A study on Canopy Gap Regeneration at Gera Forest of Jimma Zone, Oromia Regional State, Ethiopia

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A Study on Canopy Gap Regeneration at Gera Forest of Jimma Zone Oromia Regional State, Ethiopia.

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Abstract

Forest is a dynamic place where changes occur continuously and these changes bring about different structural changes in the forest stand. Change in the recruitment and forest community depends on the dynamics and formation of canopy gaps. Canopy gaps and their dynamics in regeneration were investigated in Gera Forest of Jimma Zone Oromia Regional State, located western of Ethiopia at an altitude range of 1600 – 2400 meter above sea level. In the Forest the main types of natural disturbance occurred through uprooting of trees and broken branch or crown. These causes are directly related with natural causes like thunder and wind. Prunus africana was found to be most affected in the disturbance, forming six gaps in the Forest. Including Prunus africana 13 species were found to be gap formers. The mean DBH of the gap formers is 48.33 cm^2 and mean of the gaps formed became 190.83. Twenty eight species were investigated as gap filler species in the Forest. Among the gap fillers Millettia ferruginea was found to be in more gap areas than other species. Croton macrostachyus was the most dominant species that occurred in higher number (i.e.118 individual/hectare) in the gap areas. The negative correlation between species density and gap area shows that both factors have low effect on gap regeneration and recruitment in Gera Forest. The replacement probability in the Forest is weak except Millettia ferruginea, Syzygium guineense and Prunus africana, all the rest of the gap formers are replaced by other nongap forming species. Dominant species in the Forest were not found being replaced by their own seedlings or saplings and among the ten woody dominant species only seven had sapling and five had seedling stages.

Key words: - Canopy Gaps, Regeneration, Disturbance Dynamics, gap makers, Gap Fillers, I would like to express my heart full gratitude to my advisors Prof Ensermu Kelbessa and Dr. Tamirat Bekele for their valuable and unreserved efforts in advising and providing me assistances as needed in conducting this research, without which, the finalization of it was impossible.

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ACRONYMS

A.A.U	Addis Ababa University
DBH	Diameter at Breast Height
E.N.M.S.A	Ethiopian National Meteorological Station Agency
ETH	National Herbarium
G.D.A.R.D.O	Gera District Agriculture and Rural Development Office
GPS	Geographical Position System
M a.s.l	Meters above sea level

CHAPTER ONE

1. INTRODUCTION

In tropical and temperate forests, the canopy gaps affect the architecture and the establishment of plants throughout their life cycle. The gaps help to maintain the tree diversity by density effect and niche partitioning (Denslow, 1980). The possibility of gap occurrence particularly interplays with recruitment limitation, allowing the coexistence of species that otherwise could not make it (Brokaw & Busing 2000; Lima, 2005). A typical canopy gap goes through diverse stages, the initial one known as gap stage. In this stage, the invasion by lianas (Schnitzer & Carson, 2010) and bamboos (Larpkern et al., 2011) might occur. The next stage is the construction stage, in which the establishment of some species occurs, although they have not yet reached the canopy level. The last stage is the mature one, in which the canopy and the gap are virtually closed by vegetation (Lima, 2005).

Natural gaps are caused by death (or injury) of one or more canopy trees (in some cases they are caused by the fall of large branches), and are defined as small openings on the canopy of forests, usually occupying <0.1 ha (Yamamoto, 2000). This kind of transitory event is frequent in tropical forests (Brokaw, 1985), where plant species of early successional stages (Pioneers and secondary ones) might take advantage of this kind of disturbance, since they can tolerate higher micro-climate and ecological variations (Mulkey et al., 1996). The size distribution and frequency of gap occurrences in a forest is a function of local climate, topography, soil, bedrock and the composition and size distribution of trees (Denslow, 1980). All the trees, especially those in slopes, peaks, shallow or waterlogged soils, and the emerging ones, are subject to wind action, creating gaps proportional to their heights and crown sizes. Moreover, the gap-area is related to the number and orientation of falling trees. Each gap has specific geometry, climate and substratum (Lima, 2005; Denslow, 1980), which leads to important differences in spatial and temporal forest structure (Denslow 1980). The micro-climatic features of a canopy gap might change with its size from one season to another, and even with extreme climate events. These conditions may be optimal for certain species at a certain point of time, though they can change in a mid/long term (Brown, 1993). Some plant species can only regenerate in a narrow range of light availability (Whitmore, 1990). In addition to the marked variation in the canopy opening, the reduction of basal area and the increase in gap-area found in canopy gaps, Can also interfere in the process of regeneration and in the growth of tree seedlings (Sapkota & Odén, 2009).

The colonization of gaps by species of different categories or successional groups is influenced by ecophysiological responses of species in the area by the seed bank and by seedlings and/or remnant individuals, as well as by post-disturbance migrant species via dispersal processes (Martins et al., 2002). Moreover, it will also depend on the time the opening has occurred, the opening size, the substratum conditions and the relationship with herbivores as well as on density dependent factors. Increasing population size reduces available resources limiting population growth. In restricting population growth, a density-dependent factor intensifies as the population size increases, affecting each individual more strongly (Hartshorn, 1989). Understanding the dynamics of gaps in tropical forests is paramount for forest restoration, sustainable management and conservation of forest remnants (Martins et al., 2002). This study aims to identify ecological patterns related to richness and the potential of natural regeneration of tree species in natural gaps and investigate whether the tree community responds or not to different altitude level canopy openings represented by gaps of different sizes found in wet afromontane forest of Jima zone of Oromia regional state.

1.1 Objectives

1.1.1 General Objective.

- To investigate canopy gap regeneration and dynamics in Gera Forest, Jimma zone of Oromia Regional State Ethiopia.

1.1.2 Specific Objectives

- ✓ To identify gap filling species and document their richness across different gap sizes and altitudes.
- ✓ To identify modes of disturbance and relate them to gap filling species
- ✓ To evaluate the probability of self replacement of canopy tree species in gaps by comparing gap filling species with surrounding dominant canopy species
- ✓ Evaluate the degree of response of species to disturbance

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Gap Dynamics and Regeneration

Gap dynamics is a basic natural mechanism for self-maintenance of different forest ecosystems, developed over the course of many tree regenerations in the absence of catastrophic external influences. It is associated with the mortality of individual old trees, causing openings to appear in the canopy letting in light and giving smaller trees the possibility to grow and assume a place in a stand. Hence, gaps are usually considered vital areas for regeneration dynamics and diversity of various types of forest ecosystems. In the past, a number of researchers have studied and described the importance of gaps in different forest types. For instance, Runkle (1981); Brokaw (1985) Popma & Bongers (1988); Yamamoto (1989); have described the importance of gap dynamics in Mesic forest in the Eastern United States, tropical rain forest in Mexico, *nemoral Fagus* forest in Japan and humid tropical forest.

Forest ecosystems with gap dynamics have a large accumulation of dead wood on the ground, and of dead organic matter in the soil (Vitousek and Denslow, 1986). According to Bongers and Popma (1988), the occurrence of a gap causes abrupt changes in the forest structure and the availability of resources to the plants. In gaps, special soil profiles are formed as a result of the continuous falling of old trees along with their root systems. Therefore, gap formation is followed by changes in microenvironments of the forest, especially isolation on forest floors. Roberts and Gilliams (1995) have suggested that soil nutrient resources are typically assumed to change following gap formation, usually with nutrient availability increasing initially and subsequently decreasing through later stages of succession. Oliver and Larson (1990) have also indicated that the availability of water, nutrient and oxygen changes following gap formation. Thus, the special ecological conditions under the canopy, high degree of light, moisture and variety of substrates, provide forest ecosystems with a diverse plant community.

2.2 Gap Dynamics and its Importance

Establishment of seedlings of woody plants is often limited, depending upon gap size, to the first 1-5 yr following gap formation (Canham and Marks, 1985). The rate of seedling establishment is in part a function of the rate of biomass and leaf area recovery in the opening (Oliver, 1981) and the physical environment of the site *(e.g.*, light, temperature, degree of site alteration), as well as the number and distribution of new micro sites following the disturbance. Early establishment and rapid growth rate are critical for intolerant and intermediately tolerant understory plants which require high light conditions for establishment and competitive growth "rates.

AlexWatt, in his 1947 presidential address to the British Ecological Society (Watt, 1947), is generally credited with the first attempt to reconcile the notions of process and pattern in contemporary plant ecology (van der Maarel, 1996). He attempted to move plant ecology beyond the purely descriptive stage by injecting dynamic principles into the study of plant communities. This new level of explanatory knowledge allowed a more comprehensive understanding of inter- and intra-specific interactions and the forces that determine the maintenance and regeneration dynamics of particular plant communities. Watt (1947) thought it better to understand plant communities in terms of patches or phases. Considered a developmental sequence of a particular plant community, each patch or phase is joined together in a mosaic and dynamically related to others in such a manner that the community patterns persist through time. In other words, the community passes through a series of developmental stages that repeat themselves in a cyclic fashion. This cycle is in turn determined by the extent, frequency, and magnitude of various disturbances that impact the plant community. Using the terminology of Watt (1947), we may say that both process and pattern influence each other in a dynamic manner. Watt (1947) used seven different plant communities to develop his thoughts on pattern and process.

Watt (1947) defined the gap phase as that part of the forest developmental cycle dominated by the presence of tree regeneration, it being excluded from other phases. The gap phase may be initiated by small-scale disturbance such as tree-falls or by large-scale disturbance such as fire, insect or disease epidemics, and extensive windstorms. It is during the gap phase, when the mature canopy experiences sufficient disturbance, that the site is opened up, permitting the release of either advance regeneration or the recruitment of new regeneration. It should be noted that for Watt (1947) phases were synonymous with patches and that gap phase could be of widely varying spatial dimensions, it being defined simply as the stage of forest development in which regeneration was confined. As emphasized earlier, the term gap will be used in a more restrictive sense than was used by Watt (1947).Watt (1947) noted that regeneration may happen during the actual gap phase or during the phase corresponding to the mature phase. This distinction is important for it is well known that many shade-tolerant species are able to establish themselves as advance regeneration under a mature–over mature closed canopy that may be "losing its grip" on the growing space of the site (Oliver, 1981; Oliver and Larson, 1990).

Canopy gaps are important in driving forest dynamics. Often they are sites where tree regeneration is occurring because the increased lighting at the forest floor facilitates the establishment and growth of new seedlings and stump sprouts (Oliver, 1981; Oliver and Larsen, 1990). Such stand initiation takes place over several years and normally involves the creation of a sizeable gap in the canopy, though shade-tolerant trees can establish in smaller gaps and then develop through several episodes of suppression and release as multiple gaps consecutively form and close at the same location (Canham and Marks, 1985; Runkle, 1985; Runkle and Yetter, 1987). Gap closure may take a few years or several decades depending on the size of the gap and the rate of infilling by new trees and the expanding crowns of marginal trees. Effective closure occurs, for example, when regeneration has grown to 10-30 m height (Runkle, 1981, Barton *et al* 1981) or to more than two-thirds the average canopy tree height (Qinghong and Hytteborn, 1991). Recruitment of different tree species is influenced by several inter-related factors including, the size, shape, frequency and longevity of gaps. Small gaps are often filled by shade-tolerant species, whereas light-demanding species become important in filling large gaps (e.g. Bormann and Likens, 1979; Runkle, 1985).

Typically, shade-tolerant species are able to grow well in moderate-light and often establish as saplings in low-light prior to gap creation (*viz.* advance regeneration), whilst light-demanding species are better able to disperse into the centre of large gaps and grow faster in the high-light conditions (Canham and Marks 1985; Canham 1989). Canopy gap boundaries are usually delimited by the vertical projection of the edges of the crowns of the surviving trees that surround the gap with the 'expanded gap' area being defined by the base of surrounding canopy trees (Runkle 1981). Gap sizes in natural forests range from a few meter square to several hectares, but most studies of natural forests have found that the gap size frequency distribution is negative exponential, i.e. with many small gaps and very few large gaps (e.g. Runkle, 1982; Abe *et al,* 1995). This pattern arises because in natural forests most gaps are created by the death of scattered single or small groups of trees and only infrequently do major disturbances create sizeable openings: canopy disturbance rates typically average about 1% of the stand per year and, although gap size varies widely within particular regions, the range and average size of gaps is similar (Runkle, 1985).

