii* and *Acanthopale pubescens*. The domination of these climber and shrub species might be attributed to the heavy grazing of livestock in North Nandi forest. This situation might affect the germination, establishment, growth and development of seedlings of tree species and might favour that of shrubs and climbers.

In both South and North Nandi forests *Diospyros abyssinica* is the most dominant seedlings of tree species (Fig. 19 and 21). More over, it is well distributed in both forests with 98 and 77.8% frequency in South and North Nandi, respectively (Table 15). This shows that *Diospyros abyssinica* can easily germinates and establishes into seedlings in a wider range of habitats. However, as it is indicated in chapter four (section 4.3.3) this species has a 'bell' shaped diameter distribution (Fig. 15) revealing that the number of saplings and smaller trees is smaller than trees in the intermediate diameter classes. This could be happened most probably due to poor recruitment of seedlings to saplings and saplings to small tree stage due to the anthropogenic effects.

Prunus africana has frequency of 59.2% in South Nandi and 14.8% in North Nandi and this suggests that the distribution of this species is restricted to limited habitat. The number of matured tree of this species is very few in North Nandi forest and this can also affect the number of seedlings since there could be limited source of seed. Furthermore, it has been recognized that seedlings of this species are restricted only around mature trees. It has also been observed that it is extremely rare case to record seedlings of *P. africana* far from matured trees. Such clumpy distribution of seedlings around mature (adult) trees was also observed in *Lasiodiscus mildbraedii* and *Raphia farinifera* in Budongo forest (Mwavu, 2007). This kind of seedling distribution might be happened mainly due to short distance dispersal of seeds from the mother tree and lack of seeds to germinate in areas far from the seed source (i.e. mature trees). Dalling *et al*. (2002) reported that seeds of many tropical tree species dispersed not far from their source and this can result in clumpy nature of seedling distribution. The other problem that was recognized with *P. africana* was that, this species has problem in sapling recruitment. As it was presented in chapter four (section 4.3.3 Figure 14) very small number of individuals both at sapling (dbh class one i.e. 2-5 cm) and mature trees (with dbh more than 50 cm) stages were recorded and in between there was nothing. Different authors reported that seeds of *P. africana* germinate well under shade (Tsingalia, 1989; Kiama and Kiyiapi, 2001; Nzilani, 2001; Alemayehu, 2007) but it requires light gaps to survive beyond the sapling stage (Tsingalia, 1989; Kiama and Kiyiapi, 2001; Nzilani, 2001) and hence this might hampered the growth and development of the seedlings of this species in Nandi forests. Other factors that can contribute to the poor performance of seedlings of *P. africana* were also suggested by different authors. These include disease (Franklin *et al*., 1987; Waring, 1987), insect attack (Nair *et al*., 1996; Cunningham *et al*., 2002), nutrient deficiency (Hunter, 1993) and climatic fluctuation (Lwanga, 2003) or a combination of two or more of these factors.

Syzygium guineense has only 32 seedlings per ha in South Nandi and this number increased to 1045 seedlings per ha in North Nandi (Table 14). This difference could be mainly due to less number of matured trees (source of seed) in South Nandi forest than North Nandi. However, as it was shown in chapter four (section 4.3.3) even if there are more matured trees in North Nandi, the number of saplings and small trees (2-10 cm dbh) is smaller when it is compared with number of big trees (> 20 cm dbh) (Fig. 14). This could be resulted from poor seeding nature of the matured trees (due to age) or there may be seed loss due to seed predators after production (Feyera, 2006). More over, Feyera suggested that fruits of *Syzygium guineense* are usually used as food by many animals and also human, which could also affect the availability of seed for germination. The livestock may have also affected the performance seedlings due to their browsing, grazing and trampling effects.

Based on the disturbance nature and intensity, seedling quadrates of Nandi forests are well distributed on the first two axes of the ordination (Fig. 23). In North Nandi the main disturbance factor is livestock grazing, while in South Nandi tree cutting for charcoal and timber is the main cause. It has been reported that in tropical forests grazing might have either positive or negative effect on successful regeneration of woody plant species (McEvoy *et al*., 2006; Miller *et al*., 2006; Alemayehu, 2007). By removing competitive vegetation and fire hazards as well as fertilizing by droppings, light level of grazing can facilitate and improve tree regeneration in general (Alemayehu, 2007). However, when there is continuous and intensive grazing, it has negative effect on regeneration and might cause an irreversible negative consequence on the vegetation of a given area (Opperman and Merenlender, 2000). Intensive and continuous livestock grazing disturbs the ecology by changing the nature of the soil and affecting the growth and development of seedlings. For instance, livestock can compact soil, exacerbate erosion, consume and trample seedlings as well as browse saplings, and thereby preventing forest regeneration (Clark and Clark, 1984, 1991; Alemayehu, 2007). Forest productivity can be diminished by grazing since it hampers seedling growth rate and survival, and also by changing tree form (Wilkinson and Nielsen, 1995; Bulinski and McArthur, 1999; Miller *et al*., 2006).

Seedlings are more sensitive to physical damage than those of matured trees. Clark and Clark (1991) reported that smaller individuals (between one and ten cm diameter) were more likely to be damaged than larger trees by physical damage such as branch or tree fall, hence most individuals of smaller size could be died. Cutting matured trees can have either negative or positive effect on seedling bank (natural regeneration) of a given forest. The negative effect is the physical damage on seedlings and sapling due to tree or branch falls which could be very sever. Cutting can also affect seed production there by affecting the number of seedling to emerge from the produced seeds. On the other hand gap created by cutting or other factor could positively affect the emergence of seedlings, especially of those light demanding species. Higher number of *Trilepisium madagascariense* seedlings is recorded in severely disturbed part of South Nandi forest with 44.9% frequency, reveling that this species emerges succefully under ample light.

5.4.2 Sprouting

Due to various artificial and/or natural causes most global biomes suffer from disturbances, which can result in loss of above ground biomass of plants (Clarke *et al*., 2010). These disturbances include wind throw, frost, drought, sever herbivory and fire (Vesk *et al*, 2004; Clarke *et al*., 2010). The response of the plants to these physical damages is either to die or to survive after the damage, by sprouting from the remaining stumps or root. In most cases the damaged plants do not die; rather, they persist through sprouting from meristems and stabilize plant populations where disturbance may cause demographic bottlenecks (Clarke *et al*., 2010).

Hence, the result of this study showed that Nandi forests exposed to disturbance both anthropogenic and natural which resulted in stumps. It has been observed that the majority of the stumps (83.9%) are resulted from cutting (i.e. harvesting of saplings, poles and mature trees). This might attributed to the closeness of the forests to human settlements. As it was observed, these forests are the main source of wood and wood products for construction, fuel wood and charcoal for the communities living around. Similar observation was also reported in Budongo forest of Uganda (Mwavu, 2007). Different surveys revealed that in Kenya people who are living adjacent to forests that are managed by KFS, are reliant on forest recourses, with approximately 60% of average household income directly tied to forest uses (Sharp, 1993;

Emerton, 1994; Nambiro, 2000). Hence, it is this huge dependency of the local community around Nandi forests that resulted in large number of stumps due to cutting.

Stumps of 56 species (all woody plants including trees, shrubs and woody climbers) were investigated for their sprouting ability in this study and 54 of them (96.4%) were sprouted. Similar observation was reported in Budong forest of Uganda where 97.5% of the investigated tree species were able to coppice (Mwavu, 2007). So far, this is the only work in Africa that was encountered during this study in this regard. The result of this study is fairly higher than reported elsewhere in the tropics out side of Africa. For instance, in the semi-evergreen rainforest of Queensland 90.2% of the species (i.e. 74 out of 82) were able to give shoot (Stocker, 1981). In a moist tropical forest situated in eastern Paraguay 60.3% of the investigated species (35 species out of 58) were able to coppice from stumps (Kammesheidt, 1998). McLaren and McDonald (2003) reported that in Jamaica, in a tropical dry limestone forsest out of 51 species sampled 48 of them (i.e. 94.1%) were able to coppice. Zimmerman *et al*. (1994) and Bellingham *et al*. (1995) reported that 54-87% of trees of various size classes sprouted after hurricane damage, in Jamaica, Puerto Rico and Nicaragua. In addition to species difference, environmental variables can have their impact on the response of woody plants to physical damage. For example, humid forests and tropical sites have been identified with higher community-wide sprouting ability than the temperate forests (Mwavu, 2007). Sprouting ability is also proportional to site quality (Roth and Hepting, 1943 and Johnson, 1977 cited by Weigel and Peng, 2002).

Sproutng ablity of species in Nandi forests ranges from 0-100%. The two species that did not sprout are *Syzygium guineense* and *Croton megalocarpus* with 11 and ten stumps respectively. These two species might have sprouted but the shoot (sprout) might die for various reasons which were not recognizable during data collection. Manishi, *et al*. (2010) reported that some of *Eurya japonica* stumps died after sprouting. Hence, this kind of phenomenon might be happened in some of the species in this study. Those with 100% sprouting ability have less than ten stumps except *Dovyalis macrocalyx* which has 12 stumps (Table 21). Among species that have more than ten species *Mimulopsis arborescens* (12 stumps) has the lowest coppicing percentage (16. 7% i.e. two out of twelve stumps). The second lowest was *Macaranga kilimandscharia* with 37.5% of sprouting ability. *Strombosia scheffleri* has the highest sprouting ability (88.5%) followed by *Alchornea hirtella* (85%) and *Cassipourea ruwensorensis* (84.3%) from those having more than 12 stumps. The highest mean number of sprout per stump (11.5) was recorded for *Allophylus abyssinicus* which has only two stumps. Among species that have ten or more stumps *Strombosia scheffleri* has the highest mean number of sprouts per stump followed *by Dovyalis macrocalyx and Tabernaemontana stapfiana*. It has been seen that stumps which have stump diameter less than or equal to ten cm, have the highest sprouting ability. Furthermore, most of the species (54 out of 56 species) able to give new shoot from the stumps. This is in agreement with what is stated in literature. Evans (1992) explained that most broadleaved tree species have the ability to coppice and this is confirmed in this study though there is difference in sprouting ability among species.

Differences in sprouting ability and mean number of sprout per stump could be attributed to the difference in species, age of the parent plant, diameter and height of the stumps as well as the site quality where the species grown (Weigel and Peng, 2002; Randall *et al*., 2005; Sands and Abrams, 2009; Ashish *et al*., 2010; Imanishi, *et al*., 2010); environmental conditions (Forrester *et al*., 2003) and susceptibility to decay, mortality and long-term survival of sprouts (Khan and Tripathi, 1986;1989). Sprouting vigour is also influenced by other factors such as chopping method, intensity of harvesting and season of cutting (Babeux and Mauffette, 1994; Ewel; 1996; Gardiner, *et al*., 2000). In this study, it has been seen that about 75.4% stumps (420 out of 557) with stump diameter ≤ 30 sprouted but for those with diameter > 30 cm only 26.9% (32 out of 119 stumps) were able to sprout (Table 23). Similar trend was observed in Budongo forest where 98.8% of the stumps with < 30 cm stump diameter coppiced while those having > 30 cm diameter only 66.7% (8 out of 12) were sprouted (Mwavu, 2007). This finding is also in agreement with the reports that stated sprouting ability is inversely proportional to stump diameter which is a function of age of the parent plants (Weigel and Peng, 2002; Randall *et al*., 2005 Sands and Abrams, 2009; Ashish *et al*., 2010; Imanishi, *et al*., 2010). Many species sprout at juvenile stage but, their ability to sprout at adult stage decrease (Everham and Brokaw, 1996; Bellingham and Sparrow, 2000). Specie may also have difference in other factors such as meristematic capacity (numbers of available buds), root-shoot partitioning (Zimmerman *et al.* 1994), stored carbohydrate and nutrient reserves (Pate *et al.*, 1990; Bowen, and Pate, 1993; Canadell and Lopez-Soria, 1998; Bell and Ojeda, 1999) which can affect their sprouting ability in return.

In general, this study shows that the seedling bank of Nandi forests is highly influenced by livestock grazing and cutting of matured trees for charcoal making and local timber production. Regarding to regeneration through resprouting most of the woody plant species of Nandi forests are able to resprout after physicall damage from the remaining above ground biomass.

Therefore, both regeneration through seedlings and coppice can be used to maintain the diversity of woody plants of Nandi forests.

6 Human Impact on Vascular Plant Diversity, Population Structure, Seedling Bank and Resprouting of South Nandi Forest

6.1 Introduction

Forests give different benefits such as economic, social, environmental and aesthetic values to human beings. They provide raw material for industries, play an important role in plant improvement programs as well as in regulating local and global climate (Yeshitela, 2008). For instance, tropical forests sequestrate large amount (half of) terrestrial carbon dioxide (Gorte and Sheikh, 2010) and maintain atmospheric humidity (Lalfakawma, 2010). Environmentally forests are crucial in reducing soil erosion, maintaining soil moisture and regulating stream flow as well as budgeting heat of the area and provide shelter to diverse variety of flora and fauna (Lalfakawma, 2010).

Despite all these benefit currently there is high rate of deforestation especially in the tropics (Whitmore and Sayer 1992; Turner, 1996; Whitemore, 1997). Main factors responsible for such huge destruction of natural forests are combination of agricultural expansion, commercial harvest, free livestock grazing, unsustainable firewood collection and charcoal production, and inappropriate land and tree tenure regimes (GEO-2000 1999; MEA 2005b; Alemayehu, 2007).

South Nandi forest is one of the natural forests found in Kenya. It is situated on the Nandi hills where there is competition of land for other use than forestry. It has been observed that huge areas of land covered by tea plantation and there is still expansion of commercial tea farming in the forest area. Lambrechts *et al.,* (2007) reported that illegal settlement, agricultural filed expansion, charcoal production and logging are main threat to South Nandi forest.

Environmentally, South Nandi forest is very important in protecting the catchment of Lake Victoria basin. The Kimondi and Sirua rivers merge within this forest to form the Yala River, which subsequently flows through Kakamega forest and finally drains into Lake Victoria (KIFCON, 1994a). This forest harbors about 253 vascular plant species (see chapter 3 of this manuscript for details) including economically important tree species. However, currently it is under huge human pressure due to the above mentioned factors. Therefore, the main objective of this study is to investigate the human impact on the vascular plant species diversity, woody plant population structure, seedling bank and resprouting of woody species after physical damege.

6.2 Materials and Methods

6.2.1 Study sites

This study was under taken in South Nandi Forest, which is found in the Rift Valley Province of western Kenya. The detailed description about South Nandi forest is given in chapter two (section 2.1). Two different sites of South Nandi forest were used for this study. Kobujoi is found in the southern part of the forest (Fig. 27) and it is relatively better side of this forest. Bonjoge is situated in the south western side of South Nandi forest and it is highly disturbed side of the forest.

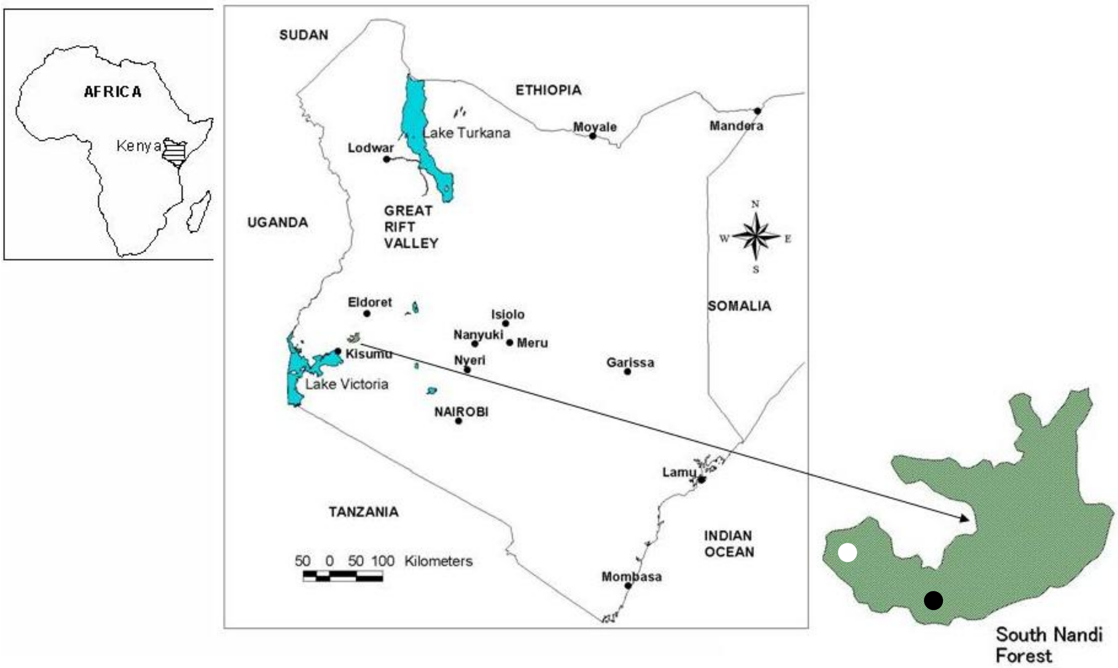


Figure 27 Location of Kobujoi (black circle) and Bonjoge (white circle) in South Nandi forest

6.2.2 Data collection and analysis

Data collection

The detailed plot lay out is described in chapter two section 2.2.1. Totally 49 quadrates of 400 m^2 (20 X 20 m) of which 27 of them were from Kobujoi and the rest from Bonjoge were used to collect vegetation information. The quadrates were distributed along transects that ranges from one km to 1.6 km which were laid parallel to the slope. The distance between adjacent transects was 500 m while the distance between consecutive plot is 100 m.Within each big 20 m X 20 m quadrates five small plots of three by three meter were laid at the four corners and the center of the plot.

In each major quadrate all woody plants which are ≥ 2 cm diameter at breast height (dbh at 1.3m above ground) and height > 1m were identified, measured and recorded. The diameter was measured using diameter tape while height of individual trees was measured using hypsometer and marked stick (for smaller individuals). All lianas encountered in the major plot were recorded and the diameter of the lianas was measured according to Gerwing *et al*, (2006). If the height of lianas was difficult to measure, estimation was used in comparison to the height of supporting trees. Plants with multiple stems below 1.3 m height were treated as a single individual and the dbh of all the stems were taken and then the average of the diameter was used for basal area calculation. If a tree was buttressed and abnormal at 1.3 m, the diameter was measured just above the buttress where the stem assumes near cylindrical shape. When epiphytes and ferns were found they were identified and recorded.

The diameter and height of stumps in the major plot were measured using diameter tape and measuring tape respectively. The stumps were identified at species level. When it was difficult to identify the species, local people were asked for the local name of the species then that name is checked in botanical books. Number of shouts per stump was recorded.

In the five smaller plots (3 m X 3 m) which were set up at the four corners and at the centre of the major plot, herbaceous plants and seedlings of all woody plants (shrub, liana and trees) were recorded. Herbaceous plants were identified and counted.

Species were identified at species level in the field. For species that were proved to be difficult to identify in the field, herbarium specimens were collected, dried properly and transported to the East African (EA) herbarium, National Museums of Kenya, in Nairobi for identification. Plant nomenclature is followed Letouzey (1982), Troupin (1988), Agnew and Agnew (1994), Beentje (1994), and Fischer and Killman (2008). Family names are followed Angiosperm Phylogeny Group (APG III) naming from an open acces website.

Altitude and geographical coordinates were measured using Gramin GPS in the middle of the main plots. Engineering compass was used to measure direction and aspect of plots. The canopy cover was visually assessed and recorded on 1 to 3 scale bases. When the canopy cover was estimated to be ≤ 33% (open canopy) 1 was given, 2 was given when it was estimated between 33 and 66 per cent (medium shade) and 3 when the canopy cover was estimated to be > 66% (high shade canopy).

Data analysis

Diversity measures

Diversity measures such as Shannon diversity (H ') and evenness (E') indices, Fischer's α and Beta diversity were calculated. Both incidence and abundance based Sørensen and Jaccard similarity indices were also calculated. The detailed formulae of these measurements were given in chapter three under section 3.2.3. To compare the species richness between Kobujoi and Bonjoge, sample based rarefaction curves (Gotelli and Colwell, 2001) were used. Shannon diversity and evenness indices were calculated using PC-ORD version 5.22 (McCunne and Grace, 2006). EstimateS was used to calculate Fischer's α and similarity indices. Non-parametric test was undertaken to compare mean number of species per plot using SPSS version 16.0 statistical software.

Species richnes (number of species) estimation

To estimate the true number of species both at Kobujoi and Bonjoge, different species richness estimatarors were used. Abundance-based Coverage Estimator (ACE), Chao 1, Caho 2, Jack 1, Jack 2 and Bootstrap were the estimators that were used in this study. The detail formulae of these estimators are given in chapter three under section 3.2.3.

Population structure

For both sites size class distribution of height and diameter at breast height (dbh) were constructed. Basal area (BA) of each woody plant species that has dbh ≥ 2 cm was computed. In addition Importance Value (IV) species was calculated. See chapter four section 4.2.2 for the detailed formulae of BA and IV.

6.3 Results

6.3.1 Floristic composition

As it was described in chapter 3, including plants that were found out of the study plots, totally 253 species comprising 82 families and 201 genera were identified in South Nandi forest (Fig. 6). However, out of these 253 species only 211 of them from 169 genera and 72 families were recorded in the study quadrates. In the relatively better part of South Nandi Forest (Kobujoi) 172 vascular plant species comprising 66 families and 142 genera were recorded (Fig. 28). In the heavily disturbed side of South Nandi forest (Bonjoge) this number declined to 138 species, 56 families and 120 genera (Fig. 28).

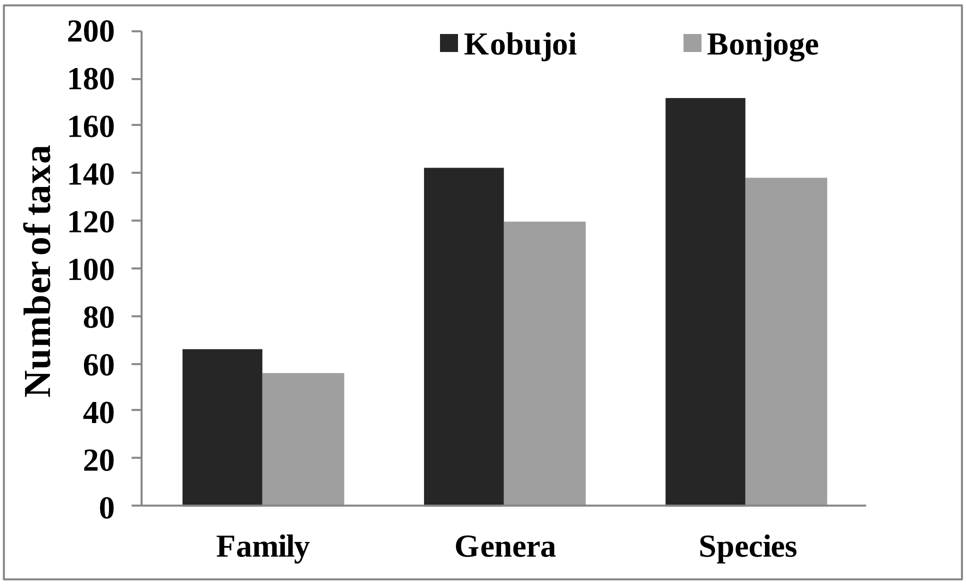


Figure 28 Number of Taxa recorded in the study quadrates at Kobujoi and Bonjoge (South Nandi Forest)

The species rich family in South Nandi Forest is Asteraceae with 21 species and 16 genera (see chapter three section 3.3.1 for the detail). However, at Kobujoi the richest family is Rubiaceae represented by 16 species and 14 genera followed by Asteraceae (10 species and 9 genera) and Euphorbiaceae (9 species and 7 genera) (Table 25). The order is a little bit changed at Bonjoge where Asteraceae became the richest family encompassing 11 species and eight genera. The second and third rich families in this part of the forest are Rubiaceae (10 species and 9 genera) and Euphorbiaceae (8 species and 7 genera), respectively (Table 25). In both sites considerable number of the families is represented only by one species. At Kobujoi 32 of the families (48.5 %) and at Bonjoge 25 families (44.6 %) which were recorded in the study quadrates were represented only by a single species. At Kobujoi the top ten species rich families contribute to 44.2% of the species and the top 15 species rich families comprise 55.2% species recorded in this site. At Bonjoge the top ten species rich families contribute to 41.3% and the top 15 species rich families contain 56.5% of the species recorded in this site.

