THE EFFECT OF COFFEE EXPANSION ON REGENERATION AND CARBON STOCK OF NATURAL FOREST IN GIDAME WOREDA, WEST ETHIOPIA

MSc. THESIS

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A THESIS SUBMITTED TOTHE

SCHOOL OF GRADUATE STUDIES, DEPARTMENT OF GENERAL FORESTRY,

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APPROVAL SHEET I

This is to certify that the thesis entitled "The Effect of Coffee Expansion on Regeneration and Carbon Stock of Natural Forest in Gidame Woreda, West Ethiopia" submitted in partial fulfillment of the requirements for the degree of Master of science with specialization in Forest Resource Assessment and Monitoring, under the Department of General Forestry and has been carried out by Yadesa Akena Dinsa Id. No MSC/FRAM/R022/10, under our supervision. Therefore we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department and the school of post graduate studies.

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Name of Major Adviser	Signature	Date
Dr. Kidist Fekadu	________________	___________
Name of Co-Adviser	Signature	Date

Approval Sheet II

We, the undersigned, members of the Board of examiners of the final open defense by Yadesa Akena Dinsa have read and evaluated his thesis entitled "The Effect of Coffee Expansion on Regeneration and Carbon Stock of Natural Forest in Gidame Woreda, West Ethiopia", and examined the candidate. Therefore, this is to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science with specialization in Forest Resource Assessment and Monitoring, under the Department of General Forestry.

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LIST OF ACRONYMS AND ABBREVIATIONS

AGB Above ground Biomass

BA	Basal Area
BGB	Below Ground Biomass
BMC	Biomass Carbon
BSDW	Biomass of Standing Dead Wood
CCP	Commercial Coffee Plantation
DBH	Diameter at Breast Height
ENMSA	Ethiopian National Meteorological Service Agency
FAO	Food and Agricultural Organization
FC	Forest Coffee
GC	Garden Coffee
GHG	Greenhouse Gases
GPS	Geographic Positioning System
IPCC	Intergovernmental Panel for Climate Change
LSD	Least Significant Difference
PFM	Participatory Forest Management
R:S	Root to Shoot ratio
SBD	Soil Bulk Density
SFC	Semi-Forest Coffee
SOC	Soil Organic Carbon
SPC	Semi-Plantation Coffee
WD	Wood Density

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ABSTRACT

The regeneration of natural forest isessential for maintaining forest ecosystem functioning, which is globally threatened by human disturbance. The important climate-related functions of the regenerated forest ecosystem are carbon sequestration, regulating the global carbon cycle and climate change mitigation. About 80% of the terrestrial carbon is stored as forest biomass and soil organic carbon. Deforestation and forest degradation show an alarming high, mainly due to the conversion of natural foresttocommercial and cereal crop production. By considering this issue this study was conducted with the aim to assess the effect of coffee expansion on regeneration and carbon stock of the natural forest ecosystem in Gidame *woreda. The primary data were collected from field forest and soil inventories. The study site was stratified in two strata: undisturbed natural forest and disturbed coffee forest. In the investigation of regeneration status and biomass carbon stock estimation, a total of 71 nested square sample plot was determined, proportionally allocated (29 for undisturbed and 42 for disturbed/coffee forest) and randomly distributed within each stratum. In both cases, seedlings and saplings were counted and recorded. The diameter at breast height and tree height were measured; litter sample was collected byharvesting and weighing technique. A total of 72 composite soil samples were collected from proportionally and randomly selected 24 sample plots; 10 from undisturbed natural forest and 14 from disturbed coffee forest for SOC quantification in three layers(0-15 cm, 16-30 cm, and 31-45 cm). From forest inventory data, the aboveground biomass carbon stock was estimated by using allometric equations. The below-ground biomass carbon stock was derived from the aboveground carbon stock. The results showed that regeneration of undisturbed natural forest was "good" as the present in seedlings density greater than saplings greater than mature plants.The enumerated mean densities of seedlings, saplings, and mature trees in undisturbed natural forestwere 4583±67plants/ha, 3287 ±35 plants/ha and 740 ± 14 stems/ha respectively.In the disturbed coffee forest, the density of seedlings less than saplings less than mature plants showed poor regeneration due to coffee management activities in natural forest.Themean densities of seedlings, saplings, and mature trees indisturbed coffee forestwere 237±7.3plants/ha, 314±73 plants/ha and 344 ±15 stems/ha respectively. The seedlings, saplings and mature plant species densitiesin the disturbed coffee forest were decreased by 94.83%, 90.45%, and 53.51% respectively as compared to undisturbed natural forest.The biomass carbon stock was298.758± 9.4 tc/ha for undisturbed natural forest and199.895 ± 11tc/ha for disturbedcoffee forest and the difference is statistically significant asp<0.05. This revealed that the disturbance of this natural forest ecosystem, which is associated with the conversion of natural forest to the coffee cultivation area, resulted in the loss of 33.09% of the biomass carbon stock. The SOC is 148.40 ± 12 tc/ha for undisturbed forest and 153.80 ± 4.30 tc/ha fordisturbedcoffeeforest hasnosignificant difference asp>0.05.Therefore,maintaining the regeneration and biomass carbon sequestration potential of this natural forest ecosystem should be required through the implementation of different conservation mechanisms.*

Keywords/ Phrases:coffee forest, coffee management, disturbed forest, forest degradation, undisturbed forest

1. INTRODUCTION

1.1. Background

Natural forest is a multilayered vegetation dominated by trees (evergreen or semi-deciduous), whose combined strata overlapping crowns (i.e., 75 % and more), and where grasses in the herbaceous stratum are generally rare (Geldenhuys, 2004). It is reproduced naturally from the previous original forest cover, spontaneously generated itself on the location and which consists of indigenous tree species. Through a natural process, this native species reproduced by self-sown seeds, vegetative recovery, and coppice or root suckers. There are no clearly visible indications of human activities, and the ecological processes are not significantly disturbed (Mackey *et al*., 2015). The natural tree composition, occurrence of dead woods and age structure are not disturbed; and the area of land is also large enough to maintain its natural characteristics (FAO, 2010). Because, for many indigenous tree species natural regeneration is effective where near the parent plants were existed (Devaney*et al*., 2014).

Forest is one of the largest terrestrial carbon stock pools (Aricak *et al*., 2015). The important climate-related functions of the regenerated forest ecosystems are carbon sequestration and carbon storage, which create carbon stocks. It is the most faithful option for carbon sequestration, plays a crucial role in regulating the global carbon cycle and climate change mitigation (Virgilio and Marshall, 2009). About 80% of the terrestrial carbon is stored as forest biomass and soil organic carbon (Hamdan *et al*., 2011). Among these terrestrial carbon sequestrations, the carbon stored in the aboveground living biomass of trees is typically the largest pool. Below Ground Biomass (BGB) also forms an important carbon pool for many vegetation types and land-use systems (Sahoo, 2017). Forest absorbs CO_2 gas from the atmosphere through photosynthesis process and stores huge amounts of carbon as biomass that makes up their bark, wood, leaves, and roots when trees are growing. The stored carbon in all living and dead vegetation can be released or emitted in the form of CO_2 into the atmosphere by human activities when forests are destroyed either by burning or through deforestation and forest degradation. So, forest acts as the sources and sinks of atmospheric carbon dioxide. The emission from deforestation and forest degradation accounts for about 25% of the summed emissions per year (Pearson *et al*., 2007).

Soil is also the carbon reservoir of the terrestrial carbon cycle next to biomass carbon. Soil carbon sequestration is a process in which CO_2 is removed from the atmosphere and stored in the soil carbon pool (Ontl and Schulte, 2012).About50% of the soil carbon is stored in forests (Tremblay *et al*., 2006), which include dead organic matter and soil organic matter(IPCC, 2006).This soil carbon is exposed and lost to the atmosphere depends upon soil type and management regime. The emitted CO_2 into the atmosphere from the destruction of biomass and soil organic carbon contributes to global warming; which occurs from increased atmospheric concentrations of Greenhouse Gases (GHG) leading to the net increase of the global mean temperature (Bhartendu, 2012).

Ethiopia is endowed with its high species diversitiesin natural forests. Because of its rugged highlands, different agro-ecologies in altitude ranges from Dalol depression (116 m below sea level) in the northeast Afar Region to 4,620 m above sea level in Semien mountain, rainfall pattern and soil variability; it has an immense ecological diversity and a huge wealth of biological resources. These are principally attributed to socioeconomic, cultural diversity and complex topography of the country. From these ecological diversities and diversities of plant species in natural forests, the South WestMoistAfromontane forest of Ethiopia is the origin and genetic diversity of *Coffea arabica* species and named as the birthplace of *Coffea arabica* (Getachew WeldeMichael *et al*., 2013 and Kumar, 2015). As a result, Ethiopia is known as one of the centers of the primary coffee plant domestication country in the world (Engels*et al*., 2002).

Even though Ethiopia has different vegetation types and species diversity of natural forests, these natural forest areas with the occurrence of wild coffee gene pools are under constant threats. Land use and land cover changes, including legal and illegal deforestation, and forest degradation are the most important factors that contribute to social, economic, and environmental challenges facing mankind in the recent century. This is largely due to anthropogenic factor, including coffee management intensification (Taye Kufa and Burkhardt, 2011). From the four coffee production systems, namely forest coffee, semi-forest coffee, garden coffee and plantation coffee; semi-forest coffee and plantation coffee management systems are the major causes of forest degradation in Ethiopia especially in the west part of the country.Feyera Senbeta and Denich,(2006) and Kitessa Hundera *et al*.,(2013)show that semi-forest coffee management system decreases the forest basal area, tree regeneration, reduces tree density and eventually leads to the disappearance of the forest tree species. The only selected old trees of shade value are maintained, which eventually endangers the functions of the shade value. Because, at some point in time, a significant portion of the selected shade trees could be lost due to their old age.

The intensive coffee management under the selected shade trees heavily affects tree seedlings that could serve as future shade trees. The traditional coffee cultivation system, selective cuttings of some tree species which the farmers believe to reduce coffee production affects the biodiversity-based stock of active carbon pool growing seedlings (Aerts *et al*., 2011). Rapid land-use conversion and modification in support of Agro-industrial developments lead to the removal of natural forest cover with a corresponding loss of natural regeneration and biodiversity-based forest biomass carbon stock (Basnyat, 2008). These effects are being observed in some places in the country. The only preferred coffee shade trees *Albizia gummifera, Acacia abyssinica, and Millettia ferruginea* tree species are left in the rich biodiversity of the natural moist evergreen Afromontane forests of the South West Ethiopia (Kitessa Hundera, 2013 and 2016). The disappearance of the forest is threatening the communities that depend on natural forests for their livelihoods and affects water supply to lowland areas (Mulugeta Lemenih *et al*., 2015).