2.3 Gap Origin

A gap is part of a forest stand where one or more trees (or limbs) have created an empty space in the canopy either through death or through death and subsequent felling, and where regenerating tree species have not reached more than 2/3 of the average canopy tree height (Runkle, 1981; Lui and Hytteborn, 1991). According to Kint *et al.*, (2004), gap origin is linked to minor disturbance events which cause the death and toppling of trees through the forest. In other words, a gap can exist only in a matrix of mature trees, with a recognizable more or less continuous border consisting of trees. The tree, which creates gap, is said to be gap maker (Obiri and Lawes, 2004). Various factors such as fungal and insect attacks and/or wind or fire contribute to the death of gap makers. On the other hand, the mode of mortality of gap makers varies among tree species. For instance according to wood properties in a tropical forest are most important in determining the mode of death.

2.4 Gap Formation

Gaps are formed by the death (or injury) of one or a few canopy trees (in some cases, by the fall of large branches), and gaps are defined as small openings formed in a forest canopy and generally occupying < 0.1 ha in area in various forest types. Brokaw (1982) defined a gap as a hole extending through all layers of the surrounding vegetation to within 2 m of the ground. Runkle (1981) defined two types of gaps: canopy gaps were the areas directly under canopy openings caused by dead trees or branches; expanded gaps were canopy gaps plus the adjacent area extending to the bases of canopy trees bordering the gap. The concept of expanded gap is useful for a major reason that it includes areas directly and indirectly affected by the canopy opening; the effects of light often were offset from the gap center (Runkle, 1981). However, there have been many definitions and measurement methods for gaps, so we have to pay attention to them in the reading of the literature (*e.g.*, Brokaw, 1982; Runkle, 1989; Nakashizuka *et al.*, 1995; Yamamoto, 2000).

2.5 Disturbance Regime

Disturbances are relatively discrete events in time that disrupt the ecosystem, community, or population structure and bring about a change in resources, substrate availability, or the physical environment. On the basis of previous studies (Runkle, 1985) noted that the "disturbance regime" of a vegetation system, which is the sum of all disturbances affecting the system, can be characterized by several parameters: kind, spatial characteristics, temporal characteristics, specificity, magnitude and synergisms. Kind refers to the type of disturbances, which vary with climate, topography, substrate and biota. Spatial characteristics are the area, shape, and spatial distribution of patches created by disturbances. Temporal characteristics are the frequency, return interval, cycle, and rotation period of disturbances. Specificity is the correlations between a type of disturbance and specific characteristics of disturbed sites, such as species, size class, seral stage and location. Magnitude includes the intensity (the physical force per event per area per time) and severity (the impact on organisms and ecosystem structure and composition) of disturbances, and generates patch variations, internal heterogeneity and biological legacies. Synergisms are the interactions among different kinds of disturbances.

It has been suggested that it is impossible to define natural vegetative disturbance regimes in a strict sense, given a changing climate and resultant shifts in disturbance regimes over the past several centuries. Non-equilibrium ecological views are largely based on inevitable ecosystem changes linked with climate instability (Sprugel *et al.* 2000). Lloret *et al.* (2002) also stated that no a priori time period or spatial range should be used to define "natural variability," which is spatio-temporal ecosystem variability driven by disturbances. However, with respect to conservation practices, the term "natural" often means "without human influence" In restoration ecology, resource management and ecosystem approaches, the term generally refers to ecological variations after excluding anthropogenic effects. Thereby, although climate instability significantly alters vegetation structures and disturbance regimes, it should be embedded in disturbance-based management issues. In my study, natural disturbance regimes are thus referred to in a broader sense by accepting climatic effects on disturbance regimes as a natural driver.

Natural disturbances sometimes bring new things to human society. For instance, in the case of terrestrial ecosystems, infrequent catastrophic events such as typhoons, hurricanes, cyclones, forest fires, volcanic eruption, and avalanches may thoroughly destroy ecosystems and landscapes. At first glance this may seem like devastation, which in reality it could be giving rise to many diverse habitats to various creatures, promoting natural ecological processes. There is no single trajectory of long-term ecosystem regeneration process, producing heterogeneity and diversity in terrestrial systems.

In the past and even currently we may try to build watercourses in order to suppress or redirect floods to agricultural land. This action sometimes have resulted in further catastrophe such as massive drought and flooding, which in turn threatened biota in some areas, as well as an outbreak of algae bloom due to nutrient loadings from agricultural drainage. Therefore, lately it is thought important to promote natural disturbances rather than suppress them to bring necessary changes to ecosystems.

The ability of ecosystems or social-ecological systems to cope with such changes and impacts is called "resilience". Ecological resilience is originally defined as the amount of disturbance that a system can absorb without shifting into a different state In managing social-ecological systems and ecosystems, which are prone to changes, it is useful to evaluate the ability of an ecosystem to cope with disturbance-driven changes. Currently, it is thought that resilience includes the ability of a system to restore itself after a disturbance. In resilient systems, disturbances are promoted to foster necessary changes. The definition of resilience is continually evolving. The important thing to pay attention here is that an ecosystem is not always restored to the same ecosystem that it was before disturbance. Just focusing on returning to its original state is not a management approach to cope with changes (van der Maarel, 1996).

Ecosystems with great resilience have a strong tolerance and a powerful ability of restoring themselves after a disturbance. However, human activities such as deforestation, exploitation, pollution, global warming are thought to reduce resilience in a system, making it unable to absorb effects of disturbances that they used to be able to have before. The example of flood control cited above shows that resilience can be eroded by human activity, resulting in many serious environmental problems. This teaches us that it is unnatural to consider ecosystems and human society separately; the concept of resilience therefore is also the ability of social-ecological systems to face changes. In other words, a society with greater resilience would have lesser confusion, damage and disaster relief payment, and could restore itself soon after massive natural disasters.

2.6. Causes of Disturbance

In the ecological context, disturbance is regarded as an event of intense environmental stress occurring over a relatively short period of time and causing large changes in the affected ecosystem. Disturbance can result from natural causes or from the activities of humans.

Disturbance can be caused by physical stressors such as volcanic eruptions, hurricanes, tornadoes, earthquakes, and over geological time, glacial advance, and retreat. Humans can also cause physical disturbances, for example, through construction activities. Wildfire is a type of chemical disturbance caused by the rapid combustion of much of the biomass of an ecosystem and often causing mortality of the dominant species of the community such as trees in the case of a forest fire. Wildfires can ignite naturally, usually through a lightning strike, or humans can start the blaze. Sometimes fires are set deliberately as a management activity in forestry or agriculture

(Lloret *et al* 2002). Events of unusually severe pollution by toxic chemicals, nutrients, or heat may also be regarded as a type of disturbance if they are severe enough to result in substantial ecological damages. Disturbance can also be biological, as when a severe infestation of defoliating insects causes substantial mortality of trees in a forest, or of crops in agriculture. The harvesting of forests and other ecosystems by humans is another type of biological disturbance.

Ecologic disturbance can occur at a variety of spatial scales. The most extensive disturbances involve landscape-scale events, such as glaciations, which can affect entire continents. Tornadoes, hurricanes and wildfires can also affect very large areas; sometimes wildfires extend over millions of acres.

2.7 Variables Affecting Gap Regeneration

The effect of canopy gap on the environment and vegetation inside or near it depends on characteristics of the gap, of which the most important is gap size (Bongers and Popma, 1988). Gaps vary in shape and size. These variations as have been suggested by Marthews *et al* (2008), are the products of the mechanism of gap formation and the tree species involved in the process. The gap size distribution depends upon the distribution between single and multiple tree fall gaps. Gap size is mainly responsible for variation of light intensity, which plays a major role in forest regeneration. According to Dirzo *et al*. (1992), the influence of gap size on light environment is important in understanding the dynamics of communities. In his study, Williams (1992 sited in Yamamoto, 2000) found that gap size affects both survivorship and performance of gap colonists via competitive interactions and the effects of gap microclimate. Dirzo *et al.* (1992) further suggested that gap size affects both species richness and the nature of seedling populations. Canopy gap size can play a major role in determining composition of tree regeneration after disturbance (Runkle, 1982). In other words, species response to canopy gaps varies. Limited dispersal leads species to require relatively large gaps and or gaps that remain open for relatively long periods. This factor may prevent the evolution of other gap species. Some species may survive and become established in fairly small gaps. Runkle (1985) have indicated that gap composition is closely linked to site conditions, including slope, soil conditions and site location. Runkle (1981) also found that with increased gap size, vegetation within gaps increased in woody species diversity, total basal area and total number of stems, where stems also showed accelerated growth into larger size classes. On the other hand within single tree gaps, light conditions are optimal for the advanced regeneration of seedlings established prior to gap formation that grows rapidly without the risk of massive regeneration of competing species (Kint *et al.*, 2004). The species composition of the regeneration phases is largely determined by the size of the gaps where as the regeneration of light demanding species is expected to occur in big gaps (Lui and Hytteborn, 1991).

CHAPTER THREE

3. MATERIAL AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The study was conducted in Gera District, Jimma zone of Oromia National Regional State, Ethiopia. The Forest is located at about 380 km south west of Addis Ababa and has a total area of 80,830.4 ha. The altitudinal range of the study area is from1300 to 2400 m a.s.l. Gera District is bordered on the south by Gojeb River which separates it from the Southern Nations, Nationalities and Peoples Region, on the northwest by Sigmo, on the north by Setema, on the northeast by Gomma, and on the east by Seka Chekorsa Districts. The administrative center of Gera district is Chira town. Other towns in Gera District include Cheriko and Dusta (Figure 1).

3.1.2 Topography

Gera District is characterized by mountains (Waka, Kimbibit and Timba), plateaus (Chewra and Kella), plains (Walla, Kecho, Tuta and Tuam Mayi) and valleys (Naso and Gojeb). Gera Forest is situated at the intermediate altitudinal range between 1300-2400 m a.s.l.

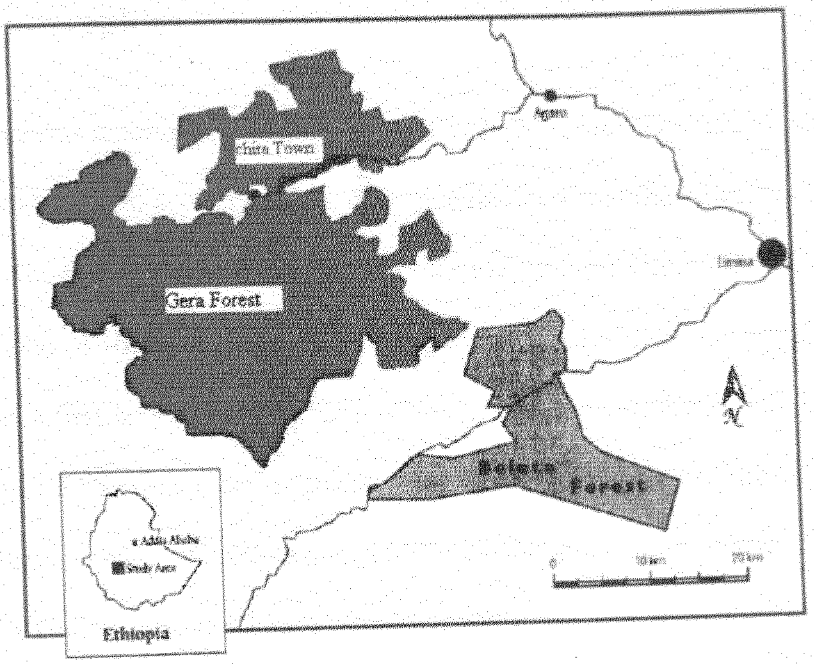


Figure 1 Map of Ethiopia and Jima zone showing the study area Gera forest

3.1.3 Geology and Soil

The study area has a drastic nitosol soil type, which is deep, clay red soil. The soil is porous and has good potential for agriculture, good physical properties, stable structure, deep rooting volume, and high moisture storage volume. Orthic acrisol and drastic nitosol are the major soil types found in Gera District (G.D.A.R.D.O., 2012).