Table 25 The first ten species rich families at Kobujoi and Bonjoge (South Nandi Forest)

Kobujoi			**Bonjoge**		
Families	**Number of species**	**Number of genera**	**Families**	**Number of species**	**Number of genera**
Rubiaceae	16	14	Asteraceae	11	8
Asteraceae	10	9	Rubiaceae	9	8
Euphorbiaceae	9	7	Euphorbiaceae	8	7
Acanthaceae	8	6	Acanthaceae	7	6
Aspleniaceae	8	1	Fabaceae	5	5
Fabaceae	6	5	Moraceae	5	3
Urticaceae	6	5	Sapotaceae	4	4
Orchidaceae	5	5	Rutaceae	4	4
Salicaceae	4	4	Salicaceae	4	4
Celastraceae	4	4	Malvaceae	4	3

Out of the 77 families recorded in South Nandi (in the study quadrates) 50 of them occurred in both sites. Sixteen families i.e. 20.8% of the families recorded in South Nandi (i.e. Aspleniaceae, Campanulaceae, Caryophyllaceae, Commelinaceae, Cyperaceae, Dryopteridaceae, Monimiaceae, Podocarpaceae, Polypodiaceae, Pteridaceae, Ranunculaceae, Simlacaceae, Thelypteridaceae, Vittariaceae, Woodsiaceae and Zingiberaceae) recorded only at Kobujoi. Six families (7.8% of the families recorded in the study plots of South Nandi) including Clusiaceae, Connaraceae, Convolvulaceae, Dioscoreaceae, Musaceae and Phytolaccaceae occurred only in plots of Bonjoge.

6.3.2 Alpha and beta diversity

Kobujoi which is located close to Kobujoi town is relatively better side of South Nandi forest. As indicated in Figure 29 the mean number of species per plot (400 m^2) is higher at Kobujoi

(67.1) than that of Bonjoge (50.4). The non parametric analysis showed that this difference is statistically very significant (Mann-Whitney U = 14 and $p < 0.001$).

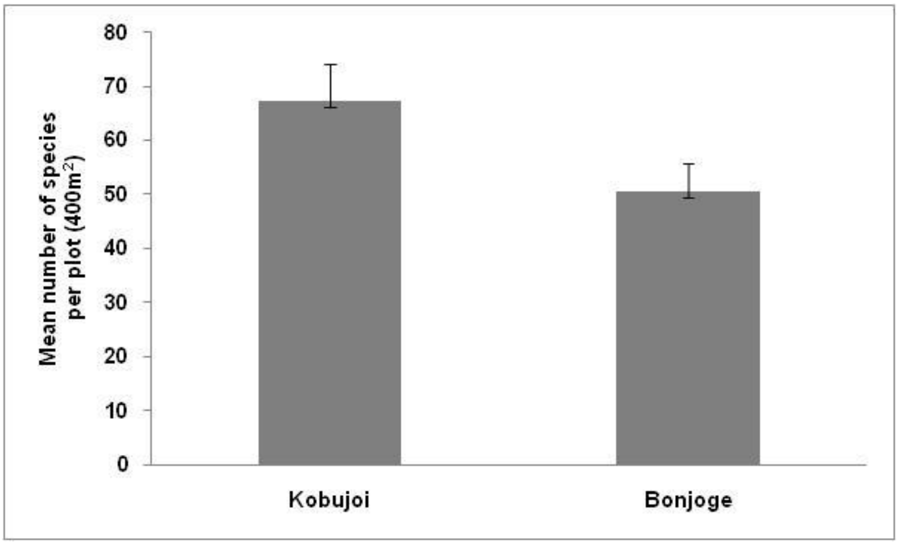


Figure 29 Mean number of species per plot per study site of South Nandi Forest (values are mean ± SD)

Different diverstiy measures are calculated for Kobujoi and Bonjoge. As it is presented in Table 26, higher Fisher's α was obtained at Kobujoi (22.65) than that of Bonjoge (20.96). Even if higher species richness per plot has been recorded at Kobujoi than that of Bonjoge (Fig. 29), both sites are having almost equivalent evenness index which is 0.64 for Kobujoi and 0.69 for that of Bonjoge. Similarly, the Shanon diversity (H') indinces of these sites of are almost equale (i.e. Kobujoi is having 2.68 and 2.72 for that of Bonjoge) (Table 25). But, Whittaker beta diversity is higher at Bonjoge than that of Kobujoi (Table 26).

Table 26 Various diversity parameters calculated at Kobujoi and Bonjoge (South Nandi Forest)

Diversity measurment	**Relatively better site (Kobujoi)**	**Highly disturbed site (Bonjoge)**
Fisher's α	22.65	20.96
Shanon diversity (H')	2.68	2.72
Evenness index (E')	0.64	0.69
Whittaker beta diversity (β_w)	1.56	1.74

Species accumulation curve

Accumulation curve (rarefaction) was also plotted for the vascular plants recorded at Kobujoi and Bonjoge of South Nandi forest. This graph was plotted for the cumulative number of species recoded as a function of sampling effort i.e. the number of samples pooled. From Figure 30 it can be depicted that there is higher rate of new species inclusion at Kobujoi as the sampling continues. However, this rate is decreasing when it is compared with that of the beginning of the sampling stage. The rarefied number of species based on 22 plots (plots of Bonjoge) resulted in 165.4 species at Kobujoi but at the same number of plot at Bonjoge 138 species were recorded. Moreover, from this graph it can be concluded that species richness (number of species) of Kobujoi is significantly higher than that of Bonjoge (Fig. 30) as observed species accumulation curve of Bonjoge is outside of the 95% confidence interval of Kobujoi which has higher species richness.

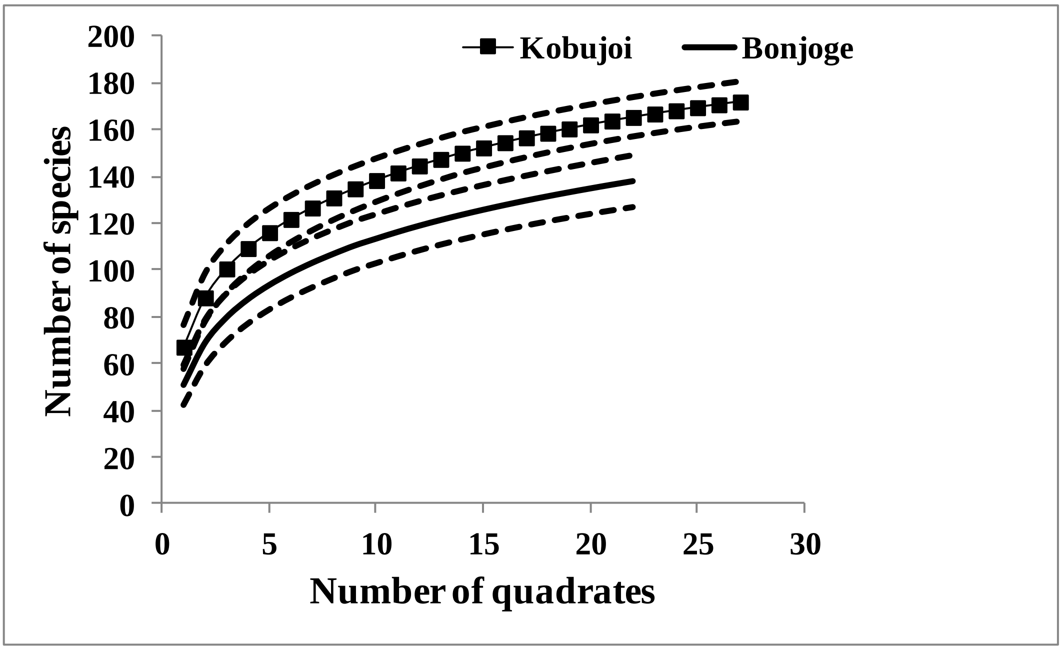


Figure 30. Species accumulation (rarefaction) curves (solid lines) and 95% confidence intervals (dashed lines) of Kobujoi and Bonjoge (South Nandi forest).

Species richness estimation

The true species richiness of both relatively better and heavily disturbed sites of South Nandi forest was estimated based on different estimators. Table 27 showed that Chao 1 gave the lowest estimate for both sites (i.e. 177.69 species for Kobujoi and 149.18 species for Bonjoge). Similarly, the highest estimate (i.e. 212.86 at Kobujoi and 190.11 at Bonjoge) was obtained by

Jackknife 2. As it is shown in Table 27 80.8-96.8% of species at Kobujoi and 72.6-92.5% of species at Bonjoge were recorded in this study based on these estimates.

Table 27. Number of samples, individuals, observed species and estimated species richness (based on different methods) at Kobujoi and Bonjoge of South Nandi Forest

	Kobujoi	**Bonjoge**
Number of samples	27	22
Number of individuals	45317	15146
S_{obs}	172	138
ACE	180.01	153.21
Chao 1	177.69±4.19	149.18±6.66
Chao 2	192.77±9.71	176.25±17.68
Jackknife 1	202.81±7.22	170.45±5.82
Jackknife 2	212.86	190.11
Bootstrap	186.97	152.41
Species collection degree	80.8-96.8%	72.6-92.5%

Floristic similarities

Medium similarity between Kobujoi and Bonjoge was observed based on Sørensen similarity index (incidence based) but the other incidence based index (i.e. Jaccard) resulted in low similarity, i.e. 0.57 and 0.39, respectively (Table 28). However, both Chao- Sørensen and Chao-Jaccard (abundance based similarity inices) showed higher similarity i.e. 0.77 (Chao- Sørensen estimator) and 0.65 (Chao-Jaccard estimator).

Table 28 Incidence and abundance based similarity between Kobujoi and Bonjoge (South Nandi Forest)

Incidence based similarity indices		**Abundance based similarity indices**	
Sørensen	0.57	Chao-Sørensen estimator	0.77
Jaccard	0.39	Chao-Jaccard estimator	0.65

6.3.3 Population structure

Growth forms

Tree species comprises the highest proportion of the species recoded at Bonjoge having 35.5% of the total species (Fig. 31). Climbers, herbs, shrubs and epiphytes accounted for 23.2, 19.6, 18.8 and 2.9%, respectively. Similarly at Kobujoi, trees accounted for 29.7% of the total species followed by herbs (28.5%), climbers (18%), shrubs (17.4%) and epiphytes (6.4%) (Fig. 31).

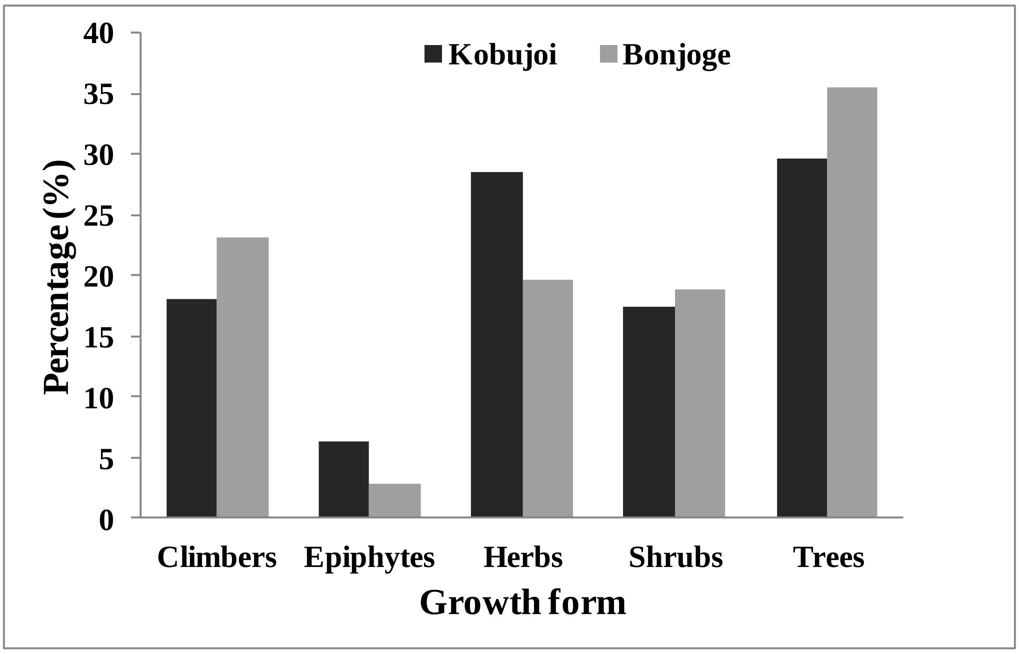


Figure 31 Species proportion in terms of growth forms at Kobujoi and Bonjoge (South Nandi forest).

Height class distribution

Both at Kobujoi and Bonjoge higher proportion of the woody plants were found in the lower height class resulting in an inverted 'J' distribution. Figure 32 showed that the height class distribution of woody plants of South Nandi forest from both Kobujoi and Bonjoge. As indicated in Figure 32, 89.3% of the woody plants indentified at Kobujoi were found in height class 1 which ranges from 1 to 5 m. At Bonjoge this height class contained 91% of the woody plant individuals recorded in this part of South Nandi forest. The second height class consisted 8.5% and 8% of the individuals at Kobujoi and Bonjoge, respectively. The remaining height classes contributed only 0.95% of the individuals at Bonjoge (i.e. the third, fourth, fifth and sixth height class contributed 0.38, 0.45, 0.09 and 0.03%, respectively). At Kobujoi, individuals in the third and above height classes accounted for 2.2% of the total individuals (i.e. 0.98, 0.81, 0.18, 0.18 and 0.02 % for the height classes 3 to 7, respectively).

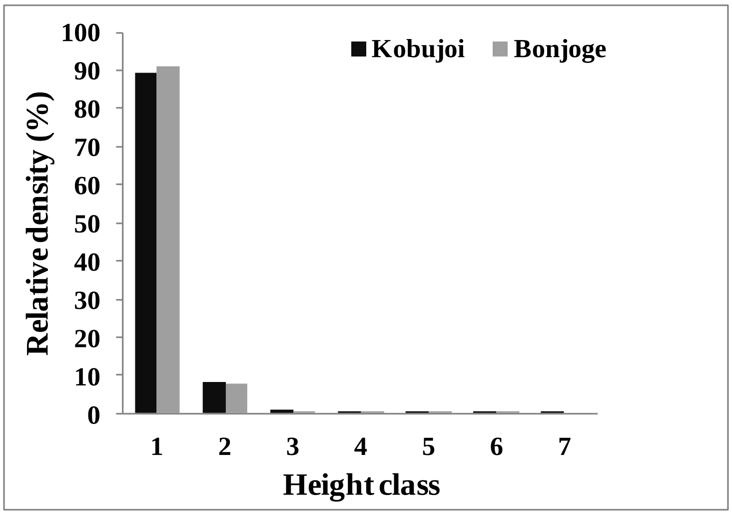


Figure 32 Height class distributions of woody plant species at Kobujoi and Bonjoge (South Nandi forests). Height class: 1 = 1-5 m, 2 = 5-10 m, 3 = 10-15 m, 4 = 15-20 m, 5 = 20-25 m, 6 = 25-30 m and 7 > 30 m.

Diameter class distribution

Similar to that of height class distribution, the diameter class distribution both at Kobujoi and Bonjoge has also showed an inverted 'J' distribution (Fig. 33) reaveling that higher proportion of the woody plant individuals is found in the lower diameter classes. For instance at Kobujoi, the lower three diameter class comprised 95.8% of the total individuals (i.e. 78.2, 12.6 and 5.1% for the first, second and third diameter classes in the same order). At Bonjoge the same diameter classes accounted for 98.1% of the individuals (i.e. 77.9, 17.3 and 2.9% for diameter class 1, 2 and 3, respectively). As it is observed in Figure 33 the proportion of individuals is deacreasing dramatically at both sites. The upper four classes contributed only 4.1% of the individuals at Kobujoi while the same classes accounted for only 1.9% at Bonjoge (Fig. 33).

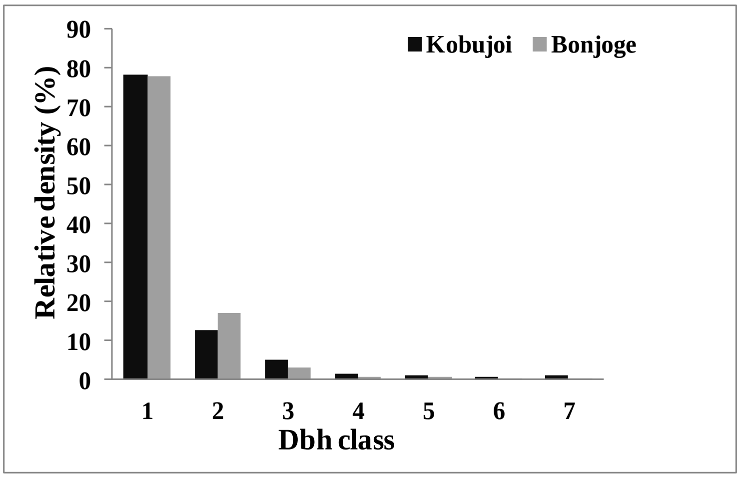
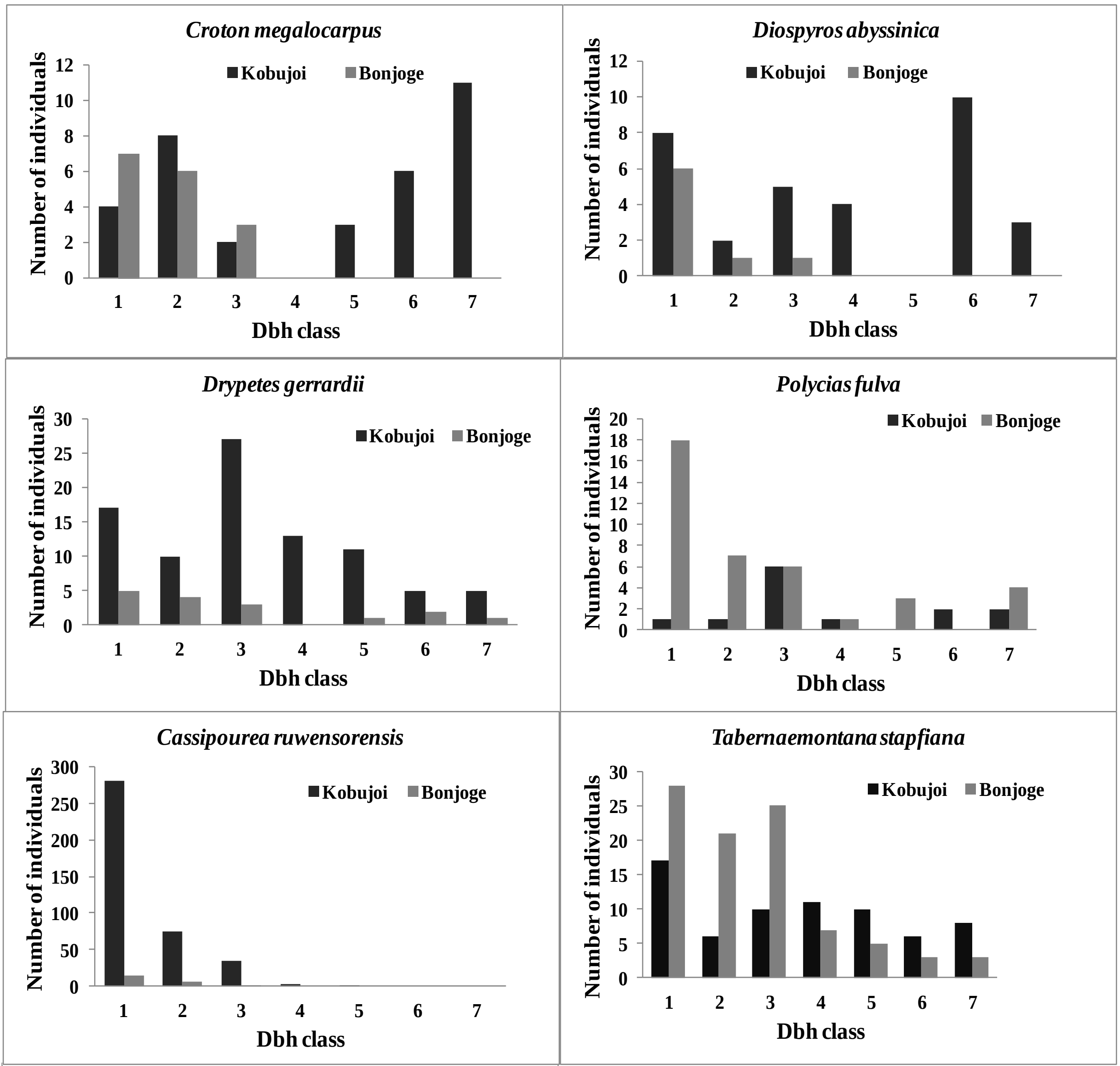


Figure 33 Diameter class frequency distribution of woody plants at Kobujoi and Bonjoge (South Nandi forests). Diameter at breast height (Dbh) class: 1 = 2-5 cm, 2 = 5-10 cm, 3= 10-20 cm, 4 = 20-30 cm, 5 = 30-40 cm, 6 = 40-50 cm and 7 > 50 cm

Different population distribution of the same species was observed at Kobujoi and Bonjoge. For example, *Croton megalocarpus* and *Diospyros abyssinica* have shown a kind of 'U' shape distribution at Kobujoi (Fig. 34). Having relatively higher proportion of individuals at the lower and higher Dbh classes, *Croton megalocarpus* has the lowest frequency (i.e. not represented) at Dbh class four while *Diospyros abyssinica* was absent in dbh class five. The same species showed different distribution at Bonjoge as presented in Figure 34. Both species were represented only in the first three Dbh classes. At Bonjoge *Diospyros abyssinica* has a type of inverted 'J' distribution with relatively higher number of individuals at the first Dbh class but the second and third classes have small number of individuals. In the case of *Croton megalocarpus* the number of individuals is decreasing from the first to the third class even though it did not show an inverted 'J' distribution.

On the other hand *Drypetes gerrardii* and *Polyscias fulva* have 'Bell' shaped distribution at Kobujoi (Fig. 34) having relatively higher number of individuals in the intermediate diameter class. However, in the lower and higher diameter classes smaller number of individuals represented these species. Inverted 'J' population distribution was observed at Bonjoge in the case of *Polyscias fulva*. *Drypetes gerrardii* is represented by almost similar small number of individuals at all diameter class except at class four where it is absent at Bonjoge.