1.2. Statements of the Problem

Forest plays a critical role in environmental, social and economical especially for humans who rely on for the provision of energy and clean water. In Gidame woreda, local communities living near natural forest use the products of the natural forest for their livelihoods and the prohibition of harvesting the forest for timber and non-timber forest products. It provides fodder, firewood, and subsistence timber goods for which they are still the major sources for most of the households. However, the main cause of the problem in the demarcated natural forest area is driven by the need to expand coffee cultivation in natural forest. Near to local people only the knowledge of understanding the ongoing processes at the forest margin as deforestation; but not to consider the extent of the persisting forest patch degradation. Land shortage in traditional farming system, rapid population growth, poor economic performance, and the need for economic growth were increase competition of encroachment among these people and converting natural forest to the coffee cultivation area to improve their livelihood economy. The evergreen moist montane forest of this woreda is under great threat of rapid degradation and converted to coffee cultivation area. Even though this woreda has high coverage of natural forest, the forest is threatened by the pressure from coffee expansion. There is no study on how the conversion is affecting regeneration and carbon stockin Gidame woreda natural forest.

1.3. Objectives

1.3.1. General Objective

This study is conducted to assess the effect of coffee expansion on regeneration and carbon stock of the natural forest ecosystem in Gidame woreda.

1.3.2. Specific Objectives

The specific objectives of this study are;

- To assess the effect of coffee expansion in natural forest on natural regeneration of woody species.
- To estimate the effect of coffee expansion in natural forest on carbon stock of the study area.

1.4. Research Questions

This research explored the effect of coffee expansion on natural regeneration and carbon stock of the natural forest ecosystem. The research addresses the following questions.

1. What is the effect of coffee expansion in natural forest on the natural regeneration of woody species?

2. How do coffee management in naturalforest affect biomass and soil organic carbonstock?

1.5. Significance of the Study

The findings of this study is indispensable for all stakeholders who haveinterest to minimize or avoid the adverse effects of deforestation and forest degradation by conserving forests in the concerned area. It provides basic information for the decision and/or policy-makers, and forestry administers in planning forruminant and hot spot natural forest ecosystem management intervention. The understanding of human activities which lead to the decline of natural regeneration and biomass carbon stock density is the fundamental bases for the development of policies which aim to alter current trends in forest activities toward a more climate and environmental-friendly outcomes. The findings of this study also serves as a good basis for forthcoming researchers who may have a strong desire for this research or related topics in this woreda or elsewhere and contributes to piece kind of literature and serves as additional source of background.

1.6. Scope of the study

This study is conducted to investigate the aspect of the effect of coffee expansion and its management activities on carbon stock and the regeneration of natural forest in Gidame woreda in Kellem Wollega Zone Oromia Region, Western Ethiopia. The study area of this natural forest covers four (4) kebeles (i.e., Lalo Gare, Komi Koji, Horo Kundi, and Boti Akeyu) of Gidame woreda.

2. LITERATURE REVIEW

2.1. Natural Forest and its Regeneration

Forest regeneration is essential for maintaining forest ecosystem functioning which is globally threatened by human disturbance. Native species that are adapted to the prevailing conditions re-establish on their growth following natural succession, leading to the recovery of native ecosystems (Chokkalingam *et al*., 2018). It is also been a component of forest and landscape restoration(Chazdon *et al*., 2016).The success of this natural regeneration is determined by the re-growth per square meter (Ozel *et al.*, 2010).In the absence of further disturbance and by avoiding replanting with exotic species, forests regain their diverse native status (Dobrowolska, 2010). The indigenous forests with least disturbed native forests have a much higher regenerating seedlings and saplings than in the most disturbed forest (Omoro and Luukkanen, 2011). Human disturbance is a significant negative impact on forest regeneration (Neuschulz *et al*., 2016).

Forest regeneration is crucial to a variety of ecosystem processes, including changes in forest structure, succession and population dynamics. It is also necessary for maintenance of biodiversity and promoting forest sustainability (Chookkalingam *e al*., 2018; Stewart, 2017). Forest predominantly composed of trees established through natural regeneration (ICEEM, 2014). Seedlings from natural regeneration not likely survive unless on low hazard sites; disturbances influence the regeneration of forest stands (Stewart, 2017).Saplings density is a good measure to notice influence of human disturbance on forest regeneration status (Napit and Paudel, 2015).

2.2. Biomass Carbon Stock in Natural Forest

The IPCC Guideline (2006) defines five carbon pools: living aboveground biomass, living below-ground biomass, deadwood, litter, and soil organic carbon. The forest biomass carbon stock pools account for over 45% of terrestrial carbon stocks, with approximately 70% and 30% contained within the above and below-ground biomass, respectively. The carbon stocked in natural forest's biodiversity-based resilience processes is more likely to persist and accumulate large carbon stock particularly in large old trees. The very large trees in natural forests play an important role in ecosystem structure and function (Fichtler *et al*., 2003). For accurately assessing the forest ecosystem carbon pools and influence of human disturbance, standing dead and downed wood are important variables to be measured (Kauffman and Donato, 2012). Forest information is highly relevant to those considering policy options aimed at avoiding carbon emissions caused by natural forest clearing or degradation. The aboveground carbon stock losses from clearing a hectare of native forests are likely large. Because the dominant tree species have a strong influence on carbon stock in a natural forest ecosystem (Ali, 2015).Below ground biomass, which usually represents between 15% and 30% of the aboveground biomass is also influenced by numerous biotic and abiotic factors at any given time (Tang *et al*., 2017). Carbon storage in tree root biomass increased steadily over time with the growth of stand age (Peichl and Arain, 2006).

2.3. Forest Biomass Estimation Methods

Several studies were conducted to estimate biomass of trees using different methods. Forest biomass can be estimated through field measurement and remote sensing and GIS methods (Ravindranath *et al*., 2008). There are two available principal methods of field biomass estimation. The first one is the destructive method and the second approach is the nondestructive method. Among all the available biomass estimation methods, the destructive method, also known as the harvest method is the most direct method for estimation of aboveground biomass and the carbon stored in the forest ecosystems (Gibbs *et al*., 2007).But the non-destructive method or the allometric relationship is often the preferred method for estimating forest biomass as this method provides a nondestructive and indirect measurement of biomass and comparatively, it is less time consuming and less expensive (Vashum and Jayakumar, 2012).

2.4. Review of Forest Biomass Carbon Stock Empirical Data

There are some empirical studies' data on non-degraded and degraded moist montane forests in Ethiopia. The moist non-degraded Bale mountain store 289 tc/ha biomass carbon, 199 tc/ha carbon in degraded forest (Watson *et al*., 2013) and 237.19 tc/ha (OFWE, 2014). In the Afro-montane landscapes of South West Ethiopia around Jima zone indigenous forests stock 336.96 tc/ha and semi-forest coffee production fragments stocked 179.92 tc/ha (Vanderhaegen *et al*., 2015). Similarly, in the South West of Ethiopia around Jimma Zone, Dereje Denu (2016) assessed 82 tc/ha from natural forest and 61.5 tc/ha from the coffee forest. In South West of Ethiopian highlands413 tc/ha for moist Afromontane and 387 tc/ha for semi forest Vanderhaegen *et al*., 2017), and 150.73 tc/ha in Gera coffee forest (Mohammed Abaoli and Bekele Lemma, 2014). For Ethiopian moist Afromontane forests EFRL (2017) determined 248 tc/ha as reference level. The terrestrial biomasscarbon storedin forest ecosystem (Aricak *et al*., 2015; Baral *et al*., 2009) and stored long-term in wood (Wellbrock *et al*., 2017).

2.5. Trends of Ethiopian Natural Forest Cover

Several authors have carried out assessments and documented the extent of forest resources of Ethiopia. Based on the potential climatic climax, the natural high forests of the country might have once covered about 35% of the total land area of the country and well-endowed in natural high forest resources (Rahmato, 2011). However, the country's forest resources have been declining both in size and quality or degraded. The country's economy is heavily dependent on rain-fed agriculture for generating employment income and foreign currency, where most of the Ethiopian population is remaining active in the agricultural sector. The main pressure in most areas remained land clearing for crops and cattle farming, particularly by present investors. They are looking at the natural dry-land forests for crop production and divert moist Afromontane forests into commercial crops, resulting in the clearing of large areas of forest (Barton and Dlouha, 2014). In a rural area of Ethiopia, where the livelihoods of 83% of the population reside and dependent on renewable natural resources, the pressure on forest resources is high (Wakshum Shiferaw *et al.,* 2018). In the early 1950s, the high forest areas were reduced to 16%, from 1973 to 1990 the land area covered by closed forest was 2.64% (Reusing, 2000). It was again reduced to 2.36% in 2000 (Demel Teketay, 2001; Tigabu Dinkayoh, 2016).

2.5.1. Causes of Deforestation and Forest Degradation in Ethiopia

The construction of infrastructures for forest management, such as base camps, roads networks, and other forest opening human activities, potentially reduce forest. In addition to these commercial agriculture is the most important driver of deforestation, followed by subsistence agriculture (Hosonuma *et al*., 2012). The loss of ecosystem services by deforestation and forest degradation is one of the global concern and particularly important to population who relies on natural resources for their livelihoods (Stas, 2014). According to Fekadu Gurmessa (2015), the most recent estimates of the rates of deforestation, 75 percent of forest losses are attributable to agricultural expansion. It is estimated that over the next 25 years the agricultural sector will require an additional 250 to 300 million hectares of new land to accommodate the demands of commercial farming, subsistence cropping, pasture, and range development. Forest loss has been reinforced by the recognition that, deforestation and forest degradation accounts for roughly one-sixth of total anthropogenic emissions of greenhouse gases. It is a serious environmental, social and economic problem; and its fragmentation leads to forest biodiversity loss by reducing the available habitat of forest-dependent species and indirectly through disruption of major ecological processes such as pollination, seed dispersal and gene flow (Simula, 2011).

2.5.2. Deforestation and Forest Degradation in Western Ethiopia

At the beginning of the 20th century, the southwestern part of the Ethiopian highlands had been completely covered by montane rain forests (Reusing, 2000). The direct drivers of deforestation and forest degradation were human activities and actions that directly impact forest cover and result in loss of forest biomass (Kissinger *et al*., 2012). It was mainly caused by shifting cultivation by smallholders, which was partly driven by the expansion of commodity crops. The displacement of shifting cultivation into the forest margins was pushed by market crop expansions (Meyfroidt *et al*., 2013). The situation of forest was changed with new settlers or migrants from the central and northern part of the country to southwest Ethiopia. Deforestation and forest degradation in the region continued on a larger scale after the resettlement of these people from the degraded and drought-affected regions of the country (Mekuria Argaw, 2005). With the new settlers, a new farming system was introduced that was not adapted to the environmental conditions of this area (Amogne Asfaw, 2014). In a short period, vast areas of the country's natural high forests have been degraded and deforested (Reusing, 1998). Still, the natural forest areas are under constant threats largely due to anthropogenic activities (Taye Kufa and Burkhardt, 2011).

2.6. Soil Organic Carbon Stock in Natural Forest

SOC plays an important role in carbon cycling of terrestrial ecosystems and its level is determined mainly by the rate of decomposition of the organic material (Yigini and Panagos, 2016). The average forest soil carbon content is 161.8 tons per hectare (Bautista, 2012). But the amount of carbon in soil varies widely, depending on the environment and the history of the site (Gorte, 2009).In tropical wet evergreen rainforest more than 20% of total carbon stock was stored in the soil as soil organic carbon (Sahoo, 2017).During forest succession, there is a continuous soil carbon sequestration (Thuille *et al*., 2000).This soil carbon is also slowly released to the atmosphere as the vegetation decomposed. Soil bulk densities were higher where the porosity percentages were lower in the unprotected site. This could be attributed to the negative effects of human activities such as deforestation that leave the land more susceptible to soil degradation including soil microbial community (Nang, 2016). Soil disturbance also leads to increased erosion and nutrient leaching from soils, which have led to eutrophication and resultant algal blooms within inland, aquatic and coastal ecosystems, ultimately resulting in dead zones in the ocean (Ontl and Schulte, 2012).