3.1.4 Demographics

The 2007 national census reported a total population of 112,395 for this District, of which 56,488 were men and 55,907 women. 4,746 or 4.22% of its population were urban dwellers and the rest live in rural areas. The three largest ethnic groups in Gera District are Oromo (86.08%), Amhara (8.27%), and Kafficho (4.16%); all other ethnic groups made up 1.49% of the population. Afan oromo is spoken as a first language by 86.02%, while 9.71% speak Amharic, and 3.48% speak Kafa; the remaining 1.52% speak other languages rather than the stated once. The majority of the inhabitants are Muslim, with 85.64% while 11.9% of the population where followers of Ethiopian Orthodox Christianity, and 2.36% were Protestant.

3.1.5 Climate and agro climatic zones

The rainfall and temperature data for the study area were collected from National Meteorological Service Agency (NMA, 2012). The mean annual temperature is about 18.4^{0}C and the mean minimum and maximum temperatures are 11.7 ^{0}C and 26. 5^{0} C respectively. The hottest months are from January to May with a maximum temperature record of 26 0 C in and the coldest months range from June to October with a minimum temperature of 12.2^{0} C. The mean annual rainfall of the study area is 1805 mm. The rainfall pattern is unimodal, with little or no rainfall in January and February, and gradually increasing to a peak period between June and September and decreasing in November and December (Figure 2). Gera is classified into Dega (5%), Woinadega (75%) and Kolla (20%) agro climatic zones (G.D.A.R.D.O, 2012).

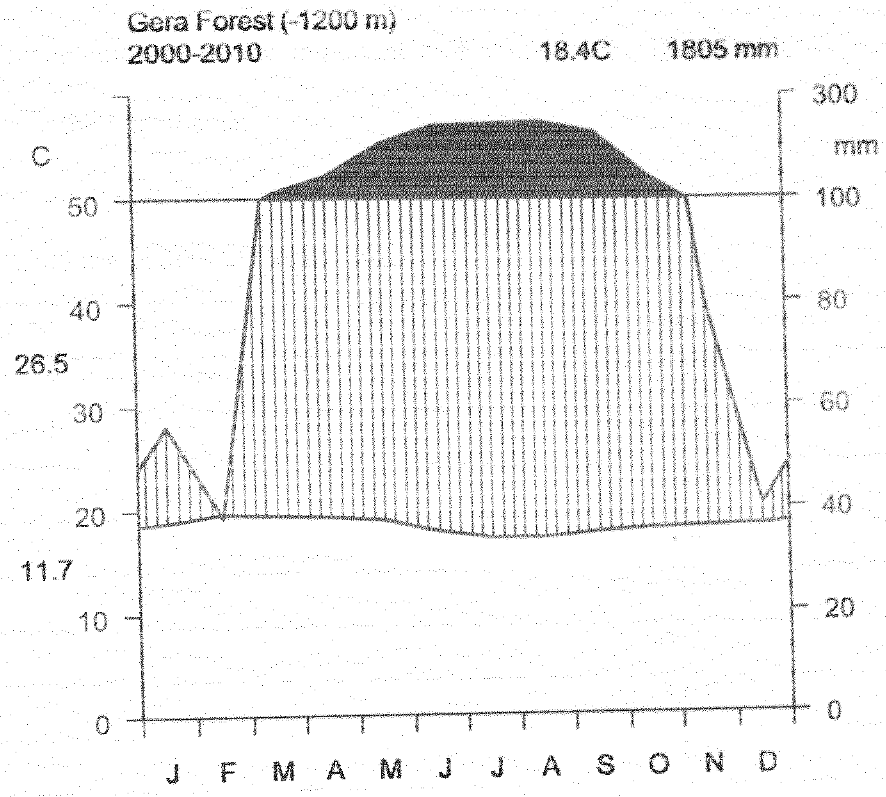


Figure 2 Climate diagram of the study area (source E.M.A)

3.1.6 Land use and Agriculture

The proportion of arable, grazing and Forestlands in Gera District is 15.47%, 5.6% and 56% respectively (G.D.A.R.D.O., 2012). The remaining land area is either degraded, houses has built-up or serves for other purpose (Table 1). High forest, woodland and plantation Forests are available in the District. The majority of the natural Forest patches are under the government protection. Gera District has 226,754 cattle, 54,801 sheep, 14,473 goats, 7,041 mules, 30,532 horses, 1934 donkeys and 21, 205 poultry. There are some retail traders, small shops, and open markets, in the District. Teff, maize, wheat, sorghum, barely, horse bean, field pea, peppers, fruits, spices, and coffee are important cash crops in the District. Honey production is also practiced in the Forest area.

Table 1 Land use pattern of Gera District

No.	Land use Type	Area in hectare	%
1	Potential arable land	22,323	15.47
2	Grazing land	8089.22	5.6
3	Forest	80,830.4	56
4	Cultivable land	3,148	2.18
5	Uncultivable land	5,901.76	4.09
6	Construction	9002.62	6.24
7	Others	15,045	10.42
	Total	**144,340**	**100**

Source: G.D.A.R.D.O. (2012)

3.1.7 Wildlife

The Forest vegetation of Gera District hosts various species of wild animals including mammals, birds, reptiles and amphibians. Commonly found mammals found in the Forest are buffalos, lions, Colobus monkeys, Gelada baboons, Vervet monkeys, tigers, warthogs, pigs, civet cats and antelopes. However, the populations of these animals are under severe threat due to deforestation and habitat fragmentation mainly because of human encroachment.

3.1.8 Drainage

Gera District is characterized by a wide topographic land forms. It is endowed with numerous streams and rivers. Several perennial rivers such as Naso and Gojeb, and intermittent streams (Atta, Naniya, Sisay, Koka, Dacho, etc.) are flowing through the District. Locally protected springs, rivers, developed springs and wells are the major sources of drinking water in Gera.

Figure 3 Picture showing partial view of Gera Forest

3.1.9 Vegetation

The forest vegetation was stratified into four different layers, namely, upper canopy, sub-canopy, shrub layer and the ground layer. The upper canopy is occupied the spectacular emergent trees of *Pouteria adolfi-friederici. Podocarpus falcatus* become important in the mixed broad-leaved forests of the Gera Mountains, although conifers are generally less important in moist forests of Ethiopia. Other characteristic species in the canopy include *Olea welwitschii* and *O. capensis* subsp. *macrocarpa*, *Prunus africana*, *Albizia schimperiana*, *Millettia ferruginea* and *Celtis africana.* Others such as *Polyscias fulva*, *Schefflera volkensii*, *Trilepisium madagascariense*, *Schefflera abyssinica*, *Bersama abyssinica* and *Mimusops kummel* are also associated to it. Sub-canopy species include *Croton macrostachyus*, *Cordia africana*, *Dracaena steudenri*, *Syzygium guineense* subsp. *afromontanum*, *Sapium ellipticum*, *Ilex mitis*, *Erythrina brucei* and *Rothmannia urcelliformis*. The shrub layer consists species of *Coffea arabica*, *Galiniera saxifraga*, *Teclea nobilis*, *Ocotea kenyensis*, *Clausena anisata*, *Maesa lanceolata* and *Maytenus* spp. The woody climbers are *Urera hypselodendron*, *Landolphia buchananii*, *Embelia schimperi* and *Jasminum* spp. The ground vegetation are mainly herbaceous plants including *Acanthus*, *Justicia*, *Piperoma*, *Galinsoga*, *Impatiens*, *Urtica* and several grass species. In the attempt of classification of the vegetation types in montane moist forests of Ethiopia Bekele-Tesemma,*et al* (1993).

3.2 Materials used

For this research different materials had been used for taking plant specimen. Secateurs, plant pres, pole cutter, plastic bags and news papers were used for the specimen collection from the filed

3.3 Data collection

A reconnaissance survey of the study area was conducted from November 15 up to December 13, 2012 to obtain information on the species composition and distribution as well as pattern of canopy gap distribution. For all the gaps, altitude and slope were recorded using GPS. The gaps were identified on the basis of their causative factors as natural gaps and human made gaps. In the present study, only natural gaps were analyzed. To differentiate the human made gaps from natural gaps mode of tree death is considered. Data on the gap formers and gap filler species were collected.

The data was collected using 3 transect lines

1. from Chira city to Anfalo river following the road
2. from Chira to the non coffee forest
3. From Chira to Agaro road following the road and entering 200 meters to the forest.

The selection of gaps for the data collection follows systematic sampling.

To see the dominant tree species in the forest filed notes were taken and literature was reviewed from the secondary data sources.

3.3 Data from Gap Formers

Mode of death and gap formation were identified and recorded. Gap types were identified and the gap formers were categorized as follows. Standing dead (Figure 4), bole snapped (Figure 5), uprooted (Figure 6), cut, unclassified, broken branch/crown (Figure 7). (Lui Qinghong and Hytteborn, 1991). Standing dead trees are trees that died but remain rooted. Some gaps are formed due to broken crown or branch

Figure 4 Standing dead *Pouteria adolfi-friederici* tree in Gera Forest

Figure 5 Bole snapped *Albizia gummifera* trees in Gera Forest

Figure 6 Uprooted *Schefflera abyssinica* tree in Gera Forest

Figure 7 Gap caused due to broken crown or branch of *Prunus africana* tree in Gera Forest

For two dimensional measurements of gap shape and size there are three main strategies:

(i) Assume uniform, elliptical shape and take two measurements;

(ii) Assume irregular shape and take many measurements; and

(iii) Assume irregular shape and calculate area based on photographic data.

To quantify the three dimensional shape, Hu and Zhu (2009) proposed a method using hemispherical photographs. Other researchers have suggested calculating a gap diameter to canopy height ratio as an appropriate measure of effective size. The size of uniform, ellipse-shaped gaps may be calculated quickly by measuring the length and width of each gap (Runkle, 1981). Such uniform-shaped gaps are rare, and gap sizes calculated in this manner may be imprecise (Lertzman and Krebs, 1991).

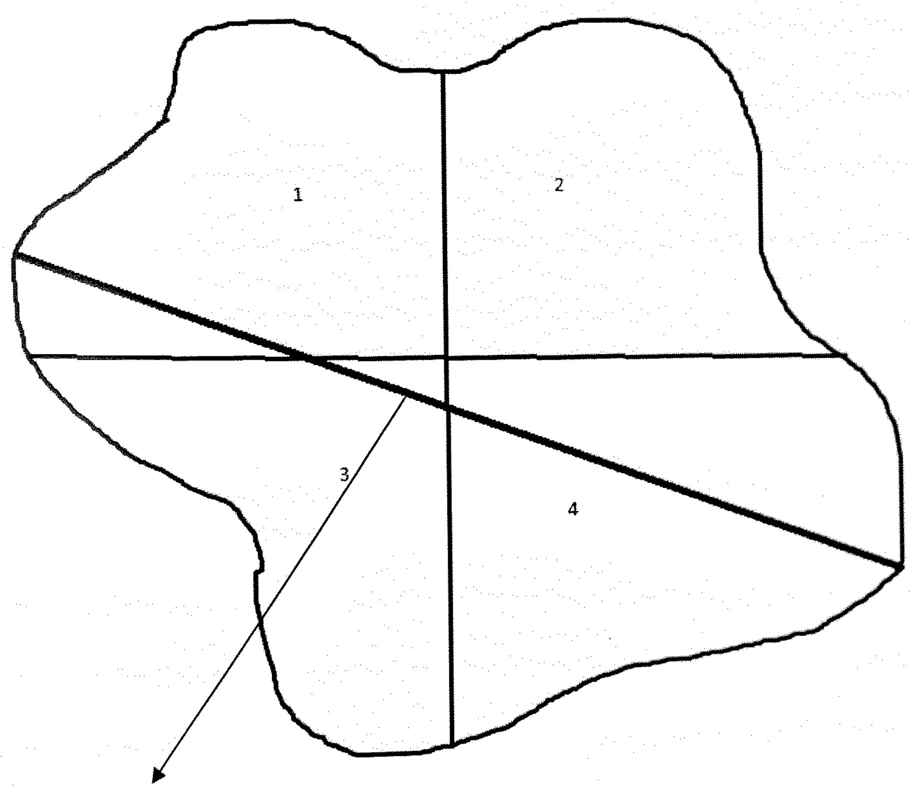


Figure 8 Gap area measurement schematic diagram

Irregularly shaped gaps can be subdivided into smaller sections and each section measured (Brokaw, 1982) and finally the acquired values from different measurements' fit to the appropriate geometrical formula to get the value of the gap area.