Casearia battiscombei and *Strombosia scheffleri* have inverted 'J' distripution at Kobujoi. While *Strombosia scheffleri* maintained the same inverted 'J' population distribution at Bonjoge, *Casearia battiscombei* has different distribution pattern having equivalently small number of individuals in all Dbh classes (Fig. 34). *Syzygium guineense* was recorded only at Kobujoi having a kind of broken inverted 'J' population distribution in which relatively higher number of individuals appeared in the lower class but, individuals in Dbh class five and six are absent. At Bonjoge *Trilepisium madagascariense* has almost similar distribution with that of *Syzygium guineense* at Kobujoi. *Trilepisium madagascariense* has a broken inverted 'J' population distribution with most of the individuals appearing in the first Dbh class and decreasing till Dbh class 3 and it is absent in class 4,5 and 6 and appearing at the highest Dbh class again. The same species has an inverted 'J' distribution pattern at Kobujoi, however, it is not represented in the higher Dbh classes beyond Dbh class 3 (Fig. 34). *Celtis africana* has also a broken inverted 'J' distribution at Kobujoi where individuals were absent in Dbh class 4 and 6 but this species was represented only in Dbh class one and three at Bonjoge (Fig. 34).



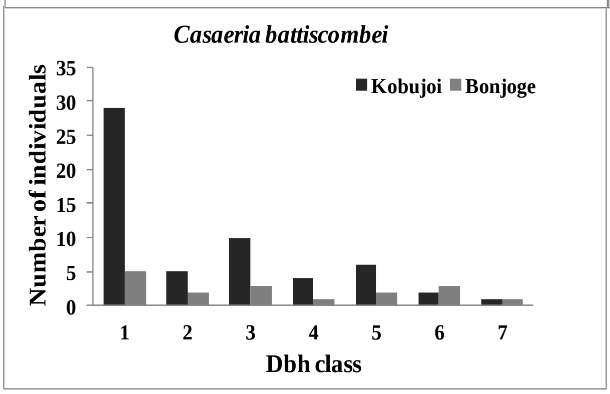
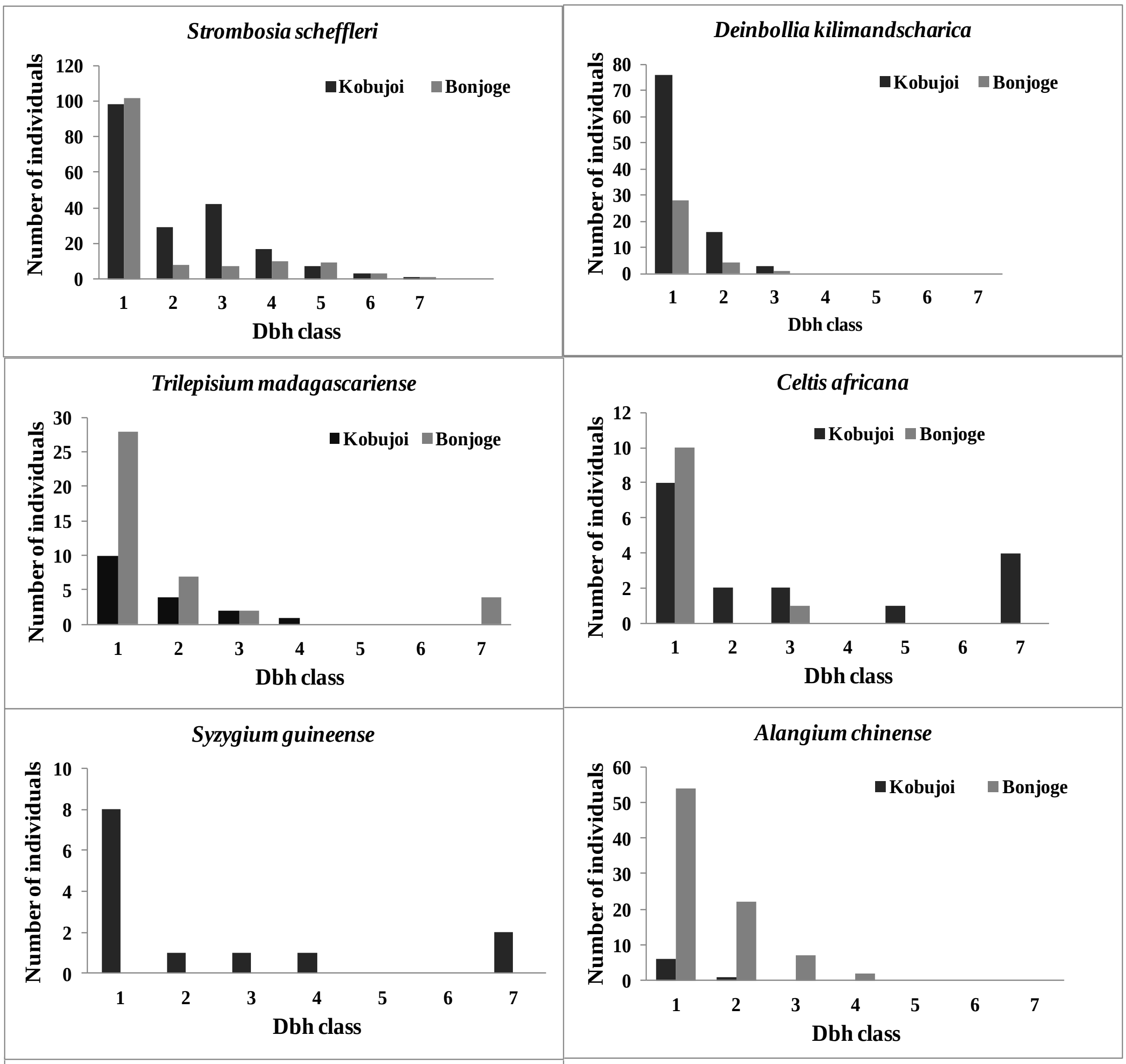


Figure 34 Diameter class frequency distribution of selected tree species at Kobujoi and Bonjoge (South Nandi forests). Diameter at breast height (Dbh) class: 1 = 2-5 cm, 2 = 5-10 cm, 3= 10-20 cm, 4 = 20-30 cm, 5 = 30-40 cm, 6 = 40-50 cm and 7 > 50 cm



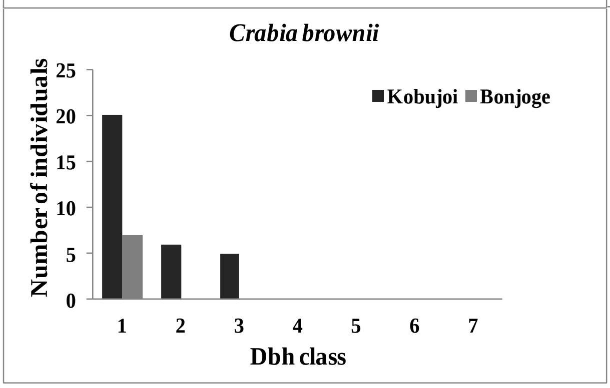


Figure 34 (continued) Diameter class frequency distribution of selected tree species at Kobujoi and Bonjoge (South Nandi forests). Diameter at breast height (Dbh) class: 1 = 2-5 cm, 2 = 5-10 cm, 3= 10-20 cm, 4 = 20-30 cm, 5 = 30-40 cm, 6 = 40-50 cm and 7 > 50 cm

Large number of *Cassipourea ruwensorensis* individuals were recorded at Kobujoi and most of them were found in the first Dbh class and the number subsequently decreased till class five beyond which the species is not presented. However, very few individuals of this species were recorded at Bonjoge in general and these few indviduals appeared only in the first three Dbh classes. *Craibia brownii* was recorded in the first three Dbh classes at Kobujoi while it appeared only in the first class at Bonjoge. On the other hand, *Alangium chinensee* was at Bonjoge having an inverted 'J' distribution even if individuals are absent in the higher diameter classes (class 5, 6 and 7). This species was represented by few individuals at Kobujoi in class one and two. *Deinbollia kilimandscharica* has also relatively higher number of individuals at Kobujoi than at Bonjoge having the same inverted 'J' distribution and only represented in the first three Dbh classes at both sites. At Bonjoge, *Tabernaemontana stapfiana* is more abundant in the first three diameter classes and then it subsequently decreases from class 3 onwards (Fig. 34). At Kobujoi there are more individuals of *Tabernaemontana stapfiana* in Dbh class 1 and then the number decreased at class 2 and it has almost equal number of individuals from class 3 onwards.

Basal area and abundance

It was observed that there is statistically very significant difference between the mean basal area of the two sites of South Nandi forest (t-value=3.77 and $p<0.01$). As indicated in Figure 35, mean basal area per hectare at Kobujoi (38.36 m^2) is higher than than that of Bonjoge (24.66 m^2).

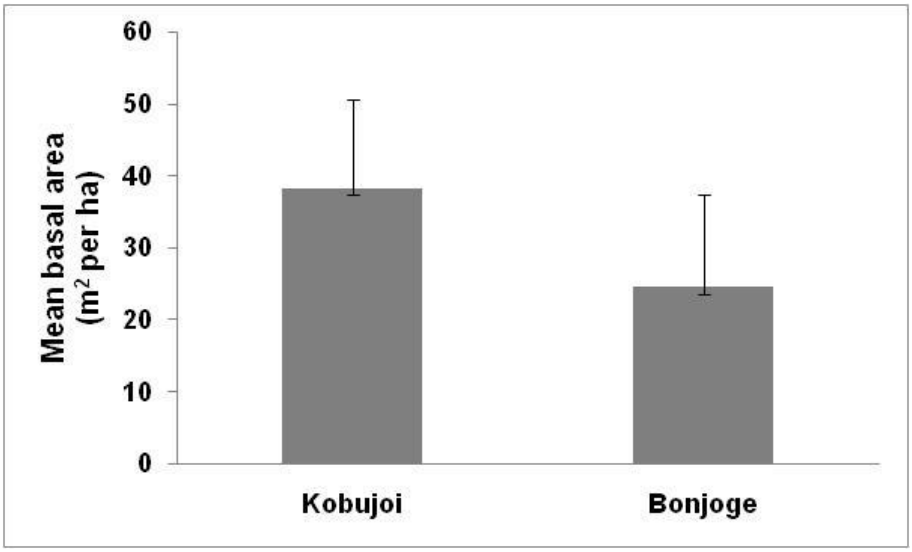


Figure 35 Mean basal area (m^2 per ha) of Nandi forest at Kobujoi and Bonjoge (mean value ± SD).

As it is presented in Table 29 density of wood plants was higher at Kobujoi. Totally 29351 individuals of woody plants per ha were recorded at Kobujoi, however; the number of individuals per ha decreased at Bonjoge to 14418. Both minimum and maximum density of woody plants per plot (400 m^2) was higher at Kobujoi (Table 29).

Table 29 Density of woody plants at Kobujoi and Bonjoge (South Nandi forest)

Characteristics	Kobujoi	Bonjoge
Total plots	27	22
Total Density	31699	12688
Minimum Density per plot	451	302
Maximum Density per plot	2281	973
Density per hectare	29351	14418

Importance value of wood species

In terms of importance value (IV) index *Culcasia falcifolia, Croton megalocarpus and Drypetes gerrardii* are the top dominant species at Kobujoi with IV of 39.99, 16.96 and 14.82%, respectively (Table 30). At Kobujoi trees are the dominant growth forms, for example, among the top 15 dominant woody plant species, only three species are climbers or shrubs (i.e. *Culcasia falcifolia, Alchornea hirtella* and *Acanthus eminens*) and the rest species are trees (Table 30). *Culcasia falcifolia* is the only climber species found at Kobujoi in the top 15 dominant species.

In the case of Bonjoge, *Solanum mauritianum* became the most dominant species with the highest IV index followed by *Trilepisium madagascariense and Strombosia scheffleri* (i.e. 42.49, 20.27 and 19.35%, respectively). In this part of South Nandi forest shrubs became more dominant than that of Kobujoi. For instance, among the top 15 dominant species, four of them are shrubs; these include *Solanum mauritianum, Macrorungia pubinervia, Mimulopsis arborescens* and *Alchornea hirtella* (Table 30). *Culcasia falcifolia* and *Hippocratea africana* are the two climber species represented in the top 15 dominant species at Bonjoge. The other trees which have IV of 4.76% and higher include *Tabernaemontana stapfiana, Prunus africana, Polyscias fulva, Drypetes gerrardii, Casearia battiscombei, Ficus sur* and *Lepidotrichilia volkensii* are all in the top 15 dominant species (Table 30).

Table 30 Importance Value (IV) of the top 15 common woody plant species at Kobujoi and Bonjoge of South Nandi Forest (where Abu= abundance or number of individuals per ha, RF= relative frequency, RDen= relative density, and RDom= relative dominance).

Site	**Name**	**Growth Form**	**Abu (No. indiv. / ha)**	**RF (%)**	**RDen (%)**	**RDom (%)**	**IV (%)**
Kobujoi	*Culcasia falcifolia*	Climber	11316	1.43	38.55	-	39.99
	Croton megalocarpus	Tree	61	1.05	0.21	15.71	16.96
	Drypetes gerrardii	Tree	134	1.49	0.46	12.87	14.82
	Tabernaemontana stapfiana	Tree	82	1.38	0.28	12.99	14.65
	Diospyros abyssinica	Tree	1876	1.49	6.39	5.78	13.66
	Prunus africana	Tree	887	1.32	2.99	9.22	13.53
	Strombosia scheffleri	Tree	988	1.49	3.37	7.44	12.29
	Cassipourea ruwensorensis	Tree	1630	1.49	5.55	2.87	9.91
	Heinsenia diervilleoides	Tree	1127	1.49	3.84	3.67	9.00
	Alchornea hirtella	Shrub	1312	0.83	4.47	3.33	8.62
	Macaranga kilimandscharica	Tree	125	1.27	0.43	3.70	5.40
	Acanthus eminens	Shrub	1077	1.49	3.67	0.14	5.30
	Casearia battiscombei	Tree	71	1.10	0.24	3.63	4.98
	Polyscias fulva	Tree	37	0.94	0.13	3.91	4.97
	Celtis africana	Tree	60	1.27	0.21	3.30	4.77
	Total other species (92)		8568	80.47	29.23	11.44	
	Total		29351	100	100	100	
Bonjoge	*Solanum mauritianum*	Shrub	3591	1.98	24.91	15.60	42.49
	Trilepisium madagascariense	Tree	1128	1.98	7.83	10.46	20.27
	Strombosia scheffleri	Tree	949	1.98	6.58	10.68	19.25
	Tabernaemontana stapfiana	Tree	157	1.89	1.09	13.14	16.12
	Culcasia falcifolia	Climber	2019	1.98	14.01	-	15.99
	Prunus africana	Tree	24	0.72	0.17	11.67	12.56
	Polyscias fulva	Tree	127	1.71	0.88	8.17	10.76
	Macrorungia pubinervia	Shrub	1135	1.98	7.87	0.55	10.40
	Mimulopsis arborescens	Shrub	498	1.89	3.45	4.65	9.99
	Alchornea hirtella	Shrub	688	1.08	4.77	1.91	7.76
	Hippocratea africana	Climber	783	1.98	5.43	0.03	7.44
	Drypetes gerrardii	Tree	152	1.89	1.06	3.65	6.60
	Casearia battiscombei	Tree	22	0.54	0.15	4.58	5.27
	Ficus sur	Tree	103	1.53	0.72	2.99	5.24
	Lepidotrichilia volkensii	Tree	331	1.80	2.29	0.67	4.76
	Total other species (89)		2711	75.1	18.8	11.25	
	Total		14418	100	100	100	

6.3.4 Natural regeneration

6.3.4.1. Seedling bank

As it was presented in section 5.3.1, seedlings of 97 woody plant species were recorded in South Nandi forest. When this forest is analysed based on disturbance status, at Kobujoi totally 78,848 seedlings per ha of 80 species from 41 families and 75 genera were recoded. In the highly disturbed site (Bonjoge) totally 41,950 seedlings per ha of 73 species composed of 40 families and 66 genera were recorded.

Mean number of seedlings per plot (45 $m^{2)}$ was also higher at Kobujoi (355) than Bonjoge (189) (Fig. 36). This difference is stasticaly highly significant (t-value 4.24, $p<0.001$).

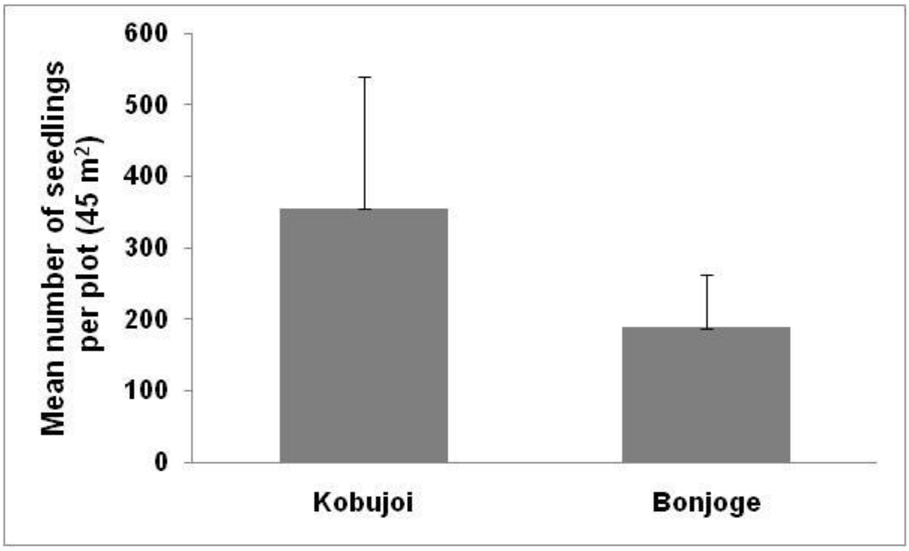


Figure 36 Mean number of seedlings per plot (45 m^2) at Kobujoi and Bonjoge (South Nandi forest)

Rubiaceae is the most abundantly represented family in the seedling population both at Kobujoi and Bonjoge (i.e. represented by 13 species, 12 genera at Kobujoi and by 8 species, 8 genera at Bonjoge) (Table 31). At both sites the second species rich family is Euphorbiaceae having 6 species and 5 genera (Table 31) followed by Acanthaceae (5 species and 5 genera) at Kobujoi and Rutaceae (4 species and 4 genera) at Bonjoge. Generaly, as indicated in table 31 six families at Kobujoi were reperesnted by 3 or more species and at Bonjoge seven families were represented by 3 or more species. Another 11 families are represented by two species while the remaining 24 families have only one species at Kobujoi. Similarly at Bonjoge, ten families are represented by two species and the remaining 23 families were represented only by one species

Table 31 Families represented by three or more species in the seedling population at Kobujoi and Bonjoge (South Nandi forest)

Kobujoi			Bonjoge		
Families	**Number of species**	**Number of genera**	**Families**	**Number of species**	**Number of genera**
Rubiaceae	13	12	Rubiaceae	8	8
Euphorbiaceae	6	5	Euphorbiaceae	6	5
Acanthaceae	5	5	Rutacea	4	4
Sapotaceae	4	3	Acanthaceae	3	3
Salicaceae	3	3	Solanaceae	3	1
Meliaceae	3	3	Asparagaceae	3	1
			Sapindaceae	3	2

At both sites seedlings of tree species dominated the seedling population (Fig. 37). For instance, at Kobujoi seedlings of trees accounted for 55.1 % while that of climbers and shrubs contributed 19.3 and 25.6 %, respectively. In the case of Bonjoge, seedlings of tree species consisted of 54% of the total seedlings where as climbers and shrubs comprised 20.6 and 25.4%, respectively.

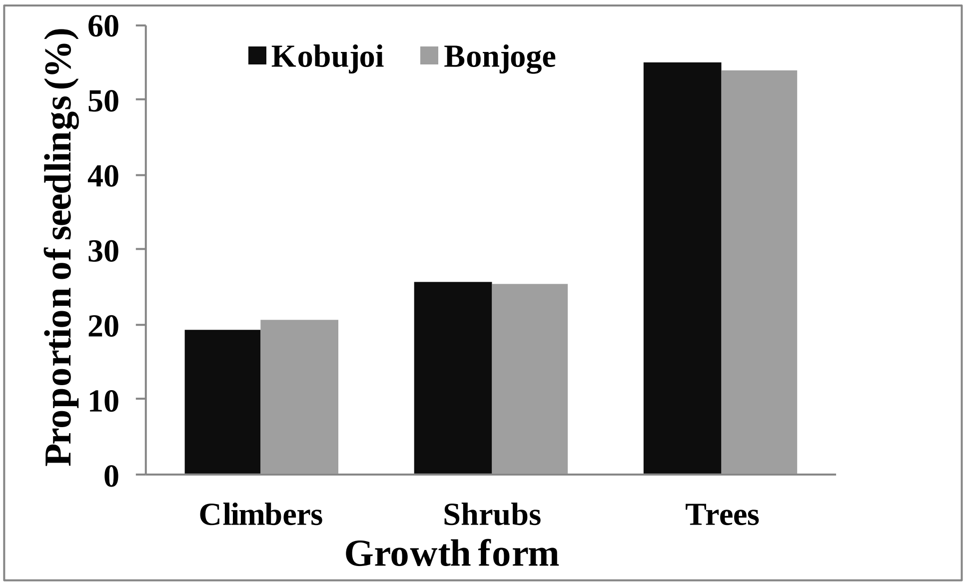


Figure 37 Relative propotion of seedlings in terms of species growth form at Kobujoi and Bonjoge (South Nandi forest)

As it was described in section 5.3.1 seedling population of South Nandi forest is dominated by few species. Similarly both at Kobujoi and Bonjoge few species have the lion share of the seedling population. For example, the first 15 seedling rich species contributed for 86.8% of the seedlings at Kobugoi and 93.8% at Bonjoge (Fig. 38 a and b).

