ASSESSMENT OF WOODY SPECIES DIVERSITY, VEGETATION STRUCTURE, AND REGENERATION STATUS AS INDICATORS OF FOREST DEGRADATION LEVELS FOR RESTORATION OF MOIST AFROMONTANE FOREST IN WANABOLA AND GOPA, SOUTHWEST ETHIOPIA

MSc. THESIS

BY

AYENEW MEKONNEN BIWOTA

JUNE, 2024

JIMMA, ETHIOPIA

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MSc. Thesis

Submitted to the school of graduate studies, Jimma University College of Agriculture and Veterinary Medicine in Partial Fulfillment of the Requirement for the Degree of Master of Natural Resource Management (Forest and Nature Management)

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Major Advisor: Zerihun Kebebew (PhD)

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I declare that the proposed research work has not been done anywhere else before or not part of ongoing work.

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We have agreed to supervise the proposed research. We have evaluated the contents of the proposal and found to be satisfactory, complete and according to the standards and formats of the university. We have also verified that the work has not been done anywhere else before.

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Chairperson, DGC Signature Date

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DEDICATION

I dedicate this thesis to my beloved family**,** who with love and effort has accompanied me in this process, without hesitating at any moment of seeing my dreams come true, which is also their dream. To my little sister Beza, my motivator!

STATEMENT OF THE AUTHOR

I declare that this thesis is my original work and is not submitted to any institution elsewhere for the award of any academic degree, diploma, or certificate and all sources of materials used in this thesis have been duly acknowledged. This thesis has been submitted in Partial Fulfillment of the Requirements for the Master Science Degree in Natural Resource Management (specialized in Forest and Nature Management) at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) and is deposited at the University library to be made available to the borrower under the rules of the library

BIOGRAPHICAL SKETCH

The author, Ayenew Mekonnen Biwota was born in the Chena district of Kafa Zone in 1983 G.C. When his age was reached education, he joined Chena Elementary School in 1990 G.C and attended his education from grades 1- 7th. He attended grades, 8th – 12th at Mizan Tefferi and Bonga Senior Secondary Schools from 1994–1999 at Mizan Tefferi and Bonga Towns, Bench Sheko, and Kafa Zones of SWEP Regional state. After he completed grade 12, he joined Mekelle University, Facility of Dry Land Agriculture and Natural Resources in 1999 and attended BSc. Degree in Land Resources Management and Environmental Protection (LaRMEP) and graduated on July 12, 2003.

He was employed by Mizan Teffri ATVET College as a junior instructor from October 1/2003 to January 30/2005, by a local NGO called SOS Sahel Ethiopia as a community worker for Decha district from February 1/2005 to September 30/2007, and by a local NGO called EWNRA from November 1/2008 to July 30/2020 in different positions, including Woreda project officer, PFM officer, and CBO capacity building and sub-office coordinator in Gesha and Masha.

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LIST OF ABBREVIATIONS/ACRONYMS

CRGE	Climate Resilient Green Economy
DBH	Diameter at breast Height
EFAP	Ethiopian Forestry Action Program
FAO	Food and Agricultural Organization
FDRE	Federal Democratic Republic of Ethiopia
FLR	Forest Landscape Restoration
GIS	Geographical Information System
GPFLR	The Global Partnership on Forest and Landscape Restoration
HDF	Highly Degraded Forest
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
IVI	Important Value Index
LDF	Less Degraded Forest
MDF	Moderately Degraded Forest
MEFCC	Ministry of Environment Forest and Climate Change
Mha	Mega per hectares
NABU	The Nature and Biodiversity Conservation Union
NDVI	Normalized Vegetation Differential Index
NTFPs	Non-Timber Forest Products
PFM	Participatory Forest Management
RD	Relative density
RDO	Relative Dominance
RF	Relative frequency
SHWAO	Shishoinde Woreda Agricultural Office
SLM	Sustainable Land Management
UNEP	United Nation Environmental Program
UNFCCC	United Nation Framework of Convention for Climate Change
WRI	World Resource Institution

WWF	World Wide Fund for Nature

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ABSTRACT

In Ethiopia, deforestation has been increasing at an alarming rate, endangering much of the nation's distinctive biodiversity. This study was conducted to assess the species diversity, vegetation structure, and regeneration status of woody species in different degradation-level forest patches of the Shishoinde district of Gopa and Wanabolla forest sites to prioritize forest patches for restoration in moist Afromontane Forest. A Stratified systematic sampling method was deployed to collect vegetation data from Less Degraded Forests (LDF), Moderately Degraded Forests (MDF), and Highly Degraded Forests (HDF). A total of 60 main quadrants of 20 m × 20 m, were laid at every 100 m along parallel transect lines, and sub-quadrants of 5 × 5 m, 1m×1m were used. Height, DBH, number of trees, shrubs, seedlings, and saplings, and disturbance intensity were recorded. A total of 43 woody species, categorized into 25 families were identified. In both forest sites, the Shannon diversity index of 2.92 & 3.17 at LDF, 2.65 &3.03 at MDF, 2.2 & 2.81 at HDF, and species evenness of 0.99 & 0.94 at LDF, 0.80 & 0.81 at MDF, and 0.76 & 0.76 at HDF were recorded, their value is significantly higher in LDF than MDF and HDF. The species diversity, richness, basal area, and density of woody species decrease as the forest degradation level increases. The LDF and MDF had shown good regeneration status. HDF showed poor regeneration status, with fewer seedlings and saplings than trees/shrubs. LDF exhibited light, whereas MDF and HDF showed moderate and heavy disturbance intensities respectively. The canopy cover forest degradation map of the study area is positively complemented by the study findings. The MDF was prioritized for restocking degraded natural forests through enrichment plantation & assisted natural regeneration whereas the HDF was for restoring secondary forests through reforestation, afforestation, and area exclosure.

Keywords: *Moist Afromontane, Forest degradation levels, Diversity, richness, disturbances*

1 INTRODUCTION

1.1 Background & Justification

Globally, 52% of the total forests are in tropical regions and they play an important role in sustainable development, climate change, and floristic biodiversity (Kelbessa, et al., 2000; Kelbessa and Demissew, 2014). Tropical forests are playing a key role globally as important natural resources, improving the livelihood of poor people through meeting their daily subsistence necessities, serving in soil and water conservation, and providing habitat for terrestrial biodiversity holding 96% of the world's tree species (Mammo, 2019). This diversity is an indicator that allows appreciating links between the richness and the abundance of individuals' trees; it reflects the degree of heterogeneity or stability of vegetation (Mammo et al., 2017)

Ethiopia is a nation with a highly diverse physiographic, altitudinal, climatic, and edaphic landscape, where the diverse climate of various ecological regions of the country has driven the establishment of diverse vegetation types and habitats that are home to a large array of endemic plant and animal species (Kelbessa, et al., 2000 and Asefa et al., 2020). Ethiopia has been named a global 200 Eco region, one of the most significant in the world for protecting biodiversity (Olson and Dinerstein, 2002). There are around 6027 species of higher vascular plants, of which 10% are Indigenous to the nation. Significant changes in temperature, topography, and geology throughout a range of periods, together with past historical events, are the causes of the abundance of plant species. (Kelbessa and Demissew, 2014; Mammo et al., 2017).

Even though the presence of endemic species and a high floristic composition, deforestation is spreading at an alarming rate in several regions of Ethiopia, endangering much of the nation's distinctive biodiversity (Senbeta and Teketay, 2003) as well as the way of life for the local people. Throughout the many regions of Ethiopia, environmental deterioration and deforestation have been occurring for centuries, and it is one of the greatest worries in the country (Defaru, 2010; although the exact areas are debated and difficult to estimate (McCann, 1997). Ethiopia covered 11.9% (0.13 million km2) in 2005 and declined at an alarming rate of 1.1% annually between 2000 and 2005 (GFRA, 2005).

Forest cover reduction in Ethiopia is caused by deforestation and degradation, which has its origin in a cascade of events (Mammo et al., 2018). The expansion of cultivated fields at the expense of the forest and other land use types like grazing and shrub lands was a direct outcome of Ethiopia's geometric population growth, which also increased rural demand for agricultural areas (Rosel et al., 2017). As a result of the population's desire for more farmland for agriculture and grazing pastures for their animals, Ethiopia's vegetation, especially its forest resources, is under several pressures (Kelbessa and Soromessa, 2008). The key drivers of deforestation & forest degradation mainly population growth, expansion of agricultural lands, overgrazing, and the demand for biomass have resulted in increased soil erosion, reductions in water quality and quantity, reduced livestock and agricultural productivity, soil nutrient depletion, and wide-scale landscape degradation (Tigabu et al, 2014). Continued forest and land degradation poses serious obstacles to the elimination of poverty and hunger and the reversal of biodiversity loss in many parts of the world including Ethiopia (FAO, 2015).

The forest landscape restoration concept in the country is understood to include activities that restore ecological and productive functions of degraded forests and agricultural landscapes along the forest farm continuum to better support human well-being now and in the future (Kassa et al., 2022). Generally, the most important state-led FLR initiatives aimed at reducing forest and land degradation in Ethiopia include engaging communities in the management of state-owned natural forests through participatory forest management (PFM), assisting natural regeneration in degraded lands by excluding human and animal interference through the establishment of area enclosures/enclosure’s, and mobilization of communities and engaging them in soil and water conservation works and tree planting campaigns through sustainable land management programs and the recent Green Legacy Initiative (SLM-GLI) to promote tree planting and increase national forest cover (Kassa et al., 2022).

1.2 Problem Statement

In Ethiopia, most of the remaining patches of fragmented forests are confined to the south and the southwestern parts of the country (Yeshitela and Bekele, 2002). However, currently, the remnant natural forests in these areas are also constantly threatened by anthropogenic associated factors (Reusing, 2000). Kafa biosphere forest, under the SW Ethiopia

Afromontane forest which encompasses the study area forest resources is already declining. In 1986, 50% of the biosphere reserve area was forest land but declined to 30.5% in 2019, while agricultural land increased dramatically from 23% to 45%. Anthropogenic factors have a negative impact on the Biosphere Reserve's forested ecosystem, which will affect the biodiversity, ecosystem function, and services (Mengist et al 2021). This indicates that deforestation and forest degradation become a very serious environmental problem and an attempt to reverse the degraded trend requires human interventions such as landscape restoration.

In 2018, the MFCCC developed the national potential and priorities of a tree-based landscape restoration map based on the best available national datasets, which classified regions according to their degree of degradation and urgency for restoration needs. Accordingly, the South West Ethiopian Afromontane Forest, which constitutes the Kafa Biosphere Forest Area, is a priority for landscape restoration (MFCCC, 2018) to enhance forest protection and restoration to support sustainable livelihood, food, and water, and conserve the natural ecosystem and biodiversity (NABU, 2023).

However, the national potential and priorities of tree-based landscape restoration maps need to be strengthened with additional regional and local input before it is being used for implementation (MFCCC, 2018). Among the input data that could enrich the national restoration map and that has crucial importance for FLR implementation are clear and tangible information on the level of degradation of the different forest patches and their specific restoration measures of local areas (IUCN and WRI, 2014). Effective and successful implementation of forest landscape restoration requires proper planning and this plan should also be based on adequate and tangible ground-based information about the restoration areas, the levels of degradation, and their drivers for successful completion of FLR implementation (Stanturf et al., 2017).

Several scholars have conducted various studies in SW Ethiopia Afromontane forest which include Biodiversity and ecology of Afromontane forest (Senbeta, 2006), On forest landscape restoration in Ethiopia: progress and challenges (Kassa et al., 2022); population structure and regeneration status of woody species in southwest (Balemlaym and Siraj, 2021); Species diversity and structural analysis of moist evergreen forest (Geneme et al., 2015); trade-off between forest conservation and agricultural expansion Southwest Ethiopia (Tsegaye et al., 2022); Forest fragmentation in a forest Biosphere Reserve (Mengist et al. 2022); NABU Ethiopia has also developed forest degradation levels of the Kafa zone in 2022 using nationally agreed canopy cover classification. However, studies that looked into the indicator-based assessment of forest degradation levels in forest patches and linked distinct forest degradation levels with corresponding restoration needs are generally absent. This study will be used as a springboard for similar future studies and will initiate the provision of tangible information for regional governments and projects that have planned to implement FLR projects in SW Ethiopia. Moreover, it will contribute as an additional source of information for national-level initiatives

1.3 Objectives of the study

1.3.1 General Objective

The general objective of the study is to investigate species composition, diversity, vegetation structure, and regeneration status of woody species in different degradation-level forest patches as well as to prioritize forest patches for landscape restoration measures taking the case of Shishoinde district, Kafa Zone, Southwest Ethiopia.

1.3.2 Specific objectives

- To assess the species composition, diversity, and richness of the woody species in forest patches of different degradation levels.
- To assess the vegetation structure & regeneration status of forest patches of different degradation levels.
- To determine the severity of forest disturbances in forest patches of different degradation levels and to prioritize for forest landscape restoration measures.

1.4 Research Questions

1 What does species composition, diversity and richness of the woody species in forest patches?

2 What does look like the vegetation structure & regeneration status of forest patches?

3 How could be prioritize the forest patches for forest landscape restoration measures?

2 REVIEW OF LITERATURE

2.1 Vegetation types of Ethiopia

Ethiopia has a complex relief and a variety of climates and thus, diverse habitats with rich flora and fauna. The vegetation of Ethiopia is diverse and ranges from afro-alpine vegetation to desert scrub. The total flora of Ethiopia consists of 6500 - 7000 species of which 12 % are considered endemic (Gebre Egziabher 1991; Demel Teketay 2004). However, the flora of Ethiopia has not been exhaustively studied (Friis 1992). The recent discovery of *Acacia fumosa*, and *Asplenium balense* (Chaerle and Viane 2007) as new plant species from Ethiopia is evidence of this. A large proportion of the Eastern Afromontane and Horn of Africa biodiversity hotspots lie in Ethiopia, and the country is one of the biodiversity centers of the world (Conservation International, 2007). The Ethiopian vegetation is highly influenced by climate, which is associated with elevation (Dugdale 1964).