Soil organic carbon content varies greatly depending upon the nature of the vegetation characteristics and the kind of hummus and depth of soil. To investigate the effect of anthropogenic activities, estimation of soil organic carbon stock requires bulk density measurements and percent of soil carbon contents. Variability in BD contributes to carbon stock uncertainty, in turn affecting how large a change in stock can be observed over time or space (Holmes *et al*., 2012). The measurement of parameters carbon content in percentage, soil depth, and bulk density analysis (weight, and volume of the coarse fragments, and total volume of sampled soil) were acquired from the soil sample. There are numerous soil sampling tools and methods. Of the three most common methods which include core, clod, and excavation methods the core method is by far the most commonly used (Gross and Harrison, 2018).

2.7. Coffee Cultivation System and Forest Degradation

The Ethiopian Afro-montane natural forests were repositories and gene pools for several domesticated and/or important wild plants and wild relatives of domesticated crops (IBC, 2009). Coffee has naturally grown in its ancestor home in the wild forest. It has grown under natural forest cover in the wild and gathered by farmers from trees with minor tree maintenance. They live together for mutual benefit with an ecological balance. Depending on the intensity of the management level of coffee domestication and diversity of shade trees, forest-based coffee production systems distinguished into four broad categories(Woldetsadik and Kebede, 2000). The difference between these systems is manifested by the level of forest management intensities (Dereje Denu*et al*., 2016).

2.7.1. Forest Coffee (FC) System

Wild coffee plants grow as under-storey plants in the natural forest; local farmers can simply pick the coffee beans from those plants with very little way of management interference in the forest for improving production (Schmitt *et al*., 2010). In the FC system, the composition, diversity, and structure of the forest are little modified or affected by human interference. But yields from forest coffee are much lower (Stellmacher and Grote, 2011).

2.7.2. Semi Forest Coffee System (SFCS)

In SFC cultivation system, the highest density ofcoffee plants was found in the higher size classes suggestive of the removal of young non-coffee plants during coffee management (Feyera Senbeta and Denich, 2006). Shade tree reduction is an ongoing process in the conversion of forest coffee system into a semi forest coffee system (Tscharntke *et al.*, 2011). The management of the canopy layer in function of coffee production had important consequences of forest degradation in moist Afro-montane rain forests (Aerts *et al*., 2011).

Farmers undertake considerable interventions in the forest ecosystem to increase their coffee yields (Stellmacher and Grote, 2011). They simply avoid competition from other plants by clearing non-coffee shrubs (De Beenhouwer, 2011). The competition with other species is minimized, but competition among coffee plants increases due to an increase in coffee population (Tadesse WoldeMariam *et al*., 2015). Shade tree management and coffee light use efficiency increased by 50%, leaving net primary productivity (Charbonnier *et al*., 2017). Intensification of forest coffee cultivation to maximize coffee production in Ethiopian moist evergreen Afro-montane forests results in structural degradation and causes a shift in tree species composition toward an early succession community (Kitessa Hundera *et al*., 2013).

This was strongly related to tree thinning and slashing of undergrowth shrubs and lianas (Weyessa Garedew *et al*., 2017).

2.7.3. Garden Coffee (GC) System

Garden coffees are planted by farmers in the vicinity of their residences and often inter-cropped with other crops or trees (Nyarko *et al*., 2014). The production system involves weed control and application of organic fertilizer and modern production practices. It is better and efficient as compared to the forest coffee and semi forest coffee production systems. Maximize light interception and tend to increase carbon gain at low solar irradiance through more efficient investment in photosynthetic machinery in plants that are grown under low light conditions. Light shade trees are often maintained, old and less productive trees are usually pruned. The productivity of this system is much higher as compared with forest coffee production system (Stellmacher and Grote, 2011).

2.7.4. Commercial Coffee Plantation (CCPS) System

Commercial coffee plantation is grown on large commercial farms, by the private or state farms (Minten *et al*., 2014). In CCP system, improved commercial cultivar with high productivity has cultivated under intensive management. The promotion of modern commercial coffee plantations in connection with deforestation and forest degradation threaten the natural gene pool, which was rich in variation and harmony with its landscape. Intensive coffee management impacts ecological systems and socioeconomic livelihoods, rendering these two aspects of coffee cultivation inextricably linked at local, regional, and global scale (Jha *et al*., 2011).

As a general, the tree species that are less efficient in shading and slow-growing species are cut, resulting in 30% fewer canopy trees in the SFC system (Schmitt *et al.*, 2010). These modifications of the forest have led to a uniform, species-poor in terms of canopy tree (Aerts *et al*., 2011). In more intensely managed coffee forests, there is no intermediate canopy layer and further intensification leads to the conversion of semi forest to semi plantation coffee, causing significant diversity losses and the collapse of forest structure and dominant tree. In the long term, this will have serious implications for the regeneration of the forest when the mature trees reach a post productive stadium (De Beenhouwer, 2011). The conversion of FC into SFC and PC production systems eventually results in the loss of ecological services of the coffee forest. The intensification of forest productivity starts with the conversion of forest coffee to semi forest coffee, which has significant negative effects on tree seedling abundances. Further management intensification leads to the conversion of semi forest to semi plantation coffee, causing significant diversity losses and the collapse of forest structure decreases stem density, basal area, crown cover and dominant trees (Kitessa Hundera*et al*., 2013).

2.8. Deforestation, Forest Degradation, and Climate Change

Deforestation refers to the entire loss of patches of forest through clearing and conversion to other land uses, while forest degradation refers to the loss of biomass (living vegetation) in forests through timber harvesting, fuel-wood gathering, fire, and other activities which do not result complete conversion to other land uses (Virgilio and Marshall, 2009).

The role of forests as carbon source and sink has been widely explored. Forests store in above andbelow ground biomass carbon to make forest ecosystems crucial for maintaining the global carbon balance and mitigating climate change (IPCC, 2001). Forests play an important role in mitigating climate change naturally by taking carbon out of the atmosphere (Perschel *et al*., 2007). Carbon storage in forest biomass was an essential attribute of stable forest ecosystems and a key link in the global carbon cycle. Carbon dioxide naturally cycles rapidly in the atmosphere, oceans, and land. Forest carbon sequestration was a measure that can be taken up to mitigate climate change (Karki *et al*., 2016). Where, the endless rise of carbon emission was one of today's major concerns as it was the main causal factor for climate change (Muluken Nega *et al*., 2015). The impact of climate change on Ethiopia was more pronounced by an alarming loss of forest resources (Fekadu Gurmessa, 2015). The reliance of rural households on forest resources has critical for climate change ramifications (Bluffstone *et al*., 2013). The degradation of forests and woodlands has impacts on large-scale loss of global forest cover changes (Temesgen Gashaw*et al*., 2014). Where, climate change is an important component of degrading the quality of both the environment and human well-being (Aime *et al*., 2015).

3. MATERIAL AND METHODS

3.1. Description of Study Area

3.1.1. Geographical Location

The study was conducted in Gidame woreda, in Kellem Wollega Zone, Oromia Region, Ethiopia, which is located at 688 km west of Addis Ababa. It is bordered on the North by Beghi woreda, on the South by Anfillo woreda, on the East by Jimma Horo woreda, and on the West by South Sudan country. Geographically it is located between 8^0 38' 0'' N to 9^0 12' 0'' N Latitude and 34^0 10' 0'' E to 34^0 42' 0'' E Longitude, altitude ranges 1500-2300 m asl and its town Gidame.

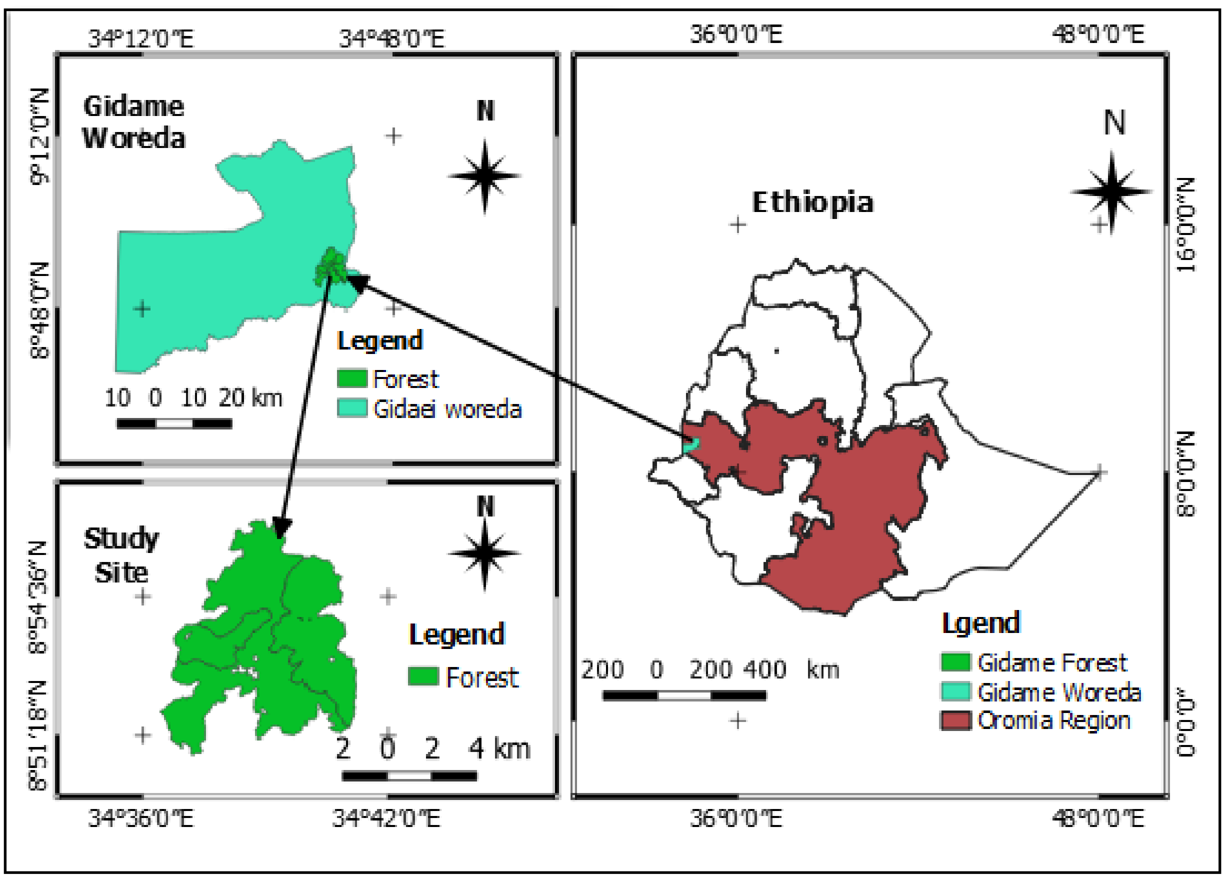

Figure 1. Map and geographical location of Gidame woreda and the study area of forest

3.1.2. Agro ecology and Land Use and Land Cover of the Woreda

The major agro-ecologies of Gidame woreda are 8% Dega, 75% Woina-Dega and 17% Kolla. The maximum temperature ranges from 23 to 26 ^{0}C with an average annual temperature of 25.2 ^{0}C and the lowest annual temperature ranges from 7.6–19.8 ^{0}C with an average of 12.16^{0}C. The rain seasons are spring (March–May), summer (June–August) and autumn (September–November). The average annual rainfall of the district ranges between 941-1635 mm and uni-modal rainfall (ENMSA, 2019).Gidame woreda covers a total area of 219,031 hectares. From this total area of land 47,004 hectares covered by evergreen moist montane natural forest, 12,721 plantation forests, 59,872 hectares covered by coffee, 15,283 hectares grazing land, 71,584 hectares cropland and 12,567 hectares of other land uses.