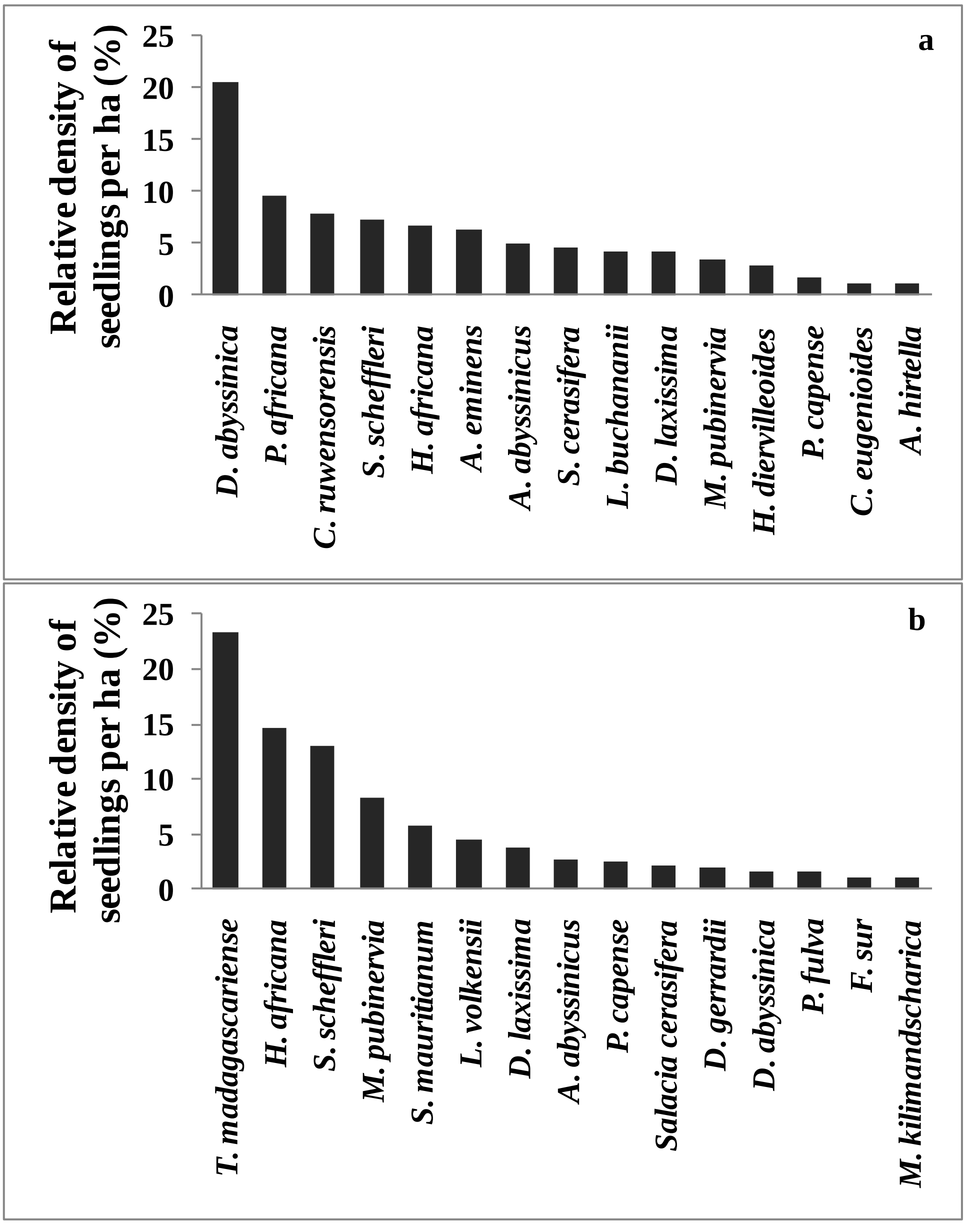


Figure 38 Relative density of top 15 seedling rich woody plant species at Kobujoi (a) and Bonjoge (b) of South Nandi forest.

Diospyros abyssinica is the most seedling rich species per ha at Kobujoi (16189 seedlings per ha) followed by *Prunus africana* (7539) and *Cassipourea ruwensorensis* (6214), contributing to 38% of the seedlings (Fig. 38a). At Bonjoge the seedling population is dominated by *Trilepisium madagascariense* (9848), *Hippocratea africana* (6152) and *Strombosia scheffleri* (5505), comprising 51.3 % of the total seedling population (Fig. 38b). At Kobujoi, the first four seedling rich species are tree species comprising 45.2% of the seedlings, however, at Bonjoge from the top ten seedling rich species only the first and the third seedling rich species are trees, contributing 36.6% of the seedlings.

Seedlings species diversity

Higher mean number of seedling species per plot was observed at Kobujoi (29.5 per 45 m^2) than that of Bonjoge (22.2 per 45 m^2) (Table 32). Statistically, this difference is very significant (t-value 6.06, p<0.01). As depicted in Table 32, higher Shannon diversity index (2.5) was recorded at Kobujoi than that of Bonjoge (2.2). The result from T-test showed that this difference is statistically very significant (t-value 2.73, p<0.01). Evenness index was also relatively higher at Kobujoi (Table 32). On the other hand Fisher alpha and Whittaker beta diversity are higher at Bonjoge than that of Kobujoi (Table 32)

Table 32 Different diversity characterstics of seedlings at Kobujoi and Bonjoge (South Nandi forest)

Diversity measurment	Kobujoi	Bonjoge
Mean number of species per plot	29.5	22.2
Fisher's α	12	12.6
Shannon diversity (H')	2.5	2.2
Evenness index (E')	0.74	0.72
Whittaker beta diversity (β_w)	1.71	2.29

Similarities

Similarites between seedlings population of Kobujoi and Bonjoge was estimated and presented in Table 32. Sørensen similarity index resulted in 0.48 and that of Jaccard was 0.32. In the case of Chao-Sørensen and Chao-Jaccard estimator these indices are raised to 0.68 and 0.54, respectively (Table 33).

Table 33 Incidence and abundance based similarity indices of seedlings at Kobujoi and Bonjoge in South Nandi Forest

Incidence based similarity indices		Abundance based similarity indices	
Sørensen	0.48	Chao-Sørensen estimator	0.68
Jaccard	0.32	Chao-Jaccard estimator	0.54

Similarly similarities between trees recorded in the biger plot (400 m^2) and seedlings of tree species were evaluated. As it is presented in Table 34 at Kobojoi Sørensen and Jaccard similarity indices gave similarity value of 0.57 and 0.41, respectively. Their respective abundance based similarity estimators resulted in 0.82 and 0.73 similary indices in the same order (Table 34). At Bonjoge, classic Sørensen and Jaccard smilarity indices resulted in 0.53 and 0.36, respectively and their respective abundance based indices have higher values (i.e. Chao-Sørensen estimator (0.75) and Chao-Jaccard estimator (0.63)).

Table 34 Incidence and abundance based similarity indices of trees and tree species seedlings at Kobujoi and Bonjoge (South Nandi forests)

Kobujoi				**Bonjoge**			
Incidence based		**Abundance based**		**Incidence based**		**Abundance based**	
Sørensen	0.57	Chao-Sørensen estimator	0.82	Sørensen	0.53	Chao-Sørensen estimator	0.75
Jaccard	0.41	Chao-Jaccard estimator	0.73	Jaccard	0.36	Chao-Jaccard estimator	0.63

6.3.4.2 Regeneration from stumps

Causes and level of damage

As described in chapter five section 5.3.2 totally 523 stumps of 45 species were identified in South Nandi forest. However, the majority of them i.e. 279 stumps (53.3%) from 34 species (22 families and 33 genera) were found at Bonjoge. At Kobujoi 244 stumps (46.7% of South Nandi forest stumps) from 35 species (23 families and 34 genera) were recorded. Mean number of stumps per plot is higher at Bojoge (12.7) than that of Kobujoi (9) and this is statistically significant (t-value= 2.45 and p=0.02) (Table 35).

Table 35 Mean number of stumps per plot and hectare at Kobujoi and Bonjoge in South Nandi Forest (* values are mean and SD)

Forest sites	Mean stumps per* plot	Stumps per ha
Kobujoi	9±5.1	226
Bonjoge	12.7±5.3	317

When the causes of stem damage compared, 73 stumps at Kobujoi (29.9%) were resulted from branch and/or tree fall while the remaining 69.2% (171 stumps) resulted from cutting. In the case of Bonjoge those created due to cutting were 264 stumps (94.6%) and the remaining 15 stumps (5.4%) are resulted from tree and/or branch fall on them.

Species and sprouting ability

Out of the total 244 stumps recorded at Kobujoi 188 (77 %) of them were able to resprout and the remaining 56 (23 %) stumps did not coppice. At Bonjoge 56.6 % (158) of the stumps were able to coppice and the remaining 43.4 % (121) stumps were not able to resprout.

As it is already described in chapter 5 Table 21, *Drypetes gerrardii* is the most targeted tree species of South Nandi forest. The majority of the stumps of this species (73%, 54 stumps out of 74) were recorded at Bonjoge (Table 35) where this species is mainly exploted for charcoal production. As indicated in Table 36, 50% of the stumps of *Drypetes gerrardii* wer able to resprout after damage. Among the species that have ten or more stumps *Cassipourea ruwensorensis, Heinsenia diervilleoides* and *Deinbollia kilmandscharica* are species that have more stumps at Kobujoi, the remaining species have higher number of stumps at Bonjoge (Table 36). Totally 13 stumps were not identified as they were roten and out of these 13 stumps nein of them were recorded at Bonjoge. Out of the ten stumps of *Croton megalocarpus* four of them are found at Kobujoi and the remaining were recorded at Bonjoge and none of these stumps gave shoot.

Table 36 Species with ten or more stumps at Kobujoi and Bonjoge with their resprouting percentage

Species Name	Total stumps	Kobujoi	Bonjoge	Sprouted	Not sprouted	Percent of sprouted
Drypetes gerrardii	74	20	54	37	37	50
Cassipourea ruwensorensis	62	55	7	53	11	85.5
Strombosia scheffleri	53	23	30	47	6	88.7
Heinsenia diervilleoides	47	46	1	35	13	74.5
Alchornea hirtella	46	21	25	39	7	84.8
Solanum mauritianum	32	4	28	15	17	46.9
Macaranga kilimandscharica	24	5	19	5	20	20.8
Unidentified stumps	13	4	9	0	24	0
Tabernaemontana stapfiana	22	4	18	18	4	81.8
Trilepisium madagascariense	16	1	15	9	7	56.3
Deinbollia kilmandscharica	10	8	2	8	3	80
Mimulopsis arborescens	12	2	10	2	10	16.7
Croton megalocarpus	10	4	6	0	10	0

Among the species that have ten or more stumps, *Strombosia scheffleri* has the highest sprouting ability (88.7%) followed by *Cassipourea ruwensorensis* and *Alchornea hirtella* with 85.5 and 84.8 % sprouting ability, respectively (Table 36). Execpt *Croton megalocarpus* and the 13 unidentified stumps, all woody plant stumps recorded at both sites are able to coppice. As indicated in Table 36 among the species that have ten or more stumps except three species, including *Solanum mauritianum, Macaranga kilimandscharica* and *Mimulopsis arborescens* which have less than 50 % sprouting ability while in the remaining eight species at least 50% of the coppicing ability was recorded.

6.4 Discussion

6.4.1 Floristic composition

In this study it has been observed that both mean number of species per plot and species richness decrease along disturbance gradient. As it is shown in Figure 28 and 29 the number of species (172) and mean number of species per plot (67.1) at Kobujoi are higher than that of Bonjoge (138 and 50.4, respectively). Similar trend was reported for Kakamega forest (Rembold, 2011). As explained by Rembold, the most intact part of Kakamega forest (Isiukhu) has higher mean number of vascular plant species per plot that that of Yala, Colobus and Kisere which are relatively disturbed parts of Kakamega. However, the number again increased at Canteen which is the most disturbed part of Kakamega forest (Rembold, 2011). The result of this study is opposite to what was reported for Kakamega by Althof (2005). Althof reported that higher number of species was recorded in highly disturbed sites of Kakamega forest. The difference in disturbance might not be the only cause for difference in number of species between Kobujoi and Bonjoge. There could be other environmental factors such as soil, moisture, and other factors that can be coupled with human disturbance to result in different number of species as well as different species composition. Such difference was observed in Kakamega forest between northern and southern parts of the forest (Althof, 2005; Dalitz and Gliniars, 2010).

Although higher mean number of species per plot and Shannon diversity index are observed at Kobujoi than that of Bonjoge, Whittaker beta diversity and Fisher’s α are higher at Bonjoge (Table 26). Beta diversity is used to measure species turnover along environmental gradients (Vellend, 2001). Higher Whittaker beta diversity at Bonjoge might be resulted from disturbance which could create habitat for new species to appear there by higher species turnover resulted. Higher number of species resulted in higher Shannon diversity index (Krebs, 1999). However, the higher species richness at Kobujoi did not give higher Shannon diversity index when it is compared with that of Bonjoge. Shannon diversity index is composed of species richness (number of species) and equitability or evenness and an increase in this index might be due to either greater richness or greater evenness or both (Magurran, 2004). Hence, the higher Shannon diversity index at Bonjoge is mainly due to higher evenness at Bonjoge than that of Kobujoi. Nevertheless, there is higher species richness at Kobujoi than Bonjoge. This can be explained by the species accumulation curves of the two sites (Fig. 30). As it was explained by Magurran (2004) if the observed diversity of smaller community lies within the 95% confidence limits of the rarefaction of the larger community then there is no significant difference between the two communities. In this study the rarefaction curve of Bonjoge is outside of the 95% confidence interval of the rarefaction curve of Kobujoi revealing that Kobujoi has significantly higher species richness (Fig. 30).

Based on different species richness estimation 80.8-96-8% of vascular plant species at Kobujoi and 72.6-92.5% of Bonjoge were recorded in this study. As it was reported by Heck *et al*. (1975) collecting or recording 50-75% of the total species of a given community might be suffice. Therefore, my study incorporated much of the species that could exist in the study sites.

Medium Sørensen and low Jaccard similarity indices were observed between Kobujoi and Bonjoge. The respective abundance based similarity indices are higher (i.e. Chao-Sørensen estimator = 0.77 and Chao-Jaccard estimator = 0.65). Abundance based similarity indices are higher than their respective classic similarity indices. This increment is mainly due to the consideration of unseen but shared species in the case of abundance based similarity indices (Chao *et al* 2005; Chao *et al*, 2006). Higher abundance based similarity (both Chao-Sørensen and Chao-Jaccard estimator) estimators resulted when more rare species are shared by any two communities (Robin Chazdon 19/03/2011 personal communication).

6.4.2 Population structure

In terms of growth forms, at Kobujoi proportion of tree sspecies is slightly higher than that of herbs. At Bonjoge the majority of the species belong to tree growth form. The proportion of climbers, shrubs and trees is higher at Bonjoge than that of Kobujoi (Fig. 31). On the other hand proportion of herbs and epiphytes is higher at Kobujoi than that of Bonjoge. In this regard, this result is similar to what has been reported by Rembold (2011) for Kakamega and Budongo. In Kakamga forest, the number of shrub species increased in disturbed sites where as herbs decrease with disturbance. In the case of Budongo, higher percentage of tree and climber species were observed in disturbed part while the herbs were decreasing. The higher proportion of tree, shrub and climber species at Bonjoge than that of Kobujoi could be mainly due to the modification of the environmental conditions such as light and humidity. As reported by

Gradstein (2008) forest disturbance is associated with loss of humidity which can affect the distribution of plants and there by affecting species composition. In this study, species belonging to herbs and epiphytes decreased at highly disturbed part showing that these growth forms are more sensitive to humidity and open light that those belong to climber, shrub and tree growth forms.

The effect of forest disturbance can be seen by its impact on the basal area of the forest. It has been seen that basal area at Kobujoi is higher than that of Bonjoge. This finding is in agreement with what was reported for Kakamega by Althof (2005) and Rembold (2011) and Budongo by Rembold (2011) where in both cases basal area is inversely related to disturbance. Disturbance also affects the density of woody plants as it has been observed in this study (Table 29). The density of woody plants at Kobujoi is double of what was recorded at Bonjoge. Lower density of woody plants per ha might reduce the probability of having individuals with bigger diameter. Higher basal area means there are large number of individuals in bigger diameter classes. However, when a given forest is heavily disturbed most of the trees with bigger diameter are removed for various reasons and result in low basal area. This is what is observed at Bonjoge.

Furthermore, the removal of trees in certain diameter class also affects the population distribution patterns of tree species. Based on disturbance, different tree species have different population structure at Kobujoi and Bonjoge. For instance, *Polycias fulva, Alangium chinensee* and *Tabernaemontana stapfiana* have higher number of individuals at Bonjoge. The former two species are considered as indicator species for highly disturbed forests (Althof, 2005) hence, they become more abundant at Bonjoge. In the case of *Tabernaemontana stapfiana,* this species probably could not be as attractive as other trees species to the local community either for charcoal or timber production. *Diospyros abyssinica* which is considered as an indicator species for low disturbed sites of Kakamega (Althof, 2005), at Bonjoge individuals of this species are found in the lower diameter classes (i.e. 2-20 cm). Hence except pioneer species such as *Polycias fulva*, *Alangium chinensee*, *Trilepisium madagascariense* and *Tabernaemontana stapfiana* most of the tree species have larger number of individuals at Kobujoi. This could be most probably due to ample light that can enhance seed germination of these species as well as establishment of seedlings and recruitment of samplings.

In terms of IV, at Kobujoi out of the top 15 woody plant species there are only one climber species (*Culcasia falcifolia)* and tow shrub species (*Alchornea hirtella* and *Acanthus eminens*).

In the case of Bonjoge, six of the species from the top 15 species are either climbers (*Culcasia falcifolia* and *Hippocratea africana*) or shrubs (*Solanum mauritianum, Macrorungia pubinervia, Mimulopsis arborescens* and *Alchornea hirtella*). *Prunus africana,* a tree native to the montane forests of Africa (Nzilani, 2001) is one of the top 15 dominant woody plant species at both Kobujoi and Bonjoge (Table 30). At both sites the importance of this species is mainly due to its large basal area which resulted from very big but few individuals. This species has generally few individuals both at lower and higher diameter classes (Fig. 14). As it was reported by (Tsingalia, 1989; Nzilani, 2001; Fashing, 2004) this species has difficulties in saplings recruitment though its seeds germinate easily. Hence, it is hard to find small trees/saplings in South Nandi forest in general.

Invasive *Solanum mauritianum* which is considered as indicator species of disturbed rainforests (Fashing *et al*., 2004; Murphy *et al*., 2008) become more dominant at Bonjoge. *Solanum mauritianum* is a native plant in Southern Brazil and it become naturalized in Africa, Australia, India and islands of the Atlantic, Indian and Pacific Oceans (Barboza *et al*, 2009). It has typical ecological characteristics of pioneer species (Denslow, 1980; Swaine and Whitmore, 1988). It colonizes disturbed habitats that are in the initial stage of ecological succession, germinates under high temperature or light conditions, its seeds can persist in soil for long time until there is favorable conditions for seedling establishment and it produce small, abundant seeds that are mainly spread by birds and bats. The invasive nature of this species is aggravated by anthropogenic disturbance (Barboza *et al*, 2009) and this is what is happening at Bonjoge. Moreovere, it was repoted that leaf leachates of *Solanum mauritianum* hamper the germination of *Hebe stricta* seeds (Bosch *et al*., 2004). Hence, the dominace of *Solanum mauritianum* might have hampered the germination as well as general regeneration of other species at Bonjoge. In general, this phenomena reveals that the species composition and population structure at Bonjoge is highly affected by human disturbance. As it was described by Lalfakawma (2010), disturbances, be it natural or anthropogenic have much influence on community composition, tree population structure and regeneration ability of forest ecosystems.

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6.4.3 Seedling bank and resprouting

Regeneration is one of the ecological processes in a plant community which enables the perpetuation of that particular community. The process of regeneration is controlled by several factors such as availability of seeds for germination (Demel, 2005; Flinn and Vellend, 2005; Svenning and Wright, 2005) and conducive environmental conditions (Murdoch and Ellis, 2000) such as moisture, light, optimum temperature, etc. Disturbances such as fire can affect flowering of plants, seed dispersal, germination, seedling establishment, plant mortality, etc (Dayamba *et al*, 2008). Therefore both biotic and abiotic factors control successful regeneration of plants in a community.

In this study it has been observed that mean number of seedlings per plot as well as total number of woody plant seedlings per ha are higher in the relatively better side of South Nandi forest (Kobujoi). This might be mainly due to relatively higher number of matured trees in less disturbed part of this forest which enables availability of quality seeds in larger quantity. On the other hand, at Bonjoge where there is heavier disturbance due to cutting of matured trees, there could be shortage of quality seeds for germination. Furthermore, anthropogenic disturbance might affect the environmental conditions there by seedling recruitment can be hampered.

At Kobujoi, the top three seedling rich species are *Diospyros abyssinica, Prunus africana* and *Cassipourea ruwensorensis*. As described by Althof (2005) *Diospyros abyssinica* is one of the indicator species of low disturbed forest, hence, having higher number of seedlings at Kobujoi is in agreement with Althof characterization of this species. Shady environment favors germination of *Prunus africana* (Tsingalia, 1989; Kiama and Kiyiapi, 2001; Nzilani, 2001; Alemayehu, 2007) and this might result in higher number of seedlings at Kobujoi. At Bonjoge *Trilepisium madagascariense, Hippocratea africana* and *Strombosia scheffleri* seedlings are the most dominant. However, some of these species are considered as indicator species of less disturbed forest for example *Hippocratea africana* (Althof, 2005) which is opposite to this finding. Although it is among the top 15 seedling rich species at Kobujoi, it has relatively higher seedling density at Bonjoge. *Hippocratea africana* might germinate and establishes its seedlings easily both at highly disturbed and less disturbed forests. Seedlings of *Trilepisium madagascariense* and *Strombosia scheffleri* are common under shady environments (Chapman *et al*., 2008) but in this study relative density of these species is higher in relatively highly disturbed site (Bonjoge).

The lower number of seedlings at Bonjoge could be also attributed to the physical damage to seedlings and saplings during cuttings of matured trees. Clark and Clark (1991) reported that smaller individuals (between one and ten cm diameter) were more likely to be damaged than larger trees by physical damage such as branch or tree fall, hence most individuals of smaller size could be died. Therefore, unsustainable cuttings of matured trees affect number of seedlings both by reducing seed source and increasing physical damage on seedlings and saplings there by negatively influencing the composition of woody plants species.

Most of the stumps recorded both at Kobujoi and Bonjoge able to coppice though there is difference in their proportion. Bigger stumps are more at Bonjoge since there is a higher illegal cutting of trees for charcoal and timber production. This might resulted to less sprouting ability of stumps (56.6% of stumps sprouted) while at Kobujoi the sprouted stumps proportion was higher (77%). This higher proportion of sprouting stumps at Kobujoi could be attributed to smaller stumps diameter at this site.

7. Conclusion and Recommendations

Nandi forests were part of Kakamega forest during the early 1900s (Schaab *et al*, 2010). However, due to heavy human pressure the big ‘U’ shaped forest block is now divided into three different forests (i.e. Kakamega, South and North Nanadi forests). Although it is not as diverse as that of Kakamega forest due to its altitude, 321 vascular plant species from 92 families are harbored in Nandi forests. South Nandi forest is a habitat for 253 vascular plants while in North Nandi 182 species are recorded. Based on the second order Jackknife it is estimated that as high as 359 vascular plant species can exist in Nandi forests. The same species richness estimator estimates the vascular plant species of South and North Nandi forests to be 284 and 209, respectively. Less number of species in North Nandi forest could be attributed to the heavy grazing of livestock that exists in this forest. All diversity measures considered in this study are higher for South Nandi forest revealing that South Nandi forest is more diverse than that of North Nandi forest. More over, the rarefaction curves of the two forests strengthen that South Nandi is more diverse (species rich). Anthropogenic impact on South Nandi forest resulted in less number of species at highly disturbed side of this forest (Bonjoge) than that of less affected part of South Nandi (Kobujoi) has more species.

Nandi forests are not only important in terms of plant biodiversity but also they are considered as important bird area of Kenya (Lewis and Pomeroy, 1989 cited in Kosgey, 1998). Both South and North Nandi forests are also important catchment area of Lake Victoria basin (KIFCON 1994a; KIFCON 1994b). In these forests, economically and ecologically very important tree species such as *Diospyros abyssinica, Syzygium guineense, Croton megalocarpus*, *Drypetes gerrardii, Prunus africana, Strombosia scheffleri,* etc are found. Furthermore, the people who live at Nandi use several plant species as medicine for different diseases (Pascaline *et al*., 2011) and some of these plants found in Nandi forests. Hence, it is very crucial to protect this imprtant forest both from biodiversty and environmental perspectives.

