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Floristic Composition, Structure, and Regeneration Status of Wakani Forest in
Guagusa Shikudad District, Awi Zone, Northwestern Ethiopia

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This is to certify that the thesis prepared by Getaye Berihun Siraw entitled: Floristic Composition, Structure, and Regeneration Status of Wakani Forest in Guagusa Shikudad District, Awi Zone, Northwestern Ethiopia, and submitted to the Department of Zoological Science in partial fulfillment of the requirements for the Degree of Master of Science in Biology complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

Floristic composition, structure, and regeneration status of Wakani Forest in Guagusa Shikudad District, Awi Zone, Northwestern Ethiopia

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Addis Ababa University, 2024

Understanding the floristic composition, structure, and regeneration status of the remnant forest provides crucial information for future forest management practices. The objective of this study, therefore, was to investigate the floristic composition, vegetation structure, and regeneration status of Wakani Forest in Guagusa Shikudad District (Ethiopia). The vegetation data was collected using a systematic sampling method in the south-to-north direction of line transects along altitude gradients. A total of 63 main sample plots of 20 x 20 m were established. Species composition and vegetation structure were analyzed using formulas and R statistical software. The result showed that a total of 64 vascular plant species belonging to 60 genera and 41 families were identified in Wakani Forest. Fabaceae was represented by the highest species (6). Of the four community types, the highest species richness (60), evenness, diversity, and importance value index were recorded in community type 4. *Gymnosporia addat* was the most dominant woody plant species followed by, *Maesa lanceolata*, *Brucea antidysenterica*, and *Vachellia abyssinica* second, third, and fourth respectively. The least dominant woody plant species in Wakani Forest was *Ficus sur* (4 individuals). According to the data analysis, *Prunus africana* was the tallest tree with an average height of 38 m followed by *Pittosporum viridiflorum*, *Astropanax abyssinica*, and *Apodytes dimidiata* with an average height of 35 m, 32 m, and 31 m respectively.

Keywords: Awi Zone, Floristic composition, Guagusa Shikudad, regeneration status, structure, Wakani Forest

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List of Abbreviations and acronyms

BA = Basal area

C = Climbers

DBH = Diameter at breast height

EFAP = Ethiopian Forestry Action Program.

EPA = Environmental Protection Authority.

EWNHS = Ethiopian Wildlife and Natural History Society

EH = Evenness

FAO = food and agricultural Organization

GSDFEDD = Guagusa Shikudad District Finance and Economic Development Department

H' = Sahnnon -Weiner diversity index

ICBP = International Council for Bird Preservation

IUCN = International Union for Conservation of Nature

IVI = Important Value Index

RD = Relative Density

RF = Relative Frequency

RDO = Relative Dominance

S = Shrubs

T = Trees

T/S = Tree/shrubs

UNDESA = United Nations Department of Economic and Social Affairs

UNEP = United Nations Environment Program

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

Ethiopia is a significant country for biological diversity as a result of its various topography, its geographical diversity with high and rugged mountains, flat-topped plateaus and deep gorges, incised river valleys, and rolling plains (Kindalem Dessie, 2021). These helped the emergency of a wide range of habitats that are suitable for the evolution and survival of various plant and animal species. Because of this, Ethiopia is regarded as one of the most important countries in Africa concerning the endemism of plant and animal species in tropical Africa (Mengesha Asefa *et al.*, 2020; Yitayh Leul *et al.*, 2023). Most of Ethiopia's highlands were once covered with dense forest. This is indicated by the numerous isolated mature forest trees or patches of forests (Mengesha Asefa *et al.*, 2020; Masresha Getinet and Yirgalem Melaku, 2022). Forests are essential to human sustenance, health, happiness, and well-being. Forests have been providing raw materials for wooden and nonwooden products, space for human settlements, and agriculture. Forests indirectly influence global climate, serve as wildlife habitats, provide a genetic pool for biotic diversity, and provide ecosystem services for water shed protection and erosion control (Ramirez-Maricial *et al.*, 2001; de Vries, 2022).

Historical documents indicated that Ethiopia had experienced substantial deforestation, change of habitat, loss of biodiversity, degradation of soil, and an increase in the area of bare land over many years. Deforestation in the highlands of Ethiopia become a continuous process dating back many hundreds of years resulting in patches of forests mainly around religious centers, inaccessible and protected areas (Alemayehu Wassie, 2007; Dessie Gessese, 2007; Gobena Abate, 2018). Thus, understanding the floristic composition, structure, and regeneration status of the remnant forest provides crucial information for future forest management practices (Nigatu Dejene *et al.*, 2019; Misganaw Meragiaw *et al.*, 2021). The main causes for deforestation, loss of biodiversity, and an increase in the area of bare land are the conversion of forests into farm land shifting cultivation, fire wood, charcoal production

overgrazing, inappropriate investments, and lack of viable land use policy (Ramirez-Maricial *et al.*, 2001).

The increasing growth rate of the human population with the increasing need for forest products and farm land has put the remaining few patches of forests on the verge of extinction (Tamrat Bekele, 1994; Bowen *et al.*, 2007). The consequences of forest cover reduction are soil erosion, reduction capacity for carbon sequestration, reduction of biodiversity and instability of the ecosystem, and reduced availability of various wood and non-wood forest products and services (Bane *et al.*, 2007). The restoration of natural vegetation and biodiversity loss is one of the leading agenda for several world conservation organizations, authorities, and interest groups (Wiene and Hobbs, 2015). Over many years, sustainable forest management has been the main focus of worldwide forest sectors. To resolve the risk, sustainable forest management has been practiced by applying conservation techniques. Some of the methods include the protection of forest areas with restricted access for the communities which have often been introduced in the forest, and developing the awareness of the community to tackle the loss of forests, and its effects (Weinberg, 2011).

Wakani forest has been affected by deforestation for timber, charcoal, fuel wood collection, and overgrazing. The current study on this forest is important to provide information for the stakeholders to tackle the problem by setting meaningful planning, effective management, and giving awareness to the people for conservation and sustainable use of the forest and the resources. Thus, the objective of the study was to identify and document the floristic composition and structure and evaluate the species richness, evenness, and diversity of the study forest.

1.2 Statement of the problem

Increased consumption and unwise use of forest products without considering the ecological and economic consequences have a negative impact (EFAP, 1994; Shackleton *et al.*, 2015). According to the International Union for Conservation of Nature (IUCN) Red List, about 21% of global plant species are currently threatened with extinction. In the tropics, the destruction of forests due to ever-increasing anthropogenic influences was identified as the main threat to 85% of threatened species (IUCN 2015). In the study area, there is unwise and excessive utilization of forests for fuel wood, timber, fencing, construction, and grazing of animals which seriously

affects its resources. There is a severe and increasing fuel gap in the country which leads to the depletion of the standing stock and hence, the degradation of the remaining forest stands (EPA, 1997; Demel Teketay *et al.*, 2010). The energy consumption of the community near Wakani Forest mainly depends on fuel wood collection in the forest to meet their energy requirement for cooking, heating, and lighting. This leads to the destruction of woody plants in the study forest.

Lack of proper management, and constant and sustainable institutional organization has resulted in total deforestation and degradation of fertile cultivable land and soil fertility, exposing the country to drought and famine, thus the earlier fertile Ethiopia is now on its way to changing to the desert (Badege Bishaw, 2001; Desalew Meseret , 2016). This is also applicable in the study forest. There is a lack of proper management, lack of information, constant and sustainable institutional organization, and awareness for the society about conservation and wise utilization of the forest.

The presence of accurate information on forest resources is a requirement for proper management and planning within the context of sustainable development (FAO, 2007). Assessments such as woody species composition and structural analysis are essential in understanding the context of plant diversity in forest ecosystems (WCMC, 1992; Dinkissa Beche , 2011). The study of woody plant composition, structure, regeneration status, diversity, and evenness to collect appropriate data is very crucial to give information for the stakeholders to apply proper management and give awareness for the society to reduce unwise utilization of the forest in the study area. The present study on Wakani Forest aims to identify the problems and recommend possible solutions.

1.3 Significance of the study

Studies on forest biodiversity are supposed to provide solutions for the problems imposed on forest biodiversity, woody plant species identification, and structural analysis of the study area, and documenting the results will help to give information on the provision of effective management for biodiversity conservation and sustainable use of the resources. Sustainable management and forest biodiversity conservation helped reduce anthropogenic impacts on different plant species diversity in the study area. These anthropogenic impacts which reduce

forest biodiversity render significant ecological and socio-economical services to the local community.

1.4 Scope of the study

There are different forest covers in this district and different aspects of forest to be studied. But the researcher was preferred only on the floristic composition, structure and regeneration status of Wakani Forest.

1.5 Limitation of the study

The limitation of the study includes materials like GPS to record specific altitude and clinometers for measuring height of trees in the field. On the other hand there was the limitation of internet connection in the study area.

1.6. Organization of the study

This study consists of 5 chapters. The first chapter deals the introduction, statement of the study, objective, and significance of the study, limitation and research questions. Chapter two deals with literature review. The material and methodologies are dealt within chapter three. Chapter four includes result and discussion. Chapter five contains conclusion and recommendation. Finally references and appendix were included.

1.7 Objectives of the study

1.7.1 General objective

The main objective of this work was to study the plant species composition, vegetation structure, diversity, and regeneration status of Wakani Forest.

1.7.2 Specific objectives

The specific objectives of this study were to:

- identify main plant community types by species richness, evenness, and diversity, and importance value index in Wakani Forest;
- examine the floristic composition and structure of Wakani Forest;

- determine density, DBH, height, basal area, frequency, and IVI of plant species in the study area;
- evaluate species diversity, evenness, and richness of plant species in Wakani Forest; and
- indicate the regeneration status of woody species in Wakani Forest.

1.8 Research questions

To achieve the above-mentioned objectives, the researcher formulated the following research questions to be answered in the present study:

1. What are the main plant community types in Wakani Forest and do they vary in diversity, i.e., in species richness, and evenness?
2. What does the floristic composition and vegetation structure look like in Wakani Forest?
3. How does the species distribute structurally in density, frequency, basal area, height, and IVI?
4. How does the species distribute in richness, evenness, and diversity in the study area?
5. What does the regeneration status of woody species look like in Wakani Forest?

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Overview of Ethiopian forests

As compared with different countries in Africa, Ethiopia is endowed with different forest biodiversity. This is because most of the country contains high plateaus and mountain ranges (Feyera Senbeta *et al.*, 2002; Haileab Zegeye, 2017). The different physical conditions and variations in altitude have resulted in a great diversity of climate soil and different vegetation cover of the country which is associated with the presence of different forest biodiversity (Feyera Senbeta *et al.*, 2002; Mengesha Asefa *et al.*, 2020).

Furthermore, Ethiopia is a significant hub for biological variety in the area. Ethiopia has significant biodiversity and is a regional hub of biological diversity in part because of its diverse topography, which includes ragged mountains, flat-topped plateaus, deep gorges, incised river valleys, and rolling plains (Ensermu Kelbessa *et al.*, 1992; Friis *et al.*, 2010; Misganaw Meragiaw *et al.*, 2018). The flora of Ethiopia is very heterogeneous and has rich endemic species of plants due to the diversity in climate vegetation and terrain. It is estimated to contain between 6500-7000 species of higher plants of which 12% are endemic (Tegenge Ayalew, 2018; Mengesha Asefa *et al.*, 2020).

It is believed that a substantial portion of the land area in high highlands of Ethiopia was covered with forests having wider coverage than at present (Ginjo Gitima *et al.*, 2022). The presence of some isolated forest trees, even on farmlands or patches of forests around churchyards and religious burial grounds in this country indicates the occurrence of forests earlier (Tamrat Bekele, 1993; Weldemedhin Tadesse and Demel Teketay, 2016).

2.1.1 Significance of forests

Forests provide many ecological significances. There are a variety of services that the forest provides. The major services that forests provide include regulation of water regions, modulating climate, maintenance of soil quality, carbon sequestration, maintenance of biodiversity, and

being the habitat for other species (Wani and Sahoo, 2021). Forests indirectly influence global climate, serve as wildlife habitats, provide a genetic pool for biotic diversity, and provide ecosystem services for watershed protection and erosion control. In addition to this, forests help to maintain the fertility of the soil, are used as a habitat for wildlife, protect water resources, and reduce natural disasters, such as landslides and flooding (Ramirez-Maricial *et al.*, 2001; Raji *et al.*, 2020).

Human beings are dependent on forest biodiversity for their substance's health well-being and enjoyment. Forests also have been providing food, recreation, spiritual sustenance, and commercially traded products ranging from pharmaceuticals to timber and non-timber products (Murthy *et al.*, 2002). Forests give a variety of products and services. The economic values of forests are the basis of a variety of industries including timber, processed wood and paper, rubber, and fruits. They also contain products that are necessary for rural communities including fuel, construction materials, and medicines (FAO, 2005; Debal, 2013). Forests play a vital role as a source of energy, for grazing, and non-timber products. The energy consumption of rural Ethiopia is mainly based on biomass sources for which fuel wood is the highest component. Rural Ethiopia households are entirely dependent on biomass fuel to meet their energy requirement for cooking, heating, and lighting (Mehari Weldemariam, 2020).

2.1.2 Causes for Ethiopian forest loss

Ethiopia has experienced substantial deforestation, soil degradation, and an increase in the area of bare land over the years. The main cause for forest biodiversity degradation frequently leading to loss of forest cover and biodiversity loss is the need for fuel wood, farmland, human settlement, shifting cultivation, grazing area, firewood, and lack of viable land policy (Ensermu Kelbessa and Teshome Soromessa, 2008; Tayachew Birhanu *et al.*, 2021).