3.2. Socioeconomic Condition

3.2.1. Demographic Characteristics

Gidame woreda has twenty-eight rural and two town administrative Kebeles; and an estimated total demographic population of 111,172 (55,890 male and 55,282female), 15,429 households (13,903 are men and 1526 are women). Out of this total population, 4,636 male and 4,404 female live in urban, 51,254 male and 50,878 female live in rural areas. The average population density of this woreda is 51persons/km^2. The largest ethnic group is the Oromo people. Afan Oromo is spoken as the first language. The majority of the inhabitants observed Orthodox Christianity, with 70.89%, while 14.99% were Muslim, and 13.6% Protestant dwellers (CSA, 2013; projection of 2017).

3.2.2. Livelihood Activities

Like in most parts of Ethiopia, mixed farming (crop production and animal husbandry) dominates the livelihood of the wereda. The land is an important asset of households for the crops production, rearing of livestock and coffee production. The major crops grown include maize (*Zia maize*), sorghum, teff (*Eraguresive teff*), barley (*Hordeumvulgare*), wheat (*Triticum vulgare*), pea (*Pisum vativum*), bean (*Vicia faba*), oats, millet, horse beans, haricot beans, chickpeas and root crop like potato(*Selenium tuberosum*), 'ancote', onion, cassava and Coffee is the most an important cash crop of the district.

3.3. Sources of Data

To achieve the objectives of this study, both primary data and secondary quantitative data was used. The primary data were obtained from the forest inventory based field surveys and observation in the study area forest which covers 4 (kebeles) of the woreda by using a non-destructive method of data collection technique. The secondary data were obtained from published previous biomass carbon stock assessment journals, thesis and project reports on evergreen moist Afromontane forests in Ethiopia for sample intensity determination.

3.3.1. Sample Size Determination, Sampling Techniques, and Design

A preliminary survey was carried out within the study area for deciding the proper type of design and intensity of sampling that was appropriate for achieving the objectives of the study regarding the natural attributes of vegetation type and forest coverage. The boundary and area of the study site (i.e., 5176 ha) were determined and delineated on its base map. Naturally, the agro-ecology and vegetation characteristics of this forest ecosystem were no difference except the influences of year to year coffee expansion and management activities. It is dominated by very large trees such as *Aningeria adolfi-friedericii, Apodytes dimidiata, Albizia gummifera, Olea welwitschii, Strychnos spinosa* and consists of other shrubs, lianas and different size tree species composition with different layers of canopies. The objective-based stratified random sampling was applied to get a representative sample from the two strata or compartments of the study site. Thus, the study site was stratified into two strata, or compartments of closed forest (i.e., undisturbed natural forest) and disturbed natural forest (i.e., where converted to coffee) depending upon anthropogenic factors (disturbance history) to make homogeneous characteristics and available for comparison by using GPS control points.

Undisturbednatural natural forest is a primary (closed) forest of native tree species where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed.

In context of this study disturbed natural forest is a naturally regenerated native tree species, which has been modified in places with indications of human activities (i.e., where coffee is planted in and converted to coffee cultivation area by local people).

The appropriate simplicity nested square plot-size rules presented in the Table 1, that can be applied to any forest research was used for sample plot size, to include all the data of vegetation types, tree size and tree species grown in this natural forest (Pearson *et al*., 2013). A reasonable balance of the appropriate nested square plot sizes is used. Because it is easily established and the real boundaries around the plot are marked by using meter tape and rope during the layout rather than the circular plot. It also has higher area coverage than a rectangular plot with the same perimeters. This decreases the edge effect of the sampling error and increases the quality of collected data.

Table 1. Nested square plot-size desired and used for data collection.

Stem diameter and litter	Square plot	Area (m^2)	Area (hectare)
Litter	1m × 1m	1	0.0001
Seedlings, saplings and trees 5—20 cm dbh	7m × 7m	49	0.0049
Trees 21—50cm dbh	25m ×25m	625	0.0625
Trees > 51cm dbh	35m ×35m	1225	0.1225

After the sample plot shape and the sample plot area were determined, the required sufficient number of representative sample plot intensities was calculated for adopting a stratified random sampling method by using the next area based formula (Avery and Burkhart, 2015).

$$n = \frac{1}{\frac{1}{N} + \left(\frac{A}{t \times wCV}\right)^2}$$

Where: n = the required number of total sample plots, A = allowable error in percent (10%), t = the sample statistics from the t-distribution for 95% confidence level, t is usually set at 2 as sample size is unknown at this stage, N = total number of sampling unit in the study area (i.e., the study area 5,176 ha divided by the area of a single plot 0.1225 ha(5176 ha/0.1225 ha = 42253)), and WCV = weighted coefficient of variation42itwas calculated for both compartments from empirical secondary cruise data sources of different previous studies on biomass carbon stock of various non-degraded and degraded moist Afromontane forest and remnant forest ecosystems in Ethiopia which are similar to forest ecosystem of the present study site(Abyot Dibaba *et al*., 2019, Bale Mountains Eco-region REDD+ Project, 2014, Dereje Denu, 2016, EFRL moist afromontane, 2017, Matthias *et al*., 2016, Mohammed

Abaoli and Bekele Lemma, 2014, OFWE, 2014, Vanderhaegen *et al*., 2015 and 2017, and Watson *et al*., 2013).

To get a representative number of samples from the two strata or compartments, these total sample plots were proportionally allocated depending upon the area coverage of the stratum/compartment.

Table 2. Area-based proportional allocation of sample plot densities used for both strata /or compartments.

Forest compartment	Area (ha)	N_i	Area fraction (Af_i)	CV_i	$ni = 71 \times [\frac{Afi \times CVi}{WCV}]$
undisturbed natural forest	2064	16849	0.4	42	29
disturbed /coffee forest	3112	25404	0.6	41	42
Total (A, Ni and wcv)	5176	42253	1	42	71

Ni= sampling frame, A= Area in hectare, Wcv = weighted coefficient of variation, Afi = area fraction, CVi = coefficient of variation for each stratum, ni = number of sample plot for each stratum.

The estimated numbers of sample plots were spatially distributed on a base map of the study area by using a stratified random sampling approach for both strata using GRASS QGIS 3.2 version software research tool vector menu as shown in Figure 2. The X and Y coordinates of all these generated sample points were recorded (Annex 1. Table1).

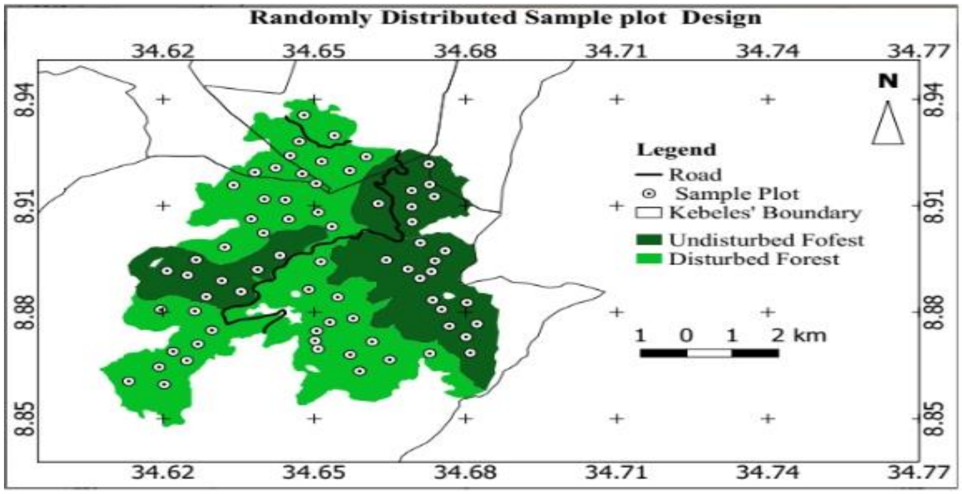

Figure 2. Randomly distributed sample plots on a base map of the study area.

The field survey checklist was prepared in a table format as shown in Annex 3 for measurements of quantitative data. Field note was also used to collect information about the collected data in a written format from observation. The positions of randomly distributed sample points were found by GPS guide on the ground. Field surveys in the selected sample station areas of the forest and personal observation were done to collect the relevant primary data for the study.

Plot establishment: Before delineating plot boundary a simple trigonometric calculation distance on the sloping ground was calculated by the desired length divided by the cosine of the angle of the slope ($d = 35$ m/cos θ) in the field for slope correction using a clinometer for inclined surface. Then after, as shown in Figure3, the desired concentric nested square plot designs were constructed on the ground by using meter tape and rope. The nested square plot design containing the smaller sub-units was used for recording discrete size classes of stems for including all forest composition of trees population characteristics in a single plot.

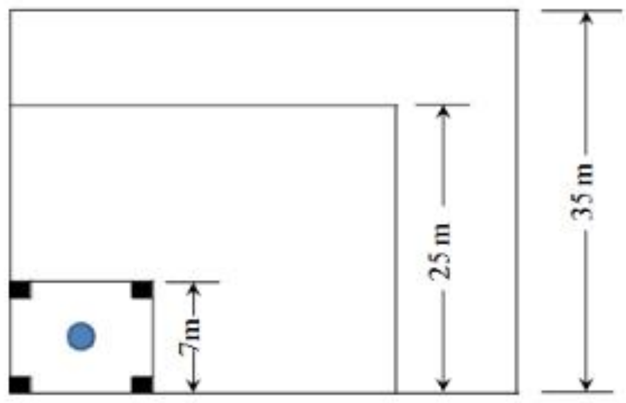

Figure 3.Layout of sample plot design on the ground used to collect data in Gidame forest ecosystem, western Ethiopia.

3.4. Data Collection

Seedlings and saplings counting: For the status of natural forest regeneration assessment, the smaller nested square sub-plots having 7 m length and width inside the larger plot was used for seedlings and sapling data collection. The individual tree seedlings (height less than 1.5 m) and saplings (height between 1.5-3 m) wereconsidered seedlings and saplings respectively (Getachew Tesfaye *et al.*, 2002) which are less than 5 cm DBH were identified, enumerated, and recorded (Karki *et al.*, 2016).