Ethiopian vegetation was divided into eight vegetation categories based on climate and elevation (Sebsebe et al., 2004). These are the same vegetation types that the Institute of Biodiversity of Ethiopia (IBC, 2005) officially uses. According to Friis et al. (2010), these vegetation types have been reclassified into 12 categories, including sub-vegetation types based on elevation and rainfall pattern. The "aquatic vegetation type" has been reclassified into three more specific vegetation types under this new classification scheme. In addition, the "Ericaceous belt" vegetation type has been included. In the highlands, Erica species predominate in the vegetation of the Ericaceous belt, which spans a limited height range of 3000–3200 meters (Asefa et. al, 2020). Afroalpine and Afromontane vegetation types, respectively, encircle this Ericaceous belt's upper and lower limits. The eight officially recognized vegetation types are almost similar to the other eight vegetation types included in this new classification system (Friis et al., 2010). Therefore, the 8 vegetation types are Afroalpine and sub-afroalpine vegetation found from 3200 to 4533m a.s.l, Dry evergreen Afromontane forest and grassland complex usually found between 1800 and 3000 m a.m.l,, Moist evergreen Afromontane forest vegetation which is distributed from 500 to 1500 m a.m.l, Acacia-Comiphora woodland vegetation found between 900 and 1900 m a.m.l, Combretum-Terminalia woodland vegetation found between 500 and 1900 m a.m.l, Lowland semi-evergreen forest vegetation found between 450 and 650 m a.m.l, Desert and semi-desert scrubland vegetation below elevations of 400 m., and Aquatic vegetation includes plants found in rivers, reservoirs, lakes, floodplains, and wetlands (Asefa et. al, 2020).

2.2 Forest Cover Change in Ethiopia

Ethiopia has one of the largest forest resources and provides a wide variety of wood products and non-wood forest products moreover its environmental functions (Moges et al., 2010). Those products are socially and commercially significant to the livelihoods of rural households (Worku, 2014). The forests represent 15.2 percent of the country's land. Net forest cover has been decreasing since 1990, although there are differences across regions. The country's rural population dependent on natural resources, loss of land productivity, and erosion have been major concerns and reasons for carrying out restoration. Several tree-planting campaigns have been carried out with massive engagement by local communities. A recent expansion of participatory forest management (PFM) reflects its promise as a tool to engage communities more actively in forest management and restoration and grant them greater and more secure rights (International Union for Conservation of Nature (IUCN, 2017).

In Ethiopia, about 35%-40% of the estimated land area is covered by natural high forests (EFAP, 1994). The country high forests have been degraded by human influence for periods. There is a decreasing trend of forest cover particularly in Ethiopia from 1973 to 1976 indicate that natural high forests covered around 6.08 % of the country. While between 1986 and 1990 the forest coverage in Ethiopia had been decreased to 3.93 %. The figure is around 163.600ha of forest land deforested for different purposes such as agricultural expansion, settlement per year. In 2000, the country's natural high forest has been reduced to 2.36% (Reusing, 2000). However, forest cover dynamics were very much serious in the highlands part of Ethiopia (Gashaw et al., 2015). This is mainly because of the conversion of forest lands into agricultural lands due to the increasing population growth (Lemineh and Kassa, 2014). In addition to this the current data on forest resources of Ethiopia reported in FAO (2010) the forest cover decreased from 15.11million ha in 1990 to 12.2 (11%) million ha of forest land in 2010, in two decay 2.65% of forest cover has been deforested (Moges et al., 2010).

The trend of forest cover change varies from region to region; in the southern nation nationality people region the reduction of forest cover is very high this was 20% to 11.6 % in 1973– 1976 and 1986–1990 respectively. In the Oromiya region, the total high forest area was reduced from 8.6% in 1973– 1976 to 8.1 % in 1986–1990. The trend of forest degradation in those regions went from closed and slightly disturbed high forests to heavily disturbed high forests (Gashaw et al., 2015). On another side forest in the northern part of Ethiopia which was once covered by forest is devoid of vegetation. In this area, small remnants of old-aged Afromontane forests are found almost only around the Ethiopian Orthodox Tewahido Churches. Forests in most other areas have been completely destroyed and converted into agricultural land and grazing lands over periods (Bongers et al., 2006).

Forest decline in different time periods is the outcome of the combination of biophysical and social situations (Dessie and Christiansson, 2008). However, the major causes are the expansion of large commercial farms land in forest areas and settlements around forest areas (Kassa, 2017), sociopolitical changes, increasing population, and consequent increases in the demand for agricultural land, fuelwood as well as construction and industrial use, unstable land tenure system (Dessie and Christiansson, 2008; Dinkayoh, 2016) and lack of community participation in forest conservation and sharing of forest benefit (Gashaw et al., 2015).

2.3 Forest Degradation

The lack of a consistent definition of forest degradation affects the ability to estimates the rates or impacts of forest degradation because the drivers of degradation are not clearly defined (Sasaki and Putz 2009). However, the drivers for deforestation (due to commercial agriculture) and forest degradation (due to timber extraction and logging) are similar in Africa, Asia and Latin America. The loss rate in tropical forest areas from 2010 to 2015 is 5.5 M ha per year. The global natural forest area also declined form 3961 Mha to 3721 Mha during the period 1990 to 2015. Similarly, the forests of sub-Saharan Africa account for 10-20% of the global plant carbon and the Congo basin forests have a carbon stock varying from 50 to 150 tons ha-1 (Hosonuma et al. 2012).

In Ethiopia, deforestation and forest degradation have a long history with an important spatial difference. deforestation has a long history in Ethiopia, especially in the central and northern highlands where survival farming and settlements have been changing landscapes for periods (Lemineh and Kassa, 2014.); extensive forest clearing for agricultural use, overgrazing, and exploitation of existing forests for fuel wood, fodder, and construction materials (Badege, 2001), while deforestation in the southern half is a relatively recent phenomenon (Darbyshire et al. 2003, Nyssen et al. 2004 and Dessie 2007). This spatial variability has been conditioned by factors such as population growth, the emergence of intensive agriculture, expansion of urban areas and trade (Dessie 2007 and Dinkayoh, 2016).

Agricultural land expansion and high dependence on biomass energy are the two most important direct drivers of deforestation and forest degradation in Ethiopia (Reusing 1998 and WBISP, 2004). With the regular increase in population, from 12 million in 1900 to 85 million in 2010, the proportional impact of agricultural land expansion on forest cover in the nation has been significant (Dessie, 2007 and Lemenih et al., 2008). The large-scale deforestation and degradation had significant social, economic, and environmental consequences both at local and national levels. The consequence of deforestation, there is an acute shortage of fuelwood, construction timber, and non-timber forest products (NTFPs) in addition to disrupted ecosystem functions (soil erosion, hydrological imbalance, loss of biodiversity, etc.) (Zeraye, 2008 and Kebede, 2009).

2.4 Principal approaches to Identification of a Degraded Forest

All approaches to define forest degradation are linked to the loss of the main forest attributes, i.e., composition, structure and function (Spies, 1997). Accordingly, the structure, composition and regeneration of the forest which a forest stand could be categorized as degraded. These categories are crucial to the study of the state of an altered forest at any given moment in time and support with the description and analysis of the forest's condition. They provide valuable information to forest managers, whose objectives are to strengthen the recovery capacity of degraded ecosystems, slow the degradation process, and improve the characteristics of their forests in terms of structure and function. According to Vásquez et al., (2018), proposed the criteria and characteristics of a forest that has been altered by human activity. It is an initial framework for stand-level evaluation of whether a forest is genuinely degraded, or rather in a successional phase from which it will recover naturally.

The forests affected by damaging human activity the main structural characteristics of a degraded forest are low total basal area of 20 m2 ha−1, high frequency of individuals in the pole and small tree diameter classes (i.e., diameter at breast height, DBH < 20 cm), low density of commercial species individuals with DBH > 65 cm and low density of potential seed trees to establish a new cohort. A reduction in canopy cover that identifies a forest as degraded will continue to occur until the deforestation threshold is reached (Vásquez et al., 2018). According to Sasaki et al. (2011) propose a canopy cover of > 20% as the starting point for evaluation of degradation. Changes in diameter distribution are characteristic of degraded forests. In the case of adult forests with a reverse- J diameter structure that are subjected to high grading, these differences may be significant (i.e., DBH (≥5 cm, ≤260 cm)), with potential gaps in some diameter classes over DBH 60 cm, and a low frequency of individuals in the intermediate diameter classes. This is most probably the result of forest interventions involving extraction of larger-diameter trees from commercial species, and the majority of highly degraded forests are composed of trees significantly below an established cut diameter (DBH < 60 cm) (Vásquez et al., 2018).

Composition of the residual forest is significantly affected, as the practice of high grading reduces the diversity of tree species, harming one or more main forest species (Cazzolla et al, 2015). This may eventually lead to the disappearance of certain species, and low relative importance values (RIV) of the remaining original species found in a given type of forest and the greater the degree of degradation, the more severe the decline in the number of tree species(Vásquez et al., 2018). The result may be an exaggerated presence of non-commercial or secondary species to the detriment of principal forest species, and high density and coverage of competitive arbore scent and/or shrub species (Cazzolla et al, 2015). In severely altered forests, where damaging selective extraction affects the composition and structure of the forest, the density and dominance of non-commercial and secondary species may reach disproportionally high levels (90% of the total stand density) (Vásquez et al., 2018).

In terms of regeneration, altered forests are characterized by moderate to low levels or indeed a complete absence of tree species regeneration, and/or high levels of secondary, arbore scent and non-commercial species regeneration, depending on the degree of degradation. Diversity of regeneration is linked to the presence or absence of adult seed trees and to the high coverage of competitive species in the understory. The presence of seed trees in degraded forests does not guarantee a successful process of seedling recruitment and seed harvesting (Pillay et al, 2018), and in highly degraded forests, the density of seedlings of non-commercial and secondary species may represent as much as 80% of the total density of tree regeneration in the stand. In summary, the structural and compositional characteristics of forests subjected to damaging human-induced alterations (with an absence of silvicultural criteria and objectives) of varying intensity and frequency become altered to a greater or lesser extent, as does the density and diversity of the tree species regenerating within the forest (Vásquez et al., 2018).

Table 1. Criteria and characteristics for categorization as Degraded

Criteria	Characteristics
Structure	Loss of canopy cover, Change in diametric structure (low frequency of intermediate diameter classes, absence of some diameter classes, low density of larger-diameter commercial species) Reduction of growing and biomass stock (basal area and volume)
Composition	Loss of species (composition and biodiversity) High density and dominance of non-commercial or secondary species High density and coverage of competitive species
Regeneration	Very low or lack of tree species regeneration Abundant regeneration of non-commercial and arborescent species

2.5 Definition & Concept of Forest Landscape Restoration

Forest landscape restoration (FLR) was first defined in 2000 by the World Wide Fund for Nature (WWF) and the International Union for Conservation of Nature (IUCN) as a planned process that aims to regain ecological honor and enhance human well-being in deforested or degraded landscapes. This definition has evolved, but in all cases, the approach retains two important features: its scale (landscapes) and its intention to reconcile both human and ecological priorities (Mansourian, 2020). The Global Partnership on Forest and Landscape Restoration (GPFLR) in 2018 defined FLR as six principles: (1) focus on landscapes; (2)

engage stakeholders and support participatory governance; (3) restore multiple functions for multiple benefits; (4) maintain and enhance natural ecosystems within landscapes; (5) tailor to the local context, using a variety of approaches; and (6) manage adaptively for long term resilience. Having multiple objectives is central to forest landscape restoration, and these can include ecosystem objectives (e.g. connectivity for wildlife, strengthening the value of protected areas, ecosystem resilience, etc.) and human objectives (e.g. alternative income-generation, improved agriculture and agroforestry for food security, disaster risk reduction, etc.). So, Forest and landscape restoration aims to reconcile both the social and ecological dimensions of restoring forested landscapes (Mansourian, 2020).

According to FAO (2018), forest landscape restoration is a process that aims to regain ecological functionality and enhance human well-being in deforested or degraded landscapes refers to forest and landscape restoration to highlight the importance of landscape restoration more widely.

The difference here concerns the role of trees in the landscape that do not necessarily qualify as forests. Thus, for example, trees in a productive landscape may play a significant role (e.g. protecting crops from wind erosion), and restoring them may lead to substantial ecological and social benefits. The intention behind FLR has always been to improve forested landscapes by returning the quality and quantity of forests in the landscape. Nevertheless, it is important to highlight that FLR was never intended to bring trees where they are not naturally occurring, e.g. in grasslands. Only landscapes where forests and trees have a natural role to play are appropriate for forest landscape restoration (Veldman et al., 2015; Bond et al., 2019).

Stanturf et al. (2014) highlight the different forms that forest restoration can take and emphasize the importance of clear terminology as well as an understanding of both baseline conditions and objectives for restoration. Forest restoration can be active, through the planting of native species, or mixes of native and non-native species and through assisted natural regeneration. It can also be passive, by removing causes of degradation to allow or encourage natural regeneration. Diverse manipulations and silviculture treatments can be applied under the broad banner of restoration, including for example, enrichment planting with desired species, removal of exotic species to reduce competition, and agroforestry to promote both tree cover and food production (Stanturf et al., 2017).

2.6 Forest Landscape Restoration Initiatives in Ethiopia

Ethiopia made the largest FLR commitment in Africa when it pledged to restore 15 million hectares of degraded lands in 2016. This is in addition to the plan to manage 7 million ha of forests and woodlands as part of its Climate Resilient Green Economy (CRGE) Strategy enacted in 2011.The strategy aims to make Ethiopia a middle-income country by 2025 and to build a carbon-neutral economy by 2030. It also aims to guide and support initiatives that would enable the country to better adapt to the impacts of climate variability and change (Climate Resilient Green Economy Strategy (CRGE), 2011). About 22 million hectares, reflect what we see as the official announcement made by the country during the 2014 New York Declaration on Forests. Sustainably managing existing forests and woodlands and establishing new forests through afforestation and reforestation were identified as priorities of the government in its recently updated nationally determined contribution (Federal Democratic Republic of Ethiopia, 2019). Forestry is expected to help create around half of the reduction potential needed to achieve the targets set in the CRGE and the NDC (Federal Democratic Republic of Ethiopia, 2015). In Ethiopia, the concept of FLR is understood to include activities that restore ecological and productive functions of degraded forests and agricultural landscapes along the forest farm continuum to better support human well-being now and in future (Kassa et al., 2017). Generally, the most important state led FLR initiatives aimed at reducing forest and land degradation in Ethiopia include engaging communities in the management of state-owned natural forests through participatory forest management (PFM), assisting natural regeneration in degraded lands by excluding human and animal interference through the establishment of area enclosures/enclosure's and mobilization of communities and engaging them in soil and water conservation works and tree planting campaigns through sustainable land management programs and the recent Green Legacy Initiative (SLM-GLI) to promote tree planting and increase national forest cover (Kassa et al., 2022).