Deforestation, natural disasters such as volcanic eruption, logging, and the conversion of forests to agricultural lands account for 40% of Ethiopia's forest loss (Haileab Zegeye, 2017). The size and distribution patterns of domestic animal and human populations, the degree of resource consumption knowledge of woody plant species in a limited sense due to low awareness, and the lack of attention paid to the conservation and sustainable use of woody plant species have all

contributed to the current acceleration of the decline in the diversity of woody plant species in Ethiopia. (Tesfaye Awas, 2007; Bekele Tona, 2016).

Ethiopia has experienced total deforestation and degradation, loss of fertile cultivable land and soil fertility, and exposure to drought and famine. This is because of high exploitation of forests without restoration, removing fragile ecosystems, forest fires, improper forest administration and management, and a lack of compatible forest proclamation (UNEP, 1995; Tayachew Birhanu *et al.*, 2021; Misganaw Meragiaw *et al.*, 2022). Expansion of agricultural land, overgrazing by livestock, and selective tree felling for charcoal, firewood, and construction are some of the anthropogenic factors (Misganaw Meragiaw *et al.*, 2018). The country's high forest and woodlands coverage has been declining in both size and quality. This is due to the increased use of forest lands for farm lands, unwise use and excessive utilization of forest products without considering future generations, and ecological and economic consequences (EFAP, 1994; Mesfin Demamu *et al.*, 2020). In addition, free grazing and browsing of domestic animals, which is very common in the study area, could have a negative effect on seedling establishment and survival in these and other woody species in the montane forests (Tesfaye Bekele, 2000).

The surviving forest patches are in danger of going extinct due to the frightening rate of population expansion and the ever-increasing demand for forest products and forest land (Tamrat Bekele, 1994).

2.1.3 Consequences of Ethiopian forest loss

Reduction in forest cover has several consequences including soil erosion and production capacity for carbon sequestration, loss of biodiversity and instability of the ecosystem, and reduced availability of various wood and non-wood forest products and services (Bane *et al.*, 2007; Haileab Zegeye, 2017). Deforestation has many negative consequences including the loss of biodiversity, climate change, and degradation of soils, disruption of hydrological cycles, desertification, economic loss, and social conflicts (Hailu Biruk, 2022). The depletion of natural vegetation in many parts of the country has also led to the treat and decline in the number and area of distribution of many plant species (Tesfaye Bekele, 2000; Wassie Simachew, 2020). Loss of forest biodiversity influences vegetation dynamics and tree density at the local and regional levels. Environmental problems such as soil degradation, erosion, decreasing biodiversity, loss of

potential natural resources, some valuable medical plants, and associated indigenous knowledge are negative effects resulting from forest biodiversity loss. Increased soil erosion, lower soil fertility, loss of genetic resources for plants and animals, climate change, increased runoff that causes flooding, decreased infiltration into the water table, and decreased water supply to rivers during dry seasons are all consequences of the overall destruction of vegetation (EFAP, 1994; Wassie Simachew, 2020).

2.1.4. Prevention of Ethiopian forest loss

One of the top priorities for many international conservation organizations, government, and interest groups at the moment is the loss of biodiversity and the conversion of natural vegetation. These parties create sustainable forest management in order to preserve biodiversity and make sustainable use of resources (UNDESA, 2004; WHO, 2015). Understanding the patterns of plant species distribution and factors influencing them is a fundamental precondition for effective conservation of biodiversity (Lee *et al.*, 2012; Sosef *et al.*, 2017). Sustainable forest management has been the main focus of the worldwide forestry sectors over many years. It aims to ensure that needs derived from the forest meet present-day needs without compromising the ability of future generations. Sustainable forest management also aims at balancing social, economic, and environmental objectives. However, only about 5% of the total forest areas in developing countries are managed properly (FAO, 2001), which is very low when compared with developed countries (Girima Amante, 2005). To minimize the risk, sustainable forest management has been practiced by applying conservation techniques, protecting forest areas with restricted access for local communities which have often been introduced in the forest to tackle deforestation and its effects (Winberg, 2010).

2.2 Biodiversity of Ethiopia

Since the country is characterized by a wide range of ecological, edaphic, and climatic conditions, Ethiopia is also very diverse in its flora composition (Friis *et al.*, 2010; Kindalem Dessie, 2021). The flora of Ethiopia is estimated to contain close to 6500-7000 species including medicinal plants; of those, 12-19% are endemic to the country (CBD -Convention on Biological

Diversity, 2008; Hedberg *et al.*, 2009; Melaku Tafese, 2021). Floristic composition includes all of the plant species found in the forest.

Ethiopia has a vast variety of ecosystems and vegetation types that are rich in indigenous flora and fauna. The country is known for its highly diversified physiographic, altitudinal, climatic, and edaphic features (Zerihun Woldu *et al.*, 1999). The number of species of higher vascular plants is about 6027, of which about 10% are endemic to the country (Ensermu Kelbessa and Sebsebe Demissew, 2014; Asegid Assefa *et al.*, 2022). This high number of plant species results from the wide variation in climate, geology, and terrain working on different time scales and past historical events (Sebsebe Demissew *et al.*, 2003).

2.2.1 Plant biodiversity of Ethiopia

The flora of Ethiopia is estimated to contain close to 6500-7000 species including medicinal plants; of those, 10-12% are endemic to the country (CBD -Convention on Biological Diversity, 2008; Hedberg *et al.*, 2009; Assefa Asegid, *et al.*, 2022). The diversity of living things is known as biodiversity, or biological diversity. It covers ecosystem diversity as well as variety within and between species. The entirety of life on Earth is referred to as biodiversity. It encompasses every gene, species, ecosystem, and ecological process that each of them is a part of (Singh, 2012).

2.2.2 The value of plant biodiversity

Medicinal plants have been used for various types of human and animal diseases in Ethiopia. According to the research findings in Ethiopia, about 80% of the human population and 90% of livestock depend on traditional medicine and also, medicinal plants have shown very effective medicinal values for some diseases of humans and livestock (Tadesse Birhanu *et al.*, 2015; Amare Bitew *et al.*, 2022).

Various plant species have different uses depending on the socio-economic conditions of a given community. Natural forests are important sources of non- timber forest products such as fruits, fodders, honey, herbal medicine, a source of tools and construction materials, timber, and food for local communities. In Ethiopia, the majority of woody species have economic uses. This has tended to promote unsustainable utilization of tree and shrub species. Such unsustainable

utilization of few species especially, for timber and fuel wood collection put them in the endangered category (Misganaw Meragiaw *et al.*, 2022).

The conversion of natural vegetation is currently one of the leading agendas for some world conservation organizations, authorities, and interest groups (UNDESA, 2004; WHO, 2015). Vegetation study is particularly urgent in countries such as Ethiopia since the natural environment has been severely altered and only a few relict patches of natural vegetation remain (Zerihun Woldu *et al.*, 1989; Kflay Gebrehiwot, 2023). The reduction of forests was also due to climatic changes and various human-induced pressures such as agriculture, overgrazing, firewood, charcoal, timber and settlements have contributed to the reduction of forests. That is human beings are dependent for their subsistence, health, well-being, and enjoyment of forests. Moreover, clearing for cultivation, burning to create pasture lands, and improper cutting practices have reduced the forest area to a small fraction of the total area of various countries including Ethiopia (Feyera Senbeta, 2006; Emiru Birhane *et al.*, 2019).

2.2.3 Diversity indices

Diversity is synonymous with heterogeneity and comprises species richness and evenness. Indices that combine both richness and evenness (heterogeneity) into a single value are diversity indices. Ecologists also use species diversity as one important measure of the structural heterogeneity of a community (Stein and Holger, 2015). There are many ways a community can be diverse in species. They may vary in number (richness) of species, degree of dominance by one or a few species, relative abundance of all species or evenness, number of rare species, number of nonnative species, vertical stratification of species, horizontal patchiness, number of growth or life forms, and so on (Whittaker, 1975) distinguished different kinds of species diversity along certain environmental gradient that are called alpha, beta and Gama diversity. Alpha diversity refers to the number of species within the sample area.

In order to describe vegetation floristically, diversity, evenness, and similarity must be examined. One of the most significant metrics for assessing the sustainability of forest communities is species diversity (Rad *et al.*, 2009). Diversity and evenness of species in a given vegetation are used to interpret variations among and within the community and help to explain the underlying reasons for such a difference (Kent, 2012). Species diversity is described based on

two concepts: these are the total number of species in the community /species richness and the relative abundance of the species (species evenness) within the sample. Thus, species diversity is the product of species richness and evenness. The species diversity index provides information about species rarity, endemism, and commonness. Measures of species diversity are usually seen to be key indicators for the well-being of ecological systems (Heywood, 1995; Shackelton, 2000).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Materials

Several materials were used for the data collection such as locally made herbarium presser for specimen collection, measuring tape for measuring DBH, and rope for making a quadrat. Marker, data recording diary and different volumes (1-8) of Flora books were used materials for this study. Moreover, a photo camera was used for capturing topographic features, plant specimens, and partial view of the plant community types.

3.2 Description of the study area

The study was conducted in Wakani Forest, around Ashefa town in Guagusa Shikudad District, Awi Zone found between Debre Markos and Bahir Dar in northwestern Ethiopia. The study area is approximately at a distance of 432 km from Addis Ababa, 142 km from Bahir Dar, and 12 km from the Tilili town to the east direction. The District is bordered by Burie District in the east, Wonbera in the south, Sekela in the north, Ankesha in the west, and Banja in the northwest direction (Figure 1).

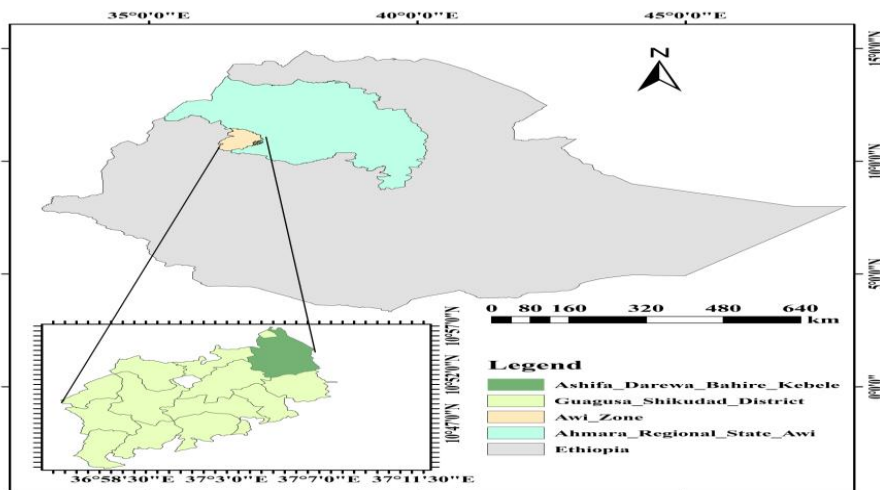


Figure 1. Map of Guagusa Shikudad District showing the location of Wakani Forest in Awi Administrative Zone of Amhara Regional State, Ethiopia

Guagusa Shikudad District has two agroecological zones, namely midland (70%) and highland (30%), locally called Weinadega and Dega, respectively. However, Wakani Forest is found in the midland part of the District. The vegetation type of the study area mainly falls in dry evergreen Afromontane Forest, which is characterized by some species such as, *Hagenia abyssinica*, *Vachellia abyssinica*, *Croton macrostachyus*, *Prunus africana*, *Albizia gummifera* and *Ficus sur*. There are two distinct rainy seasons in the region: the main one, Kiremt, which runs from mid-June to mid-September, and the intermittent secondary Belg, which runs from February to May and frequently has significantly less rainfall. It receives an annual rainfall ranging from 1140 to 3570 mm. Likewise, the temperature may range from 10 to 25 °C (Alemu Fetene *et al.*, 2020; Guagusa Shikudad District Agriculture Office, 2023).

3.2.1 Demographic and socio-economic features

Based on the 2007 national census conducted by the Central Statistical Agency of Ethiopia (CSA, 2007) the total population of the District indicated 83,930 of whom 41,427 were men and 42,503 were women; 9043 or 10.78% were urban inhabitants. The population density was estimated at 372.2 per kilometer square. According to the Guagusa Shikudad District Finance and Economic Development Department (GSDFEDD) abstract report, agriculture is the main source of the household's economy in the study area. The dominant crops grown in the District area are maize, teff, sorghum, beans, and wheat. Besides, the potato has a significant role in household food security for the Woreda.

3.3. Reconnaissance survey and sampling methods

A reconnaissance survey was carried out from September 4 to 29, 2023 to explore the secondary sources about the study area, the distribution of natural remnant vegetation, and its accessibility. A systematic sampling method was used to take samples. Sample plots were laid along line transects which were established horizontally from south to north direction at low, medium, and high altitudes. Main sampling plots of 20 × 20 m were established systematically along altitude gradient for woody species at every 50 m interval along 3 transect lines which are 300 m apart. A total of 63 main sample plots were systematically established to collect vegetation data about woody plant species, namely trees, shrubs, and climbers following the Braun-Banquet modified

scale (Mueller-Dombois and Ellenberg, 1974; Kent 2012). Within the main plots, herbaceous plant species were collected inside at four corners and one at the center of each main plot with a 1×1 m quadrat (Figure 2).



Figure 2. Establishment of sample plots, collections of sample specimens, and measuring of circumferences of DBH in the field [photo taken by Getaye Berihun, 2023].