Gaps were identified starting from 1600 to 2400 m a.s.l. For every gap examined in the forest, the longest distance between any two-canopy trees i.e. gap length and the largest distance perpendicular to the length (Figure 8) (i.e. gap width) measured and the values were fitted in an ellipse formula (Runkle, 1981), i.e.,

$$A = \frac{\pi LW}{4}$$

Where A = Gap Area

L = the longest distance

W= the largest perpendicular distance

To determine the gap age different techniques had been employed. Increased solar radiation allows vegetation to grow quickly. Over time, micro site characteristics within the gap slowly revert to those of a closed forest. Consequently, the age of a gap is an important parameter to note. There are three main methods for determining gap age:

(i) tree ring analysis,

(ii) whorl counts, and

(iii) degree of decomposition.

The most widely accepted methods for determining the age of gaps is that of tree-ring analysis. Lorimer and Frelich (1989) pointed out that when a gap is formed, the increase in light allows trees that were overtopped by the gap maker to experience growth release as reflected in increased ring width. The second method was that of Lui and Hytteborn (1993) (Table 2). Using decomposition rate (degree of decomposition) and other stated characteristics like stem color, presence and absence of bark and leaves. For this research the gap age was determined using the third technique degree of decomposition and the techniques stated by Lui and Hytteborn (1993). The method used by Lui and Hytteborn was for the temperate zones for mountain regions. The method was adopted by decreasing some characteristics due to fast decomposition in the area.

Table 2 Factors that determine age of the gap

Age of the gap	Description	Remark
1-3	Most of the leaves remain on the branch some of them are still green stem not rotten	Class 1
4-6 years	Most of the leaves removed and stem is still observable but started to rot	Class 2
7 -9 years	Without leaves most of the bark removed the wood still observable but rotten	Class 3
10-12 years	Main branch remains supporting the trunk small areas of wood found observable	Class 4

In addition to the criteria set endogenous people knowledge also used in determining the gap age. According to Taye Jara (2006), the gap age determination can be supported with endogenous knowledge it makes the information more reliable.

3.4 Data from Gap Filler Species

To investigate the species composition and density of regenerating plant species data was collected from gap found in the Forest. Counting the number of seedlings and saplings was made along a rope stretched from west to east and from north to south forming a cross inside (Figure 8). The gaps were delineated using polyethylene strings tied around four wooden pegs inserted into the ground at the four corners of the quadrants.

At each of the gaps found in the Forest counting of seedling and sapling took place within the boundary of the expanded gap. Seedlings and saplings were counted and recorded across five height classes as species having <20 c. m, 20-50 c. m, 51-100 c. m, 1 m-1.99 m, and >2 meter. The species were collected, preserved and brought to the National Herbarium (ETH) for identification and for confirmation. The species were identified using Flora of Ethiopia and Eritrea volumes 1-8 and with the help of professionals in the field of taxonomy.

The replacement property, regeneration and presence /absence of gap forming species in the gap formed by their own species were identified. To see the relationship between altitude and degree of regeneration data were obtained from gap formed at different altitude as much as possible.

3.5 Data Treatment

In order to see if there is any relationship between altitude, gap size, slope, species richness, number of saplings and gap fillers, correlation analysis was done by taking two of them at a time. The effect of gap size on the number of species and number of sapling was tested by linear regression analysis by using SPSS window for version 14. Gap size partitioning among the gap filler species was checked by examining the frequency distribution of species, their maximum occurrence (highest abundance versus gap size) and identification of species that were confined to either few gaps or too many quadrants were categorized following Obiri and Lawes (2004). Species replacement probabilities of gaps were estimated for the gap maker species by using the relative abundance of recruits' of 10 cm DBH of a species in gaps created by the same or another species. This was achieved by counting the number of gap fillers of a given species and expressing it as a proportion of the total number of gap fillers per gap maker following Runkle (1981) and Obiri and Lawes (2004). To see the survivorship of species in each level i.e. <20c.m, 20-50c.m, 51-100c.m, 1m-1.99m, and >2meter records were analyzed using Microsoft excel 2007. Finally the data is presented using tables and graphs either bar graph or pie charts.

CHAPTER FOUR

4. RESULTS

4.1 Mode of Mortality and Gap Characteristics

Gap formation in Gera Forest can be attributed to the following six reasons: - Standing dead, bole snapped, uprooted, cut, unclassified, broken branch/crown (Figure 9). Uprooted trees accounted for 41.18 % (n=14) from 34 gaps investigated. Broken crown /branch accounted for 20.58 % (n= 7), and gap caused by unclassified cause contributed 5.9% (n=2) of the 34 gaps formed in Gera Forest (Table 3).

The gaps formed in the Forest were made of either single tree or multiple tree falls. All the gaps included in this study were caused by single tree fall.

Most of the gaps had an area that fall between 120 – 250 m^2, i.e., 61.76% n=21 while nine gaps (26.47%) were 250 -350 m^2 and 8.82% (n= 3) had a gap size less than 120 m^2. A single gap had an area >350 (Figure 10).

4.2 Features of Gap Maker Species and Their Distribution

A total of thirteen species of canopy trees were involved in gap formation. Out of these, *Prunus africana* was the most common gap maker 17.68% (n=6) and *Schefflera abyssinica* was the second 14.7%, (n=5). On the other hand, species with the least number of gaps were *Cordia* *africana Olea welwitschii* and *Teclea nobilis*, each of them had contributed about 2.94% (n=1) of the thirteen species responsible for forming gaps in Gera Forest (Table 4).

Gap maker species have exhibited variations in their sizes. The mean DBH of the gap makers was 48.33 cm (n= 34). Uprooted trees had the highest mean DBH of 64.1 cm (n= 14) while trees with broken branch /crown had a DBH of 53.19 cm, (n= 7). On the other hand, dead standing trees and bole snapped trees were 48.94 and 46.47 cm respectively. *Schefflera abyssinica* was the species with the largest mean DBH of 78.18 cm (Appendix 1).

Table 3 Gap characteristics of all sampled natural gaps in Gera Forest

Cause of Gap	Bole snapped	Brocken Branch /crown	Unclassified	Uprooted	Standing dead	Cut	Total
Number of gaps	5	7	2	14	3	3	34
Mean (gap area)	182.4480027	169.9433	218.6167	160.645	228.4941	194.222	190.851
Median gap area	180	175.4	240.1	153.3	264	175.4	177.6975
Range in gap area	188.07-236.9	186.5-236.76	140.9-339.2	112.5-455	102.792-277.58	169.08/-247.1	102.792-455
Percentage of gaps	14.7	20.58 %	5.9%	41.18 %	8.82	8.82	100

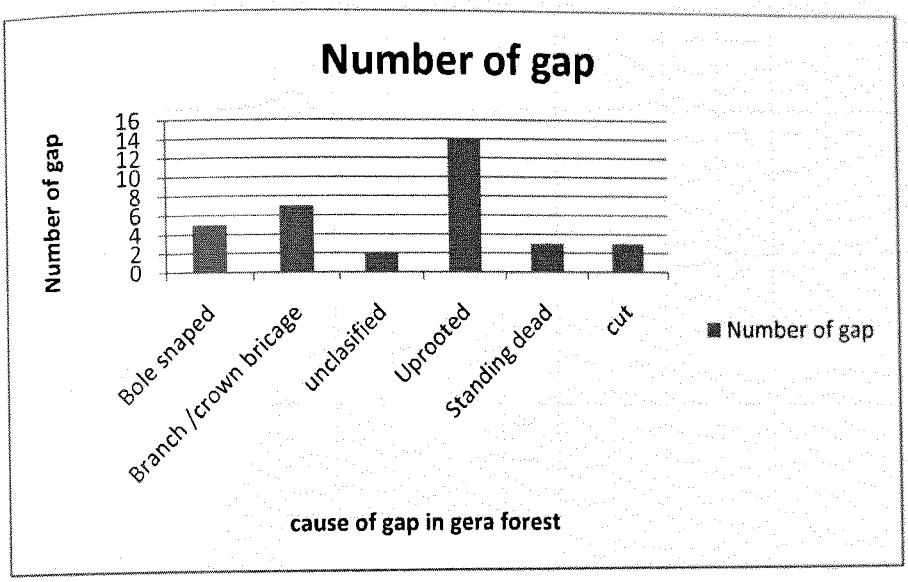


Figure 9 Number of gaps with respect to its cause

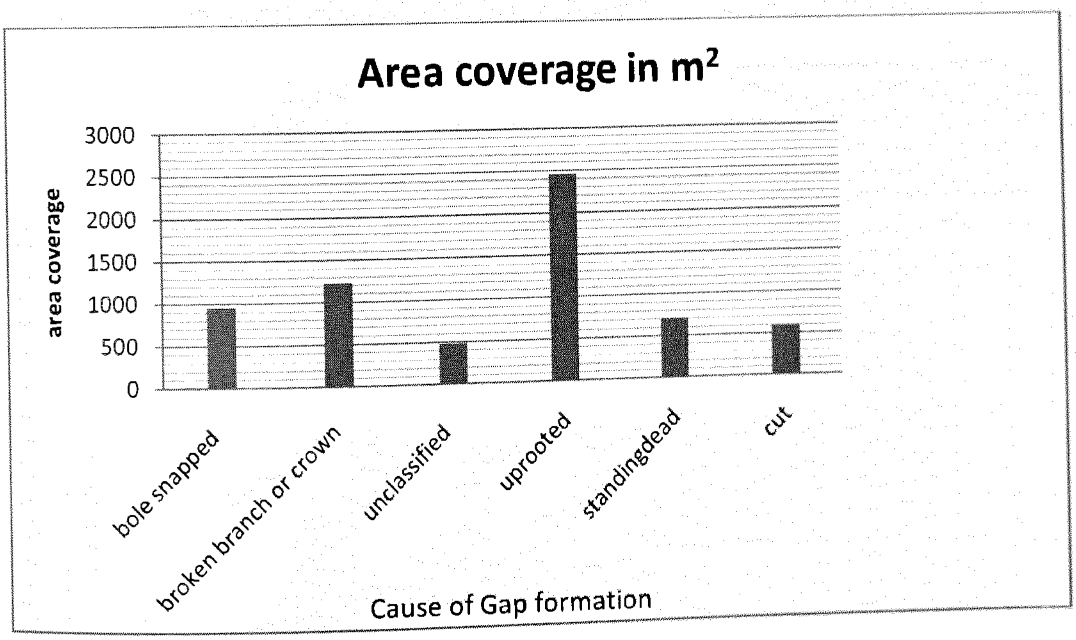


Figure 10 Area coverage by each cause forming the gap in Gera Forest

Table 4 Types of gap, gap making species and their percentage cover in Gera Forest

	Gap maker	Number of gap	Cause of gap						% of gap makers
			Bole snapped	Brocken branch or crown	Unclassified	Uprooted	Standing Dead	Cut	
1	*Apodytes dimidata* E.Mey.ex.Arm.	2	1			1			5.88
2	*Albizia gummifera (*J.F.Gmel.) C.A.Sim.	2	1	1					5.88
3	*Cordia africana* Lam.	1						1	2.94
4	*Croton macrostachyus* Del	2				2			5.88
5	*Millettia ferruginea* (Hochst.) Bak.	4	1		1	2			11.76
6	*Olea welwitschii* (Knobl) Gilg & Schellenb	1	1						2.94
7	*Podocarpus falcatus* (Thunb.) R.B.ex Mirb	2						2	5.88
8	*Polyscias fulva (*Hiern) Harms.	2	1	1					5.88
9	*Prunus africana* (Hook.f.) Kalkm.	6		1		4	1		17.68
10	*Pouteria adolfi-friederici* Rob. & Gilg.	3				2	1		8.82
11	*Schefflera abyssinica* (Hochst.ex A.Rich.)	5		2	1	1	1		14.7
12	*Syzygium guineense* (Willd.) DC.	3		2		1			8.82
13	*Teclea nobilis* Del.	1				1			2.94
	Total	34	5	7	2	14	3	3	100

Table 5 Gap formers and their altitudinal range

No	Gap making species	Altitude m a.s.l
1	*Apodytes dimidiata* E. Mey. ex Arm.	1970-2040
2	*Albizia gummifera* (J.F.Gmel.) C.A.Sim.	1700-2020
3	*Cordia africana* . Lam	2000-2010
4	*Croton macrostachyus* Del	1800-2200
5	*Millettia ferruginea* (Hochst.) Bak.	1800-2200
6	*Olea welwitschii* (Knobl.) Gilg & Schellenb	1800-2200
7	*Podocarpus falcatus* (Thunb.) R. B. ex Mirb	1800-2000
8	*Polyscias fulva* (Hiern) Harms	1700-2000
9	*Prunus africana* (Hook.f.) Kalkm	1800-2000
10	*Pouteria adolfi-friederici* Rob. & Gilg	1650-2000
11	*Schefflera abyssinica* (Hochst.ex A.Rich.)	1700-2200
12	*Syzygium guineense* (Willd.) DC	1850-2250
13	*Teclea nobilis* Del	1750-1950

Schefflera abyssinica was the second dominant gap former in the Gera Forest has been found in wider altitudenal range than the dominant gap maker *Prunus africana*. *Syzygium guineense* was also found in wider altitudnal range but formed 3 gaps in the forest. *Millettia ferruginea* and *Olea welwitschii* found in the same altitudnal range (Table 5).

