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Composition Study of Soil Seed Bank at Gera Moist Evergreen Afromontane Forest, Jimma Zone of Oromia Regional State, Southwest Ethiopia

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Abstract

Soil seed banks are important sources of new individuals for many plant populations and contribute to future genetic variability. The objective of this study was to investigate the composition of soil seed bank at Gera moist afromontane forest. A total of fifty quadrats were established in the selected sites. The quadrat size (30m × 30 m) for trees, shrubs and herbs and with seedling (height ≤ 1.0 m), sapling (height between 1 and 3 m) and mature tree/shrub (height >3 m) laid down to examine similarity between standing vegetation and seed bank flora as well as natural regeneration of the study site. Soil samples were collected from the main quadrats measuring 15 cm X 15 cm and from four soil layers, the litter layer and three successive layers (0-3 cm, 3-6 cm, and 6-9 cm). A total of 66 plant species germinated from all the soil samples collected for the investigation. Herbs dominated the soil seed bank representing nearly 65.7% of the identified species. The greatest reserves of seeds were in the surface layer of the soil (0-3 cm). Between the standing vegetation and the soil seed bank there was very low similarity (JCS = 0.08-0.28). However, there was a general tendency of appearance of native woody species from the soil seed bank as evidenced by the germination of few woody species. This implies that reliance on the soil seed bank for the recovery of native woody species is worthy for Gera moist afromontane forest.

Key words/phrases: - Gera Forest, land use type, Soil seed bank, Species composition

Introduction

Vegetation types in Ethiopia are highly diverse, varying from Afroalpine to desert vegetation. However, the vegetation resources, including forests, reduction in Ethiopia is mostly attributable to anthropogenic factors. The most prominent ones are deforestation, expansion of agricultural land, overgrazing, unsustainable utilization and invasion of exotic species, overexploitation for various purposes such as firewood, charcoal, construction material and timber, all spurred by rapid human population growth [1].

Seed banks, which are the aggregations of viable seeds in the soil potentially capable of replacing adult plants, play a critical role in vegetation maintenance, succession, ecosystem restoration, differential species management and conservation of genetic variability [2]. Soil seed bank exhibits variations in space as well as time and displays both horizontal and vertical dispersion, reflecting initial dispersal onto the soil and subsequent movement [3].

The composition of a seed bank depends on present and former aboveground vegetation and seed rain from adjacent areas. The historical composition of aboveground vegetation has often been identified as a key factor determining seed bank composition [4].

In most tropical areas, the degraded or completely destroyed forest sites are changed either to other land uses, establishment of monoculture plantations of fast growing trees [5], or permanent arable lands, which is a common practice in the tropics, in Ethiopia. In these cases, although the seed banks have the potential to initiate re-vegetation of the sites, they are continuously eliminated through weeding practices and ultimately completely exhausted. The other scenario could be the conversion of the destroyed forest sites to permanent arable lands followed by their abandonment. Here, some of the persistent seeds in the soil and the seed rain (if any) may lead to restoration of the vegetation. Plants developing from seeds in the top layer of soil, usually dicotyledonous weeds represent strong competition to the seedlings of grasses, which develop more slowly [6]. The studies about the seed banks of vegetation types can reflect community histories and play an important role in rehabilitating degenerated ecosystems.

MATERIAL AND METHODS

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Description of the Study Area

The study was conducted in Gera District, Jimma Zone of Oromia Regional State, Ethiopia. The Forest is located at about 380 km southwest of Addis Ababa and covers a total area of 80,830.4 ha. The altitudinal range of the study area is from 1300 to 2400 m a.s.l. The mean annual temperature is about 18.4°C and the mean minimum and maximum temperatures are 11.7 and 26.5° C respectively. 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.

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 [7] (Figure 1).