3. 4 Data Collection Methods

3.4.1 Floristic data collection

Floristic data were collected between November 20 to January 30. All vascular plant species in each sample plot were recorded using vernacular names or local names. The plant species identification was done both in the field and at the National Herbarium of Ethiopia (ETH) using the flora of Ethiopia and Eritrea for those that I countered some difficulty for identification, further confirmation was taken through the support of my advisor. Additionally, I used other internationally accepted plants of the world online sources (<https://powo.science.kew.org/>) for the revised taxonomy of some the taxa. Lastly, all the specimens were verified and deposited at the ETH of Addis Ababa University.

3.4.2 Structural data collection

Any woody species of trees and shrubs with a DBH ≥ 2 cm and a height of woody species ≥ 2 m was measured and recorded. Cercemferance was measured at 1.3 m for diameter at breast height (DBH). At each of the plots established, the diameter of woody species with DBH ≥ 2 cm was measured using measuring tape, and tree heights were measured by rolling meter, measured

sticks, and those which can be difficult to measure, the tree height was obtained by visual estimate. Counting of trees and shrubs with DBH ≥ 2 cm and conversion of DBH to basal area was done. After counting and measuring each woody plant, the density, frequency, basal area, dominance, and IVI of trees and shrubs were determined. The height of woody species < 2 m is recorded for the analysis of the regeneration status of the forest. Herbaceous plants were also collected at each plot for vegetation data analysis.

3.5 Data Analysis

3.5.1 Vegetation Structural Analysis

Structural analysis was performed based on density, DBH, height, frequency, basal area, and IVI. The distribution of size classes was evaluated by computing the density of individuals with DBH > 2 cm, > 10 cm, and > 20 cm as well as the ratio of DBH class > 10 cm to DBH class > 20 cm. The ratio of density at DBH class > 10 cm to the density at DBH class > 20 cm can be used as the measure of the distribution of different size classes (Grubb *et al.*, 1963). The vegetation data were computed using R statistical tools and summarized using the following formula according to (Mueller-Dombois and Ellenberg, 1974; Kent, 2012).

Frequency: is the percentage of sampling units containing the species.

Frequency (%) = [the number of plots in which that species occurs/total number of plots] x 100.

Relative frequency = [frequency of species / total frequency of all species] $\times 100$.

Density of species = the number of individuals of that species /area sampled

Relative density = (density of species A \div total density of all species) x 100

Basal area (BA) = $\pi D^2/4$

Where BA = Basal area in m^2 per hectare; D = diameter at breast height in m =C/3.14; π = phi
(3.14)

Dominance = mean basal area per species x the number of species.

Relative dominance (RDO) = basal area of species / total basal area of all species x 100.

Important Value Index (IVI): was analyzed for woody species. IVI of a species was calculated from the sum of relative frequency /RF/ relative dominance (RDO) and relative density (RD) (Kent, 2012).

$$IVI = RDO + RD + RF$$

3.5.2 Plant community analysis

The vegetation data were analyzed using R statistical environmental software following Oksanen *et al.*, (2020) and Zerihun Woldu (2017). A synoptic table analysis was produced to determine the characteristic species within each of the 63 plots. Two characteristic species with high synoptic cover-abundance values (mean frequency \times mean cover-abundance) were used to name the single plant community type following Kent (2012). The number of plant community types was a compromise between the similarity in the sub-clusters (clusters within a single community type) and the dissimilarity between the clusters. Four plant communities types were identified using hierarchical clustering strategies with Ward's method and similarity ratio.

3.5.2.1 Diversity analysis

Woody plant species diversity in the Wakani Forest was described using Shannon-Wiener indices of diversity (H), species richness, and Shannon's equitability or evenness (J), which are based on R statistical tool and the original Shannon and Wiener formula (Shannon and Wiener, 1949; Zerihun Woldu, 2017).

$$H' = - \sum_{i=1}^s p_i \ln(p_i)$$

Where: **H'** = the Shannon diversity index, p_i = the proportion of individuals of species i , and **ln** is the natural logarithm of p_i , **S** = numbers of species or species richness, and Σ = sum from species 1 to species S. Shannon diversity index varies between 1.5 and 3.5 and rarely exceeds 4.5. Shannon-Weiner diversity is high when it is above 3.0, medium when it is between 2.0 and 3.0, and low when it is smaller than 1.0 (Kent, 2012). The minimum value of H' is 0, for a plot with a single species. The different value of H' for each plot indicates the difference in species richness and evenness (Whittaker, 1975). The value of H' increases as species richness and evenness increase and vice versa.

Equitability or species evenness (J) was calculated from the ratio of observed diversity to maximum diversity using the equation.

$$J = H'/\ln S = H' / H \max$$

Where: J = Evenness; H' = Shannon-Wiener Diversity Index; H max = lnS; S = total number of species in the sample. The value of the evenness index falls between 0 and 1. The value of J = 1 indicates that the plot with complete evenness (Kent, 2012).

The formula that converts the H into the true diversity (D) is given by Jost (2007) as follows: $D = \exp(H)$ which is the exponential of H.

3.5.3 Regeneration status

The regeneration status of the study forest was analyzed by comparing seedlings and saplings of woody plants with adult or mature plants (Ahmed Endris *et al.*, 2017; Tesfaye Bogale *et al.*, 2017).

Seedling > sapling > matured plant trees →→→ good restoration.

Seedling > or ≤ sapling ≤ matured trees →→→ Fair restoration.

Classes continue only in seedlings, but no sprout (saplings may be ≤ adults) → Poor redevelopment.

Classes are established only in matured form →→→ No restoration.

classes establish only seedlings and saplings but no matured form →→→ new.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Floristic composition of Wakani Forest

A total of 64 plant species distributed within 41 families and 60 genera were identified in Wakani Forest. The complete list of these species including plot numbers, and local, botanical, and authority names is presented in Appendix 1. Fabaceae was the leading family, represented by six species (9.4%), followed by Asteraceae and Rosaceae, represented by four species (6.3%) each. While, about 49.6%(31) families are represented only by single species (Table 1). Similarly Fabaceae is the most dominant which have 6 genera and 5 species in Hereje Naural Forest (Abera Anamo *et al.*, 2023).As compared with Kibat Forest (Misganaw Meragiaw *et al.*, 2021), Wakani Forest has less number of vascular plants with their corisponding family and genera.

Table 1. Plant families with the respective number of genera and species encountered in Wakani Forest

Family	Genera	Species	% Spp.	Families	Genera	Species	% Spp.
Acanthaceae	2	3	4.7	Menispermaceae	1	1	1.6
Amaranthaceae	2	2	3.1	Moraceae	1	1	1.6
Apocynaceae	1	1	1.6	Phyllanthaceae	1	1	1.6
Araceae	1	1	1.6	Phytolacaceae	1	1	1.6
Araliaceae	1	1	1.6	Pittosporaceae	1	1	1.6
Asteraceae	4	4	6.3	Polygonaceae	1	3	4.7
Balsaminaceae	1	1	1.6	Primulaceae	3	3	4.7
Boraginaceae	1	1	1.6	Pteridaceae	1	1	1.6
Capparidaceae	1	1	1.6	Ranunculaceae	1	1	1.6
Celastraceae	1	1	1.6	Rosaceae	4	4	6.3
Crassulaceae	1	1	1.6	Rubiaceae	1	1	1.6
Cucurbitaceae	2	2	3.1	Rutaceae	1	1	1.6
Ericaceae	1	1	1.6	Sapindaceae	1	1	1.6
Euphorbiaceae	3	3	4.7	Scrophulariaceae	1	1	1.6
Fabaceae	5	6	9.4	Scrophulariaceae	1	1	1.6

Francoaceae	1	1	1.6	Simaroubaceae	1	1	1.6
Hypericaceae	1	1	1.6	Solanacrae	1	1	1.6
Icacinaceae	1	1	1.6	Stilbaceae	1	1	1.6
Lamiaceae	1	1	1.6	Thymelaeaceae	1	1	1.6
Lobeliaceae	1	1	1.6	Urticaceae	3	3	4.7
Malvavaceae	1	1	1.6	Total = 41	60	64	100.0

4.1.1 Plant growth forms in Wakani Forest

Of total species, 42 woody and 22 herbaceous species were identified. A total of 5267 plants of which 2851 individuals of woody plants and 2416 herbaceous plants were counted. Among the collected woody plants *Gymnosporia addat* was the dominant plant species with a recorded value of 329. *Maesa lanceolata*, *Brucea antidysenterica*, and *Vachellia abyssinica* are the second, third, and fourth dominant with recorded values of 314, 173, and 168 respectively. *Ficus sur* was the least dominant in the Wakani Forest with a recorded value of 4 individuals. The analysis of growth forms showed that trees accounted for one-third of the total number of species (36%), followed by herbaceous species (Table 2).

Table 2. Distribution of plant species by their growth forms in Wakani Forest

Growth forms	Total number of species	Percentage
Herb	21	32.8
Tree	23	35.9
Shrub	12	18.8
Shrub/Tree	3	4.7
Climber/liana	4	6.3
Fern	1	1.6
Total	64	100.0

4.1.2 Classification of Vegetation in Wakani Forest

The classification of community was derived from the modified Braun-Blanquet scale estimating the cover-abundance of the plot data consisting of 64 species collected in 63 plots. These vegetation data (all species with their cover-abundance), subjected to hierarchical agglomerative

classification, produced four distinct community types (C1-C4) determined at a dissimilarity height of 1.5 of the dendrogram (Figure 3). The adjacent branches of the dendrogram show proximity in altitudinal ranges and hence exhibit the corresponding similarity in species composition. The highest number of species was recorded in C4 and C3 while the least in C2.

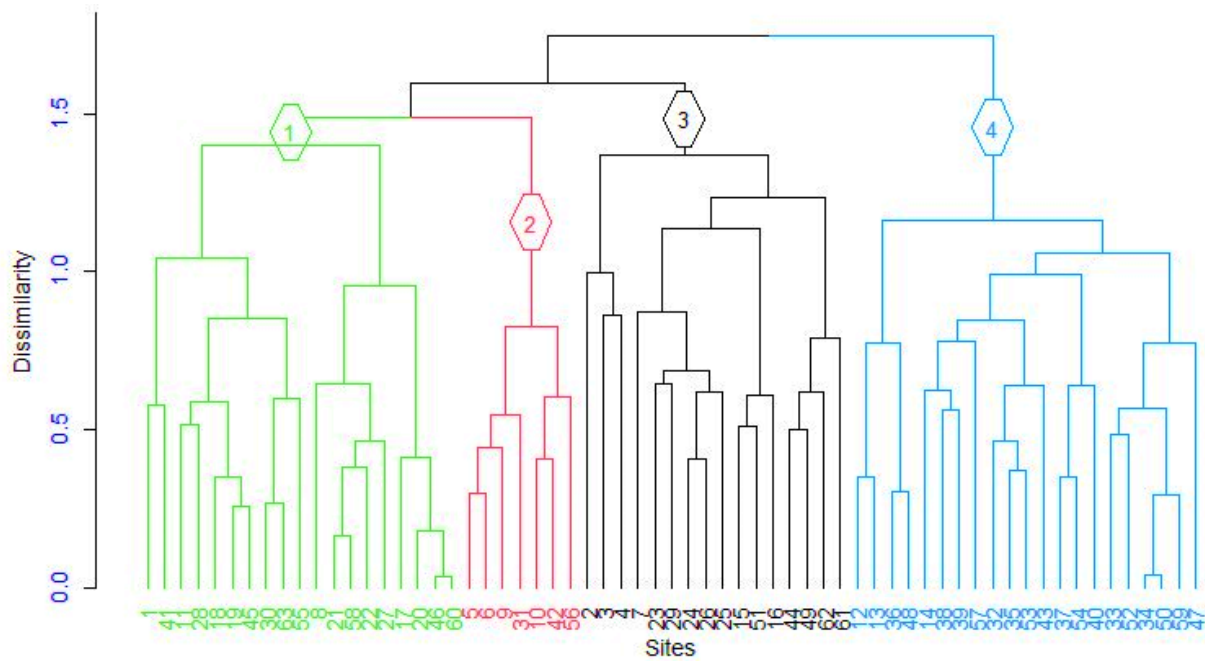


Figure 3. Dendrogram of hierarchical clustering using Ward's method showing four community types of Wakani Forest

The vertical axis of the dendrogram represents the distance or dissimilarity between labeled clusters, and the horizontal axis represents the sampled sites (plots 1–63) clustering in four branches. In the 63 quadrats studied, the largest number of plots (21) were recorded in community type 4 whereas the least number of plots (7) were in community type 2. Similarly, the highest species were recorded in community type 4 (Table 3).

Table 3. Distribution of community types (C1-C4) in 63 plots in Wakani Forest

Community	List of plots	Total plots	Total species
C1	1, 8, 11, 17, 18, 19, 20, 21, 22, 27, 28, 30, 41, 45,	19	40

	46, 55, 58, 60, 63		
C2	5, 6, 9, 10, 31, 42, 56	7	18
C3	2, 3, 4, 7, 15, 16, 23, 24, 25, 26, 29, 44, 49, 51, 61, 62	16	43
C4	12, 13, 14, 32, 33, 34, 35, 36, 37, 38, 39, 40, 43, 47, 48, 50, 52, 53, 54, 57, 59	21	60

Note: C1: *Pavetta abyssinica-Nuxia congesta*, C2: *Brucea antidysenterica-Maesa lanceolata*, C3: *Gymnosporia addat-Pittosporum viridiflorum*, C4: *Apodytes dimidiata -Dombeya torrida*.