2.6.1 Identified National Tree-Based Landscape Restoration Options of Ethiopia

Trees provide ecosystem services that can help address land-use issues both directly and indirectly. Progress toward restoring lost or degraded ecosystem services can be made by increasing the number of trees and forest cover in Ethiopian landscapes. There are numerous options for incorporating more trees into landscapes. The best option is determined by the main ecosystem services to be restored. The following are national tree-based landscape restoration options (MFCCC, 2018):

1) Potential for restoring secondary forests: Establishing forests, including natural high forests, woodlands, and bamboo forests, on land that had recent tree cover (reforestation) or on land that has been deforested for much longer (afforestation) (adapted from IPCC 2014).
2) Potential for restocking degraded natural forests: Increasing stock of existing degraded natural forests, including degraded high forests, woodlands, and bamboo forests. Common practices to restock degraded forests are enrichment planting and assisted natural regeneration.
3) Potential for agro-forestry: Increasing the number of trees on existing crop, pastoral, and agro-pastoral land with sparse tree cover.
4) Potential for woodlots and home gardens: Expanding small-scale production of wood (for example, wood fuel, timber for construction) and non-wood products (for example, fruits, forage) for domestic and commercial uses on both communal and private land.
5) Potential for commercial plantations: Expanding income-generating commercial plantations for the production of wood and tree products. This includes commercial plantations on communal/public, state-owned, and private land.
6) Potential for tree-based buffer zones along rivers, lakes, and reservoirs: Expansion of secondary forests, including natural high forests, woodlands, and bamboo forests, to protect rivers, lakes, and reservoirs.
7) Potential for tree-based urban green infrastructure: Increasing the number of trees in urban areas and industrial parks (for example, urban parkland, roadside tree planting, buffer zones around urban water bodies, protective forests).
8) Potential for roadside trees (outside of urban areas): Increasing the number of trees along roads outside of urban areas, providing this is safe for traffic and does not block scenic views.
9) Potential for tree-based corridors among religious forests: Increasing the number of trees and forest habitat among religious forests. This potential fits into the previous

tree-based landscape restoration options based on the land use-land cover where the trees and/or forests are established/restored.

2.7 Indicators of Successful Ecological Restoration

Successful restoration requires a full understanding of the ecological deficiencies in the ecosystem. There are many means of successful ecological restoration programs to monitor its progress so that one can establish the success of human-induced restoration efforts. The methods of monitoring may consist of floristic composition analyses, species composition surveys, community structure changes over time (temporal) and space (spatial), species richness, rate of growth of above- and below-ground biota, change in above-ground plant biomass using various indices such as NDVI (Normalized Vegetation Differential Index) depicted by Remote Sensing technologies using Geographical Information System (GIS) and also changes in environmental variables such as soil physicochemical properties and microclimatic profile such as soil and air temperature, relative humidity, spore concentration and the kind of bacteria and fungi above and below ground. A combination of the previously mentioned variables needs to be monitored in parallel over seasons and years to conclude the success or failure of the effort. Apart from these indicators, reference sites should also be kept such as a native forest ecosystem or a degraded unrestored site to establish the effects of human-induced restoration to be real and not just a natural process, as one might argue (Pant and Pant, 2017).

2.8 Forest Patches and its Value

In the tropics human beings covered a million of forest land to agricultural fields and pastures every year, threatening many species with extinction. The conservation of tropical biological diversity has usually concentrated on setting aside large tracts of forest in national parks and other protected areas. These large, comparatively undisturbed forests are essential for the effective conservation of complex tropical ecosystems and many forest species. Whereas deforestation in the tropics has been widespread over the past few decades, forest clearing is rarely complete and often not permanent. Patches of primary, secondary, and managed forests remain in many agricultural landscapes. While these forest patches lack some of the biological diversity of large forest zones, they do contain many species and habitats that are not found in large reserves. Forest patches provide habitat for many organisms with small home ranges, for organisms that range widely over the landscape, and for an array of species that tolerate some human disturbance (UNDP, 1994).

Forest patches, which are broadly dispersed through human-occupied landscapes, are owned and controlled by the rura1 community. Because of this, protectionist conservation strategies that would lock up these lands in reserves are neither ethically acceptable nor possible to successfully implement. Those forest patches can only be preserved by the people who own and use them. Although some protectionists would have us believe that entrusting the care of forest patches to their rural owners is a prescription for disaster, there is substantial evidence that this course may be the best hope for the conservation of many tropical species and habitats. Forest patches are not simply left-over and unutilized rand areas, they are critical components in the livelihoods of rural people. Forest patches always provide biological benefits when compared to other land uses, such as pasture and farming. Additionally, forest patches provide products for sale and subsistence, protect watersheds, and have cultural and social benefits. Forest patches can be managed to provide niches for the growing of forest and their products. As a result, rural people maintain forest patches for their economic, social, and cultural benefits, thereby protecting the diversity of organisms (Donovan, 1994).

However forest patches are altering, and in many cases disappearing, under the pressures of human population increment, increased integration of rural households, the diminishing of traditional patterns of forest use and conservation, and government policies that create incentives for conversion of forest patches into croplands and pastures. Not only will the loss of forest patches, and their products and environmental services they provide, hurt rural people, it will also have national and global impacts, because of the value of forest patches for watershed protection and management, biological conservation, and guarding against adverse global environmental changes. Established forest patches are particularly sensitive to disturbances, such as blow downs, fire, and grazing; and invasion of exotic plants and animals, native vines, and aggressive weeds discourages regeneration. Having must understand the social and economic conditions that promote forest patch conservation and how government policies can promote or harm forest patches. Therefore, need to develop management schemes that improve the capacity of forest patches to protect biodiversity and that increase their value to local people (Schelhas and Greenberg, 1994).

2.9 Diversity indices and species diversity

Floristic description of forest involves the analysis of species diversity, evenness and similarity or dissimilarity. Species diversity is one of the most important indices used for evaluating the sustainability of forest communities. Diversity and equitability of species in a given vegetation community are used to interpret the relative variation among and within the community and help to explain the underlying reasons for such a difference (Kent and Coker, 1992). Species diversity is described based on two concepts (factors), the total number of species in the community (species richness) and the relative abundance of species (species evenness) within the sample or community.

Species richness is a measure of the number of different species in a given site and can be expressed in a mathematical index to compare diversity between sites (Woldu, 1985). The species richness index is of great importance in assessing the taxonomic and ecological values of a habitat. Evenness is a measure of the relative abundance of the different species making up the richness of an area. Thus, species diversity is a product of species richness and evenness or equitability. The species diversity index provides information about species endemism, rarity, and commonness. Measures of species diversity are usually seen to be key indicators for the well-being of ecological systems. Among many species diversity indices, widely used include Simpson's index and Shannon-Weiner index (Mueller-Dombois and Ellenberge, 1974).

Species diversity can also be viewed from different perspectives: alpha, beta, and gamma diversity. Alpha diversity refers to the diversity of species within a particular habitat or community. Beta diversity is a measure of the rate and extent of change in species along a gradient from one habitat to another. It is between habitat diversity that measures turnover rates. Beta diversity is sometimes called habitat diversity (Kent and Coker, 1992). Gamma diversity is the diversity of species in comparable habitats along geographical transect and it depends on the alpha and beta diversity (Kent and Coker, 1992).

2.10 Vegetation of Ethiopia

The vegetation cover of a given area has a definite structure and composition, which is developed because of the long term interaction between biotic and a biotic factors. The pattern of distribution and vertical stratification of vegetation fluctuate due to different climatic zones, soil types, latitude and topography of the area. These in turn influence the distribution and type of plants and animals in the forest (Beche, 2011).

Vegetation is an assemblage of plants growing together in a particular location or the collective plant cover of an area (Jennings et al., 2003). Owing to the extreme variation in climate, terrain, etc., and various ecological systems that are suitable for evolution, Ethiopia possesses one of the largest and most diverse plant genetic and wildlife resources (NBSAP, 2005) According to Teketay et al., (2000), the estimate of woody plant species in the Flora of Ethiopia and Eritrea was about 1100; out of these about 300 are tree species. However, the forest cover of the country is much smaller than in the past (Hundera and Deboch, 2008).

The most recent study by Friis et al., (2010) indicated that there are twelve major vegetation types in the country. These major vegetation types include; Desert and Semi-desert scrubland; Acacia Commiphora woodland and bushland; Wooded grassland of the Western Gambela region; Combretum Terminalia woodland and wooded grassland; Dry Evergreen Afromontane Forest and grassland complex; Moist Evergreen Afromontane Forest and bushland; Transitional rain Forest; Ericaceous belt; Afro-alpine belt; Riverine vegetation; Freshwater lakes; and Salt Lakes vegetation (Friis et al., 2010).

3. MATERIALS AND METHODS

3.1 Description of Study Area

3.1.1 Location

The study was conducted in the Shishoinde district (Gopa and Wanabola Kebeles), a new district split from Chena district in 2019. It is one of the 12^{th} districts of the Kafa zone within Southwest Ethiopia People's Region state. The district was selected for the study as it is within the Kafa Biosphere Reserve, consisting of a moist Afromontane forest habitat among other districts it has also higher inhabitants per Km2 in rural Kebele (NABU, 2017 and 2020) causing higher forest disturbance and has 18,849.25ha forest cover (SHWAO, 2022). Additionally, no such studies were conducted in the district as it is new. The district is found within the southwestern plateau of Ethiopia, 526 km from the capital city of Addis Ababa and 54 km from Bonga, the capital of the zone. Geographically, it is positioned between 7°26'09''N to 7°08'32.59''N and 35° 47' 35.94'' E to 36°02' 51.73''E. The district is administratively subdivided into 22 rural kebeles and 5 municipal kebeles, including Shishoinde town. Sheshoinde is bordered on the south by the Chena and Decha districts, on the north by the Gewata district, on the east by the Gimbo and Decha districts on the west by the Bitta district of Kafa Zone.

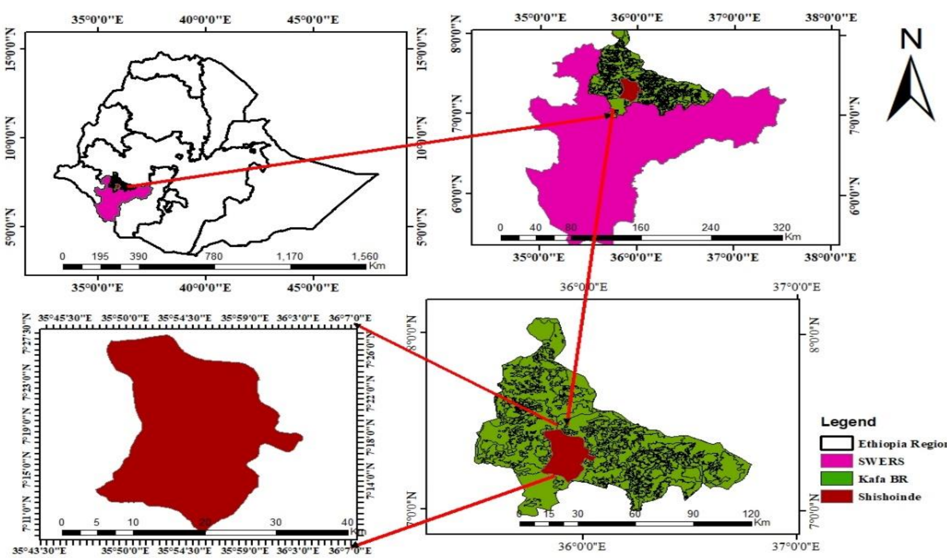

Figure 1. Study Area map

Source: Ethio-GIS (2024) and NABU Ethiopia

3.1.2 Climate

The distribution of rainfall is unimodal, characterized by a prolonged wet season from June to September (big rain) and a short dry spell of showers from mid-February to April. There is a long dry period from October to the end of February (SHWAO, 2022). Based on 15-year data, the mean annual rainfall in the study area is about 1566 mm, with a peak rainfall period between May and October and decreasing in November and December, with little or no rainfall in January and February.

The mean annual temperature is about 16.6°C, and the mean minimum temperature is 10.78°C, whereas the mean maximum temperature is 22.32°C. There is a slight temperature difference throughout the year. The hottest months are from February to May, with a maximum temperature recorded of about 24.6°C (in April/May), and the coldest months are from July to December, with a mean minimum temperature of 9.8°C (in December). Based on altitudinal variations, Shishoinda district has three agro-climatic zones that correspond to the traditional classification systems: 43% Dega (2500–3500 m), 55.56% Woina Dega (1500–2500 m), and 1.24% Kola (500–1500 m) (SHWAO, 2022).

3.1.3 Topography

Topographically, the area is generally characterized by rough topography with undulating plains, hills, slopes, deep valleys, gorges, escarpments, and dissected plateaus. Some perennial rivers, such as the Kenech River, Kurkusha River, Decha River, Wanjale River, and Shishnda River, flow into the Donbra River by crossing the forest, all of which emerge from the highlands.

3.1.4 Vegetation

The last remaining moist evergreen montane forests in the Eastern Afromontane Biodiversity hotspot can be found in the Kafa Biosphere. 26% of the biosphere reserve is comprised of the moist evergreen montane forest habitat which exists in elevation ranging from 1,500 to 2,600 m.a.s.l found in the study district as well (NABU, 2017 and 2020). The district forest is characterized by the following common species: *Pouteria adolfifriedericii, Mimusops kummel, Podocarpus falcatus, Galiniera saxifraga, Syzygium guineense spp. afromontanum, Prunus africana, Albizia gummifera, Croton macrostachyus, Cassipourea malosana,* *Ekebergia capensis, Ficus sur, Maesa lanceolata, Teclea nobilis, and Bersama abyssinica* (SHWAO, 2022*).*

3.2 Sampling Design

A reconnaissance was carried out across the forest to obtain an impression of the site conditions, to collect information on accessibility and to identify sampling sites and sampling methods to be used for vegetation data collection. After the reconnaissance visit, the entire forest area was stratified into three strata following the forest degradation map of the study area developed by NABU in 2022 based on the working document of Ethiopian Space Science and Geospatial Institution (Formally EMA) classification of forest, namely: highly degraded/sparse/forest (20-39% canopy cover), moderately degraded forest (40-79% canopy cover), and dense forest (> 80% canopy cover) as shown in Fig 2.