Plant communities of Nandi forests can be grouped into three. These communities are formed based on from where the quadrates are sampled as well as on disturbance intensity. One of the communities is formed by quadrates typically from North Nandi froests i.e. *Turraea holstii - Ehretia cymosa* community. The other two communities are from South Nandi forest which are differentiated due to disturbance. These communities are *Diospyros abyssinica-Heinsenia diervilleoides* community formed mainly by quadrates from Kobujoi which is better side of South Nandi and *Trilepisium madagascariense-Solanum mauritianum* community that is mainly from highly disturbed part (Bonjoge). The invasive *Solanum mauritianum* becomes more important and dominant at heavily disturbed sites of South Nandi forest or in *Trilepisium madagascariense-Solanum mauritianum* community. From this we can conclude that the main causes behind the formation of these communities are mainly due to the position of the forests (North or South), type of disturbance (grazing and cuttings) as well as the intensity of disturbance.

Based on both incidence and abundance based indices, it has been observed that there is a low similarity between South and North forests. On the other hand, medium (incidence bases similarity) to high similarity (abundance based) was observed between plant species of Kobujoi and Bonjoge. Low similarity between South and North Nandi forests could be mainly attributed to fragmentation, geographical location of the forests and/or altitudinal difference as well as difference in intensity and type of disturbance between the two forests or combination these factors.

Population structure is one of the forest characteristics that can be easily influenced by disturbance. Different disturbance factors also affect population structure differently. The main disturbance factors in South Nandi are illegal cuttings and charcoal production while in the North Nandi livestock grazing is very important. Hence, the basal area of North Nandi forest is greater than that of South Nandi as there are more, bigger trees in North Nandi than South Nandi. It is also clear that cuttings (be it for charcoal or timber) affect basal area as it targets bigger diameter trees, thus the basal area of highly disturbed part of South Nandi forest is inferior to that of better side.

Even if both height and diameter class distribution shows an inverted 'J' population distribution at both forests, when individual tree species are considered separately the shape might be different. Hence, different tree species showed different population structure and seven different diameter class distributions were observed in this study. In the population structure analysis *Prunus africana* and *Syzygium guineense* have poor saplings recruitment. *Prunus africana* is among top seedling rich tree species of South Nandi forest however it is poor in seedling growth and sapling recruitment. This does not only affect the continuity of this tree species but also affects birds and primates that relay on the fruits of *Prunus* africana and this situation could affect the diversity of wildlife of South Nandi forest. Though the seedlings of *Syzygium guineense* are not as high as that of *Prunus africana*, this tree species is also very important indicator of North Nandi forest. Similar to *Prunus*, *Syzyguim* has also poor recruitment into sapling and small trees having a 'J' shaped diameter class showing the perpetuation of this tree is under question mark.

In this study it has also been observed that the number of seedlings is less in North Nandi than that of South Nandi forest. In addition to this, the seedling population of North Nandi is dominated by woody plant species other than tree growth forms (i.e. climbers and shrubs contributing 40.5 and 39.1 % of the seedlings, respectively). Lower number of seedlings from trees might attributed to poor seeding of matured trees due to age, livestock grazing (can destroy seedlings by trampling and browsing), seed and/or fruit predation, etc or a combination of two or more of these factors. In the case of highly disturbed and less disturbed part of South Nandi forest, number of seedling at less disturbed part is higher. The main reason for this difference could be low seed production due to heavy logging for charcoal and timber production and physical damage on seedlings and sapling during cuttings.

Coppicing is another regeneration strategy of most woody plant species. Totally 676 stumps were investigated for their ability to resprout or not. Among these stumps 24 of them were not identified to which species they are belonged while the rest (652 stumps) are from 56 different species. The majority of the stumps (83.9%) resulted from cuttings and the remaining 16.1% are created due to fall of big trees and/or branches on them. This reveals that the main cause of above ground biomass damage is removal of stems through cutting for various purposes. Stumps from *Croton megalogarpus* and *Syzygium guineense* are not able to coppice but stumps from the remaining 54 species are able to resprout. This shows that most of the woody plant species (96.4%) of Nandi forest can easily regenerate from stumps after the above ground biomass is removed. Non sprouting ability of *Croton megalogarpus* and *Syzygium guineense* could be most probably due to old age of the trees when they are removed. In some species such as *Strombosia scheffleri*, *Diospyros abyssinica* and *Heinsenia diervilleoides* stump diameter and number of sprouts per stump have shown significant correlation. The relationship is positive in the case of *Strombosia scheffleri* however it is negative for that of *Diospyros abyssinica* and *Heinsenia diervilleoides*.

Although Nandi forests were connected to Kakamega forest and still very close to this forest, the attention given to Nandi forests both in terms of development and research is very minimal. It is very difficult to get research out puts on Nandi forest or very scanty if it is available at all, while there is ample information about Kakamega. I was informed by a researcher that South Nandi is no more exists, during the initial stage of this study though I was not discouraged by this information. However, it has its own implication how the Nandi forests are/were neglected and far from the attention of some of the scientists. Based on the observation and findings of this study the following points are recommended:

- Since these forests are very important both biologically and environmentally it is crucial to protect and conserve them so that the future generation can enjoy their benefit sustainably as the current generation does though it is not sustainably.
- South Nandi forest is mainly affected from illegal cuttings for charcoal and timber production. Especially charcoal production consumes a lot of big trees to produce small volume of charcoal, thus the government should take this issue into consideration when it plans about the development and protection of this forest.
- At least from the information gathered, North Nandi forest is under huge threat of livestock grazing. From the informal discussion I had with some of the local people it has been realized that the local community should pay to get permission to let their livestock for grazing in the forest. This permission should have to consider the carrying capacity of the sites and livestock grazing must not undermine the nature regeneration processes of the forest.
- In areas where there is less number of seedlings as well as depleted tree population it is better to think of enrichment planting of indigenous tree species.
- The government should think of managing the forests jointly with the local community as well as creating other income generating activity and alternative sources of energy.
- If it is not possible to ban or control charcoal production it is better to work on how to improve the production technology as currently the community uses traditional earth kiln to produce charcoal which is not as such efficient.
- Information on soils of Nandi forests is not available. In addition, the effect of aspect and slope on species composition is not studied, hence it is important to study the soils as well as effect of aspect and slope on species composition of these forests.
- To understand the natural regeneration potential of these forests it is crucial to have detailed information on soil seed bank and the amount of seed rain (seed production) per year in the forest, therefore it is recommended to focus on these aspects of regeneration ecology in the future.

References

Adams, L. W. 1994. Urban wildlife habitats: a landscape perspective. University of Minnesota Press, Minneapolis.

Agnew, A. D. Q. and Agnew, S. 1994. Upland Kenya Wild Flowers. A flora of the Ferns and Herbaceous flowering plants of Upland Kenya. East African Natural History Society.

Akotsi, E. F. N., Michael, G., Ndirangu, J. K. 2006. Changes in Forest Cover in Kenya´s Five "Water Towers" 2003-2005.

Alemayehu, W. E. 2007. Ethiopian Church Forests: opportunities and chalenges for restoration, PhD thesis, Wageningen Univeristy, Wageningen, The Netherlands

Allaway, J. and Cox, P. M. J. 1989. Forests and Competing Land Use in Kyna. *Evironmentmental Management* 13:171-187.

Althof, A. J. 2005. Human Impact on Flora and Vegetation of Kakamega Forest, Kenya Structure, distribution and disturbance of plant communities in an East African rainforest. PhD Dissertation University of Koblenz-Landau

Andrén, H., 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. *Oikos* 71:355-366.

Anonymous. 2002. Study on Kenya's energy supply and policy strategy for households, small-scale industries and services establishments, final draft report. Ministry of Energy, Nairobi, Kenya.

Ashish, P., Latif, M. K., and Kumar, D. A. 2010. Effect of stump girth and height on resprouting of Rhododendron arboretum following disturbance in temperate mixed leaved forest of Arunachal Pradesh, India. *Journal of Forestry Research* 21:433-437

Attiwill, P. M. 1994. The disturbance of forest ecosystems: the ecological basis for conservative management. *Forest Ecology and Management* 63:247-300.

Babeux, P. and Mauffette, Y. 1994. The effect of early and late spring cuts on the sprouting success of red maple (*Acer rubrum*) in northwestern Quebec. *Canadian Journal of Forestry Research* 24:785-791.

Barboza, D. M., Marques, M. C. M., Pedrosa-Macedo, J. H. and Olckers, T. 2009. Plant Population Structure and Insect Herbivory on *Solanum mauritianum* Scopoli (Solanaceae) in Southern Brazil: a Support to Biological Control. *Brazilian Archives of Biology and Technology* 52:413-420

Barik, S. K., Rao, P., Tripathi, R. S. and Pandey, H.N. 1996. Dynamics of tree seedling populations in a humid subtropical forest of north-east India as related to disturbance. *Canadian Journal of Forest Research* 26:584-589.

Battles, J.J. and Fahey, T.J. 2000. Gap dynamics following forest decline: A case study of Red spruce forests. *Ecological Applications* 10:760-774.

Beentje, H. 1990. The Forests of Kenya. In Proceedings of the Twelfth Plenary Meeting of AETFAT. Mitt. Inst. Allg. Bot. Hamburg.

Beentje, H. 1994. Kenya Trees, Shrubs and Lianas. National Museums of Kenya, Nairobi.

Bell, T. L. and Ojeda, F. 1999. Underground starch storage in Erica species of the Cape floristic region – differences between seeders and resprouters. *New Phytologist* 144: 143–152

Bellingham, P. J. and Sparrow, A. D. 2000. Resprouting as a life history strategy in woody plant communities. *Oikos* 89:409–416

Bellingham, P. J., Tanner, E.V.J. and Healey, J. R. 1995. Damage and responsiveness of Jamaican montane tree species after disturbance by a hurricane. *Ecology* 76: 2562-2580.

Benitez-Malvido, J. 1998. Impact of forest fragmentation on seedling abundance in a tropical rain forest. *Conservation Biology* 12:380-389.

Bewley, J. D. and Black, M. 1994. Seeds: Physiology of Development and Germination 2nd ed. Plenum Press, London.

Biondini, M. E., Bonham, C. E. and Rendente, E. F. 1985. Secondary successional patterns in a sagebrush (Artemisia tridentate) community as they relate to soil disturbance and soil biological activity. *Vegetatio* 60:25-36.

Bond, E. M. and Chase, J. M., 2002. Biodiversity and ecosystem functioning at local and regional spatial scales. *Ecology Letters* 5:467–470.

Bond, W. J. and Midgley, J. J. 2001. Ecology of sprouting in woody plants: the persistence niche. *Trends in Ecology and Evolution* 16:45-51.

Bond, W.J. and Van Wilgen, B.W. 1996. Fire and Plants (Population and Community Biology Series 14), Chapman and Hall

Bonvissuto, G. L. and Busso, C. A. 2007. Seed rain in and between vegetation patches in arid Patagonia, Argentina. *International Journal of Experimental Botany* 76:47-59

Bormann, F. H. and Berlyn, G. P. 1981. Age and growth rate of tropical trees: New directions for research. School of Forestry Environmenital Studies, Yale University Bulletin No. 94.

Bosch, E. V. D., Ward, B.G. and Clarkson, B. D. 2004. Woolly nightshade (Solanum mauritianum) and its allelopathic effects on New Zealand native Hebe stricta seed germination. *New Zealand Plant Protection* 57:98-101

Boutin, S. and Herbert, D. 2002. Landscapes ecology and forest management: developing an effective partnership. *Ecological Applications* 12:390-397.

Bowen, B. J. and Pate, J. S. 1993. The significance of root starch in post-fire shoot recovery of the resprouter *Stirlingia latifolia* R.Br. (Proteaceae). *Annals of Botany* 72:7–16

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

Bulinski, J. and McArthur, C. 1999. An experimental field study of the effects of mammalian herbivore damage on *Eucalyptus nitens* seedlings. *Forest Ecology and Management* 113:241-249.

Bunge, J. and Fitzpatrick, M. 1993. Estimating the numberof species: A review. *Journal of the American Statistical Association* 88:364–373.

Bussmann, R. W. 1994. The forest of Mount Kenya (Kenya)-Vegetation, Ecology, Destruction and Management of a tropical mountain forest ecosystem, Ph.D. Thesis, Universität Bayreuth, Germany.

Bussmann, R.W. and Beck, E. 1995. The forests of Mt. Kenya (Kenya), a phytosociological synopsis. *Phytocoenologia* 25:467-560.

Caley, M. J., Buckley, K. A. and Jones, G. P. 2001. Separating ecological effects of habitat fragmentation, degradation and loss on coral commensals. *Ecology* 82:3435-3448.

Canadell, J. and Lopez-Soria, L. 1998. Lignotuber reserves support regrowth following clipping of two Mediterranean shrubs. *Functional Ecology* 12: 31–38

Carrier, S. M., Andre, M., Letourmy, P., Olivier, I. and Mckey, D. B. 2007. Seed rain beneath remnant trees in a slash-and-burn agricultural system in southern Cameroon. *Journal of Tropical Ecology* 18:353–374.

Case, T. J. 2000. An Illustrated Guide to Theoretical Ecology. Oxford University Press, Oxford.

Caswell, H. 2001. Matrix Population Models: Construction, Analysis, and Interpretation. Sinauer Associates, Sunderland.

CBD (Convention on Biological Diversity) 2009. http://www.cbd.int/doc/bioday/2010/idb-2010-booklet-en.pdf accessed on 04.02.2010

Ceccon, E., Omstead, I., Vázquez-Yanes, C. and Campo-Alves, J. 2002. Vegetation and soil properties in two tropical dry forests of differing regeneration status in Yucatán. *Agrociencia* 36:621-631.

Chalfoun, A. D., Thompson, F. R. and Ratnaswamy, M. J. 2002. Nest predators and fragmentation: a review and meta-analysis. *Conservation Biology* 16:306-318.

Chao, A. 1984. Nonparameteric estimation of number of classes in a population. *Scandinavian Journal of Statistics* 11:265-270

Chao, A. 1987. Estimating the population size for capturing- recapturing data with unequal catchability. *Biometerics* 43:783-791.

Chao, A., Chazdon, R. L., Colwell, R. K., and Shen, T. 2005. A new statistical approach for assessing similarity of species composition with incidence and abundance data. *Ecology letters* 8:148-159

Chao, A., Chazdon, R. L., Colwell, R. K., and Shen, T. 2006. Abundance-based Similarity indices and their estimation when there are unseen species in samples. *Biometrics* 62:361-371.

Chapman, C. A., Kitajima, K., Zanne, A. E., Kaufman, L. S., and Lawes, M. J. 2008. A 10-year evaluation of the functional basis for regeneration habitat preference of trees in an African evergreen forest. *Forest Ecology and Management* 255:3790-3796

Chiarucci, A., Enright, N. J., Perry, G. L. W., Miller, B. P. and Lamont, B. B. 2003. Performance of nonparametric species richness estimators in a high diversity plant community. *Diversity Distribution* 9:283-295.

Clark D. B., Palmer M. W. and Clark D. A. 1999. Edaphic factors and the landscape-scale distributions of Tropical Rainforest Trees. *Ecology* 80:2662-2675.

Clark, D. B. and Clark, D. A. 1984. Spacing dynamics of a tropical rain forest tree: evaluation of the Janzen-Connell model. *Ameriacan Naturalist* 124:769-788

Clark, D. B. and Clark, D. A. 1991. The impact of physical damage on canopy tree regeneration in tropical rainforest. *Journal of Ecology* 79:447-457.

Clarke, P. J., Lawes, M. J. and Midgley, J. J. 2010. Resprouting as a key functional trait in woody plants – challenges to developing new organizing principles. *New Phytologist* 188:651–654

Coetzee, J. A. 1978. Phytogeographical aspects of the montane forests of the chain of mountains on the eastern side of Africa. *Erdwissenschaftliche Forschung* 11: 482-494.

Colwell, R. K. 2009. EstimateS: Statistical estimation of species richness and shared species from samples. Version 8.2. User's Guide and application published at: http://purl.oclc.org/estimates.

Colwell, R. K. and Coddington, A. J. 1994. Estimating terrestrial biodiversity through extrapolation. *Philosophical Transaction oh the Royal Society Biological Science* 345:101-118

Colwell, R. K., Mao, C. X. and Chang, J. 2004. Interpolating, extrapolating, and comparing incidence-based species accumulation curves. *Ecology* 85:2717-2727.

Condit, R., Sukumar, R. Hubbell, S. P. and Foster, R. B. 1998. Predicting population trends from size didtributions: a direct test in a tropical tree community. *American naturalit* 152:495-509.

Connell, J. H. 1978. Diversity in tropical rain forests and coral reefs. *Science* 199:1302-1303.

Cornell, H. V. 1999. Unsaturation and regional influences on species richness in ecological communities: a review of the evidence. *Ecoscience* 6:303-315.

Cowling R. M. 1990. Diversity components in a species-rich area of the Cape Floristic Region. *Journal of Vegetation Science* 1:699-710.

Cunningham, A.B., Mbenkum, F.T., 1993. Sustainability of Harvesting Prunus africana Bark in Cameroon: A Medicinal Plant in International Trade. People and Plants Working Paper 2, UNESCO, Paris.

Cunningham, A.B., Cunningham, M., 1999. Profits, Prunus, and the prostate: international trade in tropical bark. In: Zerner, C. (ed.), People, Plants, and Justice: The Politics of Nature Conservation. Columbia University Press, New York, pp. 309–329.

Cunningham, A.B., Ayuk, E., Franzel, S., Duguma, B., Asanga, C.,2002. An Economic Evaluation of Medicinal Tree Cultivation: Prunus africana in Cameroon. People and Plants Working Paper 10, UNESCO, Paris.

Dale, V. H. and Beyeler, S. C. 2001. Challenge in the development and use of ecological indicators. *Ecological Indicators* 1:3-10

Dalitz, H., Gliniars, R. 2010. Trees in the context of different environments. BIOTA East Africa Concluding Conference 2010, Kakamega, Kenya.

Dalling, J. W., Muller-Landau, H. C., Wright, S. J. and Hubbell, S. P. 2002. Role of Dispersal in the recruitment limitation of neotropical pioneer species. *Journal of Ecology* 90:14–727.

Dansereau, P. 1957. Biogeography, an ecological perspective. The Ronald Press, New York.

Dawit, S., Lehmann, J., Kanyangi, J., Amelung, W., Lobe, I., Pell, A., Riha, S., Ngoze, S., Verchot , L., Mbugua, D., Skjemstad, J. and Schäfer, T. 2007. Long-term impacts of anthropogenic perturbations on dynamics and speciation of organic carbon in tropical forest and subtropical grassland ecosystems. *Global Change Biology* 13:1–20

Dawit, S., Lehmann, J., Kanyangi, J., Pell, A., Theis, J., Riha, S., Ngoze, S., Amelung, W., Preez, C. D., Machado, S., Ellert, B. and Janzen, H. 2009. Anthropogenic and climate influences on biogeochemical dynamics and molecular-level speciation of soil sulfur. *Ecological Applications* 19:989–1002

Dayamba, S. D., Mulualem, T., Sawadogo, L and Oden, P. C. 2008. Seed germination of herbaceous and woody species of the Sudanian savanna-woodland in response to heat shock and smoke. *Forest Ecology and Management* 256:462–470

DeLong, D. C. 1996. Defining Biodiversity. *Wildlife Society Bulletin* 24:738-749

Demel, T. 1996. Seed Ecology and Regenerationin Dry Afromontane Forests of Ethiopia. Ph.D. Thesis, Swedish University of Agricultural Sciences, Umeå.

Demel, T. 1997. The impact of clearing and converting dry Afromontane forests into permanent arable land on the composition and density of soil seed banks. *Acta Oecologica* 18:557-573.

Demel, T. 2005. Seed and regeneration ecology in dry Afromontane forests of Ethiopia: I. Seed production - population structures. *Tropical Ecology* 46:29-44, 2005

Demel, T. and Granström, A. 1995. Soil seed banks in dry Afromontane forests of Ethiopia. *Journal of Vegetation Science* 6:777-786.

Denslow, J. S. G. 1980. Gap portioning among tropical rainforest trees. *Biotropica* 12:47-55. Design. USA.

Dorazio, R. M., Royel, J. A., Söderström, B. and Glimskär, A. 2006. Estimating species richness and accumulation by modelling species occurrence and detectability. *Ecology* 87:842–854

Du, X., Guo, Q., Gao, X. and Maa, K. 2007. Seed rain, soil seed bank, seed loss and regeneration of *Castanopsis fargesii* (Fagaceae) in a subtropical evergreen broad-leaved forest. *Forest Ecology and Management* 238:212–219.

Duelli, P. and Obrist, M. K. 2003. Biodiversity indicators: the choice of values and measures. *Agriculture Ecosyst and Environment* 98:87-98

Dufrêne M. and Legendre P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs* 67:345-366.

Ehrlich, P. R. and Wilson, E. O., 1991. Biodibersity studies: science and policy. *Science* 253:758-762

Eilu, G. and Obua, J. 2005. Tree condition and natural regeneration in disturbed sites of Bwindi Impenetrable forest national park, Southwestern Uganda. *Tropical Ecology* 46:99-111

Ellsworth, J. W., Harrington, R. A. and Fownes, J. H. 2004. Seedling emergence, growth, and allocation of Oriental bittersweet: effect of seed input, seed bank, and forest floor litter. *Forest Ecology and Management* 190:255-264.

Emerton, L. 1994. Summary of the current value of Kakamega forest. Unbplished report for Kenya Indigenous Forest Conservation Progamme (KIFKON), Nairobi.

Epp, G. A. 1987. The seed bank of Eupatorium odoratum along a successional gradient in a tropical rain forest in Ghana. *Journal of Tropical Ecology* 3:139-149.

Evans, J. 1992. Coppice forestry-an overview In: Buckley, G. P (ed.) Ecology and Management of Coppice woodlands. Chapman and Hall, London pp18-27.

Everham, E. M. and Brokaw, N. V. L. 1996. Forest damage and recovery from catastrophic wind. *The Botanical Review* 62: 113–185.

Ewel, J. 1983. Succession. In: Golley G. B. (ed.), Tropical rainforest ecosystems: structure and function, Ecosystems of the world 14A, pp. 9-26.

Ewel, K. C. 1996. Sprouting by pondcypress (*Taxodium distichum* var. nutans) after logging. *Southern Journal of Applied Forestry* 20:209-213

Fahrig, L. 1997. Relative effects of habitat loss and fragmentation on species extinction. Journal of Wildlife Management. 61:603–10

Fahrig, L., 2003. Effects of habitat fragmentation on Biodiversity. *Annual Review of Ecology, Evolution and Sytematics* 34: 487–515.

FAO 2001. Forest resources assessment 2000. Food and Agriculture Organization, Rome.

FAO 2003. Proceedings of Workshop on Tropical Secondary Forest Management in Africa: Reality and Perspectives Nairobi, Kenya, 09 - 13 December 2002

FAO 2006. Global forest resources assessment 2005: Progress towards sustainable forest management. FAO Forestry Paper 147.

Fashing, P. J. 2004. Mortality trends in the African cherry (Prunus africana) and the implications for colobus monkeys (*Colobus guereza*) in Kakamega Forest, Kenya *Biological Conservation* 120:449-459.

Fashing, P. J., Forrestel, A.1, Scully, C. and Cords, M. 2004. Long-term tree population dynamics and their implications for the conservation of the Kakamega Forest, Kenya. *Biodiversity and Conservation* 13:753-771

Fenner, M. 1985. Seed Ecology. Chapman and Hall, London and New York.

Feyera, S. W. 2006. Biodiversity and ecology of Afromontane rainforests with wild Coffea arabica L. populations in Ethiopia. Cuvillier Verlag, Göttingen.