The community types were named after two dominant and characteristic species. Based on the mean frequency and mean cover-abundance values of the synoptic table, four community types were recognized. These are *Pavetta abyssinica-Nuxia congesta* community type (C1), *Brucea antidysenterica-Maesa lanceolata* community type (C2), *Gymnosporia addat-Pittosporum viridiflorum* community type (C3), and *Apodytes dimidiata -Dombeya torrida* community type (C4) (Table 3). The whole list of species with their synoptic table values is given in Appendix 5.

Table 4. A partial list of synoptic tables of characteristic and dominant species in four community types (C1-C4)

Species	Cluster 1	Cluster 2	Cluster 3	Cluster 4
<i>Ficus sur</i>	0.05	0.00	0.00	0.00
<i>Albizia gummifera</i>	0.05	0.00	0.00	0.00
<i>Pavetta abyssinica</i>	0.84	0.25	0.29	0.38
<i>Nuxia congesta</i>	1.00	0.56	0.43	0.76
<i>Brucea antidysenterica</i>	0.53	1.06	0.57	0.67
<i>Maesa lanceolata</i>	1.16	1.44	1.43	1.43
<i>Gymnosporia addat</i>	1.26	1.44	1.71	1.52
<i>Pittosporum viridiflorum</i>	0.74	0.94	1.00	0.95
<i>Apodytes dimidiata</i>	0.84	0.25	0.86	1.05
<i>Dombeya torrida</i>	0.42	0.19	0.43	0.81
<i>Scepcarpus hypselodendron</i>	0.11	0.38	0.00	0.10
<i>Doviyalis abyssinica</i>	0.42	0.56	1.00	0.48
<i>Solanecio gigas</i>	0.21	0.00	0.00	0.00

<i>Bersma abyssinica</i>	0.74	0.81	0.43	0.57
<i>Embelia schimperi</i>	0.42	0.19	0.29	0.29
<i>Clausina anisata</i>	0.21	0.06	0.00	0.24
<i>Rubus steudneri</i>	0.21	0.25	0.00	0.10
<i>Allophylus abyssinicus</i>	0.58	0.31	0.29	0.24
<i>Lobelia giberroa</i>	0.16	0.00	0.14	0.10

4.1.2.1 Species richness, evenness, and diversity of the plant community types

Shannon-Wiener diversity index was computed for the four plant community types. Community true diversity decreased in the order of C4 > C3 = C1 > C2. Regarding species richness, the highest total number of species (60) was recorded in C4, followed by C3 and C1. The Shannon-Weiner diversity index varies between 1.5 and 3.5 and rarely exceeds 4.5. Shannon-Weiner diversity is high when it is above 3.0, medium when it is between 2.0 and 3.0, and low when it is smaller than 1.0 (Kent, 2012). The highest Shannon's equitability (evenness) was in C4, whereas the least was in C3. Thus, community type 4 has the highest species richness and true diversity whereas community type 2 has the least species diversity and richness. Species evenness shows the relative proportional abundance of species in a given community type: the higher value indicates, the more even distribution of species. Likewise, in that of true diversity, the highest value of Shannon's equitability (evenness) is shown in community type 4, followed by community type 2 while the least relative abundance and even distribution of individuals of different species occurred in community type 3.

Table 5. Species richness, evenness and diversity in four plant community types (C1-C4)

Community type	Species richness (S)	Diversity index (H)	True diversity	Shannon's evenness (J)	H_{max}
C1	40	3.16	24	0.86	3.69
C2	18	2.50	12	0.87	2.89
C3	43	3.16	24	0.84	3.76

C4	60	3.70	40	0.90	4.09
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4.2 Analysis of vegetation structure

4.2.1 Density of trees

The density of a tree is expressed as the number of trees per area sampled. It is a very important parameter for the sustainable management of forests. The density of tree individuals in Wakani Forest was analyzed. According to the data analysis the density of tree individuals of Wakani forest with DBH greater than 2.5cm was 1001 individuals (35.11%) with 397 individuals/hectare, those with greater than 10 cm was 791 individuals (27.75%) with 314 individuals/hectare and those greater than 20cm was 1059 individuals (37.53%) with 420 individuals/hectare. The data analysis from Table 2 showed that the majority of woody plant species were distributed in DBH class > 20cm and the least woody plant species were distributed in DBH class > 10 cm. The ratio of the density of trees with DBH greater than 10 cm to DBH greater than 20 cm for the Wakani forest is 0.8. This indicates the predominance of large-sized individuals (Figure 4).

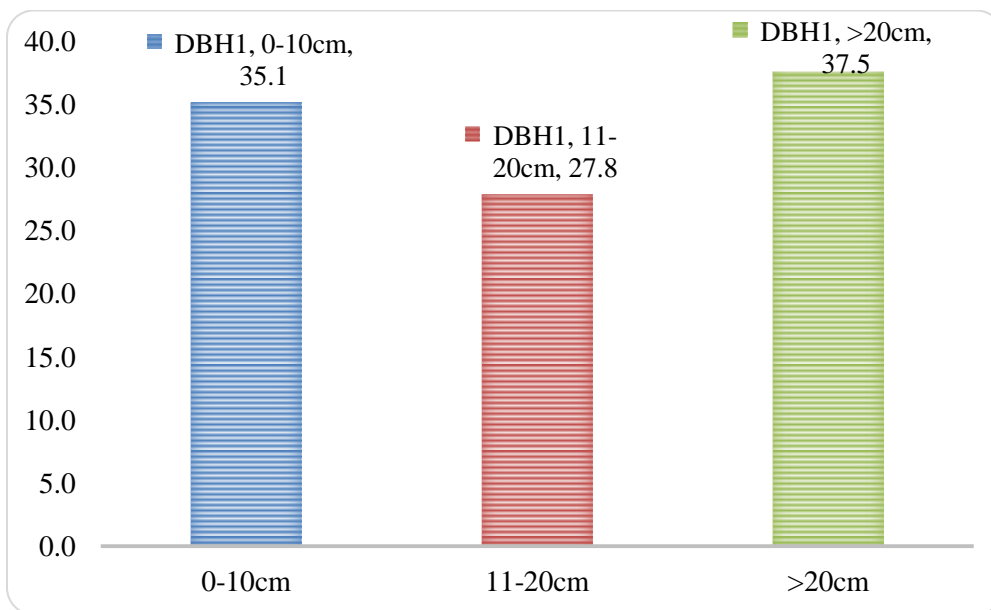


Figure 4. Percentage of tree density with DBH >2cm, >10cm, and >20cm in Wakani Forest.

Table 6. Comparison of tree density of Wakani Forest and other dry evergreen montane forests in Ethiopia

No	Forests	DBH 10.1-20 cm (a)	DBH >20 cm (b)	a/b	Source
1	Wof -Washa	329	215	1.5	Tamrat Bekele (1994).
2	Denkoro	526	285	1.9	Abate Ayalew et al (2006)
3	Menagesha Amba Mariam	155.5	197	0.8	Abiyou Tilahun (2009)
4	Wakani	313.9	420	0.8	Present study

Differences in topographic gradients, the ecological preferences of the many tree and shrub species that make up the forest, and the extent of anthropogenic influences can all be used to explain variations in density distributions (Whittaker *et al.*, 2003). The ratio of density at DBH class greater than 10 cm to the density at DBH class greater than 20 cm has been compared with Wof-wash forest (Tamrat Bekele, 1994), Denkoro forest (Abate Ayalew *et al.*, 2006) and Menagesha Amba Mariam Forest (Abiyou Tilahun, 2009). The ratio of density at DBH class greater than 10cm to the density at DBH class greater than 20 cm for the study forest is 0.8, Wofwasha Forest is 1.5, Denkoro forest is 1.9 and Menagesha Amba Mariam is 0.8. The ratio of density at DBH class greater than 10cm to the density at DBH class greater than 20 cm for Wakani Forest is less than Denkoro and Wofwasha forests but similar to Menagesha Amba Mariam forests. This indicates that there is a predominance of large-sized individuals in the study forest. This is because small-sized individuals are affected by grazing animals, firewood collection, and fencing by communities (information from field observation and community elders).

4.2.2 Diameter at Breast Height (DBH)

The distribution of woody plant individuals in different DBH classes was analyzed. The DBH was classified into five classes. Class 1 (2-10 cm), Class 2 (10.1-20 cm), Class 3 (20.1-30 cm), Class 4 (30.1-40 cm) and Class 5 (> 40 cm). The DBH analysis showed that the majority of

woody plant species distributed in the first DBH class (2-10cm) which has a total of 1001 (35.11%) individuals (Figure 5). The least woody plant species are distributed in the fourth class (30.1-40cm) with a total of 262 (9.19%) individuals, the second DBH class has a total of 791 (27.27%) individuals. The third DBH class has a total of 438 (15.36%) individuals and the fifth DBH class has a total of 359 (12.5%) individuals of woody plant species. The DBH analysis showed that more individuals were distributed in the first, second, and third DBH classes and a decrease in the DBH class 4, then a slight increase in DBH class 5 (Table 3). Similar results was reported by Lulekal *et al.*, (2008) and Tesfaye Burju *et al.*, (2013).

Table 7. Number of plants with different classes of Diameter at breast height (DBH)

no.	species name	DBH 2-10	DBH 10.1-20	DBH 20.1-30	DBH 30.1-40	DBH >40	Total
1	<i>Albizia gummifera</i>	1	1	1	4	2	9
2	<i>Allophylus abyssinicus</i>	2	2	12	28	15	59
3	<i>Apodytes dimidiata</i>	14	31	37	42	41	165
4	<i>Astropanax abyssinica</i>	1	-	1	-	36	38
5	<i>Bersama abyssinica</i>	84	33	-	1	-	118
6	<i>Bridelia micrantha</i>	-	9	5-	-	-	14
7	<i>Brucea antidysenterica</i>	156	16	1	-	-	173
8	<i>Buddleja polystachya</i>	3	19	7	5	1	35
9	<i>Calpurnia aurea</i>	13	1	-	-	-	14
10	<i>Caparis tomentosa</i>	7	-	-	-	-	7
11	<i>Clausena anisata</i>	19	-	-	-	-	19
12	<i>Clematis simensis</i>	23	-	-	-	-	23
13	<i>Croton mocrostachyus</i>	4	5	3	2	7	21
14	<i>Discopodium penninervum</i>	15	2	-	-	-	17
15	<i>Dombeya torrid</i>	-	7	11	20	47	85
16	<i>Dovyalis abyssinica</i>	53	36	5	-	-	94
17	<i>Embelia schimperii</i>	55	10	-	-	-	65

18	<i>Erica arborea</i>	1	16	14	6	-	37
19	<i>Erythrina brucei</i>	-	-	1	1	4	6
20	<i>Euphorbia abyssinica</i>	14	26	13	10	9	72
21	<i>Ficus sur</i>	-	-	-	1	3	4
22	<i>Gymathenum amygdalinum</i>	4	4	1	-	-	9
23	<i>Gymnathemum urticifolium</i>	88	-	-	-	-	88
24	<i>Gymnosporia addat</i>	81	138	80	21	9	329
25	<i>Hagenia abyssinica</i>	3	9	4	2	6	24
26	<i>Hypericum revolutum</i>	16	22	3	4	-	45
27	<i>Lasiosiphon glaucus</i>	37	19	25	7	-	88
28	<i>Lobelia giberroa</i>	27	-	-	-	-	27
29	<i>Maesa lanceolata</i>	47	190	55	22	-	314
30	<i>Myrsine melanophloeos</i>	2	1	2	-	-	5
31	<i>Nuxia congesta</i>	13	72	60	15	4	164
32	<i>Pavetta abyssinica</i>	31	55	10	1	-	97
33	<i>Phytolacca dodecandra</i>	5	-	-	-	-	5
34	<i>Pittosporum viridiflorum</i>	3	11	36	30	82	162
35	<i>Prunus africana</i>	-	1	2	2	7	12
36	<i>Rosa abyssinica</i>	100	21	-	-	-	121
37	<i>Rubus steudneri</i>	38	-	-	-	-	38
38	<i>Rumex nervosus</i>	6	2	-	-	-	8
39	<i>Scepocarpus hypselodendron</i>	10	10	-	-	-	20
40	<i>Solanecio gigas</i>	24	-	-	-	-	24
41	<i>Vachellia abyssinica</i>	1	15	38	34	80	168
42	<i>Vachellia nilotica</i>	-	7	11	4	6	28
	<i>Total</i>	1001	791	438	262	359	2851
	<i>Percentage</i>	35.11%	27.75%	15.36%	9.19%	12.59%	100%

The woody plant species in the study area could be conveniently classified into five DBH classes. Figure 5 reveals the distribution of a percentage of tree species and BA in five classes of DBH (cm).