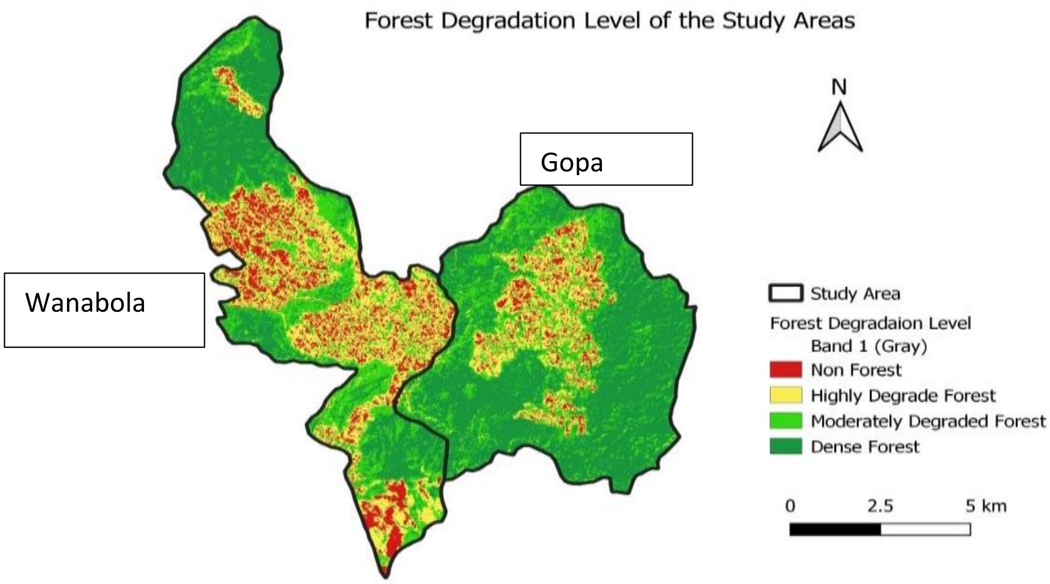

Figure 2. Forest Degradation Level of the study areas, Source NABU Ethiopia

Stratified systematic sampling procedure was followed to collect vegetation data (Bitew and Tesfaye, 2019), in which initial sample plot was taken randomly in 50 m distance away from the edge of forest to minimize boundary effect from the forest strata of the study area: highly degraded, moderately degraded, and less degraded forest. The number of sample plots per forest patch was calculated using the principles of proportional allocation according to the area (Ha) of each forest patch. These forest patches were selected in areas with approximately equal topography and altitude to eliminate their effects on woody composition and structure. A total of 60 main quadrats or plots (30 in Wanabola forest and 30 in Gapo forest) were established in the study area for vegetative data collection. Parallel transect lines were arranged for each degraded level forest site with the help of a degradation level map of the study area, and a 20 m x 20 m (400 m2) sample plot size was used. The sampling quadrats were placed at a regular interval of 100 m between each other to minimize diversity variation among plots.

A sampling method Stohlgren et al. (2012) was used to collect species richness, cover-abundance, population, height, and diameter at breast height (DBH) of tree species at multiple spatial scales, using (1m ×1m) 1 m2 sub-quadrant and (5 × 5 m) 25 m2 sub-quadrant within a 20 m × 20 m (400 m2) main quadrat (Yohannes, et al 2022). The sub-quadrats were placed at the four corners and one at the center of the main quadrat. Data on trees and shrubs was collected in the main quadrats whereas data on seedlings was collected in 1 m2 sub-quadrants and saplings were collected in 25 m2 sub-quadrats. Height was measured using a Suunto clinometer, and DBH was measured using a caliper. Individuals with DBH ≥ 2 cm and height ≥ 1.5 m were considered trees or shrubs. Individuals with a DBH between 0.5 cm and 2 cm and a height between 0.5 m and 1.5 m were considered saplings, while those with a root collar diameter ≤ 0.5 cm and height ≤ 0.5 m were considered seedlings. All the woody plant species encountered in each of the quadrats and sub-quadrats were collected using their local names with the help of PFM members engaged in data collection. These species identifications were made using the published volumes of the Flora of Ethiopia and Eritrea, Volumes II–VIII, and NABU's Biodiversity assessment at Kafa Biosphere (2017 and 2020).

3.3 Intensity of disturbance

In each quadrat, disturbance factors including grazing and disturbance human activity (marks of cutting, fuel wood collection, fire, and charcoal production) were recorded. The impact of the grazing intensity class was estimated as follows (Hines et al. 2010 and Dingamo et al. 2022) as 3 = heavy; 2 = moderate; 1 = lightly; and 0 = not grazed, while the formal human activities were estimated following (Kidane et al. 2016 and Dingamo et al. 2022) using a modified 0_3 subjective scale to determine the degree of the impacts of fuel wood collection, charcoal production, selective tree cutting, and fire. The sum of all scores for each quadrat was determined following an overall ranking of the human disturbance index in each quadrat. High ranks indicate high levels of human-encouraged disturbance, and low ranks indicate low levels of disturbance following (Venkateswaran and Parthasarathy 2003).

3.4 Data Analysis

3.4.1 Diversity

A Shannon-Wiener diversity index (H') is the most frequently used index of species diversity and is commonly used to characterize species diversity in a community. To compare woody species diversity of the different forest patches were calculated using the Shannon-wiener diversity, Simpson's diversity index, and Simpson's diversity. The Shannon diversity index was calculated as:

$$\mathbf{H'} = \sum_{\mathbf{i}}^{\mathbf{S}} \mathbf{Pi}\,\mathbf{ln}(\mathbf{Pi}) \qquad \mathbf{Eq1}$$

Where H' is the Shannon diversity index, pi is the proportion of individuals that belong to species i and S is the number of species in the sample. The proportion of species i relative to the total number of species (pi) is calculated and then multiplied by the natural logarithm of this proportion (lnpi).

Shannon's equitability (J) Shannon's equitability (E_H) can be calculated by dividing H by H_{max} (here H_{max} = lnS). Equitability assumes a value between 0 and 1 with 1 being complete evenness calculated as:

$$\mathbf{Equitability\ (J)} = \frac{\mathbf{H}}{\mathbf{Hmax}} = \frac{\mathbf{H}}{\mathbf{ln}\ \boldsymbol{S}} \qquad \mathbf{Eq2}$$

Simpson's diversity index is derived from a probability theory and it is the probability of picking two dissimilar species at random (Krebs, 1999). Simpson's diversity (D) was calculated as:

$$\boldsymbol{D} = \mathbf{1} - \sum \boldsymbol{Pi}^{\mathbf{2}} \qquad \boldsymbol{Eq}\mathbf{3}$$

3.4.2 Vegetation Structural

Following Kuma and Shibru (2015), structural parameters such as density, diameter at breast height (DBH), frequency, dominance, basal area, and IVI were used for the description of vegetation structure using the following formula: diameter at breast height (DBH), frequency, dominance, basal area, and IVI were used for the description of vegetation structure using the following formula:

Density is the total number of individuals of each species in all the quadrats divided by the total number of quadrats studied. Density is calculated by the equation:

$$\boldsymbol{Density} = \frac{\textbf{Total number of individuals of a species in all quadrat}}{\boldsymbol{Total\ number\ of\ quadrats\ studied}} \qquad \textbf{Eq4}$$

$$\boldsymbol{Relative\ Density} = \frac{\textbf{Total number of individuals of the species}}{\boldsymbol{Sum\ of\ all}\ \textbf{individuals}\ \boldsymbol{of\ all\ species}}\ \boldsymbol{x}\ \mathbf{100} \qquad \textbf{Eq5}$$

$$\textbf{Frequency}\ \% = \frac{\textbf{Number of quadrats in which the species occured}}{\textbf{Total number of quadrats studied}}\ \textbf{X 100} \qquad \textbf{Eq6}$$

$$\boldsymbol{Relative}\ \textbf{Frequency} = \frac{\textbf{Number of quadrats in which the species occured}}{\textbf{Total number of quadrats occupied by all species}}\ \textbf{X 100} \qquad \textbf{Eq7}$$

$$\boldsymbol{Abundance} = \frac{\textbf{Total number of individuals of a species in all quadrats}}{\boldsymbol{Total\ number\ of\ quadrats}\ \textbf{in which the species occured}} \qquad \boldsymbol{Eq}\mathbf{8}$$

Following Coker and Kent (2001), the basal area is the cross-sectional area of tree stems at breast height (1.3 m above ground level). Mostly, it is a measure of dominance, which refers to the degree of coverage of species that are occupied at ground level. The basal area is calculated by the equation:

$$\boldsymbol{BA} = \frac{\boldsymbol{\pi x D^2}}{\mathbf{4}} \qquad \boldsymbol{Eq}\mathbf{9}$$

Where: BA = Basal Area in $m^2\ ha^{-1}$, D = diameter at breast height (m), and $\pi = 3.14$

$$\boldsymbol{Relative\ Dominance} = \frac{\textbf{Dominance of given species}}{\boldsymbol{Total\ dominance\ all\ species}}\ \boldsymbol{x}\ \mathbf{100} \qquad \textbf{Eq10}$$

The Importance Value Index is used to decide the overall importance of each species in the community structure. It’s calculated using the percentage values of the relative density, relative frequency, and relative dominance and this value is known as the Importance Value Index (IVI) Coker and Kent, (2001).

IVI = Relative Density + Relative Frequency + Relative Dominance Eq11

3.4.3. Regeneration status

The regeneration status of the three forest patches was analyzed by comparing saplings and seedlings with the tree species (Dhaulkhandi et al. 2008 and Tiwari et al. 2010) as follows:

1. The status good regeneration if seedlings > saplings > adults;
2. The status fair regeneration if seedlings > or ≤ saplings ≤ adults;
3. The status poor regeneration if the species survives only in sapling stage, but no seedlings (saplings may be or = adults).
4. The status no regeneration if a species is present only in adult form.
5. The status new regeneration if the species has no adults but only seedlings or saplings.

   The analysis was performed by using the statistical package SPSS version 25.0 software. In addition to this Microsoft Office Excel was used for data entry and the analysis of descriptive statistics.

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4. RESULT AND DISCUSSION

3.1. Floristic Composition of Woody Species

A total of 43 woody species were identified in the three forest degradation levels patches of the two forest sites namely Wanabala and Gopa. These belonging to 25 families were recorded across all sites (Annex 1 and 2). In the case of the Gopa site, Rubiaceae, Rutaceae, Dracanaceae, and Fabaceae were the most diverse families, each represented by 6 (20%), 4 (13%), 2 (6.7%), and 2 (6.7%) species, respectively, in the LDF; whereas Rutaceae, Rubiaceae, and Fabaceae constituted the most diverse families, each represented by 3 (14.3%), 2 (9.5%), and 2 (9.5%) species, respectively, in the MDF; the rest of the 15 families were found in HDF, each represented by a single species. In the Wanabola study site, the most dominant family in terms of species number were Moraceae, followed by Rubiaceae and Rutaceae, each represented by 4 (16%), 3 (12%), and 3 (12%), respectively, in the LDF, whereas Rubiaceae and Rutaceae each represented by 3 (15.8%) and 3 (15.8%), respectively, in the MDF and Rubiaceae and Rutaceae 2 (15.4%) and 2 (15.4%) in the HDF (Annex- 1). The presence of common families with different species diversity levels across the degradation levels might suggest the similarity of ecological habitats that are experiencing different disturbance types and severity.

Compared with other studies, the number of species (43) recorded in the study area was lower than the study for Ethiopian Afromontane Forests: Bonga forest = 51 Abayneh Derero *et al. (*2003); and Kenech Forest, Southwest Ethiopia =80 Sewale and Mammo (2021).

The analysis of the habit of woody species identified from the Afromontane forest in the Gopa site revealed that trees contributed the highest species numbers of 24 (80%) and 18 (86%) in the LDF and MDF, respectively, whereas the lowest tree species number recorded was 6 (37.5%) in HDF. However, shrubs contributed the highest species number of 10 (62.5%) in HDF, whereas the lowest shrub species recorded 6 (20%) and 3 (14%) in LDF and MDF, respectively (Figure 3). Similarly, in the case of the Wanabola site, trees contributed the highest species numbers of 21 (84%) and 16 (84%) in the LDF and MDF, respectively, whereas the lowest tree species number recorded was 6 (49%) in HDF. However, shrubs contributed the highest species number of 7 (51%) in HDF, whereas the lowest shrub species recorded 4 (16%) and 3 (16%) in LDF and MDF, respectively (Figure 3). The considerable reduction in the number of tree species in HDF and having the highest number of shrubs might suggest that the prevailing selective cutting of trees for different uses has caused the loss of trees and form a degraded forest patch with high density and coverage of competitive shrub species as reported by Vásquez et al., (2018).

Three tree species common to the study sites, i.e., *Macaranga capensis*, *Clausena anisata*, and *Ehertia cymosa*, were among the woody species common to all forest degradation levels. *Brucea antidysenterica, Dracaena fragrans, Maytenus spp*., *Rothmannia urcelliformis*, and Maytenus spp. were common shrub species in the study site at all forest degradation levels.

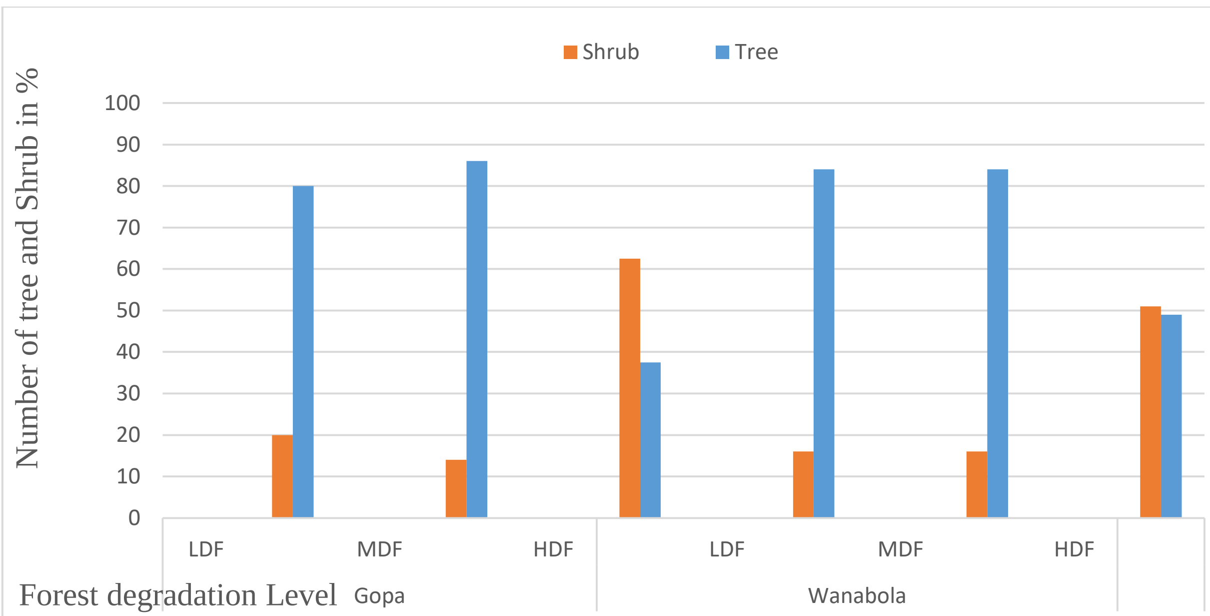


Figure 3. Composition of woody species along the forest Degradation Level

3.2. Woody Species Diversity and Richness

The Shannon Wiener diversity index of the forest along degradation levels (LDF, MDF, and HDF) in Wanabola was 2.92, 2.65, and 2.2, respectively. The Shannon diversity index was significantly higher in LDF, indicating greater diversity of species in LDF than at other levels of degradation. The Simpson index of diversity (0.93) and species evenness (0.99) for woody species was also revealed to be relatively higher in the LDF than in the MDF and HDF. The Gopa forest site diversity index of the forest degradation level revealed 3.17, 3.03, and 2.81 in the LDF, MDF, and HDF, respectively. Likewise, species evenness indexes for woody species along the LDF, MDF, and HDF were 0.94, 0.81, and 0.76, respectively. The Simpson index of diversity (0.95) and species evenness (0.94) for woody species were higher in the LDF than in the MDF and HDF (Table 4).