Figure 1

Methods of Data Collection

Sampling design

Reconnaissance survey and data collections were made between September and November 2012. The reconnaissance survey was made to obtain an impression about the variation of the study area. The survey indicated that the study area comprises a mosaic of different land use types. Gera Forest contains modern coffee plantation forest, non-coffee forest, wild coffee forest, ridge and valley. The land use types found at different altitudes have different types and levels of disturbances. Therefore, the selected area would give a chance to investigate soil seed bank regeneration potential, and to study the effects of the habitat type on potential of soil seed bank regeneration. The selected habitat types were characterized and defined in the following way: **RI** (ridge), **VA** (valley), **WCOF** (Wild Coffee forest), **NCOF** (Non-coffee forest) and **MCOFP** (Modern Coffee plantation)

Vegetation data collection and plant identification

Vegetation data were collected to examine the similarity between above ground and seed bank floras. A total of 50 quadrats were analysed. The quadrat sizes established for all growth form were 30 m x 30 m (900m^2). In each quadrat all trees, shrubs and herbs were identified. The altitude of each quadrat was recorded by using GPS. The collected specimens of each/ species in the plot were numbered, pressed, and taken to the National Herbarium (ETH), Addis Ababa University, for drying, identification and storage. Plant specimen identification and verification have been made by referring to the Flora of Ethiopia and Eritrea comparison with authenticated specimens housed at ETH and consulting experts.

Soil Seed Bank Analysis

In order to investigate the composition and density, as well as the vertical distribution of the soil seed bank in the different land use types, soil samples were collected from sampling plots measuring 15 cm x 15 cm (one at the center and the other four at the corners) and a vertical depth of nine centimeters in each sample quadrat. The Sampling method employed was systematic.

A line transect was laid along an altitudinal gradient between 1650 to 2350 m a.s.l. Along three transect lines, 1st from Chira Town to Anfalo District, 2nd Weastern part of Chira Town to non-coffee forest, and 3rd from Chira Town to Agaro town. From each sample plot four layers consisting of the litter layer and three successively deeper mineral soil layers (each three centimeters thick) were carefully removed with a field knife and a spoon and placed separately. The reason for taking the soil samples at the three soil layers were to examine if there was any variation in the depth distribution of seeds within and among the Gera Wild Coffee Forest, Non-coffee forest, Modern Coffee Plantation, Ridge and Valley Forest in the soil.

A total of 200 soil samples, including the litter layer, were collected from 50 quadrats at Gera Forest. At Chira Town-Anfalo site, a total of 16 soil samples composed of 64 different soil layers and including litter were taken. On the second study site, around Chira Town Non-Coffee area, a total of 21 soil samples composed of 84 different soil layers and including litter were taken. On the third study site, Chira to Agaro, a total of 13 soil samples composed of 52 different soil layers and including litter were taken.

For such investigation from three study sites, a total of 200 soil samples were taken from four soil layers, the litter layer and three successive layers (0-3 cm, 3-6 cm, and 6-9 cm). Soil samples from identical layers of the five subplots were mixed to form composite samples in order to reduce heterogeneity within the quadrats. Later on, the composite samples were divided into three equal parts out of which one was randomly chosen as the working sample for the study. The soil samples were transferred to cotton bags and transported to the greenhouse of the Department of Plant Biology and Biodiversity Management, Addis Ababa University.

Greenhouse germination

The seedling emergence experiments were performed in a greenhouse at the Department of Plant Biology and Biodiversity Management, Addis Ababa University under average temperature and humidity of 24°C and 57.5%, respectively. In the greenhouse, each three centimeter layer soil was spread in a labeled circular plastic tray. Prior to spreading, each sample was thoroughly mixed after removal of all twigs, roots and rhizome fragments. To facilitate proper drainage of water, the pots were perforated at the bottom. Samples were then watered with a misting nozzle every other day to initiate germination and subsequent seedlings were checked twice per day.

The first seedlings in the greenhouse appeared two weeks after the start of the germination experiment. Because of shade tolerant species the sample pots were placed under the table to control direct sun light. The emerging seedlings were collected, counted, pressed, dried, checked, and cross checked with the seedling that we collect from the study site for further identification plant species at seedling stage and identified at the National Herbarium (ETH), Department of Plant Biology and Biodiversity Management, Addis Ababa University. Identified seedlings were recorded and discarded.

Seedlings that were identified at the species level were counted and removed to reduce the possibility of germination suppression of other seeds due to competition. Seedlings that could not be identified were individually transplanted to pots and grown, where necessary, until flowering. After three months, germination in most trays ceased, partly due to colonization of the trays by mosses and liverworts. By that time, the soil samples were stirred in order to expose seeds to the light that resided in lower sections of the soil layer within the trays, which might have hampered germination. Stirring was done every three months. After 12 months (November 2012 to November 2013), few additional seeds were germinating even immediately after stirring the soil, and the experiment was concluded.