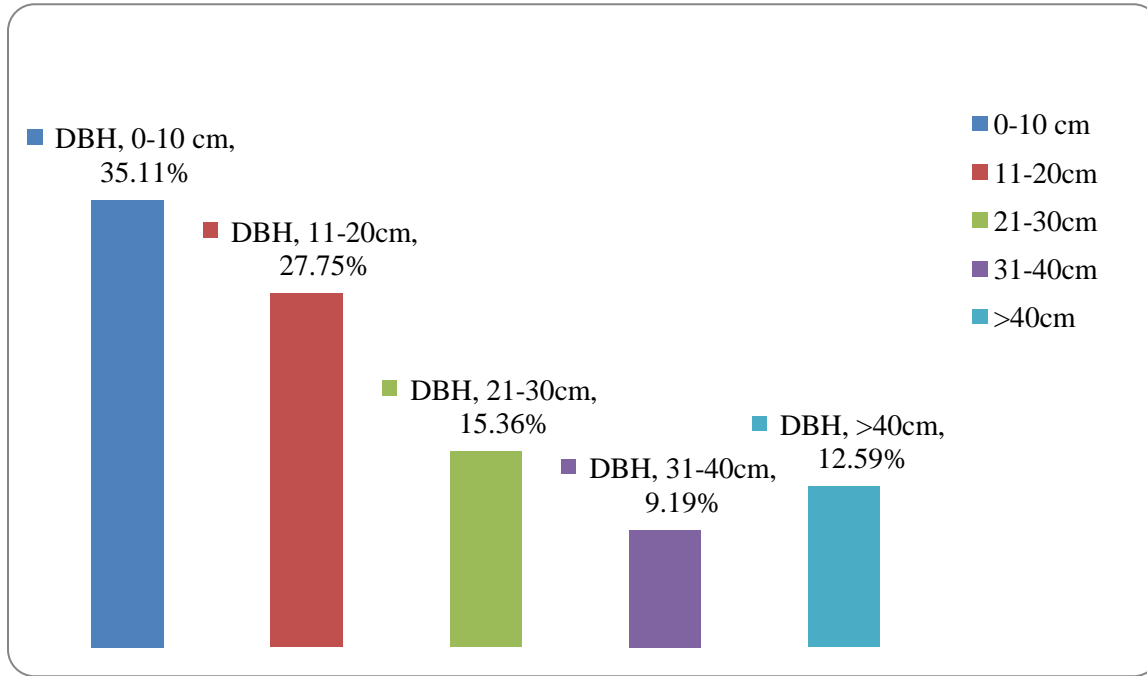


Figure 5. DBH class and percentage of the number of individuals per hectare in Wakani forest

4.2.3 Basal area

Compared to a simple stem count, the basal area offers a more accurate indication of the species' relative importance (Tamrat Bekele, 1994). The basal area of the Wakani Forest was analyzed. The total basal area of all woody plant species in the Wakani Forest was 179.43 m² per hectare (Table 8). As shown from the table below, *Vachellia abyssinica* has the highest basal area of 25.299 m²/hectare followed by *Pittosporum viridiflorum*, *Apodytes dimidiata*, *Astropanax abyssinica* and *Dombeya torrid* which has a basal area of 24.747, 20.966, 20.754 and 20.146 m²/hectare respectively. The most significant woody species in the forest are those that make up the majority of the basal area. The data analysis showed that the most, important tree species in Wakani Forest were *Vachellia abyssinica*, *Pittosporum viridiflorum*, *Apodytes dimidiata*, *Astropanax abyssinica*, and *Dombeya torrid*. Whereas woody plants with the least basal area

were *Phytolacca dodecandra* (0.02 m²/hectare), *Caparis tomentosa* (0.029 m²/hectare) and *Rumex nervosus* (0.036m²/hectare) as shown in Table 8.

Table 8. The basal area of woody plant species in Wakani Forest

no.	species name	Total basal area	Average basal area
1	<i>Albizia gummifera</i>	5.438	0.604
2	<i>Allophylus abyssinicus</i>	7.102	0.125
3	<i>Apodytes dimidiata</i>	20.966	0.127
4	<i>Astropanax abyssinica</i>	20.754	0.541
5	<i>Bersama abyssinica</i>	0.908	0.008
6	<i>Bridelia micrantha</i>	0.416	0.029
7	<i>Brucea antidysenterica</i>	0.071	0.004
8	<i>Buddleja polystachya</i>	1.336	0.038
9	<i>Calpurnia aurea</i>	0.036	0.003
10	<i>Caparis tomentosa</i>	0.029	0.004
11	<i>Clausena anisata</i>	0.063	0.003
12	<i>Clematis simensis</i>	0.043	0.002
13	<i>Croton mocrrostachyus</i>	2.157	0.103
14	<i>Discopodium penninervum</i>	0.088	0.005
15	<i>Dombeya torrida</i>	20.146	0.237
16	<i>Dovyalis abyssinica</i>	1.063	0.011

17	<i>Embelia schimperi</i>	0.341	0.005
18	<i>Erica arborea</i>	1.528	0.042
19	<i>Erythrina brucei</i>	3.241	0.54
20	<i>Euphorbia abyssinica</i>	4.578	0.064
21	<i>Ficus sur</i>	0.768	0.192
22	<i>Gymathenum amygdalinum</i>	0.181	0.02
23	<i>Gymnathenum urticifolium</i>	0.167	0.002
24	<i>Gymnosporia addat</i>	10.495	0.032
25	<i>Hagenia abyssinica</i>	2.018	0.084
26	<i>Hypericum revolutum</i>	0.856	0.019
27	<i>Lasiosiphon glaucus</i>	2.279	0.026
28	<i>Lobelia giberroa</i>	0.081	0.003
29	<i>Maesa lanceolata</i>	7.865	0.025
30	<i>Myrsine melanophloeos</i>	0.109	0.002
31	<i>Nuxia congesta</i>	6.343	0.039
32	<i>Pavetta abyssinica</i>	1.507	0.016
33	<i>Phytolacca dodecandra</i>	0.02	0.004
34	<i>Pittosporum viridiflorum</i>	24.748	0.153
35	<i>Prunus africana</i>	2.847	0.237
36	<i>Rosa abyssinica</i>	0.687	0.06

37	<i>Rubus steudneri</i>	0.038	0.001
38	<i>Rumex nervosus</i>	0.036	0.005
39	<i>Scepocarpus hypselodendron</i>	0.144	0.007
40	<i>Solanecio gigas</i>	0.039	0.002
41	<i>Vachellia abyssinica</i>	25.299	0.156
42	<i>Vachellia nilotica</i>	2.596	0.093
	<i>Total</i>	179.43	4.3

Based on this result the total Basal area of Wakani Forest is 179.43 and it was compared with Mengesha Ambamariyam Forest (Abiyu Tilahun, 2009) with a basal area of 84.17, Angada Forest (Shambel Alemu, 2011) with Basal area of 79.8 and Kenech forest (Sewale Balemlay and Mammo Siraj, 2021) with Basal area of 56.8 and Wof-washa forest with Basal area 101.8 (Tamrat Bekele, 1994). The Basal area of Wakani Forest is 179.43 (m²/hectare) which has a greater Basal area value than Forest (Table 9). This is because the studied forest has higher DBH individuals of woody plant species. From this study, it can be concluded that plants with high DBH values have also a high basal area per hectare and vice versa.

Table 9. Comparison of the Basal area of Wakani Forest with the other four forests in Ethiopia

no.	Forests	Basal area (m ² /ha)	source
1	Wakani forest	179.43	present study
2	Wof-Washa forest	101.80	Tamrat Bekele (1994)
3	Menagesha Amba Mariam forest	84.17	Abiyou Tilahun (2009)

4	Kenech forest	56.8	Sewale Balemlay and Mammo Siraj(2021)
5	Angada forest	79.8	Shambel Alemu (2011)

4.2.4 Height of trees

Forty-two (42) woody plant species with heights were analyzed. According to the data analysis, *Prunus africana* is the tallest tree with an average height of 38 m followed by *Pittosporum viridiflorum*, *Astropanax abyssinica*, and *Apodytes dimidiata* with an average height of 35 m, 32 m, and 31 m respectively.

The heights of trees measured in Wakani Natural Forest were classified in to 4 height classes. Class 1 (2-10 m), class 2 (11-20 m), class 3 (21-30m) and class 4 (31-40 m). There is a higher number of tree individuals in the height class 1 which accounts for 1004 individuals with 35.22 % of the total height classes these accounts for 398.41 individuals per hectare. Trees in height class 2 (11-20 m), account for 957 individuals with 33.57% of the total height class accounting for 379.76 individuals per hectare. Trees in height class 3 (21-30m), account for 678 individuals with 23.78% of the total height class account for 269.01 individuals per hectare. Trees in height class 4 (31-40m), account for 212 individuals with 7.44% of the total height class of these accounts 84.13 individuals per hectare. The height analysis indicated that the upper canopies of trees in the forest are dominated by tree species distributed in height classes 2 (11-20 m), height class 3 (21-30 m), and height class 4 (31-40 m). The tree height class distribution values were highest in the lower class followed by a decrease in the middle and the highest class.

Since the forest is currently in various stages of secondary development, the highest tree distribution in the lowest class height suggests that the local anthropogenic activities, such as construction, illegal wood harvesting for timber production, and selective cutting for fuel wood, have had a significant impact on the forest. There are little to medium-sized individuals and some giant trees at the moment. Small-sized individuals predominate because of good regeneration but poor recruitment, which may be a result of human activity.

Table 10. Distribution of woody plants at different height classes of Wakani Forest

No.	Height class in meter	Number of individuals	Number of individuals/ha	% of height
1	2-10m	1004	398.41	35.22%
2	11-20m	957	379.76	33.56%
3	21-30m	678	269.05	23.78%
4	31-40m	212	85.13	7.44%

4.2.5 Frequency of woody plants

Frequency is the number of quadrants in which a given species is found in an area. It provides a rough idea of how uniform and varied the vegetation is. According to Lamprecht (1989), vegetative homogeneity is indicated by high values in high-frequency classes and lower values in lower-frequency classes. In contrast, a high degree of floristic heterogeneity is indicated by a high percentage of many species in the lower-frequency classes and a low percentage of numerous species in the upper-frequency classes (Simson Shibru and Girma Balcha, 2004).

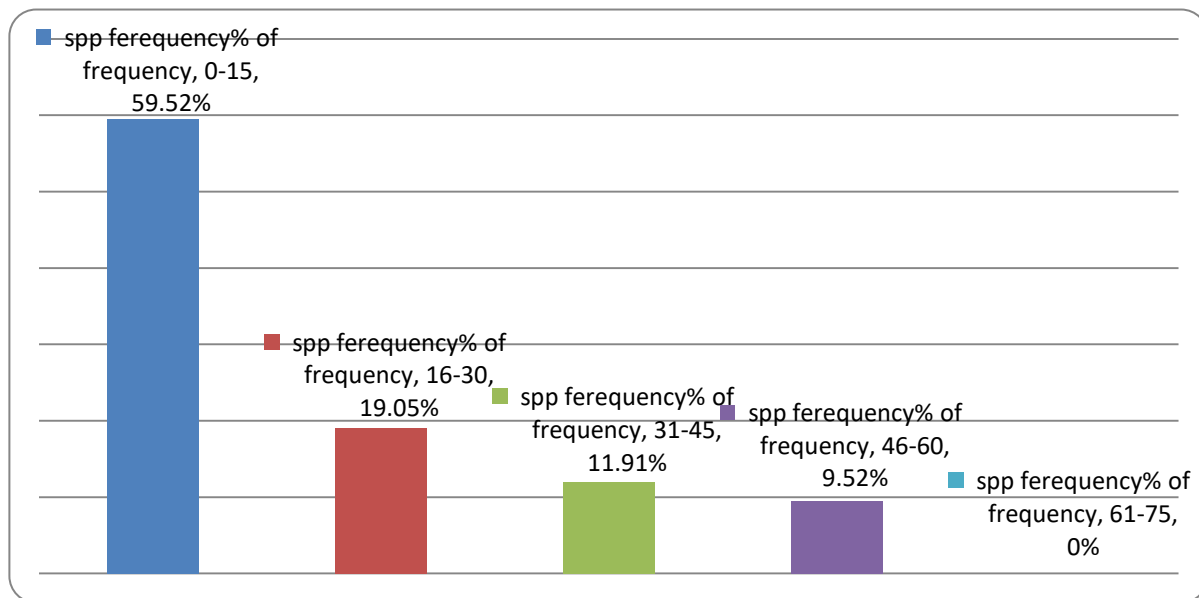
According to data analysis, the most frequent species was *Maesa lanceolata* with a percentage frequency value of 87.3% which occurred in 55 quadrates followed *Gymnosporia addat*, *Brucea antidysenterica*, and *pittosporum viridiflorum* with a percentage frequency value of 84.13%, 68.25%, and 61.9% respectively which are found in 53, 43 and 39 quadrates respectively. Based on the percentage frequency values, the woody plant species of Wakani Forest were classified into four frequency classes 1 (0-15), 2 (16-30), 3 (31-45) and 4 (46-60) which is expressed in their percentage value.

Table 11. Frequency classes of woody species of Wakani Forest

X	A	B	C	D
Frequency class	0-15	16-30	31-45	46-60

Number of Species	25	8	5	4
Percent of frequency	59.52%	19.05%	11.91%	9.52%

Frequency class 1 is represented by 25 species with 59.5% distributed (Figure 6). In the present study, high values were obtained in the low-frequency class. Therefore; according to Simson Shibru and Girma Balcha (2004), it is possible to conclude that there exists a high degree of



floristic heterogeneity in Wakani forests.

Figure 6. Frequency distribution of woody plant species in Wakani forest

4.2.6 Importance value index

The importance value index is obtained from the combination of three vegetation parameters. These are relative frequency (RF), relative density (RD), and relative dominance (RDO). Kent (2012) pointed out that IVI gives a more realistic figure of dominance from a structural point of view. It is useful to compare the ecological significance of species in which a high IVI value indicates that the species' sociological structure in the community is high (Mesfin Weldearegay *et al.*, 2018). As a result, ecologists consider IVI as the most reasonable aspect of the vegetation

study. Moreover, species with the greatest importance value are the most dominant of particular vegetation (Simon Shibru and Girma Balcha, 2004).

Based on the data analysis IVI of Wakani forest is presented (Table 12). As shown in the table, *Gymnosporia addat* was found to have the highest IVI followed by *Vachellia abyssinica*, *Pittosporum viridiflorum* and *Maesa lanceolata*. The leading dominant and ecologically most significant species might also be the most successful species in regeneration, pathogen resistance, growth in the shade, competition with other species, least preferred by browsing animals, the attraction of pollinators and seed predators that facilitate seed dispersal within the existing environmental conditions of the study area (Mohammed Gedefaw and Teshome Sormesa, 2014).