Field data measurements for aboveground biomass carbon stock estimation: The parameters needed to estimate abovegroundbiomass by using non-distinctive approaches Diameter at Breast Height (DBH) and tree height (H) were measured by using diameter tape and hypsometer respectively. For trees and coffees with multiple forks begin below 1.30 m, shrubs near to the ground or collar, and 0.40 m height respectively, the DBH of each fork were measured separately. plant species starting from small to large, living trees, climbers/Lianas, shrubs which are greater than 3 m in height and diameter classes of 5 cm to 20 cm DBH, 21-

50 cm DBH, and greater than 51 cm DBH in the nested sample plots were properly measured, counted and recorded separately according to their stem diameter class specified in desired plot size. All the trunks, dead standing trees, dead trees lying on the ground that have a diameter >10 cm and a length of > 0.5 m were sampled were they considered dead (Hairiah *et al.*, 2001). Their length and diameter halfway/at the middle length were recorded (Bhishma *et al.*, 2010), as well as notes identifying the types of wood for finding their specific wood densities were registered. The diameter of laying dead wood across the perimeter of middle subplot 25 m × 25 m were measured.

Forest floor litter biomass was measured by simply harvesting and weighing technique from $1m^2$ of the nested square plots. The weight of the fresh mass of the liter sample was weighed and recorded. After air dried, the weight was determined by weighing and recording again for the analysis. The observation was also done to support and supplement the collected data during field data collection in the study area.

Soil sampling: In both undisturbed natural forest and disturbed coffee forest of the study area, the soil samples were collected from 24 sub-sample plots. 10 sample plots from undisturbed forest and 14 sample plots from a disturbed/coffee forest in proportion to their area coverage of the stratum at three depth layers, of 0 - 15 cm, 16 - 30 cm, and 31 - 45 cm after removing the upper litter from four corners of the (7 m x 7 m) nested square sample plot. Because vegetation plays a major role in contributing soil organic carbon through litters and detritus, and the overall organic decomposition processes. It is also highly variable as a function of litter biomass. Thus, a composite 72 soil samples were proportionally (10 plots x 3 depths and

14 × 3 depths) taken for SOC content analysis with the help of a metal soil sampling corer. Stones and plant residues were removed from the soil samples and a composite soil sample of 300 g was taken from four corners for one layer by mixing and making homogeneously. From three-layer depths of one plot 900 g of soil sample were collected.

A sampler with internal 5 cm diameter core and 15 cm height steel cutting was used for sample taking to determine soil bulk density (SBD) in each of three soil depths (0 -15 cm, 16 - 30 cm, and 31- 45 cm) from the center point of the diagonals of the square plot (Figure 3). This cylindrical steel core was inserted vertically at each depth layer and hammered into the soil until the desired depth was achieved. Then it was taken out and the soil outside the steel core was removed with a sharp knife. The soil inside the core sampler was collected in plastic bags. The original volume of each soil core was measured and recorded in each three layers. The collected soil samples were brought to Wondo Genet College of Forestry and Natural Resource soil laboratory for analysis of bulk densities and percent of soil carbon contents.

3.5. Data Analysis

The quantitative research, data analysis methods were used to quantify and analyze numerical data which were collected from field survey measurements. The collected primary data were entered and arranged for analysis in Microsoft Excel Sheet 2007 version. The forest inventory data were analyzed and interpreted using quantitative statistics. The independent two sampled t-test was performed to determine whether there were significant differences between forest classes' natural regeneration status and carbon stocks by using Minitab19 version statistical software. The statistical tests for significance of differences were tested using the least significant difference (LSD) of mean at $p < 0.05$. Descriptive statistics percentage, descriptive tools, charts, and tables were employed to summarize the results and conclude with the forest disturbance indicators and supported by a concise discussion.

Regeneration data analysis: The mean of seedlings, saplings and matured tree densities per hectare was calculated. The regeneration status of undisturbed natural forest and disturbed coffee forest was analyzed by comparing within groups and between groups' seedlings, saplings and plant species with mature plants. According to Tesfaye Bogale *et al.,* (2017) categories:

1. If the present seedlings > saplings > mature trees "good regeneration"
2. If present in seedlings > saplings < mature trees "fair regeneration." and
3. If a species survives only in the sapling stage "poor regeneration" but not as seedlings. Even though saplings may be less than; more than or equal to mature.

Aboveground living plant species biomass data estimation: The aboveground biomass of all individual trees in the sample plots were calculated by using the Pan tropical mixed-species, broad leaf allometric model, which usually yields a less biased estimate with the inclusion of the country's specific wood density and tree height, for biomass estimation. The specific wood densities of indigenous tree species were taken from secondary data sources of Ethiopian appropriate wood densities estimated for 421 indigenous tree species growing in Ethiopia.

(A). $AGB = 0.0673\times (WD\times DBH^2\times H)^{0.976}$ ……………………..……. (Chave *et al*., 2014).

Lianas Biomass = exp (0.12+0.91´log (BA at DBH)). …………………………… (Putz, 1983).

For coffees above ground biomass estimation, species-specific allometric equation was used.

(B). Above ground *Coffea arabica* biomass = $0.147d^2_{40}$ ….(Mesele Negash *et al*., 2013).

Where: AGB = above ground biomass (in kg dry matter), WD = wood density (g/cm^3), DBH = Diameter at Breast Height (cm), H = total height of the tree (m), BA = basal area at 1.3 m height (m^2), and (d_{40}) is diameter at 40 cm height used for only coffee.

Biomass of shrub and saplings with DBH ≤ 5cm was calculated using the following allometric equation equation (De Walt and Chave, 2004).

(C). ln (AGBs) = -3.50 + 1.65 × ln (D) + 0.842 × ln (H)

where, AGBs = Shrub above ground biomass (kg); D = Collar diameter (cm); and, H= Total height (m)

- **Deadwood biomass data analysis:**The biomass of standing deadwood which does not have leaves 2.5% subtraction of aboveground biomass; for dead trees contain only large branches, or no branches biomass was reduced by 20% AGB and biomass of downed deadwood was estimated using decomposition levels (IPCC, 2006):
- sound (the blade does not sink or is bounced off.) and has decomposition level value of 0.90.
- Rotten (blade sinks well into the piece, there is extensive wood loss and the piece is crumbly) and has a decomposition level value of 0.50.

Biomass of LDW = V× 90% ×WD for sound and Biomass of LDW = V × 50% ×WD for rotten.

Where LDW = Lying Dead Wood, V= volume and WD = specific wood density ($0.615 g/cm^3$).

Volume (m^3) = $\pi^2 d_1^2$ / (8 × L)

Where:d = have way diameter of dead wood intersecting the line(cm). L = the length of the line, in meters (100m).

Biomass of non-wood data analysis: The amount of litter biomass per hectare of forest floor was analyzed by using the ratio of dry weight to the fresh weight method (Karki *et al*., 2016).

$$\mathrm{LBM} = \frac{\mathrm{W}\ field}{\mathrm{A}} \times \frac{\mathrm{W}\ sub\ sample, dry}{\mathrm{W}\ sub\ sample, wet} \times 10{,}000$$

Where, LBM = biomass of leaf litter (t/ha)

W field = weight of the fresh field sample of litter sampled within an area of size A (g), A = size of the area in which litter was collected (m^2), W sub-sample, dry = weight of the dried sub-sample of litter (g), W sub-sample, wet = weight of the fresh sub-sample of litter (g). The carbon content in the litter biomass was converted from dry mass to carbon by multiplying conversion factor 37% (ICC, 2006).

Below ground biomass: Below ground, carbon pool was recommended, as it is usually represented between 15-30% of the aboveground biomass carbon. While the measurement of aboveground biomass was relatively straightforward, the biomass in roots or below ground biomass of the tree is often difficult to measure directly. It was estimated by using a suitable R: S ratio established as default value for global application that expresses root biomass with aboveground biomass.

Root biomass = 27% × AGB……………………..……..……………………. (IPCC, 2006).

To express the dry weight biomass in carbon stock, the estimated aboveground and below-ground biomass was multiplied by the default value of a carbon fraction47% (IPCC, 2006).

Soil carbon analysis: In the laboratory, the soil samples collected for bulk density were oven-dried at a temperature of 105 ºC for 48 hours and weighed (Pearson *et al*., 2013; Karki *et al.*, 2016). The dried and weighed soil samples were washed through 2 mm sieve with water until substantially clean water came out. The washed soil fragments were oven-dried again normally for 24 hours to remove water moisture. The mass of these dried fragments was weighed. The volume and density of coarse fragments were determined. The fine bulk density was calculated for three layers of samples (0–15 cm, 16–30 cm and 31–45 cm) for each plot by using formula.

$$\text{Fine bulk densty } (g/cm^3) = \frac{\text{Oven dry mass (g)}}{\text{Core vlume } (cm^3) - \left[\frac{\text{Mass of coarse fragments (g)}}{\text{Density of coarse fragments } (g/cm^3)}\right]}$$

The carbon concentration (%) was analyzed from the composite soil samples. The composite soil samples were air-dried, sieved in 2mm sieve and SOC contents were quantified using (Walkley and Black, 1934) method. The amount of soil carbon stock per hectare area was calculated from fine soil bulk density, carbon concentration (%) data obtained from laboratory analysis and soil depth.

SOC (tc/ha) = [(soil bulk density (g/m^3) x soil depth (cm) x C%)] x 100 (Pearson *et al*., 2013).

4. RESULTS AND DISCUSSION

4.1. Natural Regeneration

The densities (number of plants per hectare) of seedlings, saplings and mature plant species in both forest classes were determined. The enumerated mean density of seedlings less than 1.5 m in height were 4583± 67 plants/ha in undisturbed forest and 237± 7.3 plants/ha in disturbed or coffee forest. Based on two-sampled t-test, the density of seedlings in the undisturbed natural forest was significantly higher than in the disturbed or coffee forest ($T = 77.11$ and $p < 0.05$). The determined saplings (i.e., height between 1.5 - 3 m) mean densities were 3287 ± 35 plants/ha of undisturbed forest and 314± 73 plants/ha from the disturbed or the semi-forest. The density of saplings for undisturbed natural forest was also significantly higher than that of semi-forest or coffee forest as $T = 52.75$ and $p < 0.05$. Therecorded mature plants 740 ± 14 stems/ha in the undisturbed natural forest was also greater than 344 ± 15 stems/ha in the disturbed coffee forest ($T = 18.41$ and $p <0.05$). The seedlings, saplings densities and mature plant species in the disturbed coffee forest were decreased by 94.83%, 90.45% and 53.51% respectively as compared to the undisturbed natural forest.

The results demonstrated that undisturbed natural forest regeneration potential was higher than disturbed or coffee forest. In undisturbed natural forest, the abundance of seedlings densities were > saplings > mature trees as shown in Figure 4. Most of the woody tree species have the highest number of individuals at the seedlings and sapling stage with a gradual decrease or diminishing towards maturing. This indicated that the higher and better natural regeneration potential of undisturbed natural forest. In the coffee forest, the regeneration of woody plants was poor since the number of seedlings < sapling < mature plants. This showed that the conversion of forest to coffee plantation and its management activities effect on regeneration of plant species in the study area of forest ecosystem. Frequent removal of naturally grown seedlings and saplings of plant species minimized the regeneration abundances and the shrub layer was replaced by coffee plants. The intermediate tree layer density was also minimized during coffee shad tree management activities for increasing coffee production and productivity. The only tree species with a single trunk and small leaves that can grow large in height densities were quite similar in both forest classes.