Digital information (photo) of the seedlings was taken to be included as a pictorial representation.

Data analyses

To investigate the effect of habitat types and the potential of soil seed bank flora, in terms of species composition of soil seed bank flora, the data were analyzed in the following ways. Species composition (number of species germinated per sample) and density of the soil seed bank among the study sites and between soil depths were compared using two-way analysis of Variance. Similarities of soil seed bank flora and above ground vegetation were also compared using Jaccard's Coefficient of Similarity (JCS) [8]

$$S_j = \frac{a}{a+b+c}$$

Where S_j = Jaccard similarity coeffiecient

a= number of species common to both quadrats/samples

b= number of species in quadrat/sample 1

c= number of species in quadrat/sample 2

The density of seeds/m^2 was derived from the total number of seeds recovered from the soil samples. On the other hand, to analyze the depth distribution of seeds in each land use type, the number of seeds recovered in similar layers were combined and converted to provide the density of seeds/m^2 at that particular soil depth. One-way analysis of variance through the use of Minitab version 16 was used to assess the differences in density of seed bank between habitat types. Total regenerating individuals are expressed as density per hectare. Similarity index of soil seed bank regenerated species in the different land use types was calculated using Jaccard's Coefficient of Similarity (JCS) [8]

Results

Description of the Habitat Types

Based on visual observation, five major habitat types were identified in the study area. These are acronymed as RI (Ridge), VA (Valley), WCOF (Wild Coffee Forest), NCOF (Non-coffee Forest) and MCOFP (Modern Coffee Plantation).

Species composition of soil seed banks

A total of 66 plant species representing 34 families were recovered from the litter and the 0-9cm soil samples from the study area. Herbs were dominant and represented by 44 species (66.7%), while shrubs and trees were represented by 21 species (31.8%) and climber 1 species (1.67%). The species composition in different land use types ranged from 29 to 62 species; the highest number of species was recovered in the Non-coffee forest habitat types and the lowest in the Modern Coffee plantation.

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Out of the total number of species recorded, 62 were from Non-coffee Forest, 60 from Valley habitats, 51 from Ridges, 41from Wild Coffee Forest and 29 species were recovered from Modern Coffee Plantation. Overall, only a few species of woody (shrub/tree) were recorded from the soil samples collected from Modern coffee plantation, i.e. only 7 shrubs/ trees germinated from the collected soil samples. However, all the other habitat types had more recovery of woody species (figure 2).

Figure 2

Similarity in species composition among land use types

The similarity in species composition of the soil seed bank between the five-land use types was generally high and ranged from JCS values of 0.414 (between Non-Coffee Forest and Modern Coffee Plantation forest habitat types) to 0.737 (between Ridge and Valley habitat types). The second highest similarity in species composition (Sj = 0.721) was recorded between Non-coffee Forest and Valley habitat types (Table 1).

Table 1

The similarity between the soil seed bank and aboveground flora was very low (ranging from Sj values of 0.08 for Modern Coffee Plantation Forest to 0.28 for Non-coffee forest (Table 2).

Only seventeen woody species out of 66 species (*Vernonia hochstetteri*, *Vernonia auriculifera*, *Vernonia amygdalina*, *Syzygium guineense*, *Rubus niveus*, *Podocarpus falcatus*, *Olea welwitschii*, *Millettia ferruginea*, *Maesa lanceolata*, *Macaranga capensis*, *Ehretia cymosa*, *Ficus sur*, *Erythrina brucei*, *Coffea arabica*, *Cordia africana*, *Croton macrostachyus* and *Allophylus abyssinicus*) were represented both in the aboveground vegetation and in the soil seed bank. Some woody species that are commonly found in the aboveground flora, especially in Wild Coffee Forest and Non-Coffee Forest, were not represented in the seed bank. For example, *Albizia gummifera*, *Brucea antidysenterica*, *Ekebergia capensis*, *Teclea nobilis*, *Schefflera abyssinica*, *Rhamnus prinoides*, *Ricinus communis*, *Prunus africana*, *Olea capensis* and *Pouteria adolfi-friederici* are abundant species in the aboveground flora but absent from the seed bank.