Table 12. The IVI of woody plants in Wakani Forest

No.	Species name	R.D	R.F	R.DO	IVI
1	<i>Albizia gummifera</i>	0.32	0.43	2.68	3.43
2	<i>Allophylus abyssinicus</i>	2.07	2.46	3.5	8.03
3	<i>Apodytes dimidiata</i>	5.78	4.9	10.32	21.08
4	<i>Astropanax abyssinica</i>	1.33	2.75	10.22	14.3
5	<i>Bersama abyssinica</i>	4.13	4.62	11.42	20.17
6	<i>Bridelia micrantha</i>	0.49	0.43	0.2	1.12
7	<i>Brucea antidysenterica</i>	6.06	6.31	0.35	12.78
8	<i>Buddleja polystachya</i>	1.23	1.88	0.66	3.77
9	<i>Calpurnia aurea</i>	0.49	0.58	0.02	1.09
10	<i>Caparis tomentosa</i>	0.25	0.29	0.02	0.56
11	<i>Clausena anisata</i>	0.66	1.44	0.03	2.13

12	<i>Clematis simensis</i>	0.81	1.3	0.02	2.13
13	<i>Croton mocrostachyus</i>	0.29	1.01	1.27	2.57
14	<i>Discopodium penninervum</i>	0.59	0.87	0.04	1.5
15	<i>Dombeya torrid</i>	2.98	3.76	9.92	16.66
16	<i>Dovyalis abyssinica</i>	3.23	3.64	0.52	7.39
17	<i>Embelia schimperi</i>	2.78	3.9	0.02	6.7
18	<i>Erica arborea</i>	1.30	1.30	0.05	2.65
19	<i>Erythrina brucei</i>	0.21	0.58	1.6	2.39
20	<i>Euphorbia abyssinica</i>	2.53	2.02	2.25	6.8
21	<i>Ficus sur</i>	0.14	0.14	0.34	0.62
22	<i>Gymnathemum amygdalinum</i>	0.32	0.43	0.09	0.84
23	<i>Gymnathemum urticifolium</i>	3.07	3.03	0.08	6.18
24	<i>Gymnosporia addat</i>	11.63	7.66	5.17	24.46
25	<i>Hagenia abyssinica</i>	0.84	0.72	0.99	2.55
26	<i>Hypericum revolutum</i>	1.58	1.16	0.42	3.16
27	<i>Lasiosiphon glaucus</i>	3.09	3.03	1.12	7.24
28	<i>Lobelia giberroa</i>	0.95	0.72	0.04	1.71
29	<i>Maesa lanceolata</i>	11.01	7.95	3.87	22.83
30	<i>Myrsine melanophloeos</i>	0.17	0.29	0.75	1.21
31	<i>Nuxia congesta</i>	5.75	4.91	3.12	13.78

32	<i>Pavetta abyssinica</i>	3.40	3.18	0.74	7.32
33	<i>Phytolacca dodecandra</i>	0.18	0.29	0.01	0.48
34	<i>Pittosporum viridiflorum</i>	5.68	5.64	12.18	23.5
35	<i>Prunus africana</i>	0.42	0.72	1.4	2.54
36	<i>Rosa abyssinica</i>	4.24	4.91	0.34	9.49
37	<i>Rubus steudneri</i>	1.33	1.59	0.02	2.94
38	<i>Rumex nervosus</i>	0.28	0.43	0.02	0.73
39	<i>Scepocarpus hypselodendron</i>	0.70	1.44	0.07	2.21
40	<i>Solanecio gigas</i>	0.82	0.29	0.02	1.13
41	<i>Vachellia abyssinica</i>	5.89	5.49	12.78	24.16
42	<i>Vachellia nilotica</i>	0.98	1.01	1.27	3.26

Key: RD = Relative density, RF = Relative frequency, RDO = Relative dominancy and IVI = Important value index

4.3. Regeneration Status of Woody Species in Wakani Forest

A species' regeneration behavior inside a forest can be inferred from its population structure. Successful forest species regeneration is indicated by a population structure that includes a sufficient number of seedlings, saplings, and mature trees. The presence of saplings beneath the canopies of adult trees also suggests the future community. The regeneration status of trees can be predicted by the age structure of their populations. Regeneration of a particular species is poor if seedlings and saplings are much less than mature trees. The management of natural forests is significantly impacted by research on forest tree regeneration. From the analysis of seedlings and saplings data, the total seedling density of the woody species in the Wakani forest was 1076.19 individuals per hectare. Similarly, the total density of saplings accounts for 835.92 individuals

per hectare, and that of mature trees was 1131.35 individuals per hectare. The distribution of mature individuals is greater than seedlings and saplings indicating that the regeneration status of Wakani Forest is at a low state. However, fair regeneration was experienced in the study location because of the composition, distribution, and density of seedlings and saplings less than developed individual species. The ratio of mature species to seedlings was 1.05; mature species to saplings was 1.36; and seedlings to saplings were 1.29. These demonstrate that adult woody plant species are more widely distributed overall than seedlings and saplings. Based on the results of this study, 7 species (16.67%) of the total were not represented by both seedling and sapling stages. These species were *Ficus sur*, *Albiza gummifera*, *Erythrina brucei*, *Phytolacca dodecandra*, *Gymnathemum amygdalinum*, and *Scepcarpus hypselodendron*. The possible reasons for the absence or insufficient seedlings and saplings for the woody species in the forest could be grazing and browsing, seed predation, lack of safe site for seed recruitment, nature of seeds of certain trees which seek dormancy period, litter accumulation, pathogens, species specificity, and moisture stress. From a total of 42 woody species, 12 plants (28.57%) were represented by good regeneration status with both seedlings and saplings.

4.4 Woody Plant species diversity and equitability analysis

Woody plant species diversity and equitability in Wakani Forest were analyzed by the Shannon-Weiner diversity index and equitability (evenness) index. According to Greg-Smith (1983), this diversity indicator is the most relevant. It explains the distribution of species as well as their abundance. The Shannon-Weiner diversity index varies between 1.5 and 3.5 and rarely exceeds 4.5. Shannon-Weiner diversity is high when it is above 3.0, medium when it is between 2.0 and 3.0, and low when it is smaller than 1.0 (Kent, 2012). The woody plant species diversity and evenness of Wakani Forest were analyzed. The first 21 plots were taken from the base of the forest and the next 21 plots were taken from the middle of the forest and finally, the last 21 plots were taken from the top of the forest. According to the data analysis in Table 9, the species diversity at the base of the forest is higher than at the middle and the top. The top of the forest has medium diversity. The overall Shannon-Weiner diversity index of the study forest is 2.11. This indicates that the study forest has medium diversity. This can be attributed to social and environmental influence according to (Espinosa and Cabrera, 2011).

The species evenness value ranges between 0 and 1. A single species dominates the region when it is zero, while an even distribution of species occurs when it is one. The Wakani forest's average evenness value, according to the data analysis, is 0.89. This suggests that the species were spread rather evenly throughout the study forest. The present study was compared with the Kurib Forest (Molla Belay, 2016) with the average diversity and evenness value. The studied forest has 2.11 and 0.89 average Shannon Weiner diversity index values and average evenness values respectively. Kurib Forest has 1.86 and 0.91 average Shannon Weiner diversity index and average evenness value respectively. When the study forest was compared with the above forest, it had more diversity and more or less similar evenness values.

Table 13. Woody plant species diversity and evenness in Wakani Forest

plots	Species richness	number individual(n)	ofH'	Ins	J
1	14	51	2.35	2.64	0.89
2	12	41	1.68	2.48	0.68
3	8	30	1.83	2.08	0.88
4	18	64	2.58	2.89	0.89
5	15	50	2.49	2.71	0.91
6	15	50	2.44	2.71	0.9
7	14	63	2.16	2.64	0.82
8	19	59	2.31	2.94	0.79
9	15	61	2.4	2.71	0.89
10	13	44	2.15	2.56	0.84
11	14	62	2.43	2.64	0.92
12	7	50	2.3	1.95	1.18
13	15	57	2.33	2.71	0.86
14	11	61	2.07	2.39	0.87

15	11	65	2.11	2.39	0.88
16	15	65	2.43	2.71	0.89
17	14	60	2.36	2.64	0.89
18	7	49	1.73	1.95	0.89
19	11	60	2.19	2.39	0.92
20	10	62	2.14	2.3	0.93
21	11	50	2.12	2.39	0.89
22	12	49	1.75	2.48	0.71
23	10	51	2.18	2.3	0.95
24	14	50	2.52	2.64	0.95
25	11	43	2.07	2.39	0.87
26	10	48	2.23	2.3	0.97
27	8	29	1.86	2.08	0.89
28	9	34	1.9	2.19	0.87
29	12	41	2.4	2.48	0.98
30	7	29	1.84	1.95	0.94
31	10	39	2.07	2.3	0.9
32	11	46	2.33	2.39	0.97
33	11	44	1.73	2.39	0.72
34	10	46	2.09	2.3	0.91
35	8	44	1.99	2.08	0.96
36	10	46	1.79	2.3	0.78
37	11	40	2.31	2.39	0.97
38	8	37	1.72	2.08	0.83

39	11	37	2.19	2.39	0.92
40	12	35	2.42	2.48	0.96
41	6	28	1.14	1.79	0.64
42	5	25	1.52	1.61	0.94
43	10	32	2.15	2.3	0.93
44	10	36	1.97	2.3	0.86
45	7	47	1.77	1.95	0.91
46	9	53	2.11	2.19	0.96
47	9	42	2.22	2.19	1
48	11	44	2.16	2.39	0.9
49	9	44	1.99	2.19	0.91
50	9	43	1.58	2.19	0.72
51	10	48	2.27	2.3	0.99
52	10	45	2.22	2.3	0.97
53	10	38	1.82	2.3	0.79
54	12	41	2.45	2.48	0.99
55	11	31	2.29	2.39	0.96
56	11	31	2.26	2.39	0.95
57	10	37	2.25	2.3	0.98
58	11	43	2.25	2.39	0.94
59	10	39	2.15	2.3	0.93
60	9	49	2.09	2.19	0.95
61	9	38	1.73	2.19	0.79
62	11	40	2.36	2.39	0.98

63	8	35	1.49	2.08	0.72
Total		2851	132.23		56.37
Average			2.11		0.89

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The floristic composition, vegetation structure, diversity, and regeneration status of Wakani Forest have been studied. A total of 64 plant species distributed within 41 families and 60 genera were identified in Wakani Forest. The complete list of these species including plot numbers, and local, botanical, and authority names is presented in Appendix 1. Fabaceae was the leading family, represented by six species (9.4%), followed by Asteraceae and Rosaceae, represented by four species (6.3%) each. While, about 48.4%(31) families are represented only by single species. Among the collected woody plants, *Gymnosporia addat* was the most dominant plant species. *Maesa lanceolata*, *Brucea antidysenterica* and *Vachellia abyssinica* were the second, third, fourth and fifth dominant woody plants. *Ficus sur* was the least dominant in Wakani Forest with a recorded value of 4 individuals.

The density of tree individuals of Wakani Forest with DBH greater than 2cm was 397.22 individuals per hectare, those with greater than 10 cm was 313.9 individuals per hectare and those with greater than 20 cm was 416.7 individuals per hectare. The density of trees increases with an increase in DBH class. This indicated the predominance of large-sized individuals in the higher DBH class than the lower DBH class. The total basal area of woody plant species in Wakani forest is 179.43 m² per hectare. *Vachellia abyssinica* has the highest basal area followed by *Pittosporum viridiflorum*, *Apodytes dimidiata*, and *Astropanax abyssinicus* which have the highest basal area these are the most significant tree species in the forest when weighed against the other types of woody plants found in the study forest.

In frequency analysis of woody species, *Maesa lanceolata* is the most frequent species followed by *Gymnosporia addat*, *Brucea antidysenterica*, and *Pittosporum viridiflorum*. On the other hand, the least frequent species are *Ficus sur*, *Capparis tomentosa*, *Solanicio gigas* and *Phytolacca dodicandra*. There is a high percentage of some species in lower frequency classes

and a low percentage of some species in higher frequency classes. This indicated the presence of a high degree of floristic heterogeneity in the study forest.

Regeneration analysis of woody species revealed that most tree species are with seedling and sapling stage in the forest, some tree species are without sapling stage, while others are represented by all stages (seedling, sapling, and mature).

5.2 Recommendations

Plant species have significant effects on the environment, biological variety, and socioeconomic significance as they represent a possible source of genetic resources in the future. The inclusion of local communities in forest conservation activities and management is the only realistic option to reduce the forest loss and its various resources as complex and valuable natural resource ecosystems. Based on the results of the study, the following recommendations were drawn :

- To conserve the biodiversity of the area detailed ecological and botanical studies are vital concerning the species composition, diversity, and distribution of plant species with the environmental factors such as soil type and properties.
- Wakani Forest consists of large areas that are still accessible, it provides various ecosystem services including nutrient cycling and CO₂ sequestration, and therefore, the establishment of the forest as a Biosphere Reserve is recommended.
- Tree planting by local people has to be encouraged on already degraded scrapes to create a buffer for the forest.
- Potential traditional knowledge of the people on the diverse uses of plants should be strengthened for the enrichment of ethnobotanical studies of the area. The present study is limited to species composition and structure so further studies on, environmental parameters, forest management and conservation systems, soil seed banks, and regeneration of the woody species are recommended.