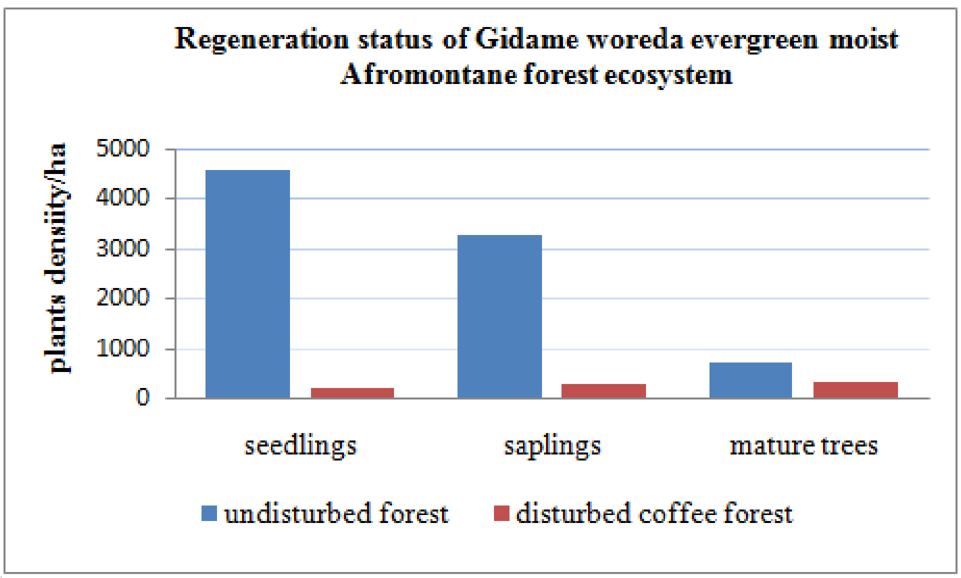

Figure 4. Population structure and growth size distribution of major trees species in undisturbed natural forest and disturbedcoffee forest in terms of mean stem densities per hectare of Gidame woreda moist evergreen montane forest.

The regeneration of these study area forest classes have similar growth forms and compared with other natural forests in Ethiopia and tropical forests. But quite different with plant densities 22,630 plants/ha, 658 plants/ha, 635plants/ha seedlings, saplings and mature plants respectively in natural forest; in coffee forest 7,110 plants/ha, 176 plants/ha and 402 plants/ha seedlings, saplings and mature plants respectively in Bale Eco-region natural forest in Ethiopia (Dejene Nigatu *et al.*, 2017). The recorded regeneration abundances in this study site were comparable with the natural regeneration of tree species in Belete moist evergreen montane forest 4,547 seedlings/ha, 1,547 saplings/ha and 265 adults/ha（Kflay Gebrehiwot and Kitessa Hundera, 2014). Only the seedling densities in this study were lower than the least disturbed sites in the tropical forest of Chhattisgarh 39,500/ha seedlings, 490/ha saplings, and 510/ha mature trees; moderately disturbed seedlings 26,000/ha, sapling 610/ha, and tree 310/ha; and highly disturbed seedlings 7,750/ha, saplings 30/ha, and trees 100/ha (Pawar *et al.*, 2012).These differences caused bydifferences in management practices, management intensities, degree of disturbance, vegetation characteristics, agro-ecology, and soil types.

The higher species densities recorded in undisturbed natural forest confirmed that with intensive management, the growth size-frequency distribution of some individual tree species were different from the cumulative growth size distribution (Siraj Mammo and Zhang, 2018). In coffee forest Lianas, shrubs and other under-story vegetation were removed and replaced with some coffee plants where shrubs were often more abundant than tree seedlings regarding the percentage of cover (Brown *et al.*, 2013).During an opening phase in SFC systems, the vegetation which considered as it would have competed with coffee plants were cleared without preferential selection and replaced by coffee plants. SFC systems also disturb the forest structure of some upper canopy layer as farmers remove 30% of the canopy trees and most of the undergrowth vegetation except the coffee plants (Schmith *et al.*, 2010).

Habitat degradation reduces seedling densities, which appears to be associated with increased canopy disturbance. Fragmentation and degradation both appear to compromise the ability of the late succession trees to reproduce and persist in human-modified landscapes (Ismail *et al.*, 2014). Most of the montane forest areas in South West Ethiopia have been deforested, and the remaining forest areas are highly fragmented (Wolde Mariam, 2003).Weeding under planted coffee removes seedlings and saplings from year to year and largely affected the regeneration of indigenous plant communities. The regeneration status of forest coffee showed that poor recruitment of mature trees by the saplings. Since trees densities and their regeneration in the forests were mostly dependent on the response of seedlings and saplings to the forest micro-environment.

Natural forest regeneration assessment is an important part of evaluations of forest status and needs for sustainable natural forest management as it is one of the thrusts full areas of forestry. Because successfully regenerating and conserving young trees is the first principle of sustainable forest management. Even though disturbance sometimes creates an environment for some light-demand species, too much and frequent disturbances minimize the overall tree diversity by eliminating sensitive and late succession plant species. The least disturbed forest site good showed regenerating because of the highest densities of seedlings and saplings in the forest site; moderately disturbed site shows better regeneration, but highly disturbed site did not show good regeneration status (Pawar *et al*., 2012).

4.2. Biomass Carbon Stock

The DBH and height of 426 individual trees from 37 species were measured and recorded with a maximum diameter of 131 cm (*Ekebergia capensis*) in the undisturbed natural forest. The average basal area of 37.52 m2/ha (minimum 19.42m2/ha and a maximum 65.42 m2/ha) was determined for undisturbed natural forest. In the same way, the DBH and height of 279 individual trees were also measured according to their diameter classes from 25 tree species in a disturbed forest or coffee forest stratum. In addition to these, for biomass carbon stock estimation, the DBH of 359 coffee plants were also measured at 40 cm height from the ground surface level. The maximum diameter recorded in the coffee forest was 127 cm (*Aningeria adolfi-friederici*) with an average basal area of 28.92 m^2/ha (minimum 9.22 m^2/ha and maximum 48.47 m^2/ha). These field inventory data showed that plant species density and basal area were higher in the undisturbed natural forest as compared to the disturbed coffee forest. With expanding coffee plantation and its management activities, the forest characteristics, tree density and basal area of natural forest ecosystem were declined.

The estimated mean biomass carbon stock density was higher in undisturbed natural forest carbon pool components than that of a disturbed forest or coffee forest. The two-sampled t-test comparison revealed that there was a significant difference (expressed at 95% confidence interval of the mean) between the two classes of forest ecosystem biomass carbon stock ($T = 6.39$ and $p < 0.05$).The disturbance of this natural forest ecosystem, which associated with the conversion of natural forest to the coffee cultivation area resulted in the loss of 33.09% of the biomass carbon stock density.

Table 3. Meanbiomass carbon stock (tc/ha) ±SE in the undisturbed natural forest and disturbed or coffee forest paired t-test comparison.

	Undisturbed natural forest (n = 29)			Disturbed coffee forest (n= 42)				
Biomass carbon pools	AGC	BGC	Total	AGC	BGC	Total	T	P
trees, lianas and shrubs	233.92 ±7.223[a]	63.158 ± 1.974[a]	297.078 ± 9.197[a]	147.672± 7.746[b]	39.871 ± 2.20[b]	187.543 ± 9.946[b]	6.38	0.000
coffee	0.094 ± 0.094[b]	0.025 ± 0.026[b]	0.119 ± 0.12[b]	8.58 ±0.75[a]	2.320 ± 0.2[a]	10.90 ± 0.95[a]	9.56	0.000
dead wood	0.435 ±0.046	-	0.435 ±0.046	0.689 ±0.073	-	0.689 ±0.073	1.63	0.109
litter	1.126 ±0.037[a]	-	1.126±0.037[a]	0.763 ±0.031[b]	-	0.763 ±0.031[b]	7.51	0.000
Total	235.575 ±7.40[a]	63.183 ±2[a]	298.758±9.40[a]	157.704 ± 8.6[b]	42.191 ± 2.40[b]	199.895 ±11[b]	6.39	0.000

Different letters show that the difference is significant at $p < 0.05$.

The biomass carbon stock density results obtained from both forest classes of this study area were larger, consistent, and comparable to earlier studies in Ethiopia and other tropical countries. They fall within the ranges reported for undisturbed and disturbed forest biomass carbon stock across in the different tropical forest ecosystem. The total biomass carbon stock in an undisturbed natural forest of this study was greater than biomass carbon stock in the tropical wet zone of the Sigiriya forest sanctuary, and forest reserve in Sri Lanka 249 tc/ha (Kuruppuarachchi *et al*., 2016) and Gesha moist Afromontane forest in Kaffa Zone 225.92 tc/ha (Admassu Addi, 2018), compared with 298.77 tc/ha for Gerba-Dima moist Afromontane forest, South-Western Ethiopia (Abyot Dibaba *et al*., 2019). But it was lower than the least disturbed wet evergreen rainforest of Eastern Himalaya 425.70 tc/ha (Sahoo, 2017) and Egdu dry Afromontane forest 333.70 tc/ha (Adugna Feyissa *et al*., 2013).

The biomass carbon stock found from the disturbed coffee forest of this study was comparable to biomass carbon stock of Giza-Sayilem moist Afromontane forest in Kaffa Zone 198.67 tc/ha (Admassu Addi *et al*., 2019), greater than Tankawati forest of Bangladesh 115.3 tc/ha (Ullah and Al-Amin, 2012), less than mild disturbed 236.08 tc/ha and greater than highly disturbed 127.38 tc/ha wet evergreen rainforest of Eastern Himalaya (Sahoo, 2017).The causes of these variations between forest types of the study areas, biomass carbon caused by different degreesanthropogenicdisturbance,models used to estimate biomass, presence of bigger sized trees in the higher basal area, ecological variation, and higher densities of woody species or vegetation characteristics.

The aboveground biomass carbon stock of undisturbed natural forest was higher than that of disturbed coffee forest aboveground biomass carbon stock. The carbon sequestration potential of this natural forest was decreased with expanding and converting to the coffee cultivation area. The two sampled comparisons, statistical tests ($T = 6.38$ and $P < 0.05$) showed that the aboveground biomass carbon stock of this forest ecosystem was significantly differed between both forest stratum. The effect of this change in a forest biomass carbon stock was mostly from the loss of above ground living trees and replacing with coffee. Based on the estimation of forest inventory data, the most substantial amount of carbon is stored in the living biomass of aerial plant parts. The removal of these living biomass of aerial plant parts and replacing with the coffee plantation caused the loss of 26.06% of the total biomass carbon stock density. The nonliving forest floor litter and dead wood biomass carbon contribute a tiny and insignificant percentage of biomass carbon to this forest ecosystem. The dead wood of this natural forest was collected by local people for firewood and use as sources of energy. The result of biomass carbon stock in this forest was an essential indicator of living tree parts' productive capacity to sequester a high amount of carbon and sources of high carbon dioxide emission due to human disturbance.

