RESEARCH ARTICLE

# Restoration in town as a reservoir of woody plant diversity in Nacho mountain forest Mecha District, Northwest Ethiopia

Tilaye Aregu Haile, Ali Seid Mohammed, Amare Bitew Mekonnen*

**Haile AT, Mohammed AS, Mekonnen AB. Restoration in town as a reservoir of woody plant diversity in Nacho mountain forest Mecha District, Northwest Ethiopia. AGBIR.2025;41(6):1-8.**

This study was conducted to evaluate the woody plant diversity, structure, and regeneration status of Nacho restoration forest. Thirty plots of 20 m × 20 m were laid at about 100 m intervals along the transect lines for vegetation data collection. The number of sampled quadrats was determined based on the principle of species-area curve. In addition, 5 subplots (5 m × 5 m) were laid within each main plot to collect seedling and sapling data of woody species. Diversity was determined using Shannon Wiener index (H') and communities were classified with SPSS-20. A total of 64 woody species belonging to 51 genera and 31 families were in the forest. The overall H' and evenness values were 3.6 and 0.9, respectively. The analysis of the Diameter at Breast Height (DBH) distribution shows an inverted J-shaped pattern indicating the healthiness of the forest. The total basal area of the forest was 226.6 $m^2ha^{-1}$. Stems $ha^{-1}$ densities were 514.2 for mature, 538.1 for saplings, and 937.5 for seedlings. These structural data revealed that the forest is in the secondary stage of development and some species require urgent conservation. Based on the results of this study appropriate restoration is recommended to develop woody plant composition, diversity, and conservation in degraded mountain forests even in towns.

**Key Words:** *Aforestation; Conservation; Plant diversity; Restoration*

## INTRODUCTION

Generally, forest provides environmental, economic, cultural, and spiritual benefits to society. Its protective function conserves biodiversity and ecological balance; prevents the loss of water and soil by erosion [1-3]. It also provides vital ecosystem services like water purification, land stabilization, erosion control, climate change mitigation, carbon sequestration, soil fertility, pollination, decomposition, water and nutrient cycling, and cultural and social development. It refreshes the atmosphere by absorbing carbon dioxide and providing oxygen [4-6].

Tropical forest areas can be used as a reservoir of biodiversity resources, known by species richness (containing about 50% of the world species), and played an integral role in the conservation of biodiversity [7,8]. This region has produced a huge amount of woody biomass $ha^{-1}$ due to favorable climatic condition.

Ethiopia has the first largest flora diversity in east Africa followed by Kenya, Malawi, and Uganda and has rich endemic elements due to the topographic diversity [9]. The number of species of higher plants in Ethiopia is estimated to be 6,000, of which 12% are endemic to the country [10]. Ethiopia's forests are increasingly under threat mainly because of fast growing population with more demand for farmland, road, energy, water infrastructure, and construction. These demands accelerate deforestation and forest degradation. From the latest data of tree cover loss from the year 2016 to 2020 around 20,000 ha of land were deforested annually. This rate of deforestation in the country was higher than eastern and southern Africa's sum total rate of deforestation, which was 0.67% per year. Reduction in forest cover has a number of consequences including soil erosion and reduced capacity for watershed protection with possible flooding, reduced yield, and loss of biodiversity. Deforestation became a serious challenge to the sustainability of forests due to forest land-use change.

The main reasons for deforestation in Ethiopia are the clearing of forests and woodlands for increasing demand of residents, farmlands, grazing, fuelwood, charcoal production, and construction materials. The fact that plantation has been very far from meeting the country's demand for wood indicates the inevitability of deforestation. These causes of deforestation are closely linked with the vicious cycle of mutually reinforcing factors such as poverty, population growth, poor economic growth, and the state of the environment [3]. In this context, urgent actions are imperative not only for the sustainable use and management of the meager remnant natural forests but also for prompt ecological restoration management in order to preserve the rich biodiversity resources of the country from complete disappearance.

Deforestation results in loss of biodiversity and a decline of ecosystem services. The problem of deforestation due to the expansion of agriculture, firewood collection, cutting, grazing, exotic tree plantation, and other human disturbances has been more pronounced in the northern and central highlands of Ethiopia [11-13]. This is because of the demographic pressure, with sedentary farming that leads to relentless land exploitation for agriculture in the region [14]. Restoration of forest resources in such areas is mandatory to regain those losses and to maintain ecosystem services.

Vegetation evaluation such as floristic composition and structure studies are essential in the inspection of their value and understanding of the degree of plant diversity in forest ecosystem [15]. The knowledge of the floristic composition, structure, and regeneration status of forest reserves is also useful in identifying important elements of plant diversity, protecting threatened and economically voluble species, and monitoring the status of the forest [16]. Even though Nacho mountain restoration forest provides ecological services and socioeconomic value to the local community, its biodiversity composition and knowledge on sustainable use and management of the forest is not clearly stated. Therefore, truthful data on forest resources are essential requirement for forest management and planning in the context of sustainable development. No such study has been conducted on the floristic composition, structure, diversity, and regeneration status of woody plant species of this forest. Thus, this study provides primary information on the floristic description that would be used to determine the status of this restored forest and to plan the future management of the forest.