- continuous mobilization of the local communities and building a sense of ownership and conservation interest through discussion and consultation to use alternative energy sources like solar energy and biogas.
- The community should minimize and modify their number of livestock breeds to resolve the problem of grazing.
- The present study can contribute to the understanding of woody plant species diversity, structure, and composition which has considerable importance in its conservation. Further ecological research is advised to be crucial to understanding the species composition, richness, and dispersion of potential plant communities in relation to other environmental variables.

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APPENDICES

Appendix 1. List of all plant species with their botanical, family and local name, habit, and number of individuals in Wakani Forest

Abbreviations: Habit- H = Herb, T = Tree, S = Shrub, T/S = Tree/Shrub, C. No. = Collection number

No	Scientific name	Family name	Local name	Habit	Plot No.	No. individuals	C. No.
1	<i>Achyranthes aspera</i> L.	Amaranthaceae	Telenj	H	5	26	GB53
2	<i>Afrocarduus schimperi</i> (Sch.Bip.) N.Garcia, Moreyra & Susanna	Asteraceae	Yemidr Koshele	H	10	21	GB48
3	<i>Allophylus abyssinicus</i> (Hochst.) Radlk.	Sapindaceae	Entatay	T	17	59	GB20
4	<i>Albizia gummifera</i> (J. F. Gmel.) C. A. Sm.	Fabaceae	Sesa	T	3	9	GB14
5	<i>Apodytes dimidiata</i> E.Mey.ex Arn.	Icacinaceae	Dong	T	34	165	GB09
6	<i>Astropanax abyssinica</i> (Hochst. ex A. Rich.) Seem.	Araliaceae	Getem	T	19	34	GB02
7	<i>Arisaema schimperianum schott</i>	Araceae	Amoch	H	7	18	GB58
8	<i>Bersama abyssinica</i> Fresen.	Francoaceae	Azamra	T	32	118	GB05
9	<i>Bidens macroptera</i> (Sch.Bi. ex Chiov.) Mesfin	Asteraceae	adeyo	H	19	213	GB45
10	<i>Bridelia micrantha</i> (Hochst.) Baill	Phyllanthaceae	Yenebir tifetr	T	3	14	GB41
11	<i>Brucea antidysenterica</i> J. F. Mill.	Simaroubaceae	Abalo	S	43	173	GB04
12	<i>Buddleja polystachya</i> Fresen.	Scrophulariaceae	Anfar	T	13	35	GB30
13	<i>Calpurnia aurea</i> (Ait.). Benth	Fabaceae	Degita	S	4	14	GB17
14	<i>Capparis tomentosa</i> Lam.	Capparidaceae	Gemero	S	2	7	GB42
15	<i>Clausena anisata</i> (Willd.) Benth	Rutaceae	Lemech	S	10	19	GB25
16	<i>Clematis simensis</i> Fresen.	Ranunculaceae	Azo hareg	C	9	23	GB19
17	<i>Croton macrostachyus</i> Hochst. ex Delile	Euphorbiaceae	Bisana	T	7	21	GB22
18	<i>Cyathula uncinulata</i> (Schard.) shinz	Amaranthaceae	Shingug	H	15	218	GB57
19	<i>Cynoglossum coeruleum</i> Hochst. ex A.DC. in DC. subsp. <i>Johnstonii</i>	Boraginaceae	Hulu-zemedede	H	7	34	GB54

20	<i>Discopodium penninervium</i> Hochst.	Solanacrae	Aluma	S	6	17	GB33
21	<i>Dombeya torrida</i> (J.F.Gmel.) Bamps	Malvaceae	Welkefa	T	26	85	GB06
22	<i>Dovyalis abyssinica</i> (A.Rich) Warb.	Apocynaceae	Koshm	S	29	94	GB13
23	<i>Embelia schimperi</i> Varke.	Primulaceae	Enkoko	C	27	65	GB11
24	<i>Erica arborea</i> L.	Ericaceae	Asta	T	9	37	GB37
25	<i>Erythrina brucei</i> Schweinf.	Fabaceae	Korch	T	4	6	GB23
26	<i>Euphorbia abyssinica</i> J.F. Gmel.	Euphorbiaceae	Kulkual	T	14	72	GB28
27	<i>Euphorbia platyphyllos</i> L.	Euphorbiaceae	Abaydem	H	10	56	GB63
28	<i>Ficus sur</i> (Forssk)	Moraceae	Shola	T	1	4	GB07
29	<i>Girardinia bullosa</i> (Hochst. ex Steud.) Wedd	Urticaceae	Kusha	H	25	246	GB49
30	<i>Gymnathemum amygdalinum</i> (Delile) Sch.Bip.	Acanthaceae	Girawa	T/S	3	9	GB40
31	<i>Gymnathemum urticifolium</i> (A. Rich.) H.Rob.	Acanthaceae	Gengerita	S	21	88	GB10
32	<i>Gymnosporia addat</i> + Loes	Celastraceae	Qoba	T	53	329	GB03
33	<i>Hagenia abyssinica</i> (Brace) J.F.Gmel.	Rosaceae	Koso	T	5	24	GB26
34	<i>Hypericum revolutum</i> Vahl.	Hypericaceae	Ameja	S	8	45	GB35
35	<i>Hypoestes forskoolii</i> (Vahl) R.Br.	Acanthaceae	Key- matebia	H	43	756	GB44
36	<i>Impatiens rothii</i> Hook.f	Balsaminaceae	gushirt	H	13	194	GB43
37	<i>Kalanchoe schimperiana</i> A.Rich.	Crassulaceae	Endehulla	H	2	8	GB55
38	<i>Laggera crispata</i> (Vahl) Hepper & J.R.I.Wood	Asteraceae	Kes bedege	H	19	68	GB46
39	<i>Lasiosiphon glaucus</i> Fresen.	Thymelaeaceae	Awora	T	21	88	GB16
40	<i>Lobelia giberroa</i> Hemsl.	Lobeliaceae	Jibera	S	5	27	GB29
41	<i>Maesa lanceolata</i> Forssk.	Primulaceae	Qilabo	T	55	314	GB12
42	<i>Momordica foetida</i> Schumach.	Cucurbitaceae	yekura hareg	H	3	8	GB 59
43	<i>Myrsine melanophloeos</i> (L.) R.Br. ex Sweet	Primulaceae	Weyl	T	2	5	GB36
44	<i>Nuxia congesta</i> R.Br.ex Fresen.	Stilbaceae	Askuar	T	34	164	GB34
45	<i>Pavetta abyssinica</i> Fresen.	Rubiaceae	Dengay seber	S	22	97	GB15
46	<i>Phytolacca dodecandra</i> L'Hér.	Phytolacaceae	Endod	C	2	5	GB39

47	<i>Pittosporum viridiflorum</i> Sims.	Pittosporaceae	Yilaho	T	39	162	GB31
48	<i>Prunus africana</i> (Hook.f.) Kalkman	Rosaceae	Homa	T	5	12	GB27
49	<i>Pteris pteridioides</i> (Hook.) F.Ballard	Pteridaceae	Etse-anbess	Fern	17	78	GB62
50	<i>Rosa abyssinica</i> R.Br. ex Lindl.	Rosaceae	Qega	T/S	34	121	GB32
51	<i>Rubus steudneri</i> Schweinf	Rosaceae	Enjory	T/S	11	38	GB21
52	<i>Rumex abyssinicus</i> Jacq.	Polygonaceae	Embari	H	10	32	GB60
53	<i>Rumex nepalensis</i> Spreng.	Polygonaceae	Tult	H	2	11	GB52
54	<i>Rumex nervosus</i> Vahl	Polygonaceae	Ambacho	S	3	8	GB36
55	<i>Salvia nilotica</i> Juss. ex Jacq.	Lamiaceae	Daba-keded	H	8	44	GB47
56	<i>Scepocarpus hypselodendron</i> (Hochst. ex A.Rich.) T. Wells & A. K. Monro	Urticaceae	Lnkesho	C	10	20	GB20
57	<i>Solanecio gigas</i> ⁺ (Vatke) C. Jeffrey	Asteraceae	Bose	S	2	24	GB08
58	<i>Stephania abyssinica</i> (Quart.-Dill. & A.Rich.) Walp.	Menispermaceae	Yeayit-hareg	H	15	86	GB50
59	<i>Trifolium repens</i> L	Fabaceae	Wajma	H	16	162	GB64
60	<i>Urtica simensis</i> + Hochst. ex A.Rich.	Urticaceae	Sama	H	3	62	GB51
61	<i>Vachellia abyssinica</i> (Hochst. ex Benth.) Kyal. & Boatwr.	Fabaceae	Girar	T	38	168	GB01
62	<i>Vachellia nilotica</i> (L.) P.J.H.Hurter & Mabb.	Fabaceae	Cheba	T	7	28	GB38
63	<i>Verbascum sinaiticum</i> Benth.	Scrophulariaceae	Ketetina	H	21	46	GB56
64	<i>Zehneria scabra</i> (L.f.) Sond.	Cucurbitaceae	Aregresa	H	18	22	GB61

Appendix 2. Density, frequency, Dominancy and important value index of woody plants in Wakani Forest

No.	Scientific name	Plot No.	No. individuals	Density	R.density	Frequency %	R.frequency	R.dominancy	IVI
1	<i>Albizia gummifera</i>	3	9	3.57	0.32	4.76	0.43	2.68	3.43
2	<i>Apodytes dimidiata</i>	34	165	65.47	5.78	53.97	4.9	10.32	21.08
3	<i>Bersama abyssinica</i>	32	118	46.82	4.13	50.79	4.62	11.42	20.17
4	<i>Brucea antidysenterica</i>	43	173	68.65	6.06	68.25	6.31	0.35	12.78
5	<i>Buddleja polystachya</i>	13	35	13.89	1.23	20.63	1.88	0.66	3.77
6	<i>Calpurnia aurea</i>	4	14	5.56	0.49	6.35	0.58	0.02	1.09
7	<i>Capparis tomentosa</i>	2	7	2.78	0.25	3.17	0.29	0.02	0.56
8	<i>Dovyalis abyssinica</i>	29	94	37.30	3.23	46.03	3.64	0.52	7.39
9	<i>Clausena anisata</i>	10	19	7.53	0.66	15.87	1.44	0.03	2.13
10	<i>Clematis simensis</i>	9	23	9.13	0.81	14.29	1.3	0.02	2.13
11	<i>Croton macrostachyus</i>	7	21	8.33	0.29	11.11	1.01	1.27	2.57
12	<i>Discopodium penninervum</i>	6	17	6.75	0.59	9.52	0.87	0.04	1.5
13	<i>Dombeya torrid</i>	26	85	33.73	2.98	41.27	3.76	9.92	16.66
14	<i>Allophylus abyssinicus</i>	17	59	23.41	2.07	26.98	2.46	3.5	8.03
15	<i>Embelia schimperi</i>	27	65	25.79	2.78	42.86	3.9	0.02	6.7

16	<i>Erica arborea</i>	9	37	14.68	1.30	14.29	1.3	0.05	2.65
17	<i>Erythrina brucei</i>	4	6	2.38	0.21	6.35	0.58	1.6	2.39
18	<i>Euphorbia abyssinica</i>	14	72	28.57	2.53	22.22	2.02	2.25	6.8
19	<i>Ficus sur</i>	1	4	1.59	0.14	1.59	0.14	0.34	0.62
20	<i>Lasiosiphon glaucus</i>	21	88	34.92	3.09	33.33	3.03	1.12	7.24
21	<i>Hagenia abyssinica</i>	5	24	9.52	0.84	7.94	0.72	0.99	2.55
22	<i>Hypericum revolutum</i>	8	45	17.86	1.58	12.7	1.16	0.42	3.16
23	<i>Lobelia giberroa</i>	5	27	10.71	0.95	7.94	0.72	0.04	1.71
24	<i>Maesa lanceolata</i>	55	314	124.60	11.01	87.3	7.95	3.87	22.83
25	<i>Gymnosporia addat</i>	53	329	130.56	11.63	84.13	7.66	5.17	24.46
26	<i>Nuxia congesta</i>	34	164	65.08	5.75	53.97	4.91	3.12	13.78
27	<i>Pavetta abyssinica</i>	22	97	38.49	3.40	34.92	3.18	0.74	7.32
28	<i>Phytolacca dodecandra</i>	2	5	1.98	0.18	3.17	0.29	0.01	0.48
29	<i>Pittosporum viridiflorum</i>	39	162	64.29	5.68	61.9	5.64	12.18	23.5
30	<i>Prunus africana</i>	5	12	4.76	0.42	7.94	0.72	1.4	2.54
31	<i>Rosa abyssinica</i>	34	121	48.02	4.24	53.97	4.91	0.34	9.49

32	<i>Rubus steudneri</i>	11	38	15.08	1.33	17.46	1.59	0.02	2.94
33	<i>Rumex nervosus</i>	3	8	3.17	0.28	4.76	0.43	0.02	0.73
34	<i>Astropanax abyssinica</i>	19	38	15.08	1.33	30.16	2.75	10.22	14.3
35	<i>Solanecio gigas</i>	2	24	9.52	0.82	3.17	0.29	0.02	1.13
36	<i>Scepocarpus hypselodendron</i>	10	20	7.94	0.70	15.87	1.44	0.07	2.21
37	<i>Vachellia abyssinica</i>	38	168	66.67	5.89	60.32	5.49	12.78	24.16
38	<i>Vachellia nilotica</i>	7	28	11.11	0.98	11.11	1.01	1.27	3.26
39	<i>Gymnathemum amygdalinum</i>	3	9	3.57	0.32	4.76	0.43	0.09	0.84
40	<i>Gymnathemum urticifolium</i>	21	88	34.92	3.07	33.33	3.03	0.08	6.18
41	<i>Myrsine melanophloeos</i>	2	5	1.98	0.17	3.17	0.29	0.75	1.21
42	<i>Bridelia micrantha</i>	3	14	5.56	0.49	4.76	0.43	0.2	1.12
	Total	63	2851	1131.35	100	1098.38		100	