4.3 Gap Regeneration

4.3.1 Composition of seedlings

Seedlings of 24 different woody species were encountered during the current study (Table 6). The aggregate density of these seedlings was 4368 individuals /hectare. *Millettia ferruginea* was found to have the highest seedling density (741 individuals /hectare) while *Grewia ferruginea* had the second highest seedling density (740 individuals /hectare) in the natural gaps studied in Gera Forest. *Ficus sur* on the other hand exhibited to have the lowest seedling density (4 individuals/ hectare) in the forest. *Podocarpus falcatus, Schefflera abyssinica, Solanecio gigas and Vepris dainellii* are not represented by their seedling (Table 6).

4.3.2 Composition and density of saplings

A total of twenty eight woody species were recorded inside the sampled natural gaps (Table 6). The aggregate density of saplings was 620 individuals/hectare. *Croton macrostachyus* had the most dominant sapling density among the rest of gap filler species in the forest (n=118). Other species also recorded different sapling densities. Other species like *Millettia ferruginea, Syzygium guineense, Teclea nobilis* and *Cordia africana* accounted for 91, 38, 34 and 30 saplings respectively. In the contrary, some species have shown low number of saplings in the natural gaps formed in Gera Forest. The lowest number of sapling was that of *Rytigynia neglecta* followed by *Brucea antidysenterica* and *Phoenix reclinata* (Table 6).

Table 6 Numbers of seedling and saplings identified under canopy openings in the forest

No	Gap filling species	Number of seedling / hectare	Number of sapling /hectare
1	*Bersama abyssinica* Fresen.	120	17
2	*Brucea antidysenterica* J.F.Mill.	55	3
3	*Calpurnia aurea* (Ait.) Benth.	45	9
4	*Coffea arabica* L.	85	21
5	*Cordia africana* Lam.	130	30
6	*Croton macrostachyus* Del.	488	118
7	*Dracaena afromontana* Mildbr.	125	17
8	*Dracaena steudneri* Engl.	137	22
9	*Ficus sur* Forssk.	4	5
10	*Grewia ferruginea* Hochst. ex A.Rich.	740	21
11	*Justicia schimperiana* (Hochst. ex Nees) T. Anders.	120	6
12	*Maesa lanceolata* Forssk.	88	5
13	*Maytenus arbutifolia* A. Rich. Wilczek	88	13
14	*Maytenus undata* (Thunb.) Blakelock	45	12
15	*Millettia ferruginea* (Hochst.) Bak.	741	91
16	*Olea capensis* L	64	26
17	*Phoenix reclinata* Jacq.	48	3
18	*Podocarpus falcatus* (Thunb.) R. B. ex Mirb	0	4
19	*Prunus africana* (Hook.f.) Kalkm	125	19
20	*Ricinus communis* L.	45	9
21	*Rytigynia neglecta* (Hiern) Robyns	44	2
22	*Schefflera abyssinica* (Hochst.ex A.Rich.) Harms	0	8
23	*Solanecio gigas* (Vatke) C.Jeffrey	0	24
24	*Syzygium guineense* (Willd.) DC.	451	38
25	*Teclea nobilis* Del.	55	34
26	*Vepris dainellii* (Pichi-Serm.) Kokwaro	0	16
27	*Vernonia amygdalina* Del.	125	35
28	*Vernonia auriculifera* Hiern	400	12
	Total	**4368**	**620**

4.4. Survivorships of Gap-fillers

Gap-filler species have shown different survivorship in the current study (Figure 11 a-f). For example, *Millettia ferruginea* (Figure 11a) *Teclea nobilis* (Figure 11b) and *Olea capensis* (Figure 11 d) have comparable survivorship curves. *Syzygium guineense*, had a minimum survivorship of its saplings (1 – 2 m) sized also had a minimum survivorship of its middle sized saplings (51cm - 100 cm) (Figure 11c). Furthermore, *Cordia africana* has a minimum survivorship as compared with other species (Figure 11e). As the graph is showing the saplings at a height of 50cm -1meter are with low degree of survivorship but the next stage i.e. 1-1.99 m show relatively better regenerating capacity. The comparable regeneration capacity of some species is presented below as a reference based on their dominancy in the Forest. *Croton macrostachyus,* one of the dominant tree in the Forest shows uniform regenerating potential as compared with other species in the Forest (Figure 11f).

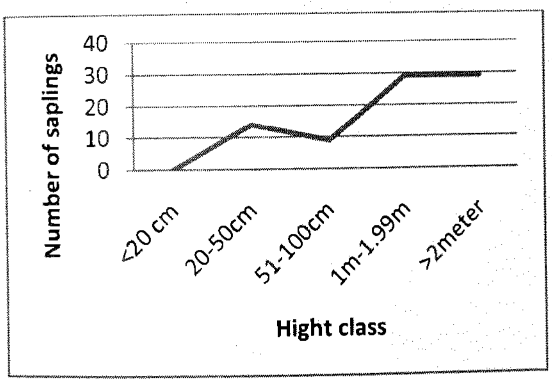


Figure 11a. *Millettia ferruginea*

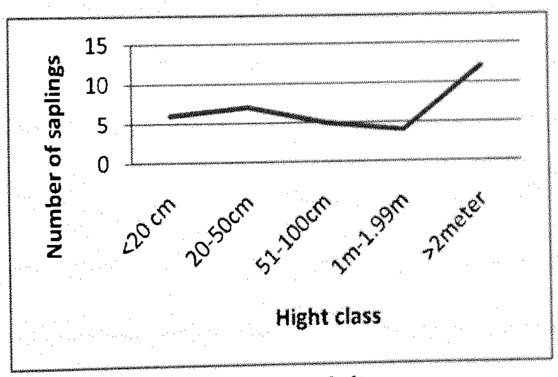


Figure 11 b. *Teclea nobilis*

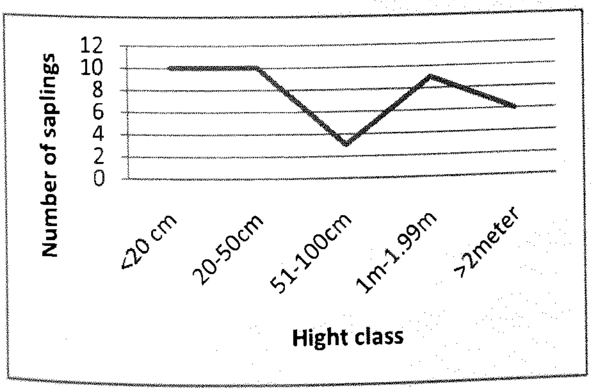


Figure 11c. *Syzygium guineense*

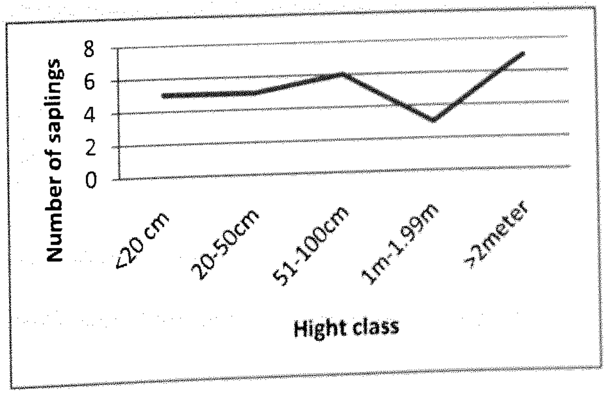
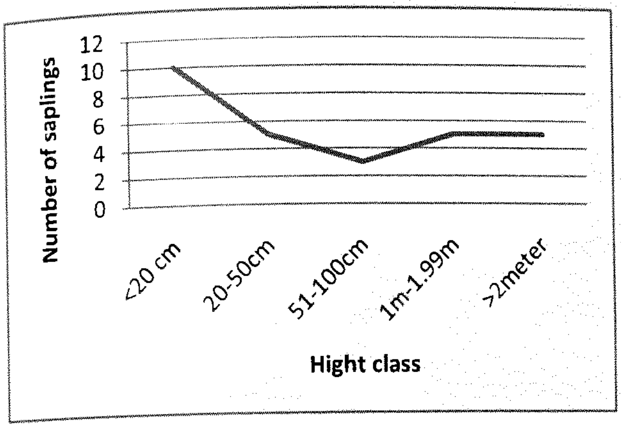


Figure 11 d. *Olea capensis*



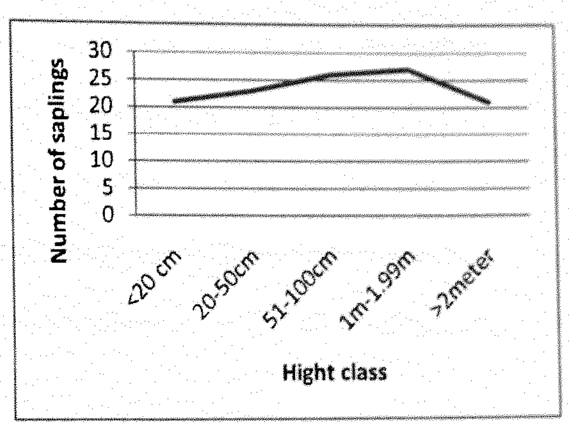


Figure 11 e. *Cordia africana*

Figure 11 f *Croton macrostachyus*

Figure 11a-f Survivorship curves of selected gap-filler species in the Gera Forest

4.5 The Response of Gap Filling Species with Altitude

The regeneration degree and species response with altitude reveals the following. At an altitudinal range of m a.s.l, 1600-1800 twenty woody species were found to regenerate in the Forest gaps. The total seedling and sapling densities of species in this altitude range were 1168 individuals/hectare and 217 individuals/hectare respectively. The highest seedling density was recorded for *Vernonia auriculifera* (250 individuals/hectare) while the highest sapling density characterized *Millettia ferruginea* (29 individuals/hectare). In the contrary density of sapling for *Vernonia amygdalina* was found to be 22 individuals /hectare, while other species like *Rytigynia neglecta, Ficus sur* and *Dracaena afromontana* were each represented by the smallest sapling density (Table 7).

Only sixteen species were recorded at an altitudinal range of 1800-2000 m a.s.l. The densities of seedlings and saplings for this range were 1041 and 189 individuals/hectare, respectively. Among the species found in this altitudinal range *Millettia ferruginea* had the highest seedling density of 250 individuals /hectare while *Croton macrostachyus* was found to have the highest sapling density of 39 individuals/hectare. In the case of others species found at this altitude, *Millettia ferruginea* and *Bersama abyssinica* had a sapling density of 20 and 17 individuals/hectare respectively. The lowest number of seedlings was exhibited in *Teclea nobilis* by having 21 individuals / hectare. One species in this altitudinal range had no seedlings i.e. .*Ficus sur* has no seedling but has four saplings (Table 7).