Fischer, E., Rembold, K., Althof, A., Obholzer, J., Malombe, I., Mwachala, G., Onyango, J., Dumbo. B. and Theisen, I. 2010 Annotated checklist of the vascular plants of the Kakamega Forest, Western Province, Kenya. *Journal of East Africa Natural History* 99:129-226.

Fischer, E. and Killman, D. 2008. Illustrated Field Guide to the Plants of Nyungwe National Park Rwanda.

Fisher, R. A., Corbet, A. S. and Williams, C. B. 1943. The relation between the number of species and the number of individuals in a random sample of an animal population. *Journal of Animal Ecology* 12:42-58.

Fisher, B. L. 1999. Improving Inventory Efficiency: A case study of leaf-Litter ant diversity in Madagascar. *Ecological Applications* 9:714-731.

Flinn, K. M., and Vellend, M. 2005. Recovery of forest plant communities in post-agricultural landscapes. *Frontiers in Ecology and the Environment* 3:243–250.

Forrester, F., Bauhus, J., and Connel, M. 2003. Competition in thinned Silvertop Ash (*Eucalyptus sirberi* L. Johnson) stands from early coppice growth. *Forest Ecology and Management* 174:459-475.

Frankel, O. H. and Soule, M. E. 1981. Conservation and Evolution. Cambridge University Press, Cambridge.

Franklin, J.E., Shugart, H.H., Harmon, M.E., 1987. Tree death as an ecological process: the causes, consequences, and variability of tree mortality. *Bioscience* 37:550–556.

Gardiner, E. S., Russell, JrD. R, Hodges, J. D. 2000. Impacts of mechanical tree felling on development of water tupelo regeneration in the Mobile Delta, Alabama. *Southern Journal of Applied Forestry* 24:65-69

Garwood, N. C. 1989. Tropical soil seed banks: a review. In: Leck, M. A., V.T. Parker and R. L. Simpson (eds.) Ecology of Soil Seed Banks. Academic Press, San Diego. pp. 149-209.

Gaston, K. J. 1994. Rarity. Chapman and Hall, London.

Gentry, A. H. and Dodson, C. H. 1987. Contribution of non-trees to species richness of a tropical rainforest. *Biotropica* 19:149-156.

Gentry, A. H. 1988. Changes in plant community diversity and floristic composition on environmental and Geographical gradients. Ann. Miss. Bot. Gard. 75(1):1-34.

Gentry, A. H. 1992 Tropical forest biodiversity: distributional patterns and their conservational significance. *Oikos* 63:19-28

Gentry, A .H. 1995. Patterns of diversity and floristic composition in neotropical montane forests. In: Churchill S. P., Balslev H., Forero E. and Luteyn J. L. (Eds.) Biodiversity and Conservation of Neotropical Montane Forests, The New York Botanical Garden, Bronx, New York, pp. 103–126.

GEO-2000 1999. The state of the Environment- Africa- Forests. United Nations Environment Programme. http//:www.unep.org/geo2000/English/0054.htm. accessed on 12.09.08

Gerwing J. J., Schnitzer, S. A., Burnham, R. J., Bongers, F., Chave, J., DeWalt, S. J., Ewango, C. E. N., Foster, R., Kenfack, D., Martínez-Ramos, M., Parren, M., Parthasarathy, N., Pérez-Salicrup, D. R., Putz, F. E. and Thomas, D.W. 2006. A standard protocol for liana sensuses. *Biotropica* 38:256-261.

Glenday, J. 2006. Carbon storage and emission offset potential in an East African tropical riainforest. *Forest Ecology and Management* 235:72-83.

Gliniars, R. 2010. Tree growth and tree regeneration in two East African rain forests as related to the abiotic anvironment after Human Disturbance. PhD Thesis University of Hohnheim, Stuttgart.

Gorte, R. W. and Sheikh, P. A. 2010. Deforestation and Climate Change. Congressional Research Service report prepared for Congress. http://assets.opencrs.com/rpts/R41144_20100324.pdf accessed on 01.01.2011

Gotelli, N. and Colwell, R. K. 2001. Quantifying biodiversity: Procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters* 4:379–391.

Grace J. B., Allian, L. and Allen, C. 2000. Vegetation association in a rare community type-coastal tallgrass praireie. *Plant Ecology* 147:105-115

Gradstein, S. R. (2008): Epiphytes of tropical montane forests - impact of deforestation and climate change. In: Gradstein, S. R., Homeier, J., Gansert, D. (eds). The Tropical Mountain Forest: patterns and processes in a biodiversity hotspot. Biodiversity and Ecology Series: volume 2. Universitätsverlag Göttingen,Göttingen. pp 51-65

Grime, J. P. and Hillier, S. H. 2000. The Contribution of Seedling Regeneration to the Structure and Dynamics of Plant Communities, Ecosystems and Larger Units of the Landscape. In: Fenner, M. (ed.) Seeds: The Ecology of Regeneration in plant Communities. 2nd Edition. CABI publishing. pp 361-374

Grubb, P. 1977. The maintenance of species richness in plant communities: the importance of the regeneration niche. *Biological Reviews* 52:107–145

Guariguata M.R. 1998. Response of forest tree sapling to experimental mechanical damage of lowland Panama. *Forest Ecology and Management* 102:103-111.

Habiyaremye, M. K. 1997. Étude Phytocoenologique de la Dorsale Orientale du lac Kivu (Rwanda). Annales Science Économiques, Vol. 24.

Hall, J.B., O’Brien, E.M. and Sinclair, F.L., 2000. Prunus africana: a monograph. School of Agricultural and Forest Sciences Publication Number X, University of Wales, Bangor.

Hamilton, A. J. 2005. Species diversity or biodiversity? *Journal of Environmental Management* 75:89–92
Harmer, R. 2001. The effect of plant competition and simulated summer browsing by deer on tree regeneration. *Journal of Applied Ecology* 38:1094-1103.
Harrison, S. and Bruna, E. 1999. Habitat fragmentation large-scale conservation:what do we know for sure? *Ecography* 22:225-232.
Haugaasen, T., Barlow, J. and Peres, C. A. 2003. Surface wildfires in central Amazonia: Short-term impact on forest structure and carbon loss. *Forest Ecology and Management*, 179:321-331.
Hawthorne, W. D. 1993. Forest regeneration after logging: findings of a study in the Bia South Game Production Reserve, Ghana. ODA Forestry Series. Natural Resources Institute, Chatham.
Hawthorne, W. D. 1994. Fire damage and forest regeneration in Ghana. ODA Forestry Series. Natural Resources Institute, Chatham.
Heck, K. L., van Belle, G. and Simberloff, D. 1975. Explicit calculation of the rarefaction diversity measurement and the determination of sufficient sample size. *Ecology* 56:1559-1461.
Hellmann, J. J. and Fowler, G. W. 1999. Bias, precision, and accuracy of four measures of species richness. *Ecological Applications* 9:824-834
Heltshe, J. F. and Forrester, N. E. 1983. Estimating species richness using the jackknife procedure. *Biometrics* 39:1-11
Heywood, V.H., 1998. The species concept as a socio-cultural phenomenon: a source of the scientific dilemma. *Theory in Biosciences* 117:203–212.
Hill, J. L. and P. J. Curran, 2005. Fragment shape and tree species composition in tropical forests: a landscape level investigation. *African Journal of Ecology* 43:35–43.
Holdgate, M. 1996. The ecological significance of biological diversity. *Ambio* 25:409-416.
Hopper, S. D. 2000. Floristics of Australian granitoid inselberg vegetation. In: Porembski, S. and W. Barthlott (eds.) Inselbergs. Ecological studies vol. 146. Springer-Verlag, Berlin. pp. 391-407.
Horvitz, C. C., and Schemske, D. W. 1994. Effects of dispersers, gaps, and predators on dormancy and seedling emergence in a tropical herb. *Ecology* 75:1949–1958.
Hunter, I.R., 1993. The role of nutrition in forest decline – a case study of Pinus radiata in New Zealand. In: Huettl, R. F., Mueller-Dombois, D. (eds.) Forest decline in the Atlantic and Pacific region. Springer-Verlag, Berlin, pp. 293–306.
Hurlbert, S. H., 1971. The nonconcept of species diversity: a critique and alternative parameters. *Ecology* 52, 577–586.
Huston, M. 1979. A general hypothesis of species diversity. *American Naturalist* 113:81-101.
Imanishi, A., Morimoto, J., Imanishi, J., Shibata, S., Nakanishi, A. and Osawa, N. 2010. Sprout initiation and growth for three years after cutting in an abandoned secondary forest in Kyoto, Japan. *Landscape and Ecological Engineering* 6:325-333.
Kammesheidt, L. 1998. The role of tree sprouts in restoration of stand structure and species diversity in tropical moist forest after slash- and – burn agriculture in Eastern Paraguay. *Plant Ecology*, 139: 155-165.
Kammesheidt L. 1999. Forest recovery by the root suckers and above-ground sprouts after slash-and-burn agriculture, fire and logging in Paraguay and Venezuela. *Journal of Tropical Ecology* 15:143-157.
Kammesheidt, L. 1998. The role of tree sprouts in the restoration of stand structure and species diversity in tropical moist forest after slash-and-burn agriculture in Eastern Paraguay. *Plant Ecology* 139:155-165.
Kellert, R. S. and Wilson, E. O. 1993. The biophilia hypothesis. Washington (DC), Island Press.

Kelly, C. K., Smith, H. B., Buckley, Y. M. *et al* 2001. Investigation in commonness and rarity: a comparative analysis of co-occurring, congeneric Mexican trees. *Eology Letter* 4:618-627.

Kent, M. and Coker, P. 1992. Vegetation Description and Analysis: A Practical Approach. John Wiley and Sons Ltd

KIFCON (Kenya Indigenous Forest Conservation Programme) 1994a. Forest Inventory Report No. 11 South Nandi and Ururu

KIFCON (Kenya Indigenous Forest Conservation Programme) 1994b. Forest Inventory Report No. 10 North Nandi, Kaptaroi and Taressia

Kershaw, K. A. 1964. Quantitative and dynamic ecology. Edward Arnold Publishing Co. Ltd, London.

Khan, M. L. and Tripathi, R. S. 1986. Tree regeneration in a disturbed sub-tropical wet hill forest of north-east India: effect of stump diameter and height on sprouting of Four tree species *Forest Ecology and Management* 17:199-209.

Khan M. L. and Tripathi, R. S. 1989. Effects of stump diameters, stump height and sprout density on sprout growth of four species in burnt and unburnt forest plots. *Acta Oecologica* 10:303-316

Kharkwal, G., Mehrotra, P., Rawat, Y. S. and Pangtey, Y. P. S. 2005. Phytodiversity and growth form in relation to altitudinal gradient in the Central Himalayan (Kumaun) region of India. *Current Science* 89:873-878

Kiama, D., Kiyiapi, J., 2001. Shade tolerance and regeneration of some tree species of a tropical rain forest in Western Kenya. *Plant Ecology* 156, 183–191.

Kigomo, B. N. 1987. Some observations on regeneration trials in the Kakamega and South Nandi natural forests, Kenya. *East African Agricultural and Forestry Journal* 52:184-195.

Kitajima, K. and Fenner, M. 2000. Ecology of seedling regeneration. In Fenner, M. (ed.) Seeds: the ecology of regeneration in plant communities 2nd Edition. CABI publishing

Knopf, F. L. 1992. Focusing conservation of a diverse wildlife resource. *Trans-national North American Wildlife and Natural Resource Conference* 57:241-242.

Köhl, M., Uuttera, J., Bachmann, P. and Päivinen, R. 1998. Assement and plannig for forest biodiversity: A European initiative. In: Dallmeier, F., Comiskey, J. A. (Eds). Forest Biodiversity Research, Monitoring and Modeling: Conceptual background and old world case studies. UNSECO UNESCO and Parthenon Publishing Group, Paris, pp. 357-363

Köhler P., Chave J., Riera B. and Huth A. 2003. Simulating the Long-term Response of Tropical Wet Forests to Fragmentation. *Ecosystems* 6:114- 128

Kosgey, D. K. 1998. Status and Habitat Choice of Turner's Eremomela *Eremomela turneri* (Van Someren 1920) in South Nandi forest Reserve, Kenya, Mphil thesis, Moi University, Eldoreth, Kenya.

Kostel-Hughes, F., Young, T. P. and Wehr, J. D. 2005. Effects of leaf litter depth on the emergence and seedling growth of deciduous forest tree species in relation to seed size. *Journal of the Torrey Botanical Society* 132:50–61.

Krebs, C. J. 1999. Ecological methodology. Addison-Welsey Publisher, Inc. California.

Kumaraswamy, S. and Udayakumar, M. 2011. Biodiversity banking: a strategic conservation Mechanism. *Biodiversity and Conservation* 20:1155-1165

Lalfakawma. 2010. Disturb and perish, conserve and flourish – regenerating forests: a review *Science vision* 10:3-7.

Lambrechts, C., Woodley, D., Litoroh, M. and Kamwara, P., 2007 Aerial Monitoring of Forest Boundaries. A Joint Kenyan Wildlife Service and Kenya Forest Service Programm. Vol. 1 UNEP, Kenya.

Laurance, W. F., Ferreira, L. V., Rankin-De Merona, J. M., Laurance, S. G., Hutchings, R.W. and Lovejoy, T. E. 1998. Effects of forest fragmentation on recruitment patterns in Amazonian tree communities. *Conservation Biology* 12:460-464

Laurance, W. F., Vasconcelos, H. L. and Lovejoy, T. E. 2000. Forest loss and fragmentation in the Amazon: implications for wildlife conservation. *Oryx* 34:39-45.

Laurance, W.F. and Bierregaard, R.O. (eds.) 1997. Tropical Forest Remnants: Ecology, Management, and Conservation of Fragmented Communities, University of Chicago Press, Chigaco, Illinois

Leach, M. K. and Givnish, T. J. 1996. Ecological determinants of species loss in remnant Prairies. *Science* 273:1555-15558.

Leak, W. B. 1965. The J-shaped probability distri bution. *Forest Science* 11:4055-419.

Legendre, P. and Legendre, L. 1998. Numerical Ecology. Second English edition, Elsevier Science B.V., Amsterdam.

Lehmann, J., Kinyangi, J. and Dawit, S. 2007. Organic matter stabilization in soil microaggregates: implications from spatial heterogeneity of organic carbon contents and carbon forms. *Biogeochemistry* 85:45–57

Leitner, W. and Turner, W. R. 2001. Measurement and analysis of biodiversity. In: Levin S. A. (ed.) Ecyclopedia of biodiversity, Vol 4. Academic Press, Princeton, pp 123-144

Letouzey, R. 1982. Manuel de Botanique Forestie're Afrique Tropicale. Tome 2 A.

Lieberman, D. and Lieberman, M. 1984. The causes and consequences of synchronous flushing in a dry tropical forest. *Biotropica* 16: 193-201.

Lindenmyer, D. B. and Fischer, J. 2006. Habitat fragmentation and landscape change: an ecological and conservation synthesis. Island Press, Washington.

Lloyd, M. and Ghelardi, R. J. 1964. A table for calculating the "equitability" component of species diversity; *Journal of Animal Ecology* 33:217–225

Lovett, J. C. and Wasser, S. K. (eds) 1993. Biogeography and ecology of the rainforests of East Africa. Cambridge University Press, Cambridge, Great Britain.

Lovett, J. C. 1998. Eastern Tropical Affrican Center of Endemism: a candidate for world heritage status? *Journal of East African Natura History* 87:359-366

Luke, Q. 2005. Annotated checklist of the plants of the Shimba Hills, Kwale district, Kenya. *Journal of East African Natural History* 94:5-120.

Lung, T. and Schaab, G. 2010. A comparative assessment of land cover dynamics of three protected forest areas in tropical eastern Africa. *Environmental Monitoring and Assessment* 161:531-548.

Lwanga, J. S. 2003. Localized tree mortality following the drought of 1999 at Ngogo, Kibale National Park. *African Journal of Ecology* 41:194–196.

MacArthur, R. H. and Wilson, E. O. 1967. The theory of island biogeography. Princeton University Press, Princeton.

MacArthur, R. H., 1957. On the relative abundance of bird species. Proceedings of the National Academy of Science, USA 43, 293–295.

Madoffe, S., Hertel, G. D., Rodgers, P., O'Connell, B., Killenga, R. 2006. Monitoring the health of selected eastern arc forests in Tanzania. *African Journal of Ecology* 44:171-177

Magurran, A. E. 1988. Ecological diversity and its measurement. Chapman and Hall, London.

Magurran, A. E. 2004. Measuring biological diversity. Blackwell Science Ltd.

Malcolm, J. R. 1994. Edge effects in central Amazonian forest fragments. *Ecology* 75: 2438-2445.

Mansergh, I. and Scotts, D. 1989. Habitat continuity and social organizations of the mountain pygmy possum restored by tunnel. *Journal of Wildlife Management* 53:701-707

Mao, C. X. and Colwell, R. K. 2005. Estimation of speciesrichness: Mixture models, the role of rare species, and inferential challenges. *Ecology* 86: 1143-1153

Mao, C. X., Colwell, R. K. and Chang, J. 2005. Estimating the species accumulation curve using mixtures. *Biometrics* 61:433-441

Marc, P. and Canard, A. 1997. Maintaining spider biodiversity in agro-ecosystems as a tool in pest control. *Agriculture, Ecosystems and Environment* 62:229-235

Margalef, D. R. 1958. Information theory in ecology. *General Systems* 3:36-71.

Matlack, G. R. 1993. Microenvironment variation within and among forest edge sites in the eastern United States. *Biological Conservation* 66: 185-194.

May, R.M., 1975. Patterns of species abundance and diversity In: Cody, M.L. and J. M. Diamond (eds.) Ecology and evolution of communities. Harvard University Press, Cambridge, MA, pp. 81–120

May, R.M. 1988. How many species on earth? *Science* 241:1441-1449.

McCune, B. and Grace, J. B. 2002. Analysis of Ecological Communities. MjM Software

McCune, B. and Grace, J. B. 2006. Multivariate Analysis of ecological Data Version 5.22, MjM software, Gleneden Beach, Oregon, USA.

McEvoy, P.M., McAdam, J. H. Mosquera-Losada, M. R. and Rigueiro-Rodri-Guez, A. 2006. Tree regeneration and sapling damage of pedunculate oak *Quercus robur* in a grazed forest in Galicia, NW Spain: a comparison of continuous and rotational grazing systems. *Agroforestry System* 66: 85-92.

McIntosh R P 1967 An index of diversity and the relation of certain concepts to diversity; *Ecology* 48 392–402

McLaren K.P. and McDonald M.A. 2003. Coppice regrowth in a disturbed tropical dry limestone forest in Jamaica. *Forest Ecology and Management* 180: 99-111.

McNaughton, S.J., 1983. Compensatory plant growth as a response to hervibory. *Oikos* 40: 329–336.

McNaughton, S.J., 1985. Ecology of a grazing ecosystem: the Serengueti. *Ecological Monographs* 55:259–294.

MEA (Millennium Ecosystem Assessment) 2005a. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

MEA (Millennium Ecosystem Assessment) 2005b. Ecosystems and Human Well-being: Current state and Trends. Island Press, Washington, DC.

Metcalfe, D. J., and P. J. Grubb. 1997. The responses to shade of seedlings of very small-seeded tree and shrub species from tropical rain forest in Singapore. *Functional Ecology* 11:215–221.

Meyer, H.A. 1952. Structure, growth and drain in balanced, uneven-aged forest. *Jouirnal of Forestry* 50:85-92.

Mielke, P. W. and Berry, K. J. 2001. Permutation Methods: a distance function approach. Springer, New York.

Miller, A.M., McArthur, C. and Smethurst, P. J. 2006. Characteristics of tree seedlings and neighbouring vegetation have an additive influence on browsing by generalist herbivores. *Forest Ecology and Management* 228:197-205.

Mitchell, N. 2004. The Exploitation and Disturbance History of Kakamega Forest, Western Kenya. In B Bleher, H Dalitz (Eds.), Bielefelder Ökologische Beiträge 20, BIOTA report no. 1. University of Bielefeld.

Mitchell, N., Lung, T.and Schaab, G. 2006. Tracing significant losses and limited gains in forest cover for the Kakamega-Nandi complex in western Kenya across 90 years by use of satellite imagery, aerial photography and maps. In: Proceedings of ISPRS (TC7) Mid-Term Symposium "Remote Sensing: From Pixels to Processes", 8-11 May, ITC Enschede, Netherlands

Molofsky, J. and Augspurger, C. K. 1992. The effect of leaf litter on early seedling establishment in a tropical forest. *Ecology* 73:68–77.

Moreno, C. E. and Halffter, G. 2000. Assessing the completeness of bat biodiversity inventories using species accumulation curves. *Journal of Applied Ecology* 37:149–158

Müller, F. G. 2002. Defining biological diversity and the agony of setting priorities. *International journal of environmental Studies* 59:399-413

Mueller-Dombois, D. and Ellenberg, H. 2002. Aims and Methods of Vegetation Ecology. Wiley, New York.

Mugo, F. and Ong, C. 2006. Lessons of eastern Africa's unsustainable charcoal trade. ICRAF Working Paper no. 20. World Agroforestry Centre. Nairobi, Kenya.

Murdoch, A. J. and Ellis, R. H. 2000. Dormancy, viability and longevity. In: Fenner, M. (ed.) Seeds: The Ecology of Regeneration in plant Communities. 2nd Edition. CABI publishing.pp183-214

Murphy, H.T., Metcalfe, D. J., Bradford, M. G., Ford, A. F., Galway, K. E., Sydes, T. A. and Westcott, D. J. 2008. Recruitment dynamics of invasive species in rainforest habitats following Cyclone Larry. *Austral Ecology* 33: 495–502

Mwavu, E. N. 2007. Human impact, plant communities, diversity and regeneration in Budongo Forest reserve, North-Western Uganda. PhD thesis, University of the Witwatersrand, Johannesburg.

Myers, N. (1988). Tropical deforestation and climate change. Environmental Conservation 15: 293-298.

Myers, N. 1994. Global biodiversity II: losses. In Meffe GK, Carroll CR, (Eds.) Principles of conservation biology. Sunderland (MA): Sinauer Associates. Pages 110-140

Nair, K.S.S., Sharma, J.K., Varma, R.V., 1996. In: Proceedings of the IUFRO Symposium on Impact of Diseases and Insect Pests in Tropical Forests, 23–26 November, 1993. Forestry Research Support Programme for Asia and the Pacific, Peechi, India.

Nambiro, E. 2000. Socio-economic baseline survey of households around Kakamega forest. Unbplished report for Kenya Indigenous Forest Conservation Progamme (KIFKON), Nairobi.

Naughton-Treves, L. and Weber, W.2001. Human dimensions of the African rain forest In. African Rain Forest Ecology and Conservation: an interdisciplinary perspective. Weber, W., White, L. J. T., Vedder, A., Naughton-Treves, L. (eds). Yale University P 30-43

Ndibi, B. P. and Kay, E. J., 1997. The regulatory framework for the exploitation of medicinal plants in Cameroon: the case of Prunus africana on Mount Cameroon. *Biodiversity and Conservation* 6:1409–1412.

Norton, D. A., Hobbs, R. J. and Atkins, L. 1995 Fragmentation, disturbance, and plant distribution – mistletoes in woodland remnants in the Western Australian wheatbelt. *Conservation Biology* 9: 426–438.