Table 2

Compositions and Density of Seedlings and Saplings in Gera Forest

Seedlings of 24 different woody species were encountered during the current study. The aggregate density of these seedlings was 4,208 individuals /hectare. *Millettia ferruginea* was found to have the highest seedling density (741individuals/hectare). While *Grewia ferruginea* had the second highest seedling density (740 individuals/hectare) in the natural gaps study conducted at Gera forest. On the other hand, some species exhibited to have the smallest seedling density (individuals/ hectare) in the forest. Twenty-seven woody species were recorded inside the sampled plots. The aggregate density of saplings was 630 individuals/hectare (Figure 6).

Figure 3

DISCUSSION

Soil Seed Banks

The seed bank in Gera Forest contains many species (66) as determined from germinated seedlings. This goes and line with earlier findings that showed vegetation maintains and increases its populations through the process of regeneration involving soil seed banks and vegetative sprouts [9]. The mean sapling was higher and seedling density was lower than in other similar montane forests. For instance, [10] recorded a density of 1331.1h^{-1} seedling and 917h^{-1} sapling in Wondo Genet moist montane forest. This difference is probably due to selective logging of Wondo Genet seed trees leaving several species with little or no offspring.

The seed banks were dominated by herbaceous species in the study area, while woody species were fewer in number. Most of the seed banks under the different habitat types were characterized by high proportions of herbs (about 65.7%) while woody plants dominated the aboveground flora recorded. Wang *et al*. (2009) stated that the high density of herbaceous seeds in the seed bank may be related to species traits **[11]**. The seed sizes of most herbs are small and easily dispersed by different mechanisms and get the opportunity to find with high density in the soil seed bank. The similarity between the seed bank and aboveground flora was low. All seeds in the soil (from the standing vegetation or dispersed from far distances) were not likely to germinate, their loss can be one of the probable reasons for the weak association between the seed bank and standing vegetation. Several studies have supported the lack of similarity in species composition between the seed in the soil and the aboveground vegetation **[12]**; **[13]**; **[4]** ; **[14]** and **[15]**. Abundance of species in standing vegetation had predictive value for abundance in the persistence seed bank. At the local scale the present study indicated that the persistent seed bank and standing vegetation have exhibited low compositional similarity, which agrees with the result obtained by **[15]**. Seeds can be buried or lost by being washed down, especially in coarse textured soils, transported into deep parts of the soil by ants and worms or may die from genetically controlled physiological responses to environmental factors **[13]**.

Moreover, there are more herbaceous seeds in the upper soil layer than in the lower soil layer. This pattern may be attributed to seed size and the vertical movement of seeds. The smallest seed size has high potential to bury in the soil and can get much transportation opportunity to travel to the soil.

Some other species, although present in the above ground vegetation, lacked viable seeds, which were observed after greenhouse experiment. It could be argued that these species may have nonviable seeds in the sampled soil although the soil samples were not subjected to sieving [15]. Before identification has been made many species were dead at seedling stage and the growth of seedlings was very slow in the green house.

Generally, the observed low representation of the standing vegetation by the seed bank could be attributed to coffee cultivation and human disturbance, inducing lack of seed reserve for vegetation to respond following a favorable condition. One of the main probable reasons for the disparity between aboveground vegetation and soil seed bank flora, as explained by [16], seeds of the woody plant species which are found in the aboveground flora germinate immediately within a few days after dispersal (have transient seeds) therefore they can't store seeds for a long period of time in the soil as herbaceous plants. Thus many woody species in forests germinate within a few days or weeks after dispersal. However, composition of the seed bank recorded resembled the aboveground vegetation in few cases; for example, *Coffea arabica, Rubus niveus, Achyranthes aspera, Alchemilla abyssinica, Galinsoga quadriradiata* and *Solanum nigrum* are indicator species for the study sites.

In the present study, herbaceous species constituted the most prevalent growth form emerging from various land use types. Their predominance in seed banks can be explained by a combination of several factors. These herbaceous plants are generally less likely to be predated on, or damaged by microorganisms than large seeds of perennial tree species. Seed size may be another factor responsible for the scarcity of many aboveground species in the seed banks, because seed size and seed longevity are often negatively correlated [11].