Appendix 3. Regeneration status of Wakani Forest

Key: G.R=Good Regeneration, F.R=Fair Regeneration, P.R=Poor Regeneration

No.	Scientific name	Family name	habit	No. of plot	No. of matured individual	no. of seedlings	no. of saplings	Regeneration status
1	<i>Albizia gummifera</i>	Fabaceae	T	3	9	-	-	none
2	<i>Apodytes dimidiata</i>	Icacinaceae	T	34	165	185	85	F.R
3	<i>Bersama abyssinica</i>	Francoaceae	T	32	118	159	160	G.R
4	<i>Brucea antidysentrica</i>	Combretaceae	S	43	173	184	178	G.R
5	<i>Buddleja polystachya</i>	Scrophulariaceae	T	13	35	15	8	F.R
6	<i>Calpurnia aurea</i>	Fabaceae	S	4	14	10	8	F.R
7	<i>Dovyalis abyssinica</i>	Apocynaceae	S	2	7	-	5	P.R
8	<i>Carissa spinarum</i>	Apocynaceae	S	29	94	45	22	F.R
9	<i>Clausena anisata</i>	Rutaceae	S	10	19	20	17	F.R
10	<i>Clematis simensis</i>	Ranunculaceae	C	9	23	15	10	F.R
11	<i>Croton macrostachyus</i>	Euphorbiasceae	T	7	21	-	5	P.R
12	<i>Discopodium penninervum</i>	Solanacrae	S	6	17	9	4	F.R
13	<i>Dombeya torrid</i>	Malvavaceae	T	26	85	25	16	F.R
14	<i>Allophylus abyssinicus</i>	Miliaceae	T	17	59	15	10	F.R
15	<i>Embelia schimperi</i>	Myrsinaceae	C	27	65	20	15	F.R
16	<i>Erica arborea</i>	Ericaceae	T	9	37	-	-	None
17	<i>Erythrina brucei</i>	Fabaceae	T	4	6	-	-	None
18	<i>Euphorbia abyssinica</i>	Euphorbiasceae	T	14	72	80	75	G.R
19	<i>Ficus sur</i>	Moraceae	T	1	4	-	-	None
20	<i>Lasiosiphon glaucus</i>	Thymelaeaceae	T	21	88	97	89	G.R
21	<i>Hagenia abyssinica</i>	Rosaceae	T	5	24	-	8	P.R
22	<i>Hypericum revolutum</i>	Hypericaceae	S	8	45	65	31	F.R

23	<i>Lobelia giberroa</i>	Lobeliaceae	S	5	27	59	43	G.R
24	<i>Maesa lanceolata</i>	Primulaceae	T	55	314	365	326	G.R
25	<i>Gymnosporia addat</i>	Celastraceae	T	53	329	376	343	G.R
26	<i>Nuxia congesta</i>	Stilbaceae	T	34	164	97	68	F.R
27	<i>Pavetta abyssinica</i>	Rubiaceae	S	22	97	92	83	F.R
28	<i>Phytolacca dodecandra</i>	Phytolacaceae	C	2	5	-	-	None
29	<i>Pittosporum viridiflorum</i>	Pittosporaceae	T	39	162	43	28	F.R
30	<i>Prunus africana</i>	Rosaceae	T	5	12	45	20	G.R
31	<i>Rosa abyssinica</i>	Rosaceae	T/S	34	121	68	34	F.R
32	<i>Rubus steudneri</i>	Rosaceae	T/S	11	38	98	55	G.R
33	<i>Rumex nervosus</i>	Polygonaceae	S	3	8	15	6	F.R
34	<i>Astropanax abyssinica</i>	Araliaceae	T	19	38	-	11	P.R
35	<i>Solanecio gigas</i>	Asteraceae	S	2	24	65	30	G.R
36	<i>Scepocarpus hypselodendron</i>	Urticaceae	C	10	20	-	-	None
37	<i>Vachellia abysinica</i>	Fabaceae	T	38	168	180	171	G.R
38	<i>Vachellia nilotica</i>	Fabaceae	T	7	28	35	15	F.R
49	<i>Gymnathemum amygdalinum</i>	Acanthaceae	T/S	3	9	-	-	None
40	<i>Gymnathemum urticifolium</i>	Asteraceae	S	21	88	185	102	G.R
41	<i>Myrsine melanophloeos</i>	Primulaceae	T	2	5	-	3	P.R
42	<i>Bridelia micrantha</i>	Phyllanthaceae	T	3	14	45	20	G.R
				63	2851	2712	2104	F.R

Appendix 4. Woody species diversity and evenness in Wakani Forest

plots	Species richness	number individual(n)	ofH'	Ins	J
1	14	51	2.35	2.64	0.89

2	12	41	1.68	2.48	0.68
3	8	30	1.83	2.08	0.88
4	18	64	2.58	2.89	0.89
5	15	50	2.49	2.71	0.91
6	15	50	2.44	2.71	0.9
7	14	63	2.16	2.64	0.82
8	19	59	2.31	2.94	0.79
9	15	61	2.4	2.71	0.89
10	13	44	2.15	2.56	0.84
11	14	62	2.43	2.64	0.92
12	7	50	2.3	1.95	1.18
13	15	57	2.33	2.71	0.86
14	11	61	2.07	2.39	0.87
15	11	65	2.11	2.39	0.88
16	15	65	2.43	2.71	0.89
17	14	60	2.36	2.64	0.89
18	7	49	1.73	1.95	0.89

19	11	60	2.19	2.39	0.92
20	10	62	2.14	2.3	0.93
21	11	50	2.12	2.39	0.89
22	12	49	1.75	2.48	0.71
23	10	51	2.18	2.3	0.95
24	14	50	2.52	2.64	0.95
25	11	43	2.07	2.39	0.87
26	10	48	2.23	2.3	0.97
27	8	29	1.86	2.08	0.89
28	9	34	1.9	2.19	0.87
29	12	41	2.4	2.48	0.98
30	7	29	1.84	1.95	0.94
31	10	39	2.07	2.3	0.9
32	11	46	2.33	2.39	0.97
33	11	44	1.73	2.39	0.72
34	10	46	2.09	2.3	0.91
35	8	44	1.99	2.08	0.96

36	10	46	1.79	2.3	0.78
37	11	40	2.31	2.39	0.97
38	8	37	1.72	2.08	0.83
39	11	37	2.19	2.39	0.92
40	12	35	2.42	2.48	0.96
41	6	28	1.14	1.79	0.64
42	5	25	1.52	1.61	0.94
43	10	32	2.15	2.3	0.93
44	10	36	1.97	2.3	0.86
45	7	47	1.77	1.95	0.91
46	9	53	2.11	2.19	0.96
47	9	42	2.22	2.19	1
48	11	44	2.16	2.39	0.9
49	9	44	1.99	2.19	0.91
50	9	43	1.58	2.19	0.72
51	10	48	2.27	2.3	0.99
52	10	45	2.22	2.3	0.97

53	10	38	1.82	2.3	0.79
54	12	41	2.45	2.48	0.99
55	11	31	2.29	2.39	0.96
56	11	31	2.26	2.39	0.95
57	10	37	2.25	2.3	0.98
58	11	43	2.25	2.39	0.94
59	10	39	2.15	2.3	0.93
60	9	49	2.09	2.19	0.95
61	9	38	1.73	2.19	0.79
62	11	40	2.36	2.39	0.98
63	8	35	1.49	2.08	0.72
Total		2851	132.23		56.37
Average			2.11		0.89

Appendix 5. List of synoptic tables of characteristic and dominant species in four community types (C1-C4)

Species	Cluster 1	Cluster 2	Cluster 3	Cluster 4
<i>D..torrida.</i>	0.11	0.00	0.00	0.00
<i>F..sur.</i>	0.05	0.00	0.00	0.00
<i>A..gummifera.</i>	0.05	0.00	0.00	0.00
<i>G.urticifolium</i>	0.00	0.06	0.00	0.00

<i>M..melanophloeos</i>	0.00	0.06	0.14	0.00
<i>V.abysinica</i>	0.00	0.00	0.14	0.00
<i>C..anisata</i>	0.00	0.00	0.00	0.05
<i>P..abysinica.</i>	0.11	0.00	0.00	0.00
<i>A..dimidiata.</i>	0.05	0.06	0.00	0.00
<i>B..antidysenterica.</i>	0.32	0.06	0.00	0.00
<i>S..hypselodendron</i>	0.11	0.38	0.00	0.10
<i>P..abysinica</i>	0.84	0.25	0.29	0.38
<i>D..abysinica</i>	0.42	0.56	1.00	0.48
<i>S..gigas</i>	0.21	0.00	0.00	0.00
<i>M..lanceolata.</i>	0.16	0.12	0.00	0.00
<i>B..abysinica</i>	0.74	0.81	0.43	0.57
<i>E..schimperi</i>	0.42	0.19	0.29	0.29
<i>B..antidysenterica</i>	0.53	1.06	0.57	0.67
<i>C..anisata</i>	0.21	0.06	0.00	0.24
<i>R..steudneri.</i>	0.21	0.25	0.00	0.10
<i>A..abysinicus</i>	0.58	0.31	0.29	0.24
<i>A..dimidiata</i>	0.84	0.25	0.86	1.05
<i>E..schimperi.</i>	0.16	0.06	0.00	0.14
<i>X.M..lanceolata</i>	0.16	0.00	0.00	0.00
<i>X.B..antidysenterica</i>	0.11	0.00	0.00	0.00
<i>X.L..glaucus</i>	0.11	0.00	0.00	0.00
<i>G..urticifolium</i>	0.05	0.00	0.00	0.00
<i>C..aurea.</i>	0.05	0.00	0.00	0.00
<i>D..torrida</i>	0.42	0.19	0.43	0.81
<i>A..abysinica</i>	0.05	0.06	0.00	0.00
<i>G..addat</i>	0.05	0.06	0.00	0.00
<i>C..aurea.</i>	0.11	0.00	0.00	0.00
<i>L..glaucus.</i>	0.11	0.00	0.00	0.00
<i>A..abysinica</i>	0.37	0.12	0.57	0.29

<i>C..simensis.</i>	0.05	0.06	0.00	0.00
<i>B..abyssinica.</i>	0.00	0.06	0.00	0.00
<i>.E..schimperii.</i>	0.00	0.12	0.00	0.00
<i>X.L..glaucus.</i>	0.00	0.06	0.00	0.00
<i>X.V..abyssinica</i>	0.00	0.12	0.00	0.00
<i>X.D..abyssinica</i>	0.00	0.06	0.00	0.00
<i>X.C..macrostachyus</i>	0.00	0.19	0.00	0.00
<i>X.P..abyssinica</i>	0.00	0.06	0.00	0.00
<i>L..giberroa</i>	0.16	0.00	0.14	0.10
<i>G..addat</i>	1.26	1.44	1.71	1.52
<i>D..penninervium</i>	0.00	0.19	0.29	0.10
<i>V..abyssinica</i>	0.74	0.75	0.86	0.86
<i>M..lanceolata</i>	1.16	1.44	1.43	1.43
<i>P..viridiflorum</i>	0.74	0.94	1.00	0.95
<i>C..simensis</i>	0.05	0.12	0.00	0.14
<i>B..polystachya</i>	0.11	0.31	0.29	0.38
<i>G..urticifolium</i>	0.58	0.44	0.14	0.29
<i>H..abyssinica</i>	0.05	0.12	0.00	0.19
<i>A..gummifera</i>	0.00	0.12	0.00	0.05
<i>C..macrostachyus</i>	0.16	0.00	0.29	0.05
<i>P..africana</i>	0.11	0.00	0.14	0.05
<i>C..aurea</i>	0.00	0.06	0.00	0.10
<i>E..brucei.</i>	0.11	0.06	0.00	0.00
<i>E..abyssinica</i>	0.37	0.44	0.14	0.24
<i>P..dodecandra</i>	0.00	0.06	0.00	0.10
<i>H..revolutum</i>	0.00	0.00	0.14	0.52
<i>C..tomentosa</i>	0.05	0.00	0.14	0.00
<i>N..congesta</i>	1.00	0.56	0.43	0.76
<i>B..micrantha</i>	0.05	0.00	0.29	0.00
<i>L..glaucus</i>	0.53	0.62	0.00	0.24

<i>Dovyalis.abysinica</i>	0.00	0.06	0.00	0.00
<i>Bersama.abysinica</i>	0.00	0.06	0.00	0.00
<i>Lobelia.giberroa</i>	0.00	0.06	0.00	0.00
<i>Apodytes.dimidiata</i>	0.00	0.06	0.00	0.00
<i>R..nervosus</i>	0.00	0.00	0.14	0.10
<i>R..abysinica</i>	0.32	0.75	0.00	0.90
<i>E..brucei</i>	0.00	0.00	0.00	0.10
<i>R..steudneri</i>	0.00	0.06	0.00	0.10
<i>Clematis.simensis</i>	0.00	0.00	0.00	0.05
<i>L...glaucus</i>	0.00	0.00	0.00	0.10
<i>V..nilotica</i>	0.21	0.06	0.29	0.10
<i>G..amygdalinum</i>	0.00	0.00	0.14	0.10
<i>E..arborea</i>	0.26	0.19	0.14	0.14
<i>Maesa.lanceolata</i>	0.11	0.00	0.00	0.00
<i>Vachellia.abysinica</i>	0.11	0.00	0.00	0.00