The study result suggests that species diversity and evenness decrease as the forest degradation level increases and this result agrees with the studies of Bitew and Tesfaye (2017). Generally, the diversity index values of the two study sites share the same result (Table 2). The two sites had a high diversity index that indicated the species richness of the areas. While comparing the two sites, there is variation in species type number. High diversity and equitability indexes imply the species richness and uniform distribution of the species in the study areas (Woldu et al, 1999).

Table 2. Species diversity and richness of forest degradation levels in the study site

Site	**Forest Patches**	**Diversity Index *(H')***	**Simpson's diversity (D)**	**Equitability (J)**	**Species Richness**
	LDF	2.92	0.93	0.99	25
Wanabola	MDF	2.65	0.92	0.80	19
	HDF	2.2	0.89	0.76	13
	LDF	3.17	0.95	0.94	30
Gopa	MDF	3.03	0.84	0.81	21
	HDF	2.81	0.72	0.76	16

In Wanabola, the species richness of the LDF, MDF, and HDF were 25, 19, and 13, respectively. At the Gopa site, the species richness across LDF, MDF, and HDF was 30, 21, and 16, respectively. In both sites, the highest woody species richness was recorded in LDF followed by MDF, whereas the lowest of recorded in HDF. Based on the results of species diversity curves in the vegetation, there is a decreasing trend in species richness as the forest degradation level increases (Figure 4), and this result agrees with a study by Bitew and Tesfaye (2017).

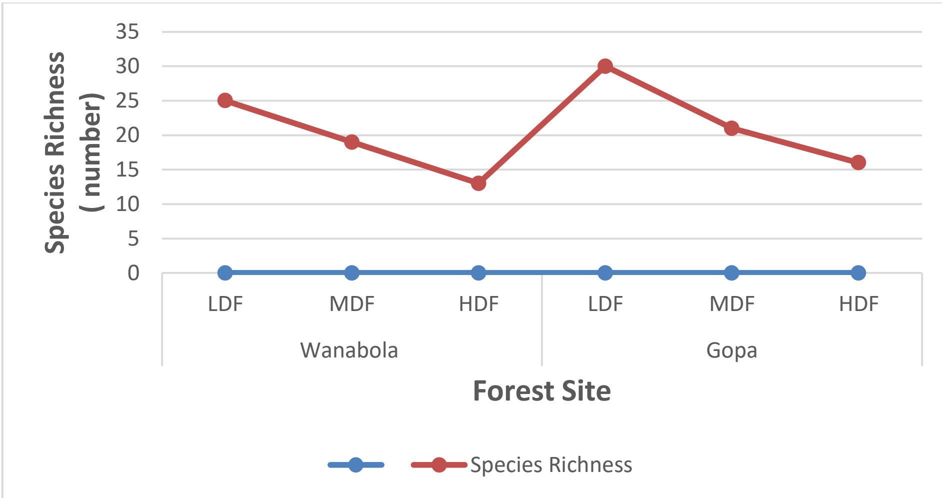


Figure 4. Species richness curve of the vegetation in each Study site

3.3. Vegetation Structure

3.3.1. Frequency

In Wanabola forests, the frequency values of the woody species ranged from 1.2% to 12.7% (Annex-3). *Rytigynia neglecta*, *Croton macrostachyus*, *Chionanthus mildbraedii*, *Maytenus spp*., and *Teclea nobilis* were the most frequently found species in the LDF. *Rytigynia neglecta* (8.7%) and *Croton macrostachyus* (8.6%) showed the highest frequency values. Whereas, *Coffee Arabica*, *Millettia ferruginea*, *Lepidotrichilia volkensis*, *Dracaena steudneri*, *and Croton macrostachyus* were the most frequently found species in the MDF. *Coffee arabica* (7%) and *Millettia ferruginea* (7%) showed the highest frequency values which might indicate that the communities deliberately allow the growth and development of both species in the modified forest by selectively cutting other "undesired" trees species to have a good yield of coffee from the preferred shade tree combination as supported by a study of Hundera (2016). Although *Chionanthus mildbraedii*, *Croton macrostachyus*, *Lepidotrichilia volkensis*, and *Teclea nobilis* were the most frequently found species in the HDF, *Chionanthus mildbraedii* (12.7%) and *Lepidotrichilia volkensis* (12%) showed the highest frequency values (Annex-3).

In the Gopa forest, *Galiniera coffeoides* (7%), *Phoenix reclinata* (6.8%), and *Croton macrostachyus* (6.4%) appeared most frequently, while *Vernonia auriculifera*, *Spathodae ssp.*, *Rothmannia urcelliformis*, *Rytigynia neglecta*, *Maytenus spp.*, *Cordia Africana*, *Ehertia cymosa*, *and Albizia gummifera rarely occurred* (1.5% each*) in LDF*. *Vepris dainelli*, *Oxyanthus speciosus, Macaranga capensis, Lepidotrichilia volkensis, and Chionanthus mildbraedii* (7% each) were the most frequently found species in the MDF. Although *Schefflera abyssinica* (6.8%), *Brucea antidysenterica, Clausena anisata, Coffee arabica, and Maytenus spp. Millettia ferruginea (*6.1% each) most frequently appeared in HDF, *Cordia Africana, Dracaena steudneri, Olea welwitschii, Pittosporum virdiflorum,* and *Rothmannia urcelliformis* rarely occurred (1.5% each) in HDF (Annex 4). The highest frequency of Scheffleria abyssinica in HDF might be attributed to its highest bee forage value in moist evergreen Afromontane forest, as supported by a study by Addi and Bareke (2019), whereas the rare occurrence of some typical climax vegetation species such as *Olea welwitschii* in HDF agrees with in the NABU (2017) study. As stated before, the highest frequency of *Coffee arabica* and *Millettia ferruginea* in HDF might be attributed to the community's desire to selectively remove "undesired" shade tree species in the forest to suit the coffee shade-tree preference match, as supported by the study of Hundera (2016).

4.3.2 Density

The total density of woody species in the Gopa forest site was 40,475 individuals per hectare. The highest density (individuals stem ha-1 (19,675) was recorded in LDF, followed by MDF (13,625 stem ha-1). However, HDF has the least density of individual ha-1 (7,175) (Table 3).

Table 3. The density of trees across forest degradation levels in the study site.

No	Forest Patches	Forest Site	
		Gopa Density (stem/ha)	**Wanabola** Density (stem/ha)
1	**LDF**	19,675	12,325
2	**MDF**	13,625	11,550
3	**HDF**	7,175	6,250
Total		**40,475**	**30,125**

Croton macrostachyus and *Chionanthus mildbraedii* in LDF, *Millettia ferruginea* and *Coffee arabica* in MDF, and *Chionanthus mildbraedii* and *Lepidotrichilia volkensis* in HDF woody species have the highest relative density (Annex-4).

In the case of the Wanabola forest site, about 30,125 total stems/ha were recorded in three forest strata. The highest density (individuals stem ha-1 (12,325) was recorded in LDF, followed by MDF (11,550 stem ha-1). However, HDF has the least density of an individual's ha-1 (6,250). (Table 3). The highest relative density is shown in *Phoenix reclinata* and *Croton macrostachyus* in LDF, *Chionanthus mildbraedii, Vepris dainelli,* and *Oxyanthus speciosus* in MDF, *Millettia ferruginea, Coffee Arabica,* and *Maytenus spp.* in HDF (Annex-3).

Generally, the study result showed that the density of woody species in both forests declines as the degradation levels in forest patches increase and this is attributed to the type and severity of the disturbances prevailing on each degradation level forest patches.

4.3.3 Dominance and Basal Area

On Wanabola forest, *Trilepisium madagascariense* (25.7%), *Scheffleria abyssinica* (22.3%), and *Allophyllus abyssinicus* (17%) were the dominant species in the LDF (Annex 3). In the case of the MDF, *Albizia gummifera* (30%), *Scheffleria abyssinica* (19.7%), and *Ficus ovata* (8.7%) were the dominant woody species. In the HDF, *Croton macrostachyus* (17.8%), *Macaranga capensis* (14.7%), and *Bersama abyssinica* (13%) were the species that dominated the woody flora. The dominance of pioneer species' (*Albizia gummifera, Croton macrostachyus*, and *Bersama abyssinica*) in more degraded forests as shown might be due to their ability to germinate in disturbed habitats but the type of species that existed along all the degradation levels are from montane forest habitats as supported by the study of NABU (2017).

In the Gopa forest, *Scheffleria abyssinica* (11.2%), *Croton macrostachyus* (7.5%), *and Millettia ferruginea* (7.4%) were the dominant species in the LDF. Similarly, *Scheffleria abyssinica* (11%) was the dominant species in MDF, followed by *Chionanthus mildbraedii* (8%) and *Ehertia cymosa* (8%). In HDF, *Cordia africana* (10.3%), *Lepidotrichilia volkensis* (9.5%), and *Scheffleria abyssinica* (8.6%) were dominant woody species (Annex 4).

The species with the main contribution to the basal area can be reflected as the most ecologically important species in the forest area (Tilahun, 2015). In Gopa, the basal areas of the forest degradation level (LDF, MDF, and HDF) were 169.13 m2 ha-1, 144.21 m2 ha-1, and 116.15 m2 ha-1, respectively (Figure 5). In this forest, *Millettia ferruginea, Croton macrostachyus, and Oxyanthus speciosus* in LDF, Scheffleria abyssinica, Allophyllus abyssinicus, and Chionanthus mildbraedii in MDF, and *Lepidotrichilia volkensis, Cordia* *africana, and Sapium ellipticum* in HDF contribute the highest basal area, whereas *Clausena anisata and Pittosporum virdiflorum* in LDF *Brucea antidysenterica* in MDF, *Rytigynia neglecta, Rothmannia urcelliformis, and Maytenus spp. Dombeya torrida* in HDF contributed to the lowest basal area/ha (Annex 4).

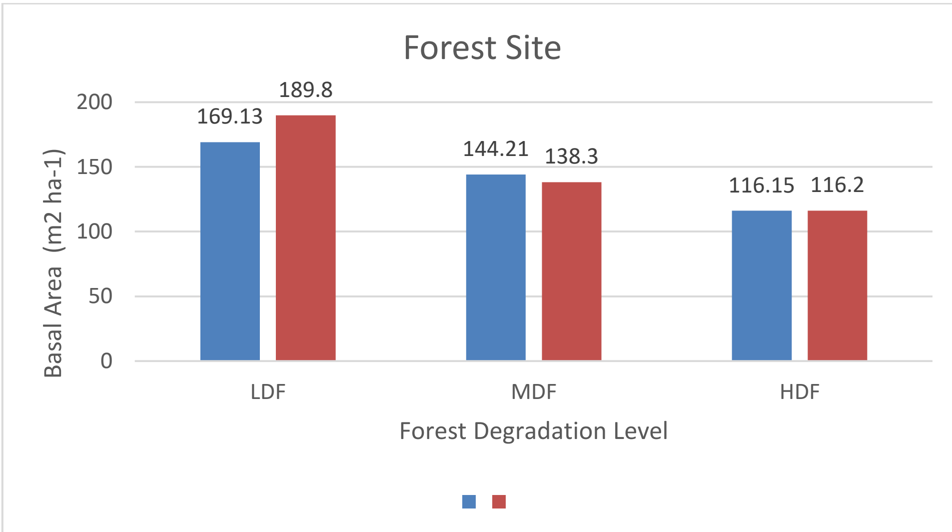


Figure 5. Basal area along Forest degradation levels

In the case of Wanabola, the highest basal area found was in LDF (189.8 m2 ha-1), followed by MDF and HDF (138.3 m2 ha-1 and 116.2 m2 ha-1 respectively) (Figure 5). Among woody species, the highest basal area/ha were recorded in *Schefferia abyssinica and Albizia gummifera* in LDF, *Schefferia abyssinica*, *Trilepisium madagascariense,* and *Allophyllus abyssinicus* in MDF, *Cordia africana, and Sapium ellipticum,* but the lowest basal area/ha were shown in *Maytenus spp. and Brucea antidysenterica* in LDF, *Dracaena fragrans and Clausena anisata* in MDF, *and Rothmannia urcelliformis and Chionanthus mildbraedii* in HDF (Annex 3).

Generally, in both forests, the amount of basal area reduces as the forest degradation level increases due to the volume of large individuals of the most valuable species being lower due to the selective cutting that degraded the forest, and this result was supported by the study of Vásquez et al., (2018).

4.3.4 Important Value Index

According to Curtis and McIntosh's (1951) Important Value Index, the sum of the RD, RF, and RDO for each woody species indicates the relative ecological importance of the forest.

Similarly, other studies show that the IVI values play an important role in understanding the ecological significance of woody species in community structure (PREMAVANI, et al., 2014).