Herbaceous species have survived through time because of their ability to resist several adverse climatic conditions, tolerating high and low temperature, dry and humid environment and variation in oxygen supply [17]. The conclusion from this study was that the seed banks usually contain a high proportion of herbaceous species, which depend on the persistent seed bank as part of their opportunistic strategy.

With continuous coffee plantation, along Chira Town to Agaro, the proportion of herbaceous forest species declines and the seeds of weedy species such as *Galinsoga quadriradiata, Acyranthes aspera and Bidens* species which are favored by continuous cultivation, increase rapidly in the soil. As the cultivation progresses, the composition and density of the seed bank start to change gradually. The change is more pronounced in the woody component of the seed bank as evidenced almost from the dominance only by a few of the woody species in the Coffee Plantation and Wild Coffee Forest. Selective trees like *Albizia gummifera* and *Pouteria adolfi-friederici* trees have been left because the shade of these species is too deep for maximum coffee growth, and because the wood is of high economic value. Since these trees are cleared from time to time, their reproductive capacity is greatly reduced. Even if they produce seeds, which eventually germinate, the seedlings are removed regularly due to continuous clearing for coffee plantation. Consequently, herbs, including grasses, would dominate the soil seed bank since many herbs grow and reproduce quickly from seeds.

Therefore, the woody species representation in the seed bank or advance regeneration is usually low or totally absent. On the other hand, seeds of the woody species may germinate soon after dispersal or may be affected by pathogens and predation agents and as a result few such species were represented in the seed bank. Seeds of several woody species are large and contain high moisture, indicative of adaptations to immediate germination and seedling establishment and survival under the canopy of forests [17]. Seed bank results also indicated that viable seeds of woody species generally decreased in some habitat (Modern Coffee Plantation and Wild Coffee Forest) in the seed bank than the other habitats. Because of clearing of trees with left of only few of tree species like *Albizia gummifera* for coffee shade. Overgrazing is highly experienced in the forest and it also can affect the density of soil seed bank.

Therefore, the sources of regrowth of woody species are totally dependent on the presence of the whole or a portion of the forest vegetation with mature individuals, since the probability of long-

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distance dispersal of most woody species is very low due to the large size of their seeds. In the event of disturbance, herbaceous species can regenerate from both the soil seed bank or from recently dispersed seeds while the woody species regenerate from pre-existing seedlings, coppice shoots or from recently dispersed seeds.

Tropical moist evergreen Afromontane forests accumulate large quantities of persistent seeds of herbaceous species in the soil that is confirmed by this study. Previous research has shown that existence and persistence of seeds in the soils are partially influenced by seed production and intrinsic attributes of seeds [18]. Dormancy is selected for in most of tropical dry evergreen Afromontane species, which are characterized by long dry seasons and unreliable rainy periods [17]. In non-dormant seeds, dormancy is induced if the seeds are dispersed under dense canopy or buried in the soil. It was observed that seed bank was concentrated on the upper soil layer (0-3 cm) for most of the species in the study. Overall species and seed numbers were lower in the lower layers than in the upper layer. With increasing soil depth, the seed density and its species composition declined. This is consistent with what has been found in other studies [17]; [15]; [4]; [19]; [20].

The number of species represented in the seed banks collected from Non-coffee Forest and Valley habitat types of the Forest was relatively high while it is low in the other land use types. In general, our results provide further evidence that consolidates the conclusions of previous studies on soil seed bank in Ethiopia.

Our result implies that the herbaceous flora has a better chance of natural recovery in the event of disturbances owing to the diverse seed banks while the regeneration of woody species, trees and shrubs, would be prevented by removal of mature individuals and their seedlings on the different habitats since most of them lack seed reserves in the soil.

The main objective of this study was to evaluate the potential of natural regeneration status in different land use types. The results showed difference between the floristic composition of the mature stand and the seed bank species. There were seedlings and/or saplings that were not counter represented by mature woody species. The results indicate higher density of seedlings than saplings. Seedlings in the Gera forest is high because they get more shade and can easily survive. But the saplings are removed regularly at least twice in a year. Our result is contrast with the density of seedlings and sapling in other area. According to Demel Teketay (1997), the main causes of seedling mortality include erosion, shade, drought, human disturbances, and biotic influences such as herbivore, disease and so on [17]. Our results showed that seed bank regeneration status is a better indicator for natural regeneration, which can provide important reference for ecological restoration globally as stated by [21]