This study confirms that the conversion of natural forest ecosystem to other land uses, modification and loss of forests due to disturbances were the large source of human-induced climate change, which accounted6–20%of anthropogenic greenhouse gas emissions (Baccini *et al*., 2012;Gullison *et al.,* 2007; Harris *et al*., 2012; IPCC, 2007). Forest disturbance influences the amount of forest carbon stock through by altering the stand structure and composition (Thong *et al*., 2016). The living vegetation, the largest aboveground carbon pool was extremely sensitive to disturbance. It was particularly affected by human disturbance, exhibiting the large decrease in carbon stock density (Berenguer *et al*., 2014). Other studies such as Chidumayo, (2013) also showed that forest degradation leads to biomass loss. This loss or reduction of forest biomass carbon stock was mainly driven by conversion to other land uses and forest degradation (MacDicken *et al*., 2016). 90 percent of the forest can be cleared before it is considered deforested; as such, forest degradation can lead to substantial carbon emissions and is often an important precursor to deforestation (Virgilio *et al.*, 2010).

In the study area, it is also observed that a significant number of coffee farmers have expanded a clearance of woody, herbaceous and Lianas or climbers vegetation to get free space for coffee plantations. This is similar to other study the site with high coffee cover had a lower coverage of lines and climbing vines (Hylander *et al*., 2013).Forest coffee management has predominantly done through undertaking the operations slashing undergrowth vegetation, cutting, debarking, removing under-story vegetation and thinning of shade trees depending upon the necessities and requirements of sunlight to maintain optimum shade for coffee production. Those tree species with many trunks, big/broad leaves, and dense canopies were debarked and burn around the root collar area. The only preferred coffee shade trees were left to maintain the production and productivity of coffee yields. The selective cutting of some none preferred tree species in the human-modified landscape during coffee management affected the ecological functions and/or ecosystem service carbon sequestration potential of the natural forest terrestrial ecosystem.

Even though the non-living biomass carbon stock density in dead woods and litter of the study site were low, it was a component of aboveground biomass. In undisturbed natural forest deadwood performs several important ecological functions for many forest-dwelling species (Lassauce *et al.,* 2011). The standing and downing dead woods of large trees also ultimately enhancing ecosystem function, including protection of soil nutrient retention (Franklin *et al*., 2002).The mean litter biomass carbon stock contribution in this forest ecosystem was insignificant when compared to other carbon pools. This is in line with the lowest carbon stock in the forest floor litter might probably the rate of litter decomposition (Abiyot Dibaba *et al*., 2019). Where the study area is located in tropical areas, the rate of decomposition is relatively fast (Fisher, 2000).

The derived mean of below-ground biomass carbon stock in undisturbed natural forest was significantly highercoffee forestT = 6.43 and $P < 0.05$ at 95% confidence interval. In this study the mean difference between both below-ground biomass carbon stock was 20.10 tc/ha. This difference showed that the destruction of root biomass caused by coffee plantation and its management activities lead to a loss of 7.03% tc/ha from the total biomass carbon stock of the forest ecosystem. This confirms that the loss of below-ground biomass carbon stock due to the conversion of natural forest to coffee by removing aerial living vegetation (Barbosa *et al.*, 2012).

As compared to other studies the obtained result of below-ground biomass carbon stock from undisturbed natural forest of this study was greater than45.97 tc/ha below ground carbon sock of Gerba-Dima moist Afromontane forest, South-Western Ethiopia (Abyot Dibaba *et al., 2019*). The BGBC result for disturbed or coffee forest was also greater than34.3tc/ha below-ground carbon sock for moist Afromontane forest in Gesha district in Kaffa (Admassu Addi *et al.*, 2019). This carbon pool was contributed a significant amount of biomass carbon to the ecosystem next to the soil carbon pool. It also forms an important carbon pool for many vegetation types and land-use systems.

4.3. Soil Organic Carbon stock.

In bothforest classes, the average soil bulk density of the study site increased with the depth increment.The conversion of natural forest to forest coffee caused soil bulk density increase mostly in the upper soil layer as compared to undisturbed natural forest class.The concentration (%) of soil organic carbon was decreased in different rates with increasing soil depth in both forest classes. The quantified carbon contents of the soil in the study area ranges from 2.98-7.85%, 2.38-6.50% and 1.81-4.41% in 0-15 cm, 16-30 cm and 31-45 cm soil layer respectively for theundisturbed natural forest. The soil carbon content ranges from 3.92-8.40%, 2.53-5.78% and2.53-3.97% in 0-15 cm, 16-30 cm and 31-45 cm soil layer respectively in the disturbedcoffee forest. The concentration (%) of soil organic carbon was decreased in different rateswith increasing soil depth in both forest classes. The summary of mean soil organic carboncontents (%), mean fine bulk densities, and their standard deviation in different soil depthswas presented in table 4 for both forest classes.

Table 4. Mean (± SE) of soil organic carbon content (%) and mean soil fine bulk densities at different soil depths in Gidame woreda forest ecosystem.

	undisturbed forest		disturbed /coffee forest	
Soil depth (cm)	fine BD (g/cm^3)	SOC content (%)	fine BD (g/cm^3)	SOC content (%)
0 －15	0.743 ± 0.0525	5.919 ± 0.555	0.793 ± 0.0193	5.801 ± 0.346
16－30	0.788 ± 0.0536	3.814 ± 0.435	0.812 ± 0.0175	3.738 ± 0.229
31－45	0.818 ± 0.0394	3.041 ± 0.269	0.821 ± 0.0212	3.191 ± 0.116

The investigated soil organic carbon stocks for 0–45 cm layers were 148.40 tc/ha from undisturbed natural forest and 153.80 tc/ha from disturbed forest coffee. In contrast to biomass carbon stocks, the mean soil organic carbon stock was higher for the disturbed coffee forest and lower for the undisturbed natural forest. However, the difference between these forest types in SOC did not show significant variation ($T = 0.48$; $P > 0.05$) at the ecosystem level. The insignificant amount of soil organic carbon stock difference in 0–15cm upper and 31-45 cm lower soil layer caused by the increment of soil bulk density rather than soil organic carbon contents. But there was no difference in soil organic carbon stock in the middle soil layer.

Table 5. Meansoil organic carbon stock (tc/ha) distribution in different soil depths in the Gidame district forest ecosystem.

	Undisturbed forest		Disturbed / coffee forest			
Soil depth (cm)	N	Mean ± SE	N	Mean ± SE	T-value	P-value
0−15	10	66.00 ± 6.20	14	69.00 ± 4.10	0.43	0.675
16−30	10	45.10 ± 5.10	14	45.50 ± 2.80	0.08	0.935
31−45	10	37.30 ± 3.30	14	39.30 ± 1.40	0.61	0.546
0−45	30	148.40 ± 12	42	153.80 ± 4.30	0.48	0.636

The SOC stock found from undisturbed natural forest in two layers (0–30) cm soil depths of this study was less than162.62 tc/ha (0–30) cm depths of soil carbon stock for Gerba-Dima moist Afromontane forest, South-Western Ethiopia (Abyot Dibaba *et al*., 2019), 128 tc/ha soil carbon sock in 0-15 cm and 15-30 cm layers for moist Afromontane forest in Gesha District in Kaffa (Admassu Addi *et al*., 2019). But greater than Gera native forest SOC stock 98.95tc/ha and coffee-based agroforestry SOC stock 94.30 tc/ha in South-Western Ethiopia (Mohammed Abaoli and Bekele Lemma, 2014), 88.40tc/ha in 0-15 cm and 15-30 cm layers of old-growth montane forest in lower montane Ecuador (Rhoades *et al.*, 2000),79.01 tc/ha and 99.65 tc/ha of the natural forests at Me Linh biodiversity station, Vinh Phuc province in Vietnam (ThiThu and Huu Thu, 2014), 106.17 tc/ha for Geza and lower than 160.00tc/ha for Mtimbwani forest ecosystem in Tanga, Tanzania (Alavaisha and Mangora, 2016).

The differences of these SOC between different studying area's forest ecosystems caused from the differences of vegetation characteristics, different management activities in native forest, soil type and soil properties, history of land use land cover and other environmental and climatic factors. Other studies considered the amount of soil organic carbon is influenced by relief, soil texture; high soil, water contents tends to conserve soil organic matter and temperature accelerates biological processes (Batjes, 2011; Victoria *et al*., 2012). Dead organic matter on the ground and plant biomass below the ground to decompose and transform into soil organic matter, and can have varying residence times in the soil (Ontl and Schulte, 2012).

The declined of mean soil carbon stock of this study when the depth and soil bulk density increased in both forest classes agreed with earlier studies that soil organic carbon content was higher at the surface than in the deeper soil layers (Zhang *et al*., 2018), and decreasing trend with soil depth (Kukal and Bawa, 2014). In contrast, as soil depth and bulk density increased, the percentage of soil carbon contents decreased (Rhoades *et al*., 2000). The majority of Soil Organic Carbon (SOC) is found primarily in the upper layer because it is the most biologically active (Wells *et al*., 2012).

The interactions among different species, vegetation were essential to maintain soil quality, ecological, and landscape integrity (Pauli *et al.,* 2012). The old-growth forests accumulated large quantities of carbon stock for centuries and contain much soil carbon content (Fontaine *et al.,* 2007),which will move back to the atmosphere or decomposed when forests were disturbed (Luyssaert *et al.*, 2008).The soil organic carbon content depends upon land management, and land uses. The higher carbon stock density in the upper soil layer of coffee plantation can be explained by soil compaction and by compensation of reduced Soil Organic Carbon (SOC) inputs from litter and debris by increased soil enrichment (De Beenhouwer *et al.*, 2016).

In the study site, farmers remove some shade trees and increase the penetration of sunlight to the forest floor for optimizing light and heat for coffee production. This might increase the ground surface temperature and the abundance of some dead wood on the forest floor. This predicts an average of dead wood and litter (Chambers *et al*., 2000) where soil organic carbon is a balance between the input of surface litter (fallen leaves and dead organisms) and the rate at which microbes break down organic compounds (Dutta *et al*., 2019). However, increasing temperatures could reduce SOC by accelerating the microbial decomposition (Victoria *et al*., 2012).

Moderate to heavy disturbance in tropical moist forests has a profound impact on fine root turnover and the related carbon transfer to the soil (Hertel *et al*., 2009). On the other hand, increasing SOC levels can be achieved by increasing carbon inputs to soils. In the case of managed soils, this can be done by increasing the input and retention of aboveground biomass (Victoria *et al*., 2012). In general, the results of this study revealed that soil carbon stock did not show a significant variation between natural forests and tropical Agroforestry landscapes (Kessler *et al*., 2012).

5. CONCLUSION

Coffeeexpansion in natural forest and its management activities significantlyaffect the natural regeneration of native tree species populationstructure and functioning of biomass carbon stock of the naturalforest ecosystem. Theseedlings, saplings and mature plant species densities weredecreased by 94.83%, 90.45%, and 53.51% respectivelyascompared to the undisturbed natural forest.In disturbed forest of this study site, the undergrowth vegetation, tree seedlings, and saplings were removed and replaced by coffee plants.Coffee expansion and its management activities also decrease forest characteristics: basal area and tree density which lead to minimize biomass carbon stock from298.758 ±9.40tc/ha to 199.895 ±11tc/ha. This indicated that the loss of 33.09% (26.06% from ABC and7.03% from BBC) biomass carbon stock from the natural forest converted to coffee forest. But the estimated soil organic carbon stock 148.40 ± 12 tc/ha for undisturbed forest and 153.80 ± 4.30 tc/ha for disturbedcoffee forest in 0–45 cm soil profiles didn’t show significant variation and the soil organic carbon stock of the study site was not affected due to coffee expansion. Therefore, the results of this study strictly indicated that the conservation of this natural forest ecosystem, enhancing its regeneration and carbon sequestration potential should be widely recognized and needs further investigation.