Table 4.Important Value Index for selected woody species in the Wanabola forest

No	LDF		MDF		HDF	
	Scientific name	IVI	Scientific name	IVI	Scientific name	IVI
1	*Croton macrostachyus*	32.8	*Albizia gummifera*	35	*Chionanthus mildbraedi*i	41.9
2	*Allophyllus abyssinicus*	27.8	*Millettia ferruginea*	22.3	*Lepidotrichilia volkensis*	34.8
3	*Trilepisium madagascariense*	27.6	*Scheffleria abyssinica*	21.5	*Croton macrostachyus*	31.6
4	*Chionanthus mildbraedi*i	20.6	*Coffea arabica*	18.4	*Bersama abyssinica*	23
5	*Scheffleria abyssinica*	24	*Croton macrostachyus*	17.1	Galiniera coffeoides	18.4

The results show that at Wanabola (Table 4) *Chionanthus mildbraedi*i, Lepidotrichilia volkensis, *Croton macrostachyus*, *Bersama abyssinica*, *Galiniera coffeoides*, *Macaranga capensis*, and *Cordia Africana* had higher IVI in HDF. Species with the highest IVI are generally abundant, frequent and dominant in the forest hence requiring less conservation effort (NABU, 2017). However, *Ehertia cymosa*, *Maesa lanceolata*, and *Rytigynia neglecta*, woody species, show less than 5% of IVI (Annex 3), as a result, they require more conservation efforts. *Albizia gummifera*, *Millettia ferruginea*, *Scheffleria abyssinica*, *Croton macrostachyus*, *Coffea Arabica*, *Chionanthus mildbraedii*, and *Lepidotrichilia volkensis* were shown to have the highest IVI in MDF (Table 4) as a result the species requires less conservation effort as they are stable in the forest. But *Rytigynia neglecta*, *Prunus Africana*, *Polyscias fulva*, *Pittosporum virdiflorum*, *Maytenus spp*., *Dracaena fragrans*, and *Clerodendrum myricoides* show less than 5% of IVI (Annex 3), as a result these species with lower IVI value requires more conservation efforts and measures. *Croton macrostachyus*, *Allophyllus abyssinicus, Trilepisium madagascariense, Scheffleria abyssinica, Chionanthus mildbraedii,* and *Dracaena steudneri* woody species show higher IVI in LDF and requires less conservation efforts, whereas *Bersama abyssinica, Brucea antidysenterica, Clausena anisata, Galiniera coffeoides, Macaranga capensis,* and *Maesa lanceolata* woody species record less than 5% of IVI in LDF and requires more conservation effort to enhance their frequency in the forest patches.

Table 5. Important Value Index for selected woody species in Gopa forest

No	LDF		MDF		HDF	
	Scientific name	**IVI**	**Scientific name**	**IVI**	**Scientific name**	**IVI**
1	*Croton macrostachyus*	23.9	*Chionanthus mildbraedii*	28	*Millettia ferruginea*	20.1
2	*Phoenix reclinata*	22.3	*Oxyanthus speciosus*	24	*Scheffleria abyssinica*	19
3	*Scheffleria abyssinica*	20.7	*Vepris dainelli*	24	*Sapium ellipticum*	17.4
4	*Oxyanthus speciosus*	18.4	*Macaranga capensis*	21	*Lepidotrichilia volkensis*	16.7
5	*Galiniera coffeoides*	18.7	*Lepidotrichilia volkensis*	20	*Coffee arabica*	14.4

In the Gopa forest site, high IVI was obtained for five woody species (Table 5). These species are, *Croton macrostachyus, Phoenix reclinata, Scheffleria abyssinica, Galiniera coffeoides,* and *Olea welwitschii* in LDF. On the other hand, *Albizia gummifera, Maytenus spp., Rytigynia neglecta,* and *Vernonia auriculifera* species had less than 5% IVI values (Annex 4) and required more conservation efforts to increase their frequency and abundance in the forest. The study reports also show that *Chionanthus mildbraedii, Oxyanthus speciosus, Vepris dainelli, Macaranga capensis,* and *Lepidotrichilia volkensis* had the highest IVI in MDF (Table 5), whereas *Clausena anisata* and *Ficus ovate* had less than 5% IVI values (Annex 4) to have more conservation attention. In the case of HDF, *Millettia ferruginea, Scheffleria* *abyssinica, Sapium ellipticum,* and *Lepidotrichilia volkensis* show the highest IVI indexes (Table 5), as a result that require less conservation effort. (Annex 4).

4.4 Regeneration Status

The density values of seedlings and saplings are considered the regeneration potential of the species (Dhaulkhandi et al., 2008). In the Gopa forest site, the total density of seedlings and saplings along the forest degradation level was 27211 ha-1 and 23012 ha-1 in LDF, 18325 ha-1 and 14375 ha-1 in MDF, and 6025 ha-1 and 6375 ha-1 in HDF, respectively. Therefore, the result indicates that the LDF and MDF had shown good regeneration status, in which the density of seedlings was higher than the density of saplings, and saplings were higher than tree/shrub individuals. However, in HDF, there was a poor regeneration status in which the density of seedlings was less than the density of saplings, and saplings were less than tree/shrub individuals (Table 4).

Table 6. Regeneration status of forest sites along the degradation level

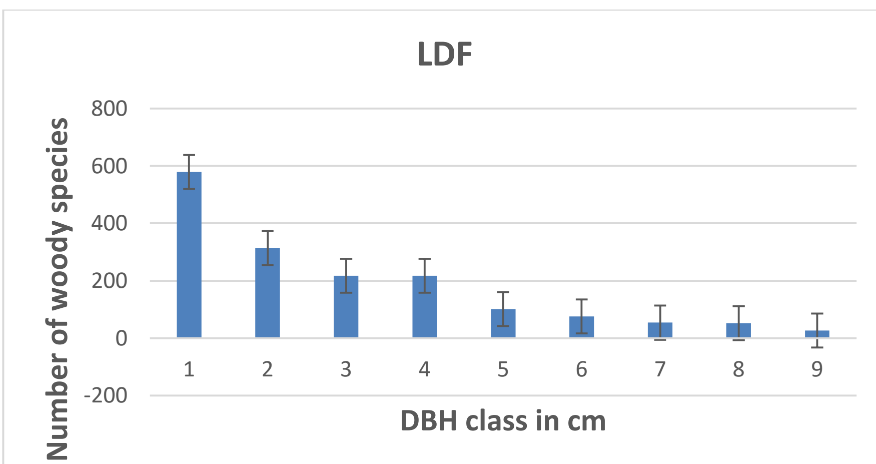
No	Life form	Gopa			Wanabola		
		LDF	**MDF**	**HDF**	**LDF**	**MDF**	**HDF**
1	Seedling	27,211	18,325	6,025	22,975	18,600	4,725
2	Sapling	23,012	14,375	6,375	22,450	16,725	5,025
3	Tree/shrub	3,125	3,000	6,750	4,700	3,725	5,550

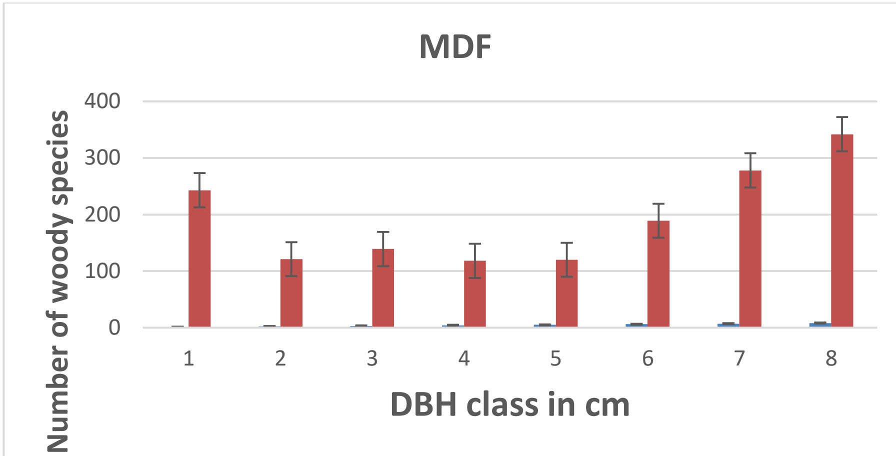
Similarly, in the Wanabola forest site, the total density of seedlings and saplings along the forest degradation level was 22,975 and 22,450 ha-1 in LDF, 18,600 and 16,725 ha-1 in MDF, and 4,725 and 5025 ha-1 in HDF, respectively. This implies that the LDF and MDF were shown to have good regeneration status, in which the density of seedlings was higher than the density of saplings, and saplings were higher than tree/shrub individuals. However, in HDF, there was a poor regeneration status in which the density of seedlings was less than the density of saplings, and saplings were less than tree/shrub individuals (Table 6). As the result indicated, the regeneration status or recruitment of HDF is poor, and this is more attributed to the disturbance types and severity prevailing at HDF that could hinder the regeneration due to a lack of seed sources or problems relating to the successful development of seedlings due to cattle grazing or suppressed by competitive shrubs to the extent that they hinder natural regeneration, as reported by Vásquez et al. (2018). According to Vásquez et al. (2018), the size and diversity of seed banks, shoots, and seedlings are inversely proportional to the degree of alteration that the forest has experienced

4.5 Diameter Breast Height class

In the Gopa forest site, the cumulative frequency distribution of DBH classes of the recorded tree species across degradation levels showed (Figure 6) various patterns of population structures. In LDF, the diameter distribution pattern was an inverted J-shaped curve. This indicates the highest number of individuals was in the lower DBH classes, and it decreased towards the higher classes of the DBH pattern. This diameter distribution pattern describes a stable stand with more recruitments in the forest. In MDF, the distribution pattern looks like a U-shaped curve that indicates the distribution of the highest number of individuals are both at lower and higher DBH classes and a decrease in middle DBH classes. This distribution pattern tries to describe that selected middle-class diameters have lower numbers as compared to higher and lower DBH classes which might be attributed to the selective cutting of middle-class DBH trees.

In HDF, the diameter distribution pattern was a normal J-shaped curve. This indicates the highest number of individuals exists in the upper diameter classes, and it decreases towards the lower diameter classes. These diameter distribution patterns try to describe the existence of lower-level recruitments in the forest patch.





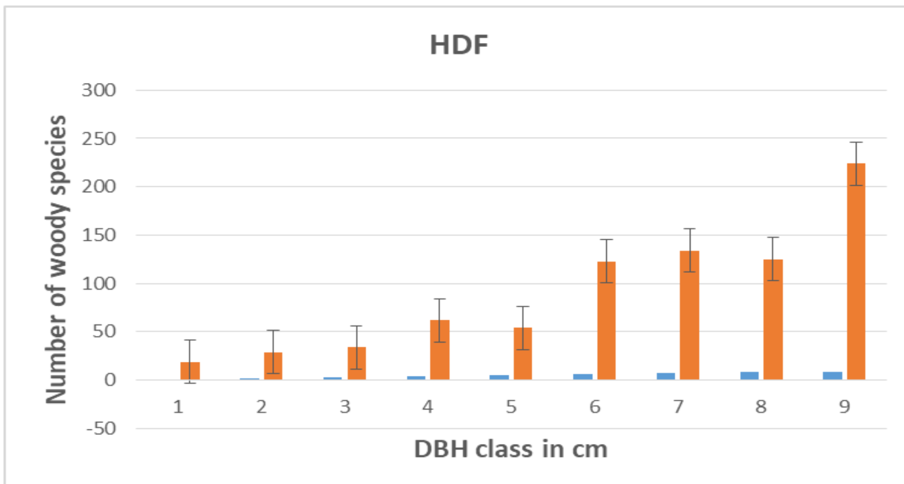
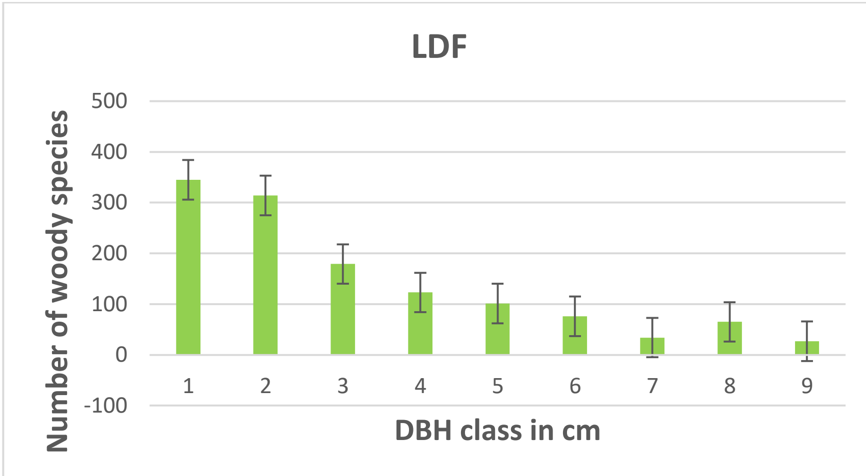
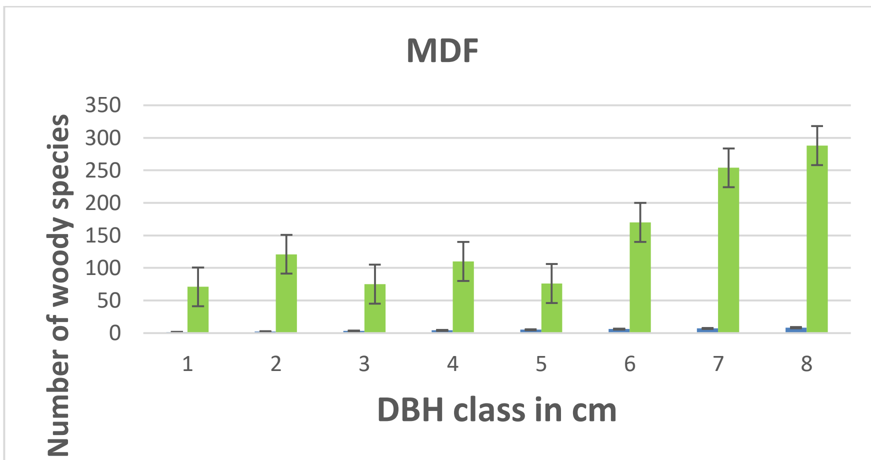


Figure 6: Frequency distribution of selected tree species over DBH classes (DBH classes: 1, 2 -10cm; 2, 10.1–20.1 cm; 3, 20.2–30.2 cm; 4, 30.3–40.3 cm; 5, 40.4.–50.4 cm; 6, 50.5–60.5 cm; 7, 60.6 – 70.6 cm; 8, 70.7 – 80.7cm; 9, 80.8 – 90.8 cm) in forest degradation levels of Gopa site.

Similarly in the Wanabola forest site, the cumulative frequency distribution of DBH classes of the recorded tree species across degradation levels showed (Figure 7) various patterns of population structures. In LDF, the diameter distribution pattern was an inverted J-shaped curve. This indicates the highest number of individuals was in the lower DBH classes, and it decreased towards the higher classes of the DBH pattern. This diameter distribution pattern describes a stable stand with more recruitments in the forest. In MDF and HDF, the diameter distribution pattern was a normal J-shaped curve. This indicates the highest number of individuals exist in the upper diameter classes and it decreases towards the lower diameter classes which in another term describes the number of lower recruitments in the forest patches.