Fifteen gap- regenerating woody species were recorded in the third altitudinal range (i.e 2000 - 2400 m a.s.l). A total seedling density of 2159 individuals/hectare and 214 individuals /hectare was recorded. It was found out that *Grewia ferruginea* had the highest seedling density of 530 individuals/ hectare and the highest sapling density was recorded by *Croton macrostachyus* with 53 individuals/ hectare followed by *Syzygium guineense* by having the seedling density of 400 individuals/ hectare and with regarding to sapling density the second regeneration species density was recorded by *Millettia ferruginea* with 42 individuals/ hectare. The least number of saplings was recorded for *Dracaena steudneri,* where three individuals /hectare while *Brucea antidysenterica* had two individuals /hectare (Table 7).

The highest numbers of forest gap regenerating woody species were encountered in the altitudinal range (1600-1800 m a.s.l). Twenty species were recorded. *Croton macrostachyus* ,*Coffea arabica, Cordia africana, Calpurnia aurea, Dracaena afromontana, Maytenus arbutifolia, Millettia ferruginea* and *Olea capensis* were the most common. The seedling and sapling density of this altitudinal range was (1168 individuals /hectare and 217 individuals/ hectare) respectively (Table 7).

Table 7 List of gap filling species encountered at different altitudinal range

Altitude	Species	Seedling density individual/hectare	Sapling density individual/hectare
1600-1800 m.a.s.l	*Calpurnia aurea.*	45	9
	Coffea arabica	85	14
	Cordia africana	66	5
	Croton macrostachyus	125	26
	Dracaena afromontana	80	3
	Dracaena steudneri	50	14
	Ficus sur	0	1
	Maytenus arbutifolia	64	6
	Millettia ferruginea	141	29
	Olea capensis	40	16
	Podocarpus falcatus	0	4
	Prunus africana	43	8
	Ricinus communis	45	9
	Rytigynia neglecta	44	2
	Schefflera abyssinica	0	8
	Syzygium guineense	0	5
	Teclea nobilis	21	12
	Vepris dainellii	0	16
	Vernonia amygdalina	69	22
	Vernonia auriculifera	250	8
	Total for this altitude range	**1168**	**217**

Table 7 Cont ...

1800-2000 m.a.s.l	*Bersama abyssinica*	120	*17*
	Coffea arabica	*0*	7
	Cordia africana	34	*7*
	Croton macrostachyus	101	*39*
	Dracaena afromontana	5	*9*
	Dracaena steudneri	20	*6*
	Ficus sur	0	*4*
	Grewia ferruginea	210	*7*
	Maesa lanceolata	88	*5*
	Maytenus arbutifolia	24	*7*
	Maytenus undata	35	*10*
	Millettia ferruginea	250	*20*
	Phoenix reclinata	48	*3*
	Prunus africana	38	*4*
	Solanecio gigas	0	*24*
	Syzygium guineense	51	*12*
	Teclea nobilis	13	*8*
	Total for this altitude range	**1041**	*189*

Table 7 cont...

2000-2400 m.a.s.l	*Brucea antidysenterica*	55	3
	Cordia africana.	40	18
	Croton macrostachyus	262	53
	Dracaena afromontana	40	5
	Dracaena steudneri	67	2
	Grewia ferruginea	530	14
	Justicia schimperiana	120	6
	Maytenus undata	0	2
	Millettia ferruginea	350	42
	Olea capensis	24	10
	Prunus africana	44	7
	Syzygium guineense	400	21
	Teclea nobilis	21	14
	Vernonia amygdalina	56	13
	Vernonia auriculifera	150	4
	Total for this altitude range	**2159**	**214**

4.6. Regeneration Status in the Forest

The regeneration status of abundant tree species was poor. The density of seedlings and saplings was not as much as their dominancy in the Forest. In Gera Forest the dominant trees being 10 species (Appendix 3). According to Yohanis Mulugeta's (2013) floristic study of the Gera Forest the number of dominant trees species was ten where seven of them were represented by their saplings but the other three species *Polyscias fulva, Galiniera saxifraga* and *Olea welwitschii* were absent in sapling stages. In the case of their seedlings among the ten dominant tree species five specie were represented but the rest five species didn't exhibit any kind of regeneration. The dominant species like *Prunus africana, Syzygium guineense, Coffea arabica, Croton macrostachyus* and *Millettia ferruginea* also vary in degree of regeneration *Millettia ferruginea, Croton macrostachyus and Syzygium guineense* were relatively at better stage of regeneration in the Forest. *Polyscias fulva, Galiniera saxifraga* and *Olea welwitschii* were not represented in both seedlings and saplings whereas *Vepris dainellii* and *Schefflera abyssinica* were represented by sapling alone.

4.7. Gap Age and Regeneration

The gaps used in this research were categorized in to the following forest gap age classes, i.e., class 1 (1-3 years), 2 (4-6 years), 3 (7 -9 years) and class 4 (10-12 years). A comparative analysis of seedling density of all gap age classes has revealed that the maximum seedling density (1,577 individuals/ hectare) was in gap age class 2 while the youngest gap age class 1 has displayed a seedling density of 1,238 individuals/ hectare (Figure 12). Furthermore, seedling densities of 1155 and 457 individuals /hectare were recorded for gap age classes 2 and 4, respectively. With regards to sapling density, the highest value was recorded for gap age class 2 (210 individuals/hectare) and the lowest for the gap age class 1 (87 individuals/ hectare) (Figure 13).

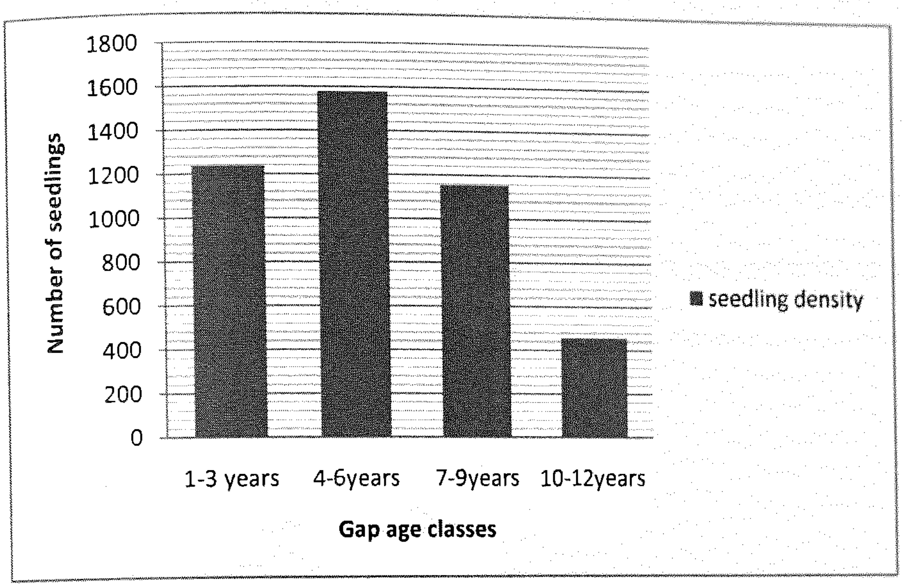


Figure 12 Seedling density/ hectare in different gap age classes

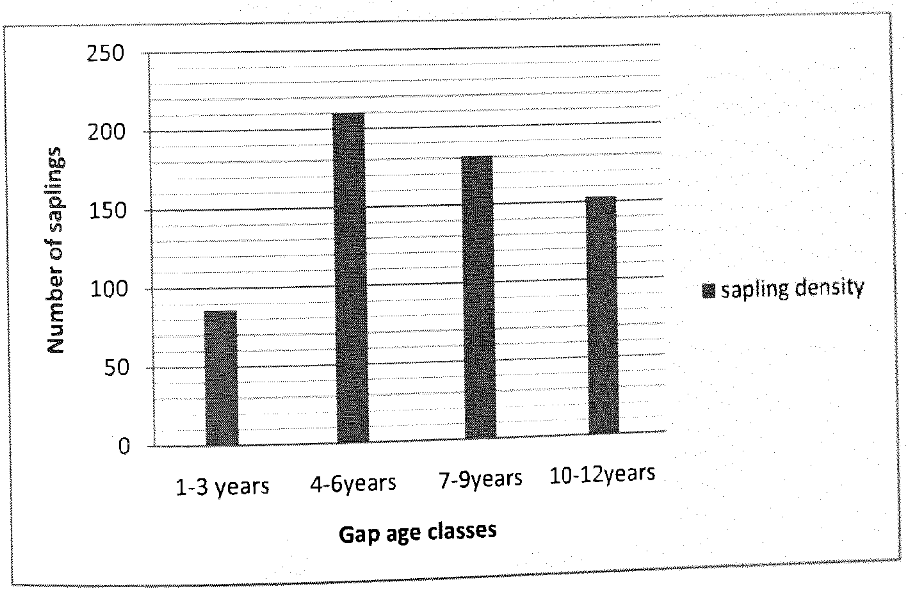


Figure 13 Sapling density/ hectare in different gap age classes

4.8. Gap Size Partitioning

In the current study, gap size partitioning was not recognized. A linear regression analysis has shown that gap size had slightly affected the number of forest gap regenerating woody species ($r=0.025$ $F=0.840$ $p=0.366$). Furthermore, gap size had also insignificant influence on sapling density (r^2= -0.023, F=0.242, p =0368,).

4.9 Gap Size and Regeneration

Most of the gap filling species occurred at any available forest gaps regardless of size as determined by species altitudinal ranges (Table 8). Furthermore, different species have exhibited variable values of regeneration in different forest gap sizes of the forest, for instance, some species like *Vernonia auriculifera, Vepris dainellii,* and *Prunus africana* have shown maximum regeneration status at the forest gaps size of 141.24 m^2. *Millettia ferruginea* had shown maximum regeneration in gap area of 221 m^2 but the species was also present in large area gaps of 455m^2 (Table8).

Table 8 Gap filler species and the gap area with their dominant gap size

No	Gap filling species	Number and size of gaps in each gap	Dominant gap
1	*Bersama abyssinica*	109.9,89.68,162.97	109.9
2	*Brucea antidysenterica*	175.36	175.36
3	*Calpurnia aurea*	170.65,263.76	170.65
4	*Coffea arabica*	128.6,187.6,187.92	187.6
5	*Cordia africana*	88,455,170.65,188.4,175.36,277.58,140.9,164.29,236.6,109.9	277.58
6	*Croton macrostachyus*	88,270,455,140.9,122.5,109.9,187.92,142.39,221.25,188.4,89.68 ,169.08,177.4,339.12,162.79,236.9	109.9
7	*Dracaena afromontana*	129.7,187.85,177.4,169.08,162.79,100.48	129.7
8	*Dracaena steudneri*	128.6129.7,187.92,254,142.39,263.79,210	254
9	*Ficus sur*	221.5	221.5
10	*Grewia ferruginea*	109.9,177.4,339.17,100.48,86.5,88,177.4,339.17,100.48,69.08	
11	*Justicia schimperiana*	140.9,122.5	122.5
12	*Maesa lanceolata*	89.68	89.68
13	*Maytenus arbutifolia*	175.6,164.29,187.92,455	164.29
14	*Maytenus undata*	129.7,137.68,189.42,247.1	247.1

15	*Millettia ferruginea*	129.7,137.68,187.68,187.58,164.29,187.92,109.9,86.5,254,142.39,170.65,221.25,263.76,188.4,339.12,162.792,100.48,175.36,277.58,175.36,140.9,122.5,264.88,210,455	221
16	*Olea capensis*	122.5,236.9,264,254,142.39,137.68,247.1,109.9,86.5	142
17	*Phoenix reclinata*	170.65,263.76,221.25,188.4	263
18	*Podocarpus falcatus*	128.6	128.6
19	*Prunus africana*	455,128.6,141.24,86.5,109.9,236.9	141.24
20	*Ricinus communis*	187.58,247.1	247.1
21	*Rytigynia neglecta*	122.6,187.58	122.6
22	*Schefflera abyssinica*	177.4	171.4
23	*Solanecio gigas*	109.9,169.08,177.4	109.9
24	*Syzygium guineense*	88,175.36,277.58,100.48,339.12,86.5109.9,169.08,177.4	339.12
25	*Teclea nobilis*	137.68,187.58,169.08,88,210,455	169.08
26	*Vepris dainellii*	109.9, 141.2, 175.36	141.2
27	*Vernonia amygdalina*	247.1,141.24,164.29,254,142.39	141
28	*Vernonia auriculifera*	137.68,141.24,89.68,88	141.24

4.10 Probabilities of Self-replacement of Gap Makers and by Gap-filler Species

Only three of the thirteen gap maker species were found to exhibit self-replacing in the course of this study (Table 9). *Millettia ferruginea* was recorded as the highest self-replacing (0.68) gap maker, whereas the other gap formers like *Syzygium guineense* and *Prunus africana* have shown much less self replacing than the dominant one by having 0.38 and 0.31 respectively.