Noss, R. F. and Cooperrider, A. Y. 1994. Saving nature's legacy: protecting and restoring biodiversity. Island Press, Washington, D.C.

Nzilani, N. J., 2001. The status of Prunus africana (Syn. Pegium africanum Hook. F.) in Kakamega and South Nandi Forests, Kenya. *Discovery and Innovation* Special Issue 57–67.

Opperman, J. J. and Merenlender, A.M. 2000. Deer herbivory as an ecological constraint to restoration of degraded riparian corridors. *Restoration Ecology* 8:41-47.

Osborne P.L. 2000. Tropical ecosystems and ecological concepts. Cambridge University Press, UK.

Palmer, M. W. (1990). The estimation of species richness by extrapolation. *Ecology* 71, 1195–1198.

Palmer, M. W. 1993. Putting things in even better order: the advantages of Canonical Correspondence Analysis. *Ecology* 74:2215-2230.

Palmer, M. W. 1995. How should one count species? *Natural areas Journal* 15:124-135

Palmer, M. W., Earls, P. G., Hoagland, B. M., White, P. S., Wohlgemuth, T. 2002. Quantitative tools for perfecting species lists. *Environmetrics* 13:124-135.

Park, C. C. 1992. Tropical rainforests. Routledge, London.

Parker, I. M., Simberloff, D., Lonsdale, W.M., Goodell, K., Wonham, M. 1999. Impact: toward a framework for understanding the ecological effects of invaders. *Biological Invasions* 1:3-19.

Parthasarathy, N. 2001. Changes in forest composition and structure in three sites of tropical evergreen forest around Sengaltheri, Western Ghats. *Current Science* 80:389-393.

Pascaline, J., Charles, M., George, O. and Lukhoba, C. 2011. An inventory of medicinal plants that the people of Nandi use to treat malaria. *Journal of Animal and Plant Sciences* 9:1192- 1200.

Pate, J. S., Froend, R. H., Bowen, B. J., Hansen, A. and Kuo, J. 1990. Seedling Growth and Storage Characteristics of Seeder and Resprouter Species of Mediterranean-type Ecosystems of S.W. Australia. *Annals of Botany* 65: 585–601

Pearson, T. R. H., Burslem, D. F. R. P., Mullins, C. E. and Dalling, J. W. 2002. Germination ecology of neotropical pioneers: interacting effects of environmental conditions and seed size. *Ecology* 83:2798–2807

Peet, R. K. 1974. The measurement of species diversity. *Annual Review of Ecology and Systematics* 5:285-307

Peltorinne, Piritta 2004. The forest types of Kenya In: Pellikka, P., J. Ylhäisi and B. Clark (eds.) Taita Hills and Kenya, 2004 – seminar, reports and journal of a field excursion to Kenya. Expedition reports of the Department of Geography, University of Helsinki. Helsinki. pp 8-13.

Peter, J., Bellingham, P. J. and Sparrow A. D. 2000. Resprouting as a Life History Strategy in Woody Plant Communities. *Oikos* 89:409-416

Peters, C. M. 1996. The ecology and management of non-timber forest resources. World Bank Technical Paper number 322.

Petraitis, P.S., R.E. Latham and R.A. Niesenbaum, 1989. The maintenance of species diversity by disturbance. *Quarterly Review of Biology* 64:393–418.

Pielou, E. C. 1966. Species diversity and pattern diversity in the study of ecological succession. *Journal of Theoretical Biology* 10 370–383

Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J., Tran, Q., Saltman, T. and Cliff, B. 1997. Economic and Environmental Benefits of Biodiversity. *BioScience* 47:247-257.

Pimm, S. L. and Askins, R. A. 1995. Forest losses predict bird extinction in eastern North America. Proceedings of the National Academy of Sciences of the U.S.A. 92:9343-9347.

Pimm, S. L. and Raven, P., 2000. Extinction by numbers. *Nature* 403:843–845.

Pineda, E. and Halffter, G. 2004. Species diversity and habitat fragmentation: frogs in a tropical montane landscape in Mexico. *Biological Conservation* 117:499-508.

Plotkin, J. B. and Muller-Landau, H. C. 2002. Sampling the species composition of a landscape. *Ecology* 83:3344-3356.

Price, D. T., Zimmermann, N. E., van der Meer, P. J., Lexer, M. J., Leadley, P., Jorritsma, T. M., Schaber, J., Clark, D. F., Lasch, P., Mcnulty, S., Wu, J., and Smith, B. 2001. Regeneration in gap models: priority issues for studying forest responses to climate change. *Climate Change* 51:475-508.

Pueyo, Y., C.L. Alados and C. Ferrer-Benimeli, 2006. Is the analysis of plant community structure better than common species-diversity indices for assessing the effects of livestock grazing on a Mediterranean arid ecosystem? *Journal of Arid Environments* 64: 698–712.

Purvis, A. and Hector, A. 2000. Getting the measure of biodiversity. *Nature* 405:212-219.

Raghubanshi, A.S. and Tripath, A. 2009. Effect of disturbance, habitat fragmentation and alien invasive plants on floral diversity in dry tropical forests of Vindhyan highland:a review. *Tropical Ecology* 50:57-69.

Ramakrishnan, P. S. 1992. Shifting agriculture and sustainable development: an interdisciplinary study from north eastern India. Man and Biosphere, 10. UNESCO. The Parthenon Publishing Group, Paris.

Randall, C. K., Durea, M. L., Vince, S. W. and English R. J. 2005. Factors influencing stump sprouting by pondcypress (*Taxodium distichum var nutans* (Ait.) Sweet). *New Forests* 29:245-260

Raunkiaer, C. 1934. The life forms of plants and Statistical Plant Geography. Clarendon Press, Oxford.

Raven, P. H, Johnson, G. B. 1992. Biology. 3rd ed. St. Louis (MO): Mosby-Year book.

Rembold, K. 2011. Conservation status of the vascular plants in East African rain forests. PhD Dissertation, University of Koblenz-Landau.

Richards, P. W. 1996. The tropical rainforest: an ecological study. 2nd edition. Cambridge University Press, London.

Richardson, D. M., Pyešk, P., Rejmánek, M., Barbour, M. G., Panetta, F. D., West, C. J., 2000. Naturalization and invasion of alien plants: concepts and definitions. *Diversity Distribution* 6:93–107.

Riswan, S. S. 1979. Natural regeneration in lowland tropicalforest in East Kalimantan, Indonesia. Symposium on Forest Regeneration in S.E. Asia. Bogor, Indonesia. Biotrop special Publc. 13.

Rosenzweig, M. L. 1995. Species Diversity in Space and Time. Cambridge University Press, Cambridge.

Rouw, A. de. 1993. Regeneration by sprouting in slash and burn rice cultivation, Tai rainforest, Cote d'Ivoire. *Journal of Tropical Ecology* 9:387-408.

Sagar, R., Raghubanshi, A. S. and Singh, J. S. 2003. Tree species composition, dispersion and diversity of along disturbance gradient in dry tropical forest region of India. *Forest Ecology and Management* 186:61-71

Sala, O. E., Chapin, F. S., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L. F., Jackson, R. B., Kinzig, A., Leemans, R., Lodge, D. M., Mooney, H. A., Oesterheld, M., Poff, N. L., Sykes, M. T., Walker, B. H., Walker, M. and Wall, D. H. 2000. Global biodiversity scenarios for the year 2100. *Science* 287:1770-1774.

Sanders, H. L. 1968. Marine benthic diversity: a comparative study. *American Naturalist* 102:243–282.

Sands, B. A. and Abrams, M. D. 2009. Effects of stump diameter on sprout number and size for three Oak species in a Pennsylvania Clearcu. *Northern Journal of Applied Forestry* 26:122-125

Sanjit, L. and Bhatt, D. 2005. How relevant are the concepts of species diversity and species richness? *Journal of Bioscience* 30:557-560

Sarkar, S. 2002. Defining "Biodiversity''; Assessing Biodiversity. *The Monist* 85:131-155

Saunders, D. A., Hobbs, R. J. and Margules, C. R. 1991. Biological consequences of ecosystem fragmentation: a review. *Conservation Biology* 5:18-32.

Saxena, A. K. and Singh, J. S. 1984. Tree population structure of certain Himalyan forest association and implications concerning their future compostion. *Vegetatio* 58:61-69.

Sayer, J. A., Harcourt, and Collins, N. M. 1992. The Conservation Atlas of Tropical Forests: Africa. The World Conservation Union.

Scariot, A. 1999. Forest fragmentation effects on palm diversity in central Amazonia. *Journal of Ecology* 87:66-76

Schaab, G., Khayota, B., Eilu, G., Wägele, W. 2010. The BIOTA East Africa Atlas – Rainforest Change over Time. Karlsruhe University of Applied Sciences, Karlsruhe.

Schifter, H. and Cunningham-van Someren, G.R. 1998. The Avifauna of the North Nandi Forest, Kenya. *Annalen des Naturhistorischen Museums in Wien* 100 B: 425-479

Schilthuizen , M., Liew, T-S., Elahan, B.B., and Lackman-Ancrenaz, I. 2005. Effects of karst forest degradation on pulmontane and prosobranch land snail communities in Sabah, Malaysian Borneo. *Conservation Biology* 19:949-954

Schmitt, K. 1991. The vegetation of the Aberdare National Park Kenya, High Mountain Research, volume 8, Universitätsverlag Wagner, Innsbruck

Schooley, R. L and Branch, L. C. 2011. Habitat quality of source patches and connectivityin fragmented landscapes. *Biodiversity and Conservation* 20:1611-1623

Schupp, E. W. 1988. Factors affecting post-dispersal seed survival in a tropical forest *Oecologia* 76:525-530

Schwarz, C. F., Thor, E. C., and Elsner, G. H. 1976. Wildland Planning Glossary. USDA Forest Service General Technichal Report PSW-13, Pacific Southwest Forest and Range Experiment Station., Berkeley, California.

Shafroth P. B., Stromberg, J. C. and Patten, D. T. 2002. Riparian vegetation response to altered disturbance and stress regimes. *Ecological Application* 12:107-123.

Sharma, C. M., Suyal, S., Gairola, S. and Ghildiyal, S. K. 2009. Species richness and diversity along an altitudinal gradient in moist temperate forest of Garhwal Himalaya. *Journal of American Science* 5:119-128

Sharp, A. F. G. 1993. Kakamega Forest Rural Development Report. Unbplished report for Kenya Indigenous Forest Conservation Progamme (KIFKON), Nairobi.

Shen, T. J., Chao, A., and Lin, C. F. 2003. Predicting the number of new species in further taxonomic sampling. *Ecology* 84:798–804.

Simberloff, D. 1986. Are we on the verge of a mass extinction in tropical rain forests? In: Elliott, D. K. (ed.) Dynamics of Extinction. John Wiley and Sons, New York. pp 165-180.

Simpson, E. H. 1949. Measurement of diversity. *Nature* 163: 688.

Simpson, G. G. 1964. Species density of North American recent mammals. *Systematic Zoology* 13:57–73

Sjorgen-Gulave, P. 1994. Distribution and extinction patterns within a northern metapopulation of the pool frog Rana lessonae. *Ecology* 75:1357-1367.

Skole, D. and Tucker, C. 1993. Tropical deforestation and habitat fragmentation in the Amazon: satellite data from 1978 to 1988. *Science* 260: 1905-1910.

Soberon, J. M. and Llorente, J. B. 1993. The use of species accumulation functions for the prediction of species richness. *Conservation Biology* 7:480–488.

Soule, M. E., Alberts A. C., and Bolger, D. T. 1992. The effects of habitat fragmentation on chaparral plants and vertebrates. *Oikos* 63:39–47.

Souz, A. F. 2007 Ecological interpretation of multiple population size structure in trees: the case of *Araucaria angustifolia* in South America. Austral Ecology 32:524-533

Spellerberg, I. F. 1991. Monitoring ecological change. Cambridge University Press. Cambridge.

Spellerberg, I. F. and Hardes, S. R. 1992. Biological conservation. Cambridge University Press. Cambridge, England.

Stein, B. Kutner, L. S., Adams, J.S. 2000. Precious Heritage: the status of biodiversity in the United States. Oxford University Press, Oxford.

Stevens, G. C. 1989. The latitudinal gradient in geographical range: how so many species coexist in the tropics. *American Naturalist* 133, 240-256.

Stewart, K.M., 2003. The African cherry (*Prunus africana*): can lessons be learned from an over-exploited medicinal tree? *Journal of Ethnopharmacology* 89:3–13.

Stocker G.C. 1981. Regeneration of a north Queensland forest following felling and burning. *Biotropica*, 13: 86-92.

Sugihara, G., 1980. Minimal community structure: an explanation of species abundance patterns. *American Naturalist* 116, 770–787.

Sunderland, T.C.H., Tako, C.T., 1999. The Exploitation of Prunus africana on the Island of Bioko, Equatorial Guinea. Unpublished report for the People and Plants Initiative, WWF-Germany and the IUCN/SSC Medicinal Plant Specialist Group.

Svenning, J. C., and S. J. Wright. 2005. Seed limitation in a Panamanian forest. *Journal of Ecology* 93:853–862.

Swaine, M. D. and Whitmore, T. C. 1988. On the definition of ecological species groups in tropical rain forests. *Vegetatio* 75:81-86.

Tadesse, W. G. 2003. Vegetation of the Yayu forest in SW Ethiopia: impacts of human use and implications for in situ conservation of wild Coffea arabica L. populations. Cuvillier Verlag, Göttingen.

Takacs, D. 1996. The Idea of Biodiversity: Philosophies of Paradise. The Johns Hopkins University Press, Baltimore, MD.

Tamrat, B. 1993. Studies on remnant Afromontane forests on the central plateau of Shewa, Ethiopia. *Acta Phytogeographica Suecica* 79: 1-59.

ter Braak, C. J. F. and Smilauer, P. 2004. Canoco for Windows 4.53 Biometris- Plant Research International, Wageningen University and Research Centre, the Netherlands.

ter Braak, C. J. F. Ordination. 1995. In: Jongman, R. H. G., ter Braak, C. J. F. and van Torgeren, O. F. R. (eds.) Data Analysis in Community and Landscape Ecology. Cambrige University Press, Cambrige, UK, pp. 91-173

Tester, M., and C. Morris. 1987. The penetration of light through soil. *Plant, Cell and Environment* 10:281–286.

Tilman, D. 1982. Resource Competition and Community Structure.Princeton University Press, NJ.

Tilman, D. 2000. Causes, consequences and ethics of biodiversity. *Nature* 405: 208-211.

Troupin, G. 1988. Flore du Rwanda Spermatophytes. Volume IV

Tsingalia, M.H., 1989. Variation in seedling predation and herbivory in Prunus africana in the Kakamega Forest, Kenya. African Journal of Ecology 27: 207–217.

Turner, I. M. 1996. Species loss in fragments of tropical rainforest; a review of the evidence. *Journal of Applied Ecology* 33: 200-219.

Uhl, C., Clark, H. and Clark, K. 1982. Successional patterns associated with slash and burn agriculture in the Upper Rio Negro region of the Amazon Basin. *Biotropica* 14:249-254

Valladares, G., Salvo, A. and Cagnolo, L. 2006. Habitat fragmentation effects on trophic processes of insect-plant food webs. *Conservation Biology* 20:212-217.

van den Berg, L. J. L., Bullock, J. M., Clarke, R. T., Langston, R. H. W., Rose, R. J., 2001. Territory selection by the Dartford warbler (*Sylvia undata*) in Dorset, England: the role of vegetation type, habitat fragmentation and population size. *Biological Conservation* 101:217–28

van Tongeren, O. F. R. 1995. Cluster analysis. In: Jongman, R. H. G., Ter Braak, C. J. F. And van Torgeren, O. F. R. (Eds.) Data Analysis in Community and Landscape Ecology. Cambrige University Press, Cambrige, UK, pp. 174-212

Vazquez-Yanes, C., and A. Orozco-Segovia. 1990. Seed dormancy in the tropical rain forest. Pages 247–259 in K. S. Bawa and M. Hadley, editors. Reproductive ecology of tropical forest plants. UNESCO, Paris, France.

Vazquez-Yanes, C. and Orozco- Segovia, A. 1992. Effects of litter from a tropical rainforest on tree seed germination and establishment under controlled conditions. *Tree Physiology* 11:39 -400

Vellend, M. 2001. Do commonly used indices of β-diversity measure species turnover? *Journal of Vegetation Science* 12:545-552

Vesk, P. A., Warton, D. I. and Westoby, M. 2004. Sprouting by semi-arid plants: testing a dichotomy and predictive traits. *Oikos* 107:72-89.

Wade, T. G., Riitters, K.H., Wickham, J. D., and Jones, K. B. 2006. Distribution and causes of global forest fragmentation. *Conservation Ecology* 7(2): URL: http://www.consecol.org/vol7/iss2/art7, accessed on 12.07.2010

Walker, B. H. Biodiversity and ecological redundancy. *Conservation Biology* 6: 18-23.

Walther, B. A. and Martin, J. L. 2001. Species richness estimation of bird communities: how to control for sampling effort? *Ibis* 143:413-419

Walther, B. A. and Morands, J. L. 1998. Comparative performance of species richness estimation methods. *Parasitolgy* 116:395-405.

Waring, R.H., 1987. Characteristics of trees predisposed to die. *Bioscience* 37:569–574.

Wass, P. 1995. Kenya's Indigenous Forests: Status, Management and Conservation. IUCN, Nairobi, Kenya.

Wei, S., Li, L. Walther, B. A., Ye, W., Haung, Z. Cao, H., Lian, J., Wang, Z., Chen, Y. 2010. Comparative performance of species-richness estimators using data from a subtropical forest tree community. *Ecological Research* 25:93-101.

Weigel, D. R. and Peng, C-Y. J. 2002. Predicting stump sprouting and competitive success of five Oak species in southern Indiana. *Canadian Journal of Forestry Research* 32:703-712.

Wenny, D. G. 2000. Seed dispersal, seed predation, and seedling recruitment of a neotropical montane tree. *Ecological Monographs* 70:331–351.

White, F. 1983. The Vegetation of Africa. A descriptive memoir to accompany the UNESCO/AETFAT/ UNESCO vegetation map of Africa. UNESCO.

Whitemore, T. C. 1982. Tropical rain forests of the Far East. 2nd edition. Clarendon Press, Oxford.

Whitemore, T. C. 1997. Tropical forest disturbance, disappearance and species loss. In: Laurence, W. L. and R. O. Bierregaard Jr. (eds). Tropical forest remnants. University of Chicago Press, Chicago. pp 1-3.

Whitemore, T. C. 2008. An Introduction to Tropical Forests, second edition. Oxford University Press, New York, United States.

Whitmore, T. C. and Sayer, J. A. 1992. Deforestation and species extiniction in tropical moist forests. Chapman and Hall, London.

Whittaker R. H. 1972. Evolution and measurement of species diversity. *Taxon* 21:213-251.

Whittaker, R. H. 1975. Communities and ecosystems. New York: Macmillan.

Wilcove, D.S., C.H. McLellan and A.P. Dobson, 1986. Habitat fragmentation in the temperate zone. In: Soule, M.E. and M.A. Sunderland (eds.) Conservation Biology. Sinauer. pp 237–56

Wilkinson, G. R. and Nielsen, W.A. 1995. Implications of early browsing damage on the long term productivity of eucalypt forests. *Forest Ecology and Management* 74:117-124.

Wilson, M. V. and Shmida, A. 1984. Measuring beta diversity with presence-absence data. *Journal Ecology*. 72:1055-1064.

Wilson, E. O. 1994. Biodiversity: challenge, science, opportunity. *American Zoologist* 34:5-11.

Wilson, E. O.1988. The current status of tropical biodiversity. In: Wilson, E. O. (ed.) Biodiversity. National Academy Press. Washington. pp 1-18

Winn, A. A. and Warener, P. A. 1987. Regulation of seed yields within and among populations of *Prunella vulgaris*. *Ecology* 68:1224-1233.

Wolda, H. 1981. Similarity indices, sample size and diversity. *Oecologia* 50:296-302.

Wolda, H. 1983. Diversity, diversity indices and tropical cocktoaches. *Oecologia* 58:290-298.

Yahner, R. H. 1988. Changes in wildlife communities near edges. *Conservation Biology* 2: 333-339.

Yates, C. J., Norton, D. A. and Hobbs, R. J. 2000. Grazing effects on plant cover, soil and microclimate in fragmented woodlands in south-western Australia: implications for restoration. *Austral Ecology* 25:36–47.

Yeshitela, K. 2008. Effects of anthropogenic disturbance on the diversity of foliicolous lichens in tropical rainforest of East Africa: Godere (Ethiopia), Budongo (Uganda) and Kakamega (Kenya). Cuvillier Verlag, Göttingen.