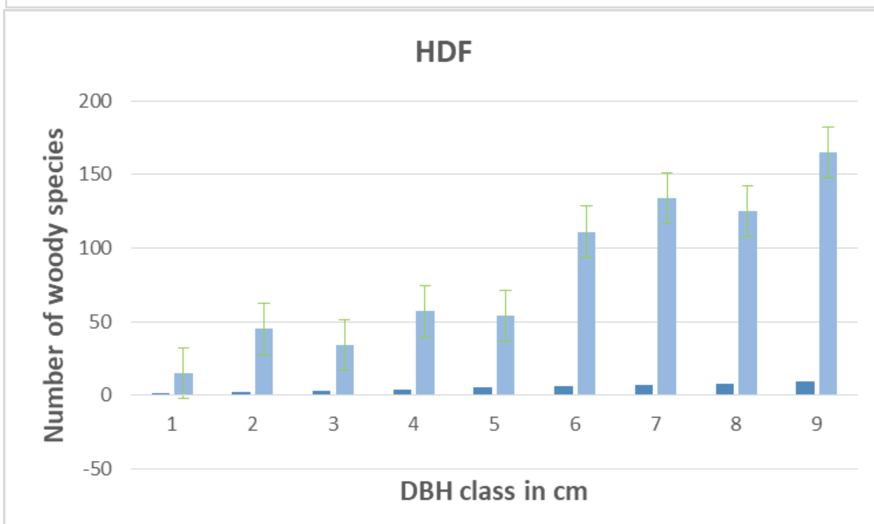


Figure-7 Frequency distribution of selected tree species over DBH classes (DBH classes: 1, 2-10cm; 2, 10.1–20.1 cm; 3, 20.2–30.2 cm; 4, 30.3–40.3 cm; 5, 40.4.–50.4 cm; 6, 50.5–60.5 cm; 7, 60.6 – 70.6 cm; 8, 70.7 – 80.7cm; 9, 80.8 – 90.8 cm) in forest degradation levels Wanabola site.

4.6. Forest Disturbances along the Degradation Levels of Forest patches

Based on the developed data collection checklist, the type and severity of the disturbances in the study area were identified. In the LDF, the prevailing disturbances were the felling of trees, charcoal production, and the existence of dead trees due to aging. As has been shown (Table 7), except for dead and felling of trees that had happened due to aging, wind, and other natural phenomena, the severity of tree felling and charcoal production induced by human intervention is light in LDF. It might be attributed to the longer distance and uneasy access they have situated. The result implies that high species diversity and evenness for LDF are due to fewer anthropogenic disturbances. Such increased plant species richness at a lower disturbance was also reported by Bitew and Tesfaye (2017).

Table 7 Disturbance factors & Severity along forest degradation level

Disturbance factors	LDF	Disturbance factors	MDF	Disturbance factors	HDF
Charcoal production	1	Charcoal production	2	Charcoal production	3
Dead trees exist due to aging	3	Dead trees exist due to aging	1	Dead trees exist due to aging	0
Fire exists	0	Fire exists	1	Fire exists	2
Felling of trees	1	Felling of trees	2	Felling of trees	2
Fuel wood collection	0	Fuel wood collection	1	Fuel wood collection	3
Grazing	0	Grazing	0	Grazing	3
Invasive species exists	0	Invasive species exists	0	Invasive species exists	0
Other disturbance	0	Other disturbance	0	Other disturbance	0

NB: - the disturbance factors & severity of forest and you decision heavy =3;

Moderate = 2; = lightly =1; and not = 0

The result shows that in MDF, the main disturbance types were the felling of trees for construction and local beehive preparation, charcoal production, and fuel wood extraction. Light disturbance intensity was recorded on fire, fuel wood collection, and feeling of trees due to aging, while, moderate disturbance intensity was shown both on charcoal production and selective cutting of trees for construction and local bee hive preparation. The possible reason for the high intensity of disturbance on MDF as compared to LDF forest patches might be due to the suitability and economic importance of such species for charcoal, construction, and other local uses of communities. The results of the present study agree with Muhammed (2018), who stated that the main reason for the destruction of woody species in different forests is the economic importance of the species.

The HDF disturbance types and their intensity result shows that livestock grazing, charcoal production, and fuel wood collection were the heavy-intensity disturbances of the forest patch. Whereas, falling of trees for construction purposes as well as for local beehive preparation, and the existence of fire were disturbances with a moderate intensity.

In this study, HDF shows the least in species evenness and richness. Low species diversity and evenness for HDF are the result of excessive human disturbances that inhibit plant growth and excessive utilization of woody species for different uses, as the HDF patches are usually situated nearer to the community and easily accessible. Similarly, Desalegn & Zerihun (2005) stated that low species diversity and evenness could be attributed to the presence of forest disturbance and the absence of adequate nutrients and moisture.

Generally, it is possible to conclude that the difference in woody species richness, diversity, and evenness between forest types is basically due to the variation in the type and intensity of human activities and forest disturbance type and intensity as a main factor. In the study, HDF exhibited multiple and heavier disturbance intensities than MDF, while LDF exhibited light disturbance intensity.

4.7 Prioritization of the forest patches for forest landscape restoration measures.

The higher species diversity helps the forests to have a more stable ecosystem functioning and enhances both productivity and stability (Kuma and Shibru, 2015). In the case of LDF, the study result shows that the rate of human disturbance was lower, the amount of basal area (m^2/ha), diversity, evenness, and the regeneration status of forest patches were highest. Therefore, prioritizing LDF for major landscape restoration measures will have less importance. However maintaining the existing forest stock and tenure security of the less degraded /dense/forest area, through sustainable forest management instead of increasing their tree cover is a priority (MFCCC, 2018).

The MDF patches had a higher diversity index and species richness as compared to HDF patches. The studied forest patches of MDF also showed good regeneration status and higher density of individuals per ha- 1 as well as the amount of basal area (m2/ha) as compared to HDF but still experiencing moderate forest disturbances intensity that has been reducing the stocking. Therefore, MDF is prioritized for restocking degraded natural forests as landscape restoration measures. The common activities to restock degraded natural forests are enrichment planting and assisted natural regeneration as measures (MEFCCC, 2018).

In the case of HDF, the study result showed that they had the lowest woody species diversity, richness, and density of individuals per ha^{-1}; the studied forest patches of HDF also showed poor regeneration status, in which the density of seedlings and saplings were lower than mature individuals and the lowest basal area/ha due to the heavy and extreme disturbances intensity they have been experiencing. Hence, HDFs with such characteristics might be prioritized for restoring secondary forests as landscape restoration measures in the study area. These measures will establish forests, including highly degraded natural forests on land that had recent tree cover in the form of reforestation as well as on land that has been degraded for much longer in the form of afforestation area exclosure and assisted natural regeneration (IPCC, 2014 and MFCCC, 2018).

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In the study area, the remnant natural forests are constantly threatened by anthropogenic-associated influences. Changes in forest structure and composition are mostly caused by human-induced disturbances, and the extent of these effects is dependent upon the type and severity of the disturbances (Bitew and Tesfay, 2019). In this study, useful information on the present condition of the woody species diversity, structure, and regeneration status of the moist Afromontane forest was obtained from Gopa and Wana Bola forest sites, which can be used as baseline information on forest landscape restoration and its measures. The study revealed that most of the trees and shrubs recorded were common at all degradation level patches with different frequencies and this witnessed the similarity of the ecological habitat with different levels of disturbance.

The results of the woody species composition in the study showed that the highest species diversity was found in less degraded forest patches followed by MDF and HDF and was dominated by large tree species; the highest number of shrub species was recorded in HDF followed by MDF and LDF.

The present study revealed that the diversity of woody species varies along disturbance gradients. Species richness decreased in all forest patches from the LDF to the MDF to the HDF. This result revealed that overuse of woody species, free grazing, and excessive anthropogenic disturbances that impede plant growth are the causes of the low species diversity and evenness for HDF.

The study also showed that the canopy cover forest degradation map of the study area is positively complemented with the study finding of woody species diversity, composition, structure and regeneration status of the different degradation level forest patches.

The study analysis of the population structure or diameter class distribution pattern of the most common species showed an inverted J shape curve for LDF patches, which indicates stable population structures. However, in MDF and HDF forest patches, the population structure or the diameter class distribution of the species recorded showed a normal J-shaped distribution pattern, which indicates a lower availability of recruitments in the forest patches.

In the LDF and MDF, regeneration analysis of woody species showed a good regeneration status, in which the density of seedlings was higher than the density of saplings and trees. However, HDF showed poor regeneration status, with seedling and sapling density lower than tree/shrub which was attributed to the type and severity of the disturbances in HDF patches that hampered regeneration.

LDF shows the highest diversity, richness, regeneration status, basal area, and relatively light disturbance intensity. Sustainable management of the existing LDF or dense forest is prioritized instead of increasing its stock. MDF with higher diversity, richness, regeneration status, and basal area than HDF but with moderate disturbance intensity is prioritized for restocking degraded natural forests. HDF exhibited the lowest diversity, richness, density, basal area, poor regeneration status, and heavy disturbance intensity for restoring secondary forests as landscape restoration measures.

5.2 Recommendation

- ✓ Raising community awareness on forest disturbances and their negative consecutive effects on human well-being, the ecosystem, and biodiversity should be regularly facilitated to reduce the disturbance of the forests through forest extension programs, PFM CBOs', and kebele council meetings.
- ✓ The in situ forest conservation system, which has been implemented in the country and been emplaced in the study forest through participatory forest management (PFM), should be strengthened through the collaboration of all stakeholders to restore highly degraded forests, reduce the prevailing excessive forest disturbances, and implement sustainable forest management.
- ✓ Forest landscape restoration measures, particularly agroforestry practices such as woodlot establishment, coffee, spice, and fodder-based agroforestry practices, should be promoted to reduce human pressure on the forest.
- ✓ Sustainable forest landscape restoration policies towards different restoration measures, socioeconomic and sustainable livelihoods incentives, and sustainable forest management mechanisms technical and financial support are needed for the effective restoration of degraded forest.

- ✓ HDF patches showed considerable loss of biodiversity, poor regeneration and stocking status, and prevailing extreme disturbance status as compared to LDF and MDF. As a result, restoring secondary forests through establishing forests on highly degraded natural forests through reforestation, afforestation, area exclosure, and assisted natural regeneration is crucial. MDF with moderate disturbance intensity, diversity, basal area, and regeneration status, restocking of degraded natural forests through enrichment plantations, and assisted natural regeneration is commendable as a restoration measure. LDF with the highest diversity, density, basal area, and regeneration status is considered for maintaining the existing dense forest through sustainable forest management engaging all pertinent stakeholders.
- ✓ The southwest Ethiopian Afromontane forest is under deforestation and degradation threat. Studies on the correlation b/n canopy cover forest degradation level maps with on-ground indicator-based assessment studies of forest degradation levels could provide tangible information for all stakeholders to decide on the type and extent of landscape restoration measures to be implemented as well as the level of complementary b/n canopy cover forest degradation level maps and field level studies. As a result, more and similar studies should be supported and conducted in the southwest Ethiopian Afromontane forest to assess the extent of complementary b/n canopy cover-based forest degradation maps and indicator-based degradation levels field studies to assist in landscape restoration of the Afromontane forest.

6 REFERENCE

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APPENDIX

Annex-1 List of plant species recorded from the study areas

No	Scientific name	Family	Local Name (Kaffi Nonoo)	Gopa			Wanabola		
				LDF	MDF	HDF	LDF	MDF	HDF
1	*Albizia gummifera (J.F.Gmil.) GA.Sm.*	Fabaceae	Caatto	x	x	x	x	x	-
2	Allophyllus abyssinicus *(Hochst) Radlk.*	Sapindaceae	She'o	x	x	x	x	-	-
3	*Bersama abyssinica Fresen*	Melianthaceae	Boqo	x	x	x	x	-	-
4	Brucea antidysenterica *J. F. Mill*	Simaroubaceae	Nuqisho	x	x	x	x	x	x
5	*Cassipourea malosana (Baker) Alston*	Rhizophoraceae	Worallo	-	-	-	x	x	-
6	*Chionanthus mildbraedii (Gilg & Schellenb.) Stearn*	Oleaceae	Shigiyo	x	--	-	-	--	-
7	*Clerodendrum myricoides (Hochst) Vatke*	*Lamiaceae*	*Agiiyo*	-	x	x	x	x	x
8	Clausena anisata *(Willd.) Hook.f. ex Benth.*	Rutaceae	Emicho	x	x	x	x	x	x
9	*Coffea arabica* L.	Rubiaceae	Bunoo	x	x	x	-	x	x
10	Cordia africana *Lam*	Boraginaceae	Di'o	x	-	x	-	-	x
11	*Croton macrostachyus Del.*	Euphorbiaceae	Wago	x	-	x	x	x	x
12	Dombeya torrida *(J.F.Gmel.) Bamps*	Sterculiaceae	Shawuko						
13	*Dracaena fragrans (L.) Ker Gawl.*	Dracanaceae	Emo	-	-	x	-	-	-
14	Dracaena steudneri *Engl.*	Dracanaceae	Yudo	x	x	x	x	x	x

No	Scientific name	Family	Local Name (Kaffi Nonoo)	Gopa			Wanabola		
				LDF	MDF	HDF	LDF	MDF	HDF
15	*Ehertia cymosa* Thonn.	Boraginaceae	Wogamo	x	x	x	x	-	-
16	Elaeodendron buchananii *(Loes.) Loes.*	Celastraceae	Washo	x	x	x	x	x	x
17	*Erythrococca trichogyne (Muell Arg.) Prain*	Euphorbiaceae	Biceeri kucoo	-	-	-	-	x	-
18	*Ficus lutea* Vahl	Moraceae	Meello	-	-	-	-	x	-
19	*Ficus ovata* Vahl	Moraceae	Caroo	-	-	-	x	-	-
20	*Ficus plamata* Forssk.	Moraceae	Shotto	x	x	x	x	x	-
21	Galiniera coffeoides	Rubiaceae	Dido	-	-	-	x	-	-
22	Lepidotrichilia volkensis (Gurke) Leory	Meliaceae	Shahiyo	x	x	x	x	-	x
23	Macaranga capensis (Baill) Sim	Euphorbiacae	Shakero	x	x	x	-	x	x
24	*Maesa lanceolata* Forssk.	Myrsinaceae	Caggo	x	x	x	x	x	x
25	*Maytenus* spp.	Celastraceae	Shiko	-	-	-	x	-	-
26	Millettia ferruginea *(Hochst.) Bak.*	Fabaceae	Bibero	x	x	x	x	x	x
27	*Olea welwitschii (Knobl) Gilg&Schellenb.*	Oleaceae	Yaho	x	x	x	-	x	x
28	*Oxyanthus speciosus DC.*	Rubiaceae	Aa'imato	x	-	x	-	x	x
29	*Phoenix reclinata* Jacq	Arecaceae	Yeeboo	x	x	-	-	-	-
30	*Phyllanthus reticulatus* Poir.	Euphorbiaceae	Meego	x	x	x	-	-	-
31	Pittosporum virdiflorum *Sims*	Pittosphoraceae	Shollo	-	x	-	-	-	-
32	*Polyscias fulva(Hiern.) Harms*	Araliaceae	Karesho	x	-	x	-	x	-