Millettia ferruginea is the most dominant species, not only by replacement but also by growing in many gap areas. It was absent only in some places where the gap former was *Syzygium guineense.*

The second most dominant species was *Croton macrostachyus,* from the 34 gaps formed by thirteen species it was found in gaps formed by nine species (Table 9). Next to *Croton macrostachyus* was *Olea capensis* by occurring in gaps formed by eight species.

Furthermore, gap makers such as *Apodytes dimidiata,* *Albizia gummifera* and *Pouteria adolfi-friederici* lacked regenerating individuals in the forest gaps. In Gera Forest, most of the gap makers were being replaced by non -gap maker gap filling species such as *Brucea antidysenterica,* *Maytenus arbutifolia* and *Maytenus undata* (Table 9).

Table 9 The replacement probability of gap formers in different gaps in Gera Forest

Gap filling species	gap forming species													
	A.dimidiata	*A.gummifera*	*C.africana.*	*C.macrostachyus*	*M. ferruginea .*	O.welwitschii	*P. falcatus*	P.fulva	*P. africana*	P. adolfi-friederici	*S. abyssinica*	*S.guineense*	*T. nobilis*	*total occupanc*
B. abyssinica				*0.41*	0.27	0.3			0.166	*0.3*	*0.22*			6
B. antidysenterica							0.2	0.23						2
C. aurea									0.25			0.38		2
C. arabica								0.03	0.5					2
C.africana	0.27	0.41			0.28		0.15				0.13	0.16		6
C.macrostachyus	0.3	0.32			0.41		0.21	0.027		0.46	0.26	0.16	0.44	9
D.afromontana			0.11		0.27		0.11	0.13		0.36		0.15		6
D.steudneri	0.17	0.15	0.172	0.35	0.26				0.22			0.23		7
F. sur		0.21		0.13						0.07				3
G. ferruginea			0.17		0.1		0.4		0.28		0.6	0.2		6
J.schimperiana					0.07			0.2						2
M.lanceolata									0.21					1
M.arbutifolia					0.23				0.15		0.07	0.15		4
M. undata			0.33			0.3				0.2	0.13			4

Table 9 cont ...

	gap forming species													
Gap filling species	*A.dimidiata*	*A.gummifera*	*C.africana.*	*C.macrostachyus*	*M. ferruginea*	O.welwitschii	*P. falcatus*	P.fulva	*P. africana*	P. adolfi-friederici	*S. abyssinica*	*S.guineense*	*T. nobilis*	*total occupanc*
M. ferruginea .	0.08	0.38	0.315	0.21	**0.61**	0.31	0.23	0.15	0.69	0.47	0.04		0.28	12
O.capensis	0.22		1.22	0.07	0.08			0.15	0.17	0.3	0.28			8
P. reclinata		0.21							0.25			0.31		3
P. falcatus									0.06					1
P. africana	0.22			0.16					**0.31**		0.25			4
R. communis.			0.16		0.1		0.14							3
R.neglecta									0.1					1
S. abyssinica	0.41		0.17		0.13				0.13	0.28				5
S. gigas				0.25			0.23	0.34						3
S.guineense				0.13	0.18		0.11	0.13	0.15		0.71	**0.38**		7
T. nobilis	0.27	0.2			0.13	0.61	0.11			0.28	0.17			7
V. dainellii .							0.13		0.1	0.07				3
V.amygdalina			0.17	0.35	0.13			0.1	0.52					5

Abbreviations: A.dimidiata = *Apodytes dimidiata,* A.gummifera = *Albizia gummifera, B. abyssinica =Bersama abyssinica, B. antidysenterica= Brucea antidysenterica, C. aurea = Calpurnia aurea, C. arabica= Coffee arabica, C.africana= Cordia africana, C.macrostachyus= Croton macrostachyus, D.afromontana =Dracaena afromontana, D.steudneri =Dracaena steudneri, F. sur =Ficus sur, G. ferruginea= Grewia ferruginea, J .schimperiana= Justicia schimperiana, M .lanceolata= Maesa lanceolata, M .arbutifolia =Maytenus arbutifolia, M. undata = Maytenus undata, M. ferruginea =Millettia ferruginea, O.capensis= Olea capensis,* O.welwitschii= *Olea welwitsch, P.reclinata= Phoenix reclinata, P.falcatus=Podocarpus falcatus, P.african=Prunes Africana,* P. adolfi-friederici =*Pouteria adolfi-friederici,* P.fulva =*Polyscias fulva, R. communis = Ricinus communis, R.neglecta Rytigynia neglecta, S. abyssinica =Schefflera abyssinica, S. gigas= Solanecio gigas, S.guineense=Syzygium guineense, T. nobilis= Teclea nobilis, V. dainellii= Vepris dainellii, V.amygdalina = Vernonia amygdalina, V. auriculifera = Vernonia auriculifera*

CHAPTER FIVE

DISCUSSION CONCLUSION AND RECOMMENDATION

5.1 Discussion

5.1.1 Tree Fall and Gap Characteristics

The formation of tree fall gaps and their influence on forest regeneration and dynamics has a long history in ecology. Whitmore (1989) suggested that gaps openings in the forest canopy drive the forest cycle and thus the gap phase is important for determination of floristic composition of a forest. The tree fall gaps exhibited in Gera Forest are taken as small sized tree fall gaps. Most of the gaps in the Forest were formed due to natural causes. According to Taye Jara (2006), in Harena Forest, the canopy gap openings were formed due to wind and found out that most of the gaps were formed due to natural agents. In Gera Forest the gaps were created with uprooted trees and broken crown or branch that accounted for 61.76% and the main reason would be wind. Even if fire outbreaks once in a while, the chance that it will be put out by the frequent rains is high. The high forests in this zone are, characteristically, found on areas of medium to high slopes making the risk of fire spread and hazard a big threat. Fire outbreak during dry seasons, associated with high temperature, low moisture and ample dry fuel, can be devastating in this zone (Demel Teketay, 2005)

Gaps formed by dead standing gap makers have a smaller size and a slower opening ratio. Growth of seedlings or saplings present at the time of the death of canopy trees (advance regeneration) in the state after gap formation became poor. In Gera Forest, gaps formed with dead standing trees show lower regeneration status. Forest under story was more disturbed by trunk broken than by dead-standing gap makers. Herbs shrubs and young juvenile trees were affected by the disturbance most. Taye Jara (2006), in the study conducted in Harenna Forest, recorded seedling and sapling density of 14872/ hectare and 678/ hectare respectively. The number of seedlings and saplings collected in this study was low as compared to that of Harenna. Uprooting gap makers bring about the most severe disturbance to the soils in the gap (Falinski, 1978). As the soil mass, adhering to the roots of uprooting gap makers generally turned over, uprooting results in pit-mound micro topography and inverted soil horizons on the ground of the gap (Peterson and Pickett, 1990).

Uprooting gap makers may leave buried viable seeds exposed to the environments required for germination (Yamamoto, 1989) such as *Fagara ailanthoides* (Yamamoto, 1989) and provide a suitable substrate for tree species requiring mineral soil for establishment (Yamamoto, 1989; Nakashizuka, 1989) such as *Betula* spp. (Yamamoto, 1989). The internal heterogeneity within gaps formed by uprooting gap makers is important to determine the species composition of re growing vegetation in gaps (Orians, 1982; Putz *et al.*, 1983; Nakashizuka, 1989). The regeneration density observed in Gera Forest was low. Fourteen gaps were formed by uprooted trees and as the data indicate dominant gap formers were found to be trees with heavy crowned. When heavily crowned tree are uprooted the crown size covers those viable seeds in the forest and the seeds are buried. The seeds which escaped from the process need favorable situations for growth and the uprooted trees bring change in the soil horizons; this would have inhibit the regeneration status of trees in Gera Forest.

Tree fall gaps are openings as opening in the forest canopy down through all foliage levels to an average regeneration height of two meters. In Gera Forest the gap size showed that only 2.94 % (n = 1) of the gap exeeded 400 m^2. Where Runkle (1982) classified the gaps as small and exte nded. The gaps found in this forest were small; 97.06% of the forest gaps are small gaps rangin g from 100.9 up to 339 m^2. A gap less than 100 m^2 was not encountered in this reaserch area. Si nce small gaps tend to be filled easily and quickly than larger gaps these gaps were easily colon ised by regenerating species and filled their canopy Yemamoto (1989).

The mean size of the gap in the study area was 190.85, with a range of 100.48 – 455 m^2. The gap in wet regions had been found to be smaller as compared with other forests like Harena forest. The study reported for mean gap size (289.74 m^2) and range (101.03 - 896.93m^2) (Taye Jara 2006). However, other studies performed in north-eastern Mexico, the Atlantic Montane Rain Forest (Lima and Moura 2008) and Western Ghat India (Chandrashekara and Ramakrishnan 1994) reported smaller mean gap areas than those we observed. The suggestions of these differences are mainly of 2 reasons. First, the gap size is often affected by forest developmental stage (Yamamoto 2000), since mean gap size is generally larger in old-growth stands than in younger stands. The mean gap size would also be affected by the type of measurement used. In Gera Forest, to measure the area the method used was the longest distance between two canopies and gap length was measured by taking the measure of the largest distance perpendicular to the length. This method has been widely used and minimizes mistakes than aerial photo method designed by Yamamoto (2000).

The negative correlation between number of seedlings and gap size (r = -0.02) may generate an assumption that gap size plays limited roles in the regeneration degree of species in the Gera

Forest. The significant differences that exist between gap types may be attributed to the variations in sizes of the species involved in gap formation. A significant difference exists in the forest canopy opening and regeneration. Most of the dominant trees and heavily crowned species such as *Schefflera abyssinica, Croton macrostachyus* and *Prunus africana* formed gaps through uprooting resulting in relatively large forest gaps. In the Forest the gap size determined by the species that formed the gap species *Millettia ferruginea, Prunus africana Pouteria adolfi-friederici, Schefflera abyssinica* and *Syzygium guineense* are the major heavily crowned trees in Gera Forest.

5.1.2 Gap Regeneration, Gap Size and Selected Physical Parameters

The observed weak relationships between density of species in gaps and gap size may suggest that most gap occupants were already present before gap formation due to advance regeneration. In other words, shade tolerant seedlings that existed before gap formation or due to re-sprouts under a shady condition could rapidly fill the gaps. It follows that out of the 28 gap-filling species recorded in the current study, saplings of 24 of them were recorded in forest gaps (Bekele-Tesemma et al, 1993).

In general, gap size is not the only factor determining regeneration in the forest gaps. Spatial location within a gap, gap shape, orientation, aspect and time of gap creation may have major influences on local regeneration (Brokaw and Busing, 2000).

According to Legesse Negash (1995), birds ingest fig pieces together with tiny seeds, and deposit the latter along with their excreta on the bifurcation point of the longer tree stem. When there is favorable condition the seed germinate. In the Gera Forest, the saplings of *Ficus sur* were exhibited in the area but not represented in seedling stage and the above statement clarifies that the occurrence was due to seed dispersal mechanisms.