You, M., Vasseur, L., Régnière, J. and Zheng, Y. 2009. The Three Dimensions of Species Diversity. *The Open Conservation Biology Journal* 3: 82-88

Young, T. P. 1984. Kenya's indigenous forests: Status , threats and prospects for conservation action. IUCN/WWF

Zimmerman, J. K., Everham III, E. M., Waide, R. B., Lodge, D. J., Taylor, C. M., and Brokaw, N.V.L. 1994. Responses of tree species to hurricane winds in subtropical wet forest in Puerto Rico: implications for tropical tree life histories. *Journal of Ecology*, 82: 911-922

Appendix

List of vascular plant species (alphabetic order) recorded in Nandi forests. N= recorded only in North Nandi, S=recorded only in South Nandi and SN = recorded in both forests

Species Name	Family	Growth form	Forest
Abutilon longicuspe A. Rich.	Malvaceae	Shrub	N
Acacia hockii De Wild.	Fabaceae	Tree	N
Acacia montigena Brenan and Exell	Fabaceae	Climber	S
Acalypha ornata A.Rich	Euphorbiaceae	Shrub	N
Acanthopale pubescens (Engl.) C. B. Cl.	Acanthaceae	Shrub	SN
Acanthus eminens C. B. Cl.	Acanthaceae	Shrub	SN
Achyranthes aspera L.	Chenopodiaceae	Herb	SN
Adenia bequaertii Robyns and Lawalree	Passifloraceae	Climber	SN
Adenia schweinfurthii Engl.	Passifloraceae	Climber	N
Adenostemma caffrum DC.	Asteraceae	Herb	SN
Aframomum zambesiacum (Baker) K. Schum.	Zingibiraceae	Herb	SN
Alangium chinensee (Lour.) Harms	Cornaceae	Tree	S
Albizia gummifera (JF Gmel.) C. A. Sm.	Fabaceae	Tree	N
Alchemilla kivuensis Engl.	Rosaceae	Herb	N
Alchornea hirtella Benth.	Euphorbiaceae	Shrub	S
Allophylus abyssinicus (Hochst.) Radlk.	Sapindaceae	Shrub	SN
Allophylus africanus P.Beauv.	Sapindaceae	Shrub	SN
Amphicarpa africana (Hook. f.) Harms	Fabaceae	Climber	N
Aningeria altissima (A.Chév.) Aubrév. and Pellegr.	Sapotaceae	Tree	S
Anthocleista grandiflora Gilg	Loganiaceae	Tree	S
Anthrophyum mannianum Hook.	Vittaraceae	Epiphyte	S
Apodytes dimidiata Arn.	Icacinaceae	Tree	N
Ardisiandra wettsteinii R. Wagner	Primulaceae	Herb	S
Artabotrys likimensis De Wild.	Annonaceae	Climber	S
Asparagus africanus Lam	Asparagaceae	Climber	N
Asparagus falcatus L.	Asparagaceae	Climber	N
Asplenium aethiopicum (Burm. f.) Bech.	Aspleniaceae	Herb	N
Asplenium ceii Pic. Serm.	Aspleniaceae	Herb	SN
Asplenium elliottii C. H. Wright	Aspleniaceae	Herb	S
Asplenium hypomelas Kuhn	Aspleniaceae	Herb	S
Asplenium linckii Kuhn	Aspleniaceae	Herb	N
Asplenium megalura Hieron.	Aspleniaceae	Epiphyte	S
Asplenium protensum Schrad.	Aspleniaceae	Herb	S
Asplenium sandersonii Hook.	Aspleniaceae	Epiphyte	SN
Asplenium sp	Aspleniaceae	Herb	S
Asplenium theciferum (Kunth) Mett.	Aspleniaceae	Epiphyte	SN
Athyrium scandicinum (Willd.) Presl	Woodsiaceae	Herb	S
Basella alba L.	Basellaceae	Climber	S
Bequaertiodendron oblanceolatum (S.Moore) Heine and J.H.Hemsl.	Sapotaceae	Tree	S

Bersama abyssinica Fres.	Melianthaceae	Tree	SN
Bidens pilosa L.	Asteraceae	Herb	S
Blechnun attenuatum (Sw.) Mett.	Blechnaceae	Herb	S
Blotiella stipitata (Alston) Faden	Dennstaedtiaceaea	Herb	N
Brillantaisia sp	Acanthaceae	Herb	S
Bulbophyllum josephii (Kuntze) Summerh.	Orchidaceae	Epiphyte	S
Canarina abyssinica Engl.	Campanulaceae	Climber	S
Cardamine africana L.	Brassicaceae	Herb	N
Carpha angustissima Cherm.	Cyperaceae	Herb	S
Casearia battiscombei R. E. Fries	Salicaceae	Tree	N
Cassipourea ruwensorensis (Engl.) Alston	Rhizophoraceae	Tree	SN
Celosia anthelminthica Aschers.	Chenopodiaceae	Herb	S
Celtis africana Burm. f.	Ulmaceae	Tree	SN
Celtis durandii Engl.	Ulmaceae	Tree	SN
Chaetacme aristata Planch.	Ulmaceae	Tree	S
Chassalia subochreata (De Wild.) Robyns	Rubiaceae	Shrub	S
Chionanthus mildbraedii (Gilg and Schellenb.) Strean	Oleaceae	Shrub	N
Chlorophytum silvaticum Dammer (C. bakeri Poelln)	Asparagaceae	Herb	N
Chlorophytum zavattarii (Cuf.) Nordal	Asparagaceae	Herb	N
Chrysophyllum albidum G. Don	Sapotaceae	Tree	S
Chrysophyllum viridifolium Wood and Franks	Sapotaceae	Tree	S
Cissus rotundifolia (Forssk.) Vahl.	Vitaceae	Climber	S
Clausena anisata (Willd.) Hook.f. ex Benth.	Rutaceae	Tree	S
Clematis brachiata Thunb.	Ranunculaceae	Climber	S
Clerodendrum johnstonii Oliv.	Verbenacea	Climber	SN
Cnestis mildbraedii Gilg.	Connaraceae	Tree	S
Coffea eugenioides S, Moore	Rubiaceae	Shrub	SN
Combretum paniculata Vent	Combretaceae	Climber	S
Commelina eckloniana Kunth	Commelinaceae	Herb	S
Commelina latifolia A. Roch.	Commelinaceae	Herb	N
Connarus longistipitatus Gilg.	Connaraceae	Climber	S
Craibia brownii Dunn	Fabaceae	Tree	S
Crassocephalum montuosum (S. Moore) MilneRedh	Asteraceae	Herb	SN
Crassocephalum rubens (Jacq.) S.Moore	Asteraceae	Herb	S
Crassocephalum vitellinum (Benth.) S. More	Asteraceae	Herb	S
Cribbia brachyceras (Summerh.) Senghas	Orchidaceae	Epiphyte	SN
Crotalaria mauensis Bak. f.	Fabaceae	Shrub	N
Croton machrostachyus Del.	Euphorbiaceae	Tree	N
Croton megalocarpus Hutch	Euphorbiaceae	Tree	S
Cucumis ficifolius A. Rich.	Cucurbitaceae	Herb	S
Culcasia falcifolia Engl.	Araceae	Climber	SN
Cussonia holstii Engl.	Araliaceae	Tree	N

Cyathea manniana Hook.	Cyatheaceae	Tree	S
Cyclosorus sp	Thelypteridaceae	Herb	S
Cynoglossum lanceolatum Forsk.	Boraginaceae	Herb	N
Cyphomandra betacea (Cav.) Miers	Solanaceae	Tree	S
Cyphostemma cyphopetalum (Fresen.) Wild and Drum.	Vitaceae	Climber	N
Cyphostemma kilimandscharica (Gilg)	Vitaceae	Climber	S
Cyrtorchis arcuata (Lindl.) Schltr.	Orchidaceae	Epiphyte	N
Dalbergia lactea Vatke	Fabaceae	Climber	SN
Deinbollia kilimandscharica Taub	Sapindaceae	Tree	SN
Desmodium adscendens (Sw.) DC.	Fabaceae	Herb	S
Desmodium repandum (Vahl) DC.	Fabaceae	Herb	N
Dichondra repens J. R. and G. Forst	Convolvulaceae	Herb	N
Dichrocephala integrifolia O. Kuntze	Asteraceae	Herb	SN
Didymochlaena truncatula (SW.) J. Sm.	Dryopteridaceae	Herb	S
Didymodoxa caffra (Thunb.) Friis and Wilmot-Dear	Urticaceae	Herb	S
Dioscorea odoratissima Pax	Dioscoreaceae	Climber	S
Diospyros abyssinica (Hiern) F. White	Ebenaceae	Tree	SN
Disperis aphylla Kraenzl.	Orchidaceae	Herb	N
Dombeya rotundifolia (Hochst.) Planch	Malvaceae	Tree	N
Dombeya torrida (J. F. Gmel.) B. Bamps	Malvaceae	Tree	S
Dorstenia brownii Rendle	Moraceae	Herb	N
Doryopteris kirkii (Hook.) Alston	Pteridaceae	Herb	N
Dovyalis macrocalyx (Oliv.) Warb.	Salicaceae	Shrub	N
Dracaena fragrans (L.) Ker-Gawl.	Asparagaceae	Shrub	S
Dracaena laxissima Engl.	Asparagaceae	Shrub	SN
Dracaena steudneri Engl.	Asparagaceae	Tree	S
Drymaria cordata (L.) Roem. and Schultes	Caryophyllaceae	Herb	S
Drynaria vokensii Hieron.	Polypodiaceae	Epiphyte	SN
Dryopteris pentheri (Krasser) C. Chr.	Dryopteridaceae	Herb	N
Drypetes gerrardii Hutch.	Euphorbiaceae	Tree	S
Ehretia cymosa Thonn.	Boraginaceae	Herb	SN
Ekebergia capensis Sparrm.	Meliaceae	Tree	N
Elatostema monticola Hook. f.	Urticaceae	Herb	S
Embelia schimperi Vatke	Myrsinaceae	Climber	N
Ensete ventricosum (Welw.) Cheesm.	Musaceae	Tree	N
Erigeron floribundum (Kunth) Sch.Bip.	Asteraceae	Herb	S
Erythrococca fischeri Pax.	Euphorbiaceae	Tree	N
Erythrococca trichogyne (Müll. Arg.) Prain	Euphorbiaceae	Shrub	N
Eulophia galeoloides Kraenzl.	Orchidaceae	Herb	S
Eulophia streptopetala Lindl.	Orchidaceae	Herb	N
Euphorbia schimperiana Scheele	Euphorbiaceae	Climber	N
Ficus asperifolia Miq.	Moraceae	Shrub	S
Ficus exasperata Vahl.	Moraceae	Tree	N

Ficus lutea Vahl.	Moraceae	Tree	S
Ficus sur Forssk.	Moraceae	Tree	S
Ficus thonningii Bl.	Moraceae	Tree	N
Ficus tremula Warb.	Moraceae	Climber	N
Ficus vasta Forssk.	Moraceae	Tree	S
Fuerstia africana T. C. E. Af.	Lamiaceae	Shrub	S
Galinsoga parviflora Cav	Asteraceae	Herb	SN
Gardenia volkensii K. Schum.	Rubiaceae	Shrub	S
Gloriosa minor Rendle	Colchicaceae	Herb	S
Gloriosa superba L.	Colchicaceae	Herb	N
Gongronema angolense (N. E. Br.) Bullock	Apocynaceae	Climber	N
Gouania longispicata Engl.	Rhamnaceae	Climber	SN
Grewia similis K. Schum.	Malvaceae	Climber	N
Gutenbergia rueppellii Sch. Bip.	Asteraceae	Herb	N
Gynura pseudochina (L.) Dc.	Asteraceae	Herb	S
Habenaria malacophylla Reichb. f.	Orchidaceae	Herb	SN
Harungana madagascariensis Poir.	Clusiaceae	Tree	S
Heinsenia diervilleoides K. Schum.	Rubiaceae	Tree	SN
Helichrysum brownei S. Moore	Asteraceae	Shrub	S
Hibiscus calyphyllus Cav.	Malvaceae	Shrub	N
Hibiscus greenwayi Bak. f.	Malvaceae	Shrub	S
Hippocratea africana (Willd.) Loes	Celastraceae	Climber	SN
Huperzia dacrydioides (Bak.) Pic. Serm.	Lycopodiaceae	Epiphyte	S
Hydrocotyle sibthorpioides Lam.	Apiaceae	Herb	N
Illigera pentaphylla Welw.	Hernandiaceae	Climber	N
Impatiens burtonii Hook. f.	Balsaminaceae	Herb	S
Impatiens cf niamniamensis Gilg.	Balsaminaceae	Herb	S
Impatiens hochstetteri Warb.	Balsaminaceae	Herb	SN
Impatiens meruensis Gilg.	Balsaminaceae	Herb	S
Impatiens sodenii Engl.	Balsaminaceae	Herb	N
Ipomoea tenuirostris Choisy	Convolvulaceae	Climber	S
Ipomoea wightii (Wall.) Choisy	Convolvulaceae	Herb	N
Jasminum floribundum Fres.	Oleaceae	Climber	N
Jasminum fluminense Vell.	Oleaceae	Climber	S
Justicia betonica L.	Acanthaceae	Climber	S
Justicia cordata (Nees) T. Anders.	Acanthaceae	Shrub	S
Justicia extensa T. Anders	Acanthaceae	Shrub	S
Justicia striata (Kl.) Bullock	Acanthaceae	Herb	SN
Kalanchoe densiflora Rolfe	Crassulaceae	Herb	SN
Keetia gueinzii (Sond.) Bridson	Rubiaceae	Climber	SN
Kigelia africana (Lam.) Benth.	Bignoniaceae	Tree	SN
Kyllinga chrysantha K.Schum.	Cyperaceae	Herb	S
Lactuca glandulifera Hook. f.	Asteraceae	Herb	S
Lagenaria abyssinica (Hook. f.) C. Jeffrey	Cucurbitaceae	Climber	S
Laggera elatior R. E. Fries	Asteraceae	Herb	SN

Laggera pterodonta Sch. Bip.	Asteraceae	Herb	S
Landolphia buchananii (Hall. f.) Stapf.	Sapotaceae	Climber	SN
Laportea alatipes Hook. f.	Urticaceae	Herb	SN
Lepidotrichilia volkensii (Gürke) Leroy	Meliaceae	Tree	N
Leptactina platyphylla (Hiern) Wernh.	Rubiaceae	Tree	S
Leucas bracteosa Guerke	Lamiaceae	Shrub	S
Leucas masaiensis Oliv.	Lamiaceae	Herb	N
Lippia kituiensis Vatke	Lamiaceae	Shrub	N
Lobelia gibberoa Hemsl.	Campanulaceae	Tree	SN
Loxogramme abyssinica (Bak.) M. G. Price	Polypodiaceae	Epiphyte	SN
Ludwigia stolonifera (Guill and Perr.) Raven	Onagraceae	Herb	N
Macaranga kilimandscharica Pax.	Euphorbiaceae	Tree	N
Macrorungia pubinervia (T. Anders) C. B.Cl.	Acanthaceae	Shrub	SN
Marattia fraxinea Sm.	Marrattiaceae	Herb	S
Margaritaria discoidea (Baill.) Webster	Euphorbiaceae	Tree	S
Mariscus tomaiophyllus (K.Schum.) C.B.Clarke	Cyperaceae	Herb	N
Markhamia lutea (Benth.) K. Schum.	Bignoniaceae	Tree	S
Maytenus heterophylla (Eckl. and Zeyh.) Robson	Celastraceae	Tree	SN
Meyna tetraphylla (Hiern) Robyns	Rubiaceae	Tree	SN
Microglossa pyrifolia (Lam.) O. Kunte	Asteraceae	Shrub	S
Microglossa pyrrhopappa (A. Rich.)	Asteraceae	Herb	S
Mikania cordata (Burm. f.) B. L. Robinson	Asteraceae	Climber	SN
Mikaniopsis usambarensis (Muschl.) Milne-Redh.	Asteraceae	Climber	S
Mimulopsis arborescens C. B. Cl.	Acanthaceae	Shrub	S
Momordica foetida Schumach.	Cucurbitaceae	Climber	SN
Momordica friesiorum (Harms) C. Jeffrey	Cucurbitaceae	Climber	SN
Mondia whytei (Hook. f.) Skeels	Apocynaceae	Climber	SN
Morus mesozugia Stapf.	Moraceae	Tree	S
Mystroxylon aethiopicum (Thunb.) Loes.	Celastraceae	Shrub	S
Neoboutonia macrocalyx Pax	Euphorbiaceae	Tree	N
Nuxia congesta Fres.	Loganiaceae	Tree	N
Ochna insculpta Sleumer	Ochnaceae	Tree	S
Ocimum lamiifolium Benth.	Lamiaceae	Shrub	N
Olea capensis L.	Oleaceae	Tree	N
Oncoba spinosa Forssk.	Salicaceae	Tree	N
Oplismenus hirtellus (L.) P.Beauv.	Poaceae	Herb	S
Oreosyce africana Hook. f.	Cucurbitaceae	Climber	S
Orobanche minor Smith	Orobanchaceae	Herb	S
Ouratea hiernii (van Tiegh.) Exell	Ochnaceae	Tree	N
Oxalis obliquifolia A. Rich.	Oxalidaceae	Herb	N
Oxyanthus speciosus DC.	Rubiaceae	Tree	SN
Passiflora edulis Sims	Passifloraceae	Climber	S
Passiflora foetida L.	Passifloraceae	Climber	S

Pavetta abyssinica Fres.	Rubiaceae	Shrub	SN
Pavonia patens (Andr.) Chiov.	Malvaceae	Shrub	S
Pavonia propinqua Garcke	Malvaceae	Shrub	N
Pavonia urens Cav.	Malvaceae	Shrub	N
Pellaea adiantoides (Willd.) J. Sm.	Adiantaceae	Herb	S
Peperomia abyssinica Miq.	Piperaceae	Epiphyte	S
Peperomia retusa (L. f.) A. Dietr.	Piperaceae	Epiphyte	SN
Peperomia tetraphylla (Forst.) Hook. and Arn.	Piperaceae	Epiphyte	SN
Persea americana Mill.	Lauraceae	Tree	S
Peucedanum elgonense H. Wolff.	Apiaceae	Herb	N
Phyllanthus fischeri Pax	Euphorbiaceae	Shrub	N
Phyllanthus nummulariifolius Poir	Euphorbiaceae	Shrub	S
Physalis minima L.	Solanaceae	Herb	S
Physalis peruviana L.	Solanaceae	Herb	S
Phytolacca dodecandra L'Hért.	Phytolaccaceae	Climber	S
Pilea johnstonii Oliv.	Urticaceae	Herb	SN
Pilea rivularis Wedd.	Urticaceae	Herb	SN
Piper capense L.	Piperaceae	Shrub	SN
Piper umbellatum L.	Piperaceae	Shrub	S
Plantago palmata Hook. f.	Plantaginaceae	Herb	N
Plectranthus luteus Gürke	Lamiaceae	Shrub	S
Podocarpus latifolius (Thunb.) Mirb.	Podocarpaceae	Tree	S
Polygonum salcifolium Willd.	Polygonaceae	Herb	N
Polyscias fulva (Hiern) Harms	Araliaceae	Tree	SN
Polystachya disiformis P.J.Cribb	Orchidaceae	Herb	N
Polystachya simplex Rendle	Orchidaceae	Herb	N
Polystachya steudneri Reichb. f.	Orchidaceae	Epiphyte	S
Prunus africana (Hook. f.) Kalkm.	Rosaceae	Tree	SN
Pseudechinolaena polystachya (Humb., Bonpl. and Kunth) Stapf	Poaceae	Herb	N
Pseuderanthemum ludovicanum (Büttner) Lindau	Acanthaceae	Shrub	S
Psidium guajava L.	Myrtaceae	Tree	S
Psychotria kirkii Hiern	Rubiaceae	Shrub	S
Psychotria mahonii C. Wright	Rubiaceae	Tree	S
Psychotria peduncularis (Salisb.) Steyerm.	Rubiaceae	Shrub	SN
Pteris auquieri Pic. Ser.	Pteridaceae	Herb	N
Pteris preussii Hieron.	Pteridaceae	Herb	S
Pteris pteridioides (Hook.) Ballard	Pteridaceae	Herb	N
Pteris sp1	Pteridaceae	Herb	S
Pteris sp2	Pteridaceae	Herb	S
Pteris sp3	Pteridaceae	Herb	S
Pterolobium stellatum (Forssk.) Brenan	Fabaceae	Shrub	N
Ranunculus multifidus Forssk.	Ranunculaceae	Herb	N
Rawsonia lucida Harv. and Sond	Salicaceae	Tree	S

Rhipsalis baccifera (J.S.Muell.) Stearn	Cactaceae	Epiphyte	S
Ritchiea albersi Gilg.	Capparaceae	Tree	SN
Rothmannia urcelliformis (Hiern) Robyns	Rubiaceae	Shrub	S
Rubus scheffleri Engl.	Rosaceae	Shrub	SN
Rubus steudneri Schweinf.	Rosaceae	Shrub	N
Rutidea orientalis Bridson	Rubiaceae	Climber	SN
Rytigynia acuminatissima (K. Schum.) Robyns	Rubiaceae	Shrub	SN
Rytigynia bugoyensis (K. Krause) Verdc.	Rubiaceae	Shrub	S
Salacia cerasifera Oliv.	Celastraceae	Climber	S
Salacia sp	Celastraceae	Climber	N
Sanicula elata D. Don	Apiaceae	Herb	SN
Sapium ellipticum (Krauss) Pax	Euphorbiaceae	Tree	N
Scadoxus multiflorus (Martyn) Raf.	Amaryllidaceae	Herb	N
Schefflera volkensii (Engl.) Harms	Araliaceae	Tree	S
Scleria distans Poir.	Cyperaceae	Herb	N
Scutia myrtina (Burm. f.) Kurz	Rhamnaceae	Climber	SN
Secamone punctulata Decne.	Apocynaceae	Climber	SN
Sericostachys scandens Gilg and Lopr.	Chenopodiaceae	Climber	S
Setaria homonyma (Steud.) Chiov.	Poaceae	Herb	S
Setaria megaphylla (Steud.) T.Durand and Schinz	Poaceae	Herb	SN
Sida rhombifolia L.	Malvaceae	Shrub	N
Simlax aspera L.	Smilacaceae	Climber	SN
Solanecio mannii (Hook. f.) C. Jeffrey	Asteraceae	Tree	SN
Solanum aculeastrum Dunal	Solanaceae	Shrub	SN
Solanum hastifolium Dunal	Solanaceae	Shrub	N
Solanum mauense Bitter	Solanaceae	Shrub	SN
Solanum mauritianum Scop.	Solanaceae	Shrub	SN
Solanum nigrum L.	Solanaceae	Herb	SN
Solanum terminale Forssk.	Solanaceae	Shrub	SN
Spermacoce princeae (K. Schum.) Verdc.	Rubiaceae	Herb	N
Sphaeranthus suaveolens Forsk.) DC.	Asteraceae	Herb	N
Spilanthes mauritiana (Pers.) DC.	Asteraceae	Herb	N
Stellaria sennii Hook. f.	Caryophyllaceae	Herb	S
Stephania abyssinica (Dillon and A. Rich.) Walp.	Menispermaceae	Climber	N
Strombosia scheffleri Engl.	Strombosiaceae	Tree	S
Syzygium guineense (Willd.) DC.	Myrtaceae	Tree	SN
Tabernaemontana stapfiana Britte	Apocynaceae	Tree	SN
Tagetes minuta L.	Asteraceae	Herb	S
Tarenna pavettoides (Harv.) Sim.	Rubiaceae	Shrub	S
Teclea nobilis Del.	Rutaceae	Tree	SN
Tectaria gemmifera (Fee) Alston	Dryopteridaceae	Herb	S
Thalictrum rhynchocarpum Quart.-Dill. and A.Rich.	Ranunculaceae	Herb	N

Thunbergia alata Sims	Acanthaceae	Climber	SN
Tiliacora funifera (Miers) Oliv.	Menispermaceae	Climber	S
Tinospora caffra (Miers) Troupin	Menispermaceae	Climber	N
Toddalia asiatica (L.) Lam.	Rutaceae	Climber	SN
Tragia brevipes Pax	Euphorbiaceae	Climber	N
Trema orientalis (L.) Bl.	Ulmaceae	Tree	S
Trichilia emetica Vahl.	Meliaceae	Tree	S
Trichomanes melanotrichum Schltdl.	Hymenophyllaceae	Epiphyte	N
Tridactyle furcistipes Summerh.	Orchidaceae	Epiphyte	S
Tridactyle tridentata (Harv.) Schltr.	Orchidaceae	Epiphyte	N
Trilepisium madagascariense DC.	Moraceae	Tree	S
Trimeria grandifolia (Hochst.) Warb	Salicaceae	Tree	N
Triumfetta brachyceras K. Schum.	Malvaceae	Shrub	SN
Triumfetta rhomboidea Jacq.	Malvaceae	Shrub	S
Turraea holstii Gürke	Meliaceae	Tree	N
Uncaria africana G. Don	Rubiaceae	Climber	S
Urera hypselodendron (A. Rich.) Wedd.	Urticaceae	Climber	SN
Vangueria apiculata K. Schum.	Rubiaceae	Tree	SN
Vangueria madagascariensis Gmel.	Rubiaceae	Tree	SN
Vernonia auriculifera Hiern	Asteraceae	Shrub	SN
Vernonia biafrae Oliv. and Hiern	Asteraceae	Shrub	S
Vittaria volkensii Hieron	Vittaraceae	Herb	S
Xymalos monospora (Harv.) Warb.	Monimiaceae	Tree	S
Zanthoxylum gilletti (De Wild.) Waterm.	Rutaceae	Tree	S

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WORK EXPERIENCE

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PUBLICATIONS

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Admasu, S., **Adane, G.** and Taye, K. 2002. Characterization of the Farming System of Metu Woreda. Research Report No. 45. EARO, Addis Ababa.

DECLARATION

I declare that this dissertation is my independent original work, it or part of it has not been presented in any other University and that all sources of materials used for the dissertation have been duly acknowledged.

Name: Adane Girma Gebreselasse

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Date of submission: ______________________________