Conclusion

The study showed that different habitat types have variations on seeds buried in the soil and natural regeneration potential. Generally, the seed bank study indicated that from Gera Forest possesses large populations of buried seeds of herbaceous species. Especially in Modern Coffee Plantation Forest and Wild Coffee Forest habitat types have low regeneration of woody species were recorded. The composition and density of soil seed bank in the study site show variation in different land use types. High seed density and composition were recorded in the Non-coffee Forest. Selective cut of Woody species followed by subsequent coffee plantation resulted in a more or less continuous exhaustion of seeds of woody species from the soil seed bank. This shows that plantation of coffee in wider manner, driven mainly by the need for more land of the forest for large coffee plantation based investment, is a threat to the diversity of the tropical Moist Afromontane forest in Ethiopia, not only through direct removal of the aboveground forest vegetation but also through gradual exhaustion of viable seed reserves of the woody species in the soil seed bank.

Gera Forest is one of the remaining forests harboring a unique gene reserve of wild coffee and several associated economic plant species. Loss of such a forest and the various threatened species would have great implications for the environment, biodiversity and socio-economic setup of the communities.

The concerned bodies have to take due consideration for conservation and sustainable utilization of this Forest resource.

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Tables and figures

Table 3: Jaccarad's coefficient of similarity in species composition of soil seed banks between the habitat types, (* the lowest similarity, ** the highest similarity)

	WCOF	**NCOF**	**MCOFP**	**RI**	**VA**
WCOF	-	0.6	0.643	0.586	0.685
NCOF		-	0.414*	0.689	0.721
MCOFP			-	0.431	0.509
RI				-	0.737**
VA	-	-	-	-	-

Table 4: Jaccard's coefficient of Similarity between soil seed bank and aboveground flora

Habitat Types	**Common Species**	**Species exclusive to aboveground flora**	**Species exclusive to soil seed bank**	**Jaccard similarity Values**
WCOF	4	22	6	0.125
NCOF	10	16	10	0.28**
MCOFP	5	21	10	0.08*

RI	6	20	4	0.2
VA	3	4	19	0.115

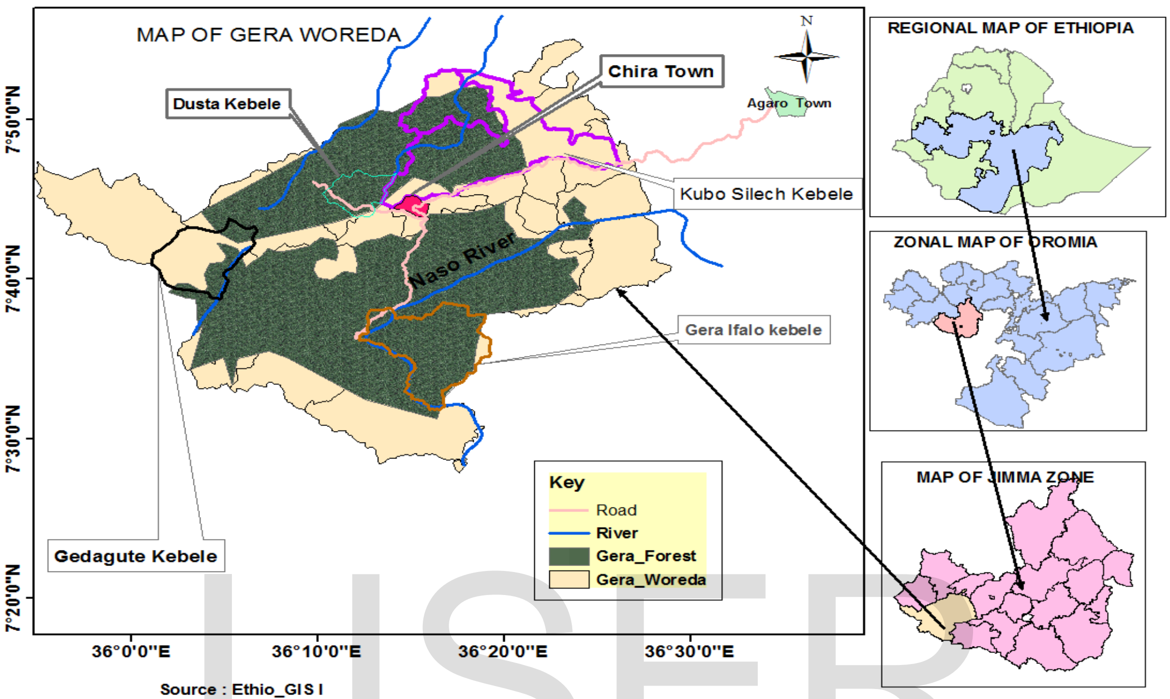
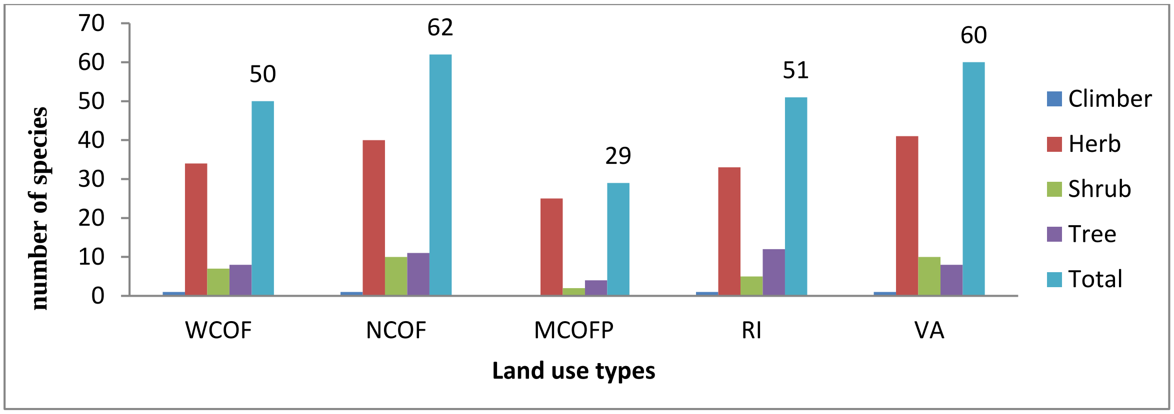