Differences in tree growth among gap sizes increased over time, indicating a lag in the adjustment of mature trees to their new environment (e.g., Williamson, 1982; McDowell *et al.*, 1996). Increased exposure from thinning or gaps can lead to negative or no growth response in mature and old-growth trees in the first decade after disturbance, or delays in positive response for up to 20 years (Garber *et al.*, 2011). In this study, differences in growth of over story species among gaps were greatest in mature stands, where growth was similar across gap sizes and varied little with some species. Some species grew in both large and small gaps but found dominant in smaller gaps than larger gaps. Similar results have been seen in other studies of trees in a vigorous condition, and suggested a primary response to additional soil moisture rather than light (McDonald *et al.,* 1996). In contrast, diameter growth of over story old-growth trees did vary with gap size and position around gap, and suggested a positive effect from intermediate increases in solar radiation and a negative effect at higher light levels in the largest gaps (McDonald *et al.*, 1996). The cause of potential negative growth effects of the large gaps in Gera Forest was also discovered to be caused due to the nature of seeds of different trees. The regeneration was also affected by the type of gap and gap forming species. As indicated above some viable seeds would easily be covered by gap former and if the gap was formed by uprooted tree the tree would have buried the seeds in the ground.

Croton macrostachyus occur in most disturbed areas. The tree is common in secondary forests. The secondary forest implies that the forest is not in natural vegetation rater it is grown after the natural forest being removed due to disturbance (Legesse Negash 1995). According to Legesse Negash (1995), the two big cotyledons are quite persistent and are thus very important for the normal growth and development of the seedling especially. The seed dispersal in *Milletttia ferruginea* helped it to regenerate in many gaps in the forest.

5.1.3 Gap Makers and Replacement Probabilities

Almost all the 28 gap-filling species encountered in Gera Forest were located at most of the available gap size ranges. There was no recognizable pattern of species composition across the gap sizes. Brokaw and Busing (2000) and Obiri and Lawes (2004) have also reported the existence of no recognizable sequence of species across the gap sizes. A self-replacement probability in Gera Forest was investigated as remarkably weak. From the 13 gap making species only three were found to be replaced by their saplings.

According to Demel Teketay (2005) most of the forests in Ethiopia have been cleared by either slashing, burning and other natural causes or both natural and anthropogenic causes. The gaps created in the forest vegetation are quickly colonized by plants recruited from the soil seed bank as well as seed rain originating from the surrounding vegetation, pre-existing seedlings and shoots sprouting from stumps of woody species. In Gera forest some species are found to be represented in their seedling but the adults were found absent this is caused due to seed rain originating from the surrounding vegetation by dispersal and other mechanisms

In many cases, the species of tree creating a gap seemed to influence the species composition of its likely successors (Runkle, 1981), which could be considered a tendency to self-replacement. However, Runkle (1982) has found an inverse relationship between the saplings and gap-makers.

Sapotka and Odén (2009) also found that in many tropical forests, the larger canopy species do not regenerate in the same locations in which the adults occur. The replacement property of gap making species in the forest was poor.

Species such as *Olea welwitschii* and *Schefflera abyssinica* were characterized by bell shaped distribution pattern in Komto Afromontane moist forest. This pattern indicates poor reproduction and recruitment, which is exhibited in Gera Forest and also associated with intense competition from surrounding trees. Senbeta et al. (2007) and Woldeyohannes (2008) reported similar reasons for a bell-shaped population structure in different forests of Sheko Forest and Alata-Bolale Forests in Ethiopia.

As Sapotka, and Odén (2009) stated the tropical heavy crown trees fail to replace themselves due to the location with the adult. *Olea welwitschii* and *Schefflera abyssinica* can be taken as examples for the replacement degree of these species which was zero which may be due to seed viability or as stated it will be location with parent tree. In most gaps *Millettia ferruginea* was present this also indicative for species having viable seed that can fill the gap so easily rather than those with orthodox seed types.

According to Legesse Negash (1995) *Millettia ferruginea* one of the dominant species as a gap filler has a tendency to grow in this kind of environment not only this germination potential of this species is high. The seed physiology of the species is well fit to the study area type of environment.

Furthermore, Obiri and Lawes (2004) found less probabilities of self-replacement in south scrap forest of South Africa. The weak self-replacement probabilities of the Harenna Afromontane Forest also indicated the unpredictable species assemblages in the forest gaps (Taye Jara, 2006). These assemblages were attributed to a chance effect of recruitment and/or dispersal limitation of species from the surrounding species pool. In Gera Forest the species poor self replacement was also caused by other factors like limitation in dispersal of seeds. The regenerating species are from the surrounding but the assemblage is directly related with chance factor.

5.2 Conclusion and Recommendation

The investigation of gap dynamics in Gera Forest revealed that small scale disturbances caused by single tree or group of trees fall are essential for maintaining the diversity of woody species in the forest. In addition to this, the mode of mortality is mainly related to the species of canopy tree that involved in the process. The variations observed in the gap sizes were due to factors such as mode of death and size of the tree that made the gap. Gap sizes differed based on mode of disturbances. Even though, gap size played an important role in determining species richness in forest structure, the effect of gap size on species richness and sapling density of the forest is very low. In the contrary the gap environment was more favorable for the recruitment of most of the woody species. A self-replacement probability in the forest was low.

The study of gap dynamics was not carried out in this moist montane forest before therefore, the current study of gap dynamics could provide some aspects of gap regeneration in the forest. This could attract various professionals to carry out further assessments on different aspects of gap dynamics of the forest. Therefore, I recommended that:

- Ecologists, biologists and other professionals should pay attention to the study of gap dynamics, as it is important in maintaining the diversity of species and stability of ecosystems.
- The trees which formed the gap were cleared from the area for fuel and other purposes this will decrease the fertility of the soil so has to be stopped.
- In some areas the regenerating species were harmed by individuals specially by those indigenous bee hive workers.
- The trees which fall in natural causes specially *Croton macrostachyus* was removed by the local community for making bee hives so this will affect the data collection.
- Species in the forest should get the appropriate attention and should be conserved in-situ (in their natural habitat) through the collaboration of local communities with the District Agriculture and Rural Development Office and other interested individuals and stakeholders; and further investigation should be carried out to identify the reasons for the absence of regeneration.

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Appendix 1 Gap forming species their cause and DBH and their area coverage in each gap

quad	gap former	cause of gap	total gap area	DBH
1	*Prunus africana*	up rooted	128.6	66.87
2	*Millettia ferruginea* .	up rooted	129.7	22.8
3	*Pouteria adolfi-friederici*	up rooted	137.68	70.06
4	*Pouteria adolfi-friederici*	up rooted	`187.58	42.1
5	*Olea welwitschii*	bole snapped	189.42	41.5
6	*Cordia africana*	cut	247.1	47.1
7	*Prunus africana*	branch/crown brecage	141.24	66.87
8	*Prunus africana*	up rooted	164.29	64.5
9	*Albizia gummifera* .	up rooted	187.92	127.38
10	*Prunus africana*	up rooted	109.9	44.5
11	*Schefflera abyssinica*	branch/crown brecage	186.5	19.23
12	*Croton macrostachyus*	up rooted	254	94
13	*Millettia ferruginea*	up rooted	142.39	62.3
14	*Prunus africana*	up rooted	170.65	42.39
15	*Syzygium guineense*	branch/crown brecage	263.76	68.5
16	*Apodytes dimidiata*	bole snapped	221.25	44.2
17	*Syzygium guineense*	up rooted	188.4	49.4
18	*Croton macrostachyus*	up rooted	109.9	35

19	*Teclea nobilis .*	up rooted	189.68	23
20	*Podocarpus falcatus*	cut	169.08	89.17
21	*Polyscias fulva*	branch/crown brecage	177.4	47.2
22	*Schefflera abyssinica*	unclassified	339.12	------
23	*Pouteria adolfi-friederici*	standing dead	162.792	52.6
24	*Syzygium guineense .*	branch/crown brecage	100.48	26
25	*Podocarpus falcatus*	cut	175.36	31
26	*Prunus africana*	standing dead	277.58	55
27	*Schefflera abyssinics*	branch/crown brecage	175.36	42
28	*Millettia ferruginea*	unclassified	140.9	-------
29	*Polyscias fulva*	bole snapped	122.5	48
30	*Albizia gummifera*	bole snapped	236.9	38.26
31	*Schefflera abyssinica*	standing dead	264	114.64
32	*Millettia ferruginea*	bole snapped	188	32
33	*Apodytes dimidiata*	up rooted	210	47
34	*Schefflera abyssinica*	up rooted	455	130.9

Appendix 2 Habit of gap filling species

no	gap filler species	Families	habit	local name
1	*Bersama abyssinica*	Meliantaceae	tree	Lolchisa
2	*Brucea antidysenterica*	Simaroubaceae	shrub	Qomenyo
3	*Calpurnia aurea*	Rubiaceae	tree	Cheka
4	*Coffea arabica.*	Fabaceae	shrub	bunae
5	*Cordia africana*	Boraginaceae	tree	wedessa
6	*Croton macrostachyus*	Euphorbiaceae	tree	bekenisa
7	*Dracaena afromontana*	Dracaenaceae	tree	Algea
8	*Dracaena steudneri*	Dracaenaceae	tree	
9	*Ficus sur*	Moraceae	tree	Harbu
10	*Grewia ferruginea*	Tiliaceae	shrub	Bururi
11	*Justicia schimperiana.*	Acanthaceae	shrub	
12	*Maesa lanceolata*	Myrsinaceae	tree	Abeyee
13	*Maytenus arbutifolia*	Celastraceae	tree	kombolcha
14	*Maytenus undata*	Celastraceae	tree	kombolcha
15	*Millettia ferruginea*	Fabaceae	tree	Askera
16	*Olea capoensis*	Oleaceae	tree	beya
17	*Phoenix reclinata*	Arecaceae	shrub	Meti
18	*Podocarpus falcatus*	Podocarpaceae	tree	Bibirsa
19	*Prunus africana*	Rosaceae	tree	Omo
20	*Ricinus communis.*	Euphorbiaceae	shrub	

21	*Rytigynia neglecta*	Rubiaceae	tree	Mito
22	*Schefflera abyssinica*	Araliaceae	tree	Botto
23	*Solanecio gigas*	Asteraceae	shrub	
24	*Syzygium guineense*	Myrtaceae	tree	Bedessa
25	*Teclea nobilis*	Rutaceae	tree	Hadesa
26	*Vepris dainellii .*	Rutaceae	tree	hadesa
27	*Vernonia amygdalina*	Asteraceae	shrub	Ebicee
28	*Vernonia auriculifera*	Asteraceae	shrub	Reji

Appendix 3 Some of the dominant species in the forest

Importance Value Index (IVI) of the dominant tree species of Gera forest

(RF =Relative Frequency, RD = Relative Density, and RDO = Relative Dominance)

Species	**RD %**	**RDO %**	**RF %**	**IVI %**
Coffea arabica	23.12	7.92	48.89	79.93
Croton macrostachyus	6.49	4.01	7.19	17.69
Galiniera saxifraga	5.37	2.12	4.37	11.86
Millettia ferruginea	8.03	4.65	4.12	16.8
Olea welwitschii	2.53	5.32	3.98	11.83
Polyscias fulva	14.20	2.55	5.19	21.94
Vepris dainellii	9.2	1.76	4.69	15.65
Prunus africana	4.57	6.34	3.62	14.53
Schefflera abyssinica	15.25	34.17	9.97	59.39
Syzygium guineense	11.07	30.7	7.90	49.67
Total	**99.83**	**99.54**	**99.92**	**299.29**

Appendix 4 Model Summary of regression analysis of gap size over number of seedlings of gap filler species

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.1599522
R Square	0.0255847
Adjusted R Square	-0.004866
Standard Error	77.492672
Observations	34

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	5045.537845	5045.538	0.840207	0.36619442
Residual	32	192163.6528	6005.114		
Total	33	197209.1906			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	200.9368	23.0626476	8.712651	5.9E-10	153.959721	247.9139	153.9597	247.9139
X	-0.13278	0.144857116	-0.91663	0.366194	-0.42784437	0.162284	-0.42784	0.162284

Appendix 5 Model Summary of regression analysis of gap size over number of saplings of gap filler species

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.086653033
R Square	0.007508748
Adjusted R Square	-0.023506604
Standard Error	78.20813507
Observations	34

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1480.794	1480.794	0.242098	0.626054
Residual	32	195728.4	6116.512		
Total	33	197209.2			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	201.8149434	39.26034	5.140428	1.32E-05	121.8443	281.7856	121.8443	281.7856
Y	-0.979803295	1.991331	-0.49203	0.626054	-5.03601	3.076405	-5.03601	3.076405