6. RECOMMENDATIONS

- Time to time regeneration status assessment of this forest patch should be neededto determine the status of the forest and take for appropriate conservation measures for the remaining natural forest.

- Regular assessment of biomass carbon stock of this natural forest should be made on its own operational plan.

- Reducing coffeeexpansion in this natural forest which destructs the natural regeneration and biomass carbon stock of this natural forestand enhancing prioritization of forest conservation through local community participation and provision of environmental awareness for forest user groups should be provided.

- The attention on the need to achieve sustainable forest management should be adoptedfor the quality of the ecosystem services especially on biodiversity based carbon sequestration potential ofthis natural forest.

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APPENDICES

Annex 1. Coordinate points of the sample plots station for field data collection.

Annex 1. Table1. Coordinate points of sample plots in the study site

Id	X-Coordinates	Y-Coordinates	Strata	Soil sample	Id	X-Coordinates	Y-Coordinates	Strata	Soil sample
1	34.6479	8.9356	SF	selected	37	34.6732	8.8915	NF	
2	34.654	8.9299	SF		38	34.6643	8.8947	NF	
3	34.647	8.9282	SF	selected	39	34.6686	8.8922	NF	selected
4	34.6452	8.9242	SF		40	34.6709	8.8896	NF	
5	34.6423	8.9208	SF		41	34.6735	8.8835	NF	
6	34.6382	8.9195	SF	selected	42	34.6752	8.8808	NF	
7	34.6339	8.9159	SF		43	34.6803	8.8827	NF	selected
8	34.6401	8.9119	SF		44	34.6822	8.8767	NF	
9	34.6374	8.9063	SF	selected	45	34.6768	8.8761	NF	
10	34.6322	8.8984	SF		46	34.6801	8.8761	NF	selected
11	34.6265	8.8948	NF	selected	47	34.6809	8.8731	NF	
12	34.6207	8.8917	NF		48	34.6729	8.8686	SF	
13	34.6248	8.8905	NF		49	34.6649	8.8684	SF	
14	34.6316	8.8889	NF	selected	50	34.659	8.8666	SF	
15	34.6387	8.8921	NF		51	34.6571	8.8634	SF	selected
16	34.6431	8.896	NF	selected	52	34.6615	8.868	SF	
17	34.6399	8.9024	SF		53	34.6507	8.8717	SF	
18	34.6449	8.9063	SF		54	34.6501	8.872	SF	
19	34.6507	8.9082	SF	selected	55	34.6504	8.8748	SF	selected
20	34.6442	8.9117	SF	selected	56	34.653	8.8772	SF	
21	34.6503	8.9163	SF		57	34.6577	8.8783	SF	
22	34.6478	8.919	SF		58	34.6546	8.8843	SF	
23	34.6514	8.9226	SF	selected	59	34.6489	8.8865	SF	selected
24	34.657	8.92	SF		60	34.6513	8.8943	SF	
25	34.6603	8.9239	SF	selected	61	34.6354	8.8858	NF	
26	34.6535	8.9042	SF		62	34.6285	8.8844	NF	
27	34.6627	8.9107	NF	selected	63	34.6195	8.8808	SF	selected
28	34.6727	8.9218	NF		64	34.6263	8.8803	SF	
29	34.6728	8.916	NF		65	34.6297	8.8749	SF	
30	34.6738	8.9127	NF		66	34.6269	8.8711	SF	
31	34.6693	8.9143	NF	selected	67	34.622	8.8689	SF	selected
32	34.6693	8.9098	NF		68	34.6247	8.8664	SF	

33	34.6694	8.9055	NF		69	34.6192	8.8646	SF	
34	34.671	8.8996	NF	selected	70	34.6202	8.8597	SF	
35	34.6759	8.8973	NF	selected	71	34.6132	8.8606	SF	selected
36	34.6739	8.8945	NF						

Annex 2. Instruments used during data collection

Annex 2. Table 1. List of instruments used for field data collection.

No	Equipment	Used for	In No.
1	GPS	For navigation to the sample plot location /center	2
2	Comps	Measuring bearings/direction	2
3	Clinometer	For measuring the top and bottom angle to the tree	2
4	Diameter tap	Measuring of the tree DBH (at 1.3m)	2
5	Meter tap	For measuring distances	2(50m)
6	Rope	Sampling plot lay out/ For plot boundary delineation	2(100m)
7	Machete	Cutting unnecessary bush / thorny wood	2
8	Note book	Writing /taking note about what to be the observed	2
9	Pens/pencil	Writing the measurements and observation	2
10	Field checklist	Writing the measurements and observation	2
11	Clip board	Writing the measurements and observation	2
12	Soil sample core (d=5 and h=15)cm	For collecting soil samples from various depths	2
13	Soil sample hammer	For bearing down on the soil core while collecting sample	2
14	Weighing machine	Mass measuring or weighing destructive samples	2
15	Sped	Soil sample scavenge	2
16	Shovel	For taking out soil core from the soil depth	2
17	Knife	Removing unwanted soil volume	2
18	Hoe	Soil digging for taking out the metal core	2
19	Plastic bag	Packing soil samples	126

20	hypsometer	for measuring tree height	2

Annex 3. Field Data Collection Formats

Annex 3. Table 1. Regeneration/ Seedling count format

The status of forest regeneration will be evaluated within a nested square plot of 7m ´7m.

The seedlings of native tree specious with its native mother tree < 1.3m in height will be counted, identified, and recorded in a field book

Date ____

Plot number:				Land use type	
Latitude				Age of land use type	
Longitude				Recorder	
No.	Species/plants name / Local name	Category	Regeneration/ Seedling count		Remark
			Mother (in number)	seedlings (in number)	

Annex 3. Table 2. For aboveground woody biomass parameters field data collection format.

Note DBH at 1.3m, under category column code ***01*** *was used for undisturbed natural forest sample and* ***02*** *stands for disturbed natural forest sample*

Plot number:	Land use type
Latitude	Age of land use type
Longitude	Recorder
Nest	Date
GPS and Compass reading of the nest	

Plant ID	Species/plants name / Local name	Cate gory	DBH (in cm)	Height (in m)			Remark
				H 1	H 2	T H	

Annex 3. Table 3. Litter biomass sample data collection format sheet.

*Note Under category column code **01** was used for undisturbed natural forest litter sample and **02** stands for disturbed natural forest litter sample.*

Plot number:			**Land use type**	
Latitude			Age of land use type	
Longitude			Recorder	
Nest			Date	
GPS and Compass reading of the nest				
Plot ID	Category	Fresh weight	Dry weight	Remark

Annex 3. Table 4. Soil sample data collection format sheet for bulk density analysis

*Note Under category column code **01** was used for undisturbed natural forest soil sample and **02** stands for disturbed natural forest soil sample.*

Plot number:			Land use type		
Latitude			Age of land use type		
Longitude			Recorder		
Nest			Date		
GPS and Compass reading of the nest					
Plot ID	Category	Depth 1 (Volume in cm^3)	Depth2, (Volume in cm^3)	Depth3, (Volume in cm^3)	Remark

Annex 3. Table 5. Soil sample data collection format sheet for carbon content analysis

*Note Under category column code **01** was used for undisturbed natural forest soil sample and **02** stands for disturbed natural forest soil sample*

Plot number:			Land use type		
Latitude			Age of land use type		
Longitude			Recorder		
Nest			Date		
GPS and Compass reading of the nest					
Plot ID	Category	Depth 1 Weight (g)	Depth2, Weight (g)	Depth3, Weight (g)	Remark

Annex 3. Table 6. After laboratory analysis of bulk density and carbon content
*Note category on the space provided code **01** was used for undisturbed natural forest soil sample and **02** stands for disturbed natural forest soil sample.*

Plot number:			Land use type			
Latitude			Age of land use type			
Longitude			Recorder			
Nest			Date			
GPS and Compass reading of the nest						
Plot ID	Depth (cm)	Category________________________________				Remark
		Oven dry mass (g)	Mass of coarse fragments (g)	density of rock fragments (g/m3)	carbon content (In %)	
	1-15					
	15-30					

	30-45					
	1-15					
	15-30					
	30-45					

Annex 4. Major tree species grown in the study area and their and dbh distribution

Annex 4. Table 1. Major tree species grown in the study area growth forms with their DBH distribution density/ha

Scientific Name	Local Name	Undisturbed natural forest (dbh classes)					Disturbed or coffee forest (dbh classes)				
		seedlings	saplings	5-20cm	21-51cm	>51cm	seedlings	saplings	5-20cm	21-51cm	>51cm
Albizia grandibracteata	Shawo	15	10	0	1	1	0	0	0	0	0
Albizia gummifera	Muka-arba	102	73	21	4	2	77	103	39	8	6
Albizia schimperiana	Yango	58	42	28	5	2	0	0	34	11	6
Aningeria adolfi-friedericii	Keraro	87	63	21	3	10	11	14	5	4	8
Apodytes dimidiata	Wondabiyo	116	84	21	1	2	0	0	0	1	1
Bersama abyssinica	Lolchisa	437	313	0	0	0	11	14	5	0	0
Celtis africana	Chayi	146	104	21	3	1	0	0	1	0	0
Cordia africana	Wadessa	15	10	0	2	2	6	9	19	6	1
Croton macrostachyus	Bakanisa	87	63	35	6	4	88	117	78	9	1
Dombeya torrida	Danisa	15	10	0	7	1	0	0	0	0	0
Dracaena steudneri	Afarfatu	44	31	7	1	1	0	0	0	0	0
Ehretia cymosa	Hulaga	73	52	14	1	0	0	0	9	1	0
Ekebergia capensis	Sombo	58	42	0	2	3	6	9	1	1	1
Ficus sur	Harbu	102	73	7	1	1	0	0	5	2	1

Grewia bicolour	Haroresa	4	3	0	1	0	0	0	0	0	0
Macaranga lophostigma	Dogoma	335	240	91	21	0	0	0	0	1	0
Maesa lanceolata	Abayi	73	52	7	2	0	22	29	2	1	0
Millettia ferruginea	Sotalo	44	31	7	2	1	4	6	0	1	0
Mimusops kummel	Bururi	306	219	70	0	0	0	0	15	0	0
Olea capensis	Gagama	87	63	21	0	0	0	0	0	0	0
Olea welwitschii	Baha	56	40	28	2	3	0	0	0	0	1
Olinia rochetiana	Sole	29	21	7	0	0	0	0	0	0	0
Oncoba spinosa	Akuku	29	21	7	1	0	0	0	0	1	0
Premna schimperi	Hurgessa	44	31	7	0	0	0	0	0	0	0
Prunus africana	Homi	73	52	35	4	2	11	14	0	1	4
Spathoda campanulata	Anunu	4	3	0	0	0	0	0	0	0	1
Strychnos henningsii	Hadesa	79	56	120	1	0	0	0	48	1	0
Strychnos spinosa	Badessa	102	73	14	6	5	0	0	0	0	1
Trema guineensis	Handalo	1965	1410	28	4	1	0	0	0	1	1
SUM		**4583**	**3287**	**617**	**81**	**42**	**237**	**314**	**261**	**50**	**33**