Figure 4: Map of Ethiopia and Jima Zone showing the study area, Gera Forest

Figure 5: Number of species and their growth forms recorded from SSB of the upper 9 cm soil depth collected from five habitat types; KEY: RI (Ridge), VA (alley), WCOF (Wild Coffee Forest), NCOF (Non-Coffee Forest) and MCOFP (Modern Coffee Plantation).



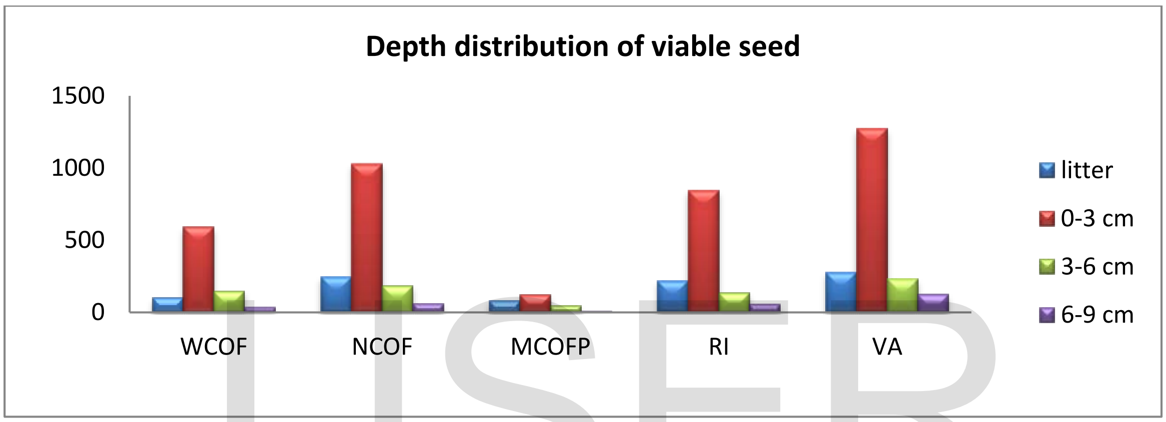


Figure 6: Composition and density of seedlings from soil seed bank (SSB), seedlings and saplings in Gera Forest