No	Scientific name	Family	Local Name (Kaffi Nonoo)	Gopa			Wanabola		
				LDF	MDF	HDF	LDF	MDF	HDF
33	Prunus africana *(Hook.f.) kalkm*	Rosaceae	Omo	-	x	x	-	x	-
34	*Rothmannia urcelliformis (Hiern.) Robyns*	Rubiaceae	Diboo	-	-	-	-	x	-
35	Rytigynia neglecta *(Hiern) Robyns*	Rubiaceae	Natacho	x	x	x	x	x	x
36	*Sapium ellipticum (Hochst.) Pax*	Euphorbiaceae	Sheddo	x	-	-	x	x	x
37	Scheffleria abyssinica *Hochst.ex A. Rich) Harrms*	Araliaceae	Buttoo	-	-	x	-	-	x
38	*Spathodae* ssp.	Bignoniacea	Yayo	x	x	x	x	x	-
39	Syzigium guineense*(Willd.) DC. ssp.* afromontanum *F*	Myrtaceae	Yino	x	-	-	x	-	-
40	*Teclea nobilis* Del.	Rutaceae	Shenigaro	x	x	-	-	-	-
41	*Trilepisium madagascariense DC*	Moraceae	Gaboo	x	x	-	x	x	x
42	Vepris dainellii *(Pichi-serm) Kokwara*	Rutaceae	Mengorexo	-	x	-	x	-	-
43	*Vernonia auriculifera* Hiern.	Asteraceae	Dangireto	x	x	-	x	x	-

Annex-2 Number of species in each Forest patches in study Site

No	Family	No. of species in each Forest patches											
		Gopa						Wanabola					
		LDF		MDF		HDF		LDF		MDF		HDF	
		No	**%**	**No**	**%**	**No**	**%**	**No**	**%**	**No**	**%**	**No**	**%**
1	Araliaceae	1	3.3	1	4.8	1	6	1	4	1	5.3	-	-
2	Arecaceae	1	3.3	1	4.8	1	6		-	-	-	-	-
3	Asteraceae	-	-	-	-	1	6		-	-	-	-	-
4	Bignoniacea	-	-	-	-	-	-	1	4	-	-	-	-
5	Boraginaceae	2	6.7	1	4.8	-	-	1	4	1	5.3	1	7.7
6	Celastraceae	1	3.3	1	4.8		-	1	4	1	5.3	1	7.7
7	Dracanaceae	2	6.7	1	4.8	1	6	2	8	1	5.3	1	7.7
8	Euphorbiacae	1	3.3	1	4.8	1	6	1	4	1	5.3	1	7.7
9	Euphorbiaceae	1	3.3	1	4.8	1	6	1	4	1	5.3	1	7.7
10	Fabaceae	2	6.7	2	9.5	1	6	1	4	1	5.3	1	7.7
11	Lamiaceae	1	3.3	-	-	-	-	-	-	-	-	-	-
12	Meliaceae	1	3.3	1	4.8	1	6	-	-	1	5.3	1	7.7
13	Melianthaceae	1	3.3	1	4.8	1	6	1	4	-	-	-	-
14	Moraceae	1	3.3	1	4.8	-	-	4	16	1	5.3	-	-
15	Myrsinaceae	-	-	-	-	-	-	1	4	-	-	-	-
16	Myrtaceae	1	3.3	1	4.8	-	-	-	-	-	-	-	-
17	Oleaceae	1	3.3	1	4.8	1	6	1	4	`1	5.3	1	7.7
18	Pittosphoraceae	1	3.3	-	-	1	6	-	-	1	5.3	-	-
19	Rhizophoraceae	-	-	-	-	-	-	1	4	1	5.3	-	-
20	Rosaceae	-	-	-	-	-	-	-	-	1	5.3	-	-
21	Rubiaceae	6	20.0	2	9.5	1	6	3	12	3	15.8	2	15.4
22	Rutaceae	4	13.3	3	14.3	1	6	3	12	3	15.8	2	15.4
23	Sapindaceae	1	3.3	1	4.8	1	6	1	4	-	-	-	-
24	Simaroubaceae	1	3.3	1	4.8	1	6	1	4	1	5.3	1	7.7
25	Sterculiaceae	-	-	-	-	1	6	-	-	-	-	-	-
Total		**30**	**100**	**21**	**100**	**16**	**100**	**25**	**100**	**19**	**100**	**13**	**100**

Annex-3 Relative frequency, density, dominance, and IVI of woody species in the three forest strata in Wanabola

Scientific name	LDF				MDF				HDF			
	RF	**RD**	**RDO**	**IVI**	**RF**	**RD**	**RDO**	**IVI**	**RF**	**RDO**	**RD**	**IVI**
Albizia gummifera	2.6	1.2	3.8	7.6	3.1	1.9	30	35	-	-	-	-
Allophyllus abyssinicus	6	4	17.6	27.8	-	-	-	-	-	-	-	-
Bersama abyssinica	3	1.4	0.04	4.5	-	-	-	-	6	13	4	23
Brucea antidysenterica	2.6	1.2	0.01	3.8	3.4	2.4	-	5.8	2.7	-	1.6	4.3
*Cassipourea malosan*a	2.6	2.4	0.48	5.5	2.7	2.2	3.5	8.3	-	-	-	-
Clerodendrum myricoides	-	-	-	-	1.2	1.1	-	2.2	-	-	-	-
*Chionanthus mildbraedi*i	8.6	12	0.03	20.6	5.7	5.6	3.2	14.6	12.7	6.8	22.4	41.9
Clausena anisata	2	1	0.01	3	2.3	1.7	0.1	4.1	3.3	-	2	5.4
Coffea arabica	-	-	-	-	7	11	0.5	18.4	4.7	-	4	8.7
Cordia africana	-	-	-	-	-	-	-	-	2.7	12.2	1.6	16.4
Croton macrostachyus	8.6	18	6.4	32.8	5.7	7.1	4.2	17.1	7.3	17.8	6.4	31.6

Scientific name	LDF				MDF				HDF			
Scheffleria abyssinica	1.3	0.6	22.3	24	1.2	0.6	19.7	21.5	-	-	-	-
Dracaena fragrans	3.9	1.8	0.01	5.7	-	1.3	0.1	3.6	5.3	-	6	11.3
Dracaena steudneri	4.8	4.2	8.3	17.3	6.1	3.7	2.6	12.4	-	-	-	-
Ehertia cymosa	3.9	3.2	1.07	8.2	3.0	1.9	0.7	5.7	2	0.1	1.2	3.3
Elaeodendron buchananii	-	-	-	-	3.8	3.7	7.6	15.2	-	-	-	-
Erythrococca trichogyne	-	-	-	-	4.2	4.3	0.2	8.7	-	-	-	-
Ficus lutea Vahl	4.8	2.2	9.3	16.3	-	-	-	-	-	-	-	-
Ficus ovata Vahl	2.6	2.0	0.01	4.6	3.07	1.1	8.7	12.9	-	-	-	-
Ficus plamata Forss	2.6	2.4	2.24	7.3	-	-	-	-	-	-	-	-
Galiniera coffeoides	1.3	0.6	0.3	2	3.4	4.3	-	13.3	7.3	1.1	10	18.4
Lepidotrichilia volkensis	-	-	-	-	6.5	4.5	4.2	15.3	12	9.6	13.2	34.8
Macaranga capensis	3.2	0.6	0.05	2	3.5	1.9	0.1	5.5	1.3	14.7	0.8	16.8
Maesa lanceolata	2	2.0	0.03	4.2	-	-	-	-	2	-	1.2	3.2
Maytenus spp.	6.5	3.0	0.01	9.5	1.5	0.9	-	2.4	5.3	-	6	11.3
Millettia ferruginea	-	-	-	-	7	14.1	1.3	22.3	2.7	9.6	1.6	13.9

Scientific name	**LDF**				**MDF**				**HDF**			
Olea welwitschii	-	-	-	-	2.7	1.5	5.4	9.6	2.7	6.3	1.6	10.6
Pittosporum virdiflorum	-	-	-	-	1.2	0.6	0.1	1.8	-	-	-	-
Polyscias fulva	-	-	-	-	0.8	0.4	0.7	1.9	-	-	-	-
Prunus Africana	-	-	-	-	2.3	0.9	-	1.6	-	-	-	-
Rothmannia urcelliformis	2.6	9.1	0.85	12.5	5.4	7.8	0.2	7.8	4	1.9	3.2	9.1
Rytigynia neglecta	8.7	4.8	0.05	13.5	0.8	0.4	-	1.2	2	0.1	1.2	3.3
Sapium ellipticum	-	-	-	-	-	-	-	-	4	6.1	5.6	15.7
Spathodae ssp.	3.4	1.6	0.01	5.1	-	-	-	-	-	-	-	-
Syzigium guineense ssp. *afromontanum*	-	-	-	-	2.3	1.3	6.6	10.2	-	-	-	-
Teclea nobilis	6.5	9.7	0.5	16.6	4.6	5.8	0.1	10.6	10	0.3	6.4	16.7
Trilepisium madagascariense	1.3	0.6	25	27.6	-	-	-	-	-	-	-	-
Vepris dainellii	4.8	9.9	0.01	14.6	5	5.6	0.2	10.8	-	-	-	-
	100	100	100	296.6	100	100	100	156.8	100	100	100	157.1

RF = Relative frequency, RD = Relative density, RDO= Relative dominance, IV = Importance value index

Annex-4 Relative frequency, density, dominance, and IVI of tree species in the three forest strata in Gopa

Scientific name	LDF				MDF				HDF			
	RF	RD	RDO	IVI	RF	RD	RDO	IVI	RF	RD O	RD	IVI
Albizia gummifera	1.5	0.5	0.3	2.3	3.8	2	1	7	4.2	4.3	3.8	12.3
Allophyllus abyssinicus	6.4	5.1	5.5	17	3.5	2	6.9	14	3.4	6.9	3.1	13.5
Bersama abyssinica	2.6	2.2	0.4	5.2	5.9	3	1	10	4.6	1.0	4.2	9.7
Brucea antidysenterica	5.7	2.5	0.4	8.6	3.1	2	1	6	6.1	0.3	5.6	12.0
Chionanthus mildbraedii	-	-	-	-	7.0	13	8	28	3.0	0.3	2.8	6.1
Clausena anisata	2.6	2.2	0.2	5	0.7		1	2	6.1	0.3	5.6	12
Coffee arabica	2.6	2.4	0.3	5.4	4.2	2	1	7	6.1	1.0	7.3	14.4
Cordia africana	1.5	0.5	6.1	8.1	-	-	-	-	1.5	10.3	1.4	13.3
Croton macrostachyus	6.4	9.9	7.5	23.9	-	-	-	-	3.0	5.2	2.8	11.0
Scheffleria abyssinica	4.9	4.6	11.2	20.7	1.7	1	11	14	6.8	8.6	3.8	19.3
Dracaena fragrans	6.0	4.1	0.4	10.5	5.2	3	2	10	2.7	0.4	2.4	5.5
Dracaena steudneri	2.6	2.7	5.7	11	2.1	1	7	10	1.5	4.3	2.8	8.6
Ehertia cymosa	1.5	3.0	4.6	9.2	1.7	1	8	11	4.2	3.4	3.8	11.5
Ficus ovata Vahl	3.4	3.0	5.7	12	1	1	1	2	2.3	7.8	3.8	13.9
Galiniera coffeoides	7.5	9.5	1.6	18.7	3.5	5	-	12	4.2	1	3.8	9.0
Lepidotrichilia volkensis	2.6	5.7	7.4	15.8	7.0	6	7	20	3.0	9.5	4.2	16.7
Macaranga capensis	-	-	-	-	7.0	8	6	21	-	-	-	-
Maytenus spp	1.5	1.5	0.4	3.5	5.9	9	1	16	6.1	0.3	7.3	13.7

Scientific name	LDF				MDF				HDF			
Millettia ferruginea	2.6	1.0	7.4	11	2.4	2	3	8	6.1	6	8	20.1
Olea welwitschii	5.7	6.2	6.1	18	-	-	-	-	1.5	6	1.4	8.9
Oxyanthus speciosus DC.ssp. globosus	6.0	5.7	6.7	18.4	7.0	12	5	24	-	-	-	-
Phoenix reclinata	6.8	10	5.5	22.3	2.1	1	4	7	4.2	3.0	3.8	11.0
Phyllanthus reticulatus	-	-	-	-	0.7		1	10	-	-	-	-
Pittosporum virdiflorum	1.9	3.7	0.2	5.8	-	-	-	-	1.5	5.2	1.4	8.1
Polyscias fulva	-	-	-	-	-	-	-	-	1.9		3.5	8.4
Rothmannia urcelliformis	1.5	3.4	1.0	6.0	4.5	3	4	11	1.5	0.3	1.4	3.3
Rytigynia neglecta	1.5	0.6	0.4	2.5	-	-	-	-	2.3	-	-	-
Sapium ellipticum	-	-	-	-	-	-	-	-	4.9	9.5	3.1	17.6
Spathodae ssp.	1.5	0.5	3.6	5.6		-	-	-	-	-	-	-
Syzigium guineense	3.4	1.8	3.0	8.1	6.3	5	5	16	-	-	-	-
Teclea nobilis	-	1.0	5.1	7.6	4.2	3	2	9	-	-	-	-
Trilepisium madagascariense	-	-	-	-	2.1	1	7	10	-	-	-	-
Vepris dainelli	6.4	6.0	2.9	15.3	7.0	12	5	24	-	-	-	12.2
Vernonia auriculifera	1.5	0.5	0.4	2.4	-	-	-	-	5.7	1.3	5.2	-
Total	**100**	**100**	**100**	**300**	**100**	**100**	**100**	**309**	**100**	**100**	**100**	**292**

RF = Relative frequency, RD = Relative density, RDO= Relative dominance, IV = Importance value index