*Department of Biology, Bahir Dar University, Bahir Dar, Ethiopia*

***Correspondence:*** *Desalegn Amenu, Department of Biology, Bahir Dar University, Bahir Dar, Ethiopia; E-mail: amarebitew8@gmail.com*

***Received:*** *24-May-2024, Manuscript No. AGBIR-24-137063;* ***Editor assigned:*** *28-May-2024, PreQC No. AGBIR-24-137063 (PQ);* ***Reviewed:*** *11-Jun-2024, QC No. AGBIR-24-137063;* ***Revised:*** *06-Nov-2025, Manuscript No. AGBIR-24-137063 (R);* ***Published:*** *13-Nov-2025, DOI: 10.37532/0970-1907.25.41(6).1-8*

MATERILAS AND METHODS

## Description of the study area

This study was conducted in Mecha district, west Gojjam administrative zone, Amhara National Regional State (ANRS), Ethiopia. Geographically this district is located within latitude 11°23'38"-11°24'00" N and longitude 37°07'23"-37°07'46"E. Specifically the study was conducted in Nacho mountain restoration forest in the administrative town of the district (Figure 1). This forest has been protected and restored since 10 years ago by local communities, the government, and other concerned bodies. It has been kept safe from animal and human disturbance with plantation in order to increase vegetation cover.

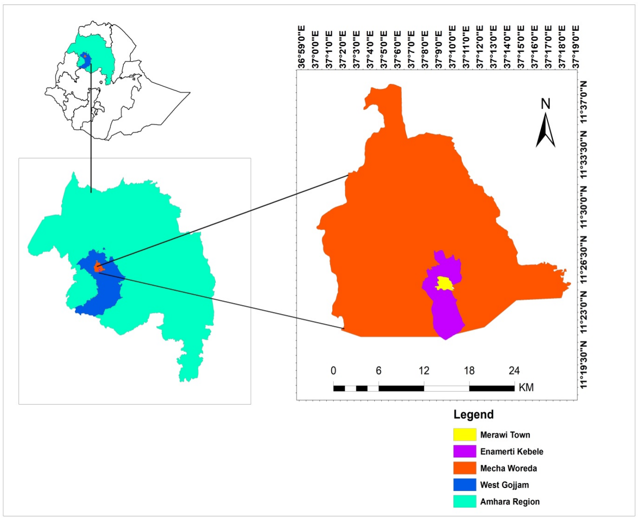


**Figure 1)** *The study area map*

## Climate and land use system

Based on the agroecological classification of Ethiopia, 20% of the district is under dega (highland climatic condition) with altitude ranges 2300-3200 masl, whereas the remaining 80% of the area falls under woynadega (midland climatic condition) with altitude ranges 1500-2300 masl [17]. The rainfall pattern is bimodal, with a wet season from June to September and a dry season from October to May; however, March to May can also have some precipitation (Figure 2).

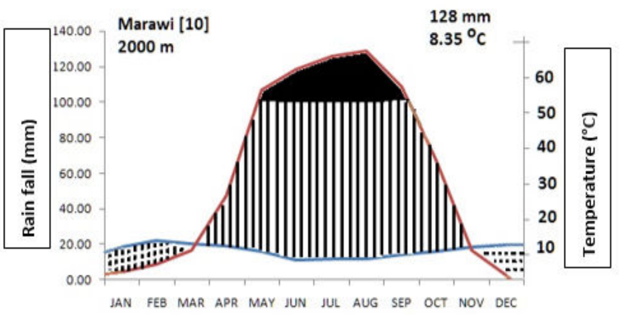


**Figure 2)** *Climadiagram of the town of Mecha district Marawi (2008–2017)*

Nacho mountain restoration forest is located at an altitude range from 1200 to 2100 meters above sea level and has 12 to 30% slope area. Some part of the forest has exotic tree such as *Eucalyptus camaldulensis* Dehnh., *Grevillea robusta* R. Br., *Cupressus lusitanica* Mill., *Acacia saligna* Labill., and others near the edge of the forest. Since the forest is found in the town of Merawi, it is under lots of pressure such as fuel wood collection, cutting, illegal building, and grazing. The district agricultural office and the regional forestry enterprise have focused by tracing and controlling those human impacts for reforestation and its recovery [18-20].

## Sampling design

Four transect lines were laid along four cardinal directions from top to down of Nacho mountain restoration forest separated at a distance of 100 m intervals in between them. Then, a total of 30 sample plots with the size of 20 m × 20 m (400 $m^2$) at a distance of 100 m between them were laid using a systematic random sampling technique along those transect lines. The number of sample plots was determined based on species accumulation curve where a point no longer adds extra new species encountered for given additional plot sampling efforts. In each main plot, 5 subplots of 5 m × 5 m (25 $m^2$) were established four at each corner of the main plot and one at the center of the main plot for seedling and sapling data collection.

## Data collection methods

All individuals of woody species with a Diameter at Breast Height (DBH) ≥ 2.5 cm in each sample plot were identified, their DBH was measured, coded, and recorded, and then grouped as trees, shrubs, and lianas. This is because DBH value of 2.5 cm is a minimum value for tree stems. Plant identification was done by using published materials like. For those plants that couldn't be identified their fresh specimens were collected, pressed, and dried properly and taken to National Herbarium (ETH), Addis Ababa University for proper identification.

DBH of woody plants calculated by (DBH)=C/π where, C is circumference and π=3.14. Since the relationship between tree height and DBH is an important data to describe forest stands; Tree height was measured by using clinometers where comfortable, calibrated (marked) bamboo stick was also used.

In each subplot, a woody individual with a DBH <1 cm and a height <1 m was considered and counted as seedling; and similarly a woody individual with a DBH <2.5 cm and a height between 1 m and 2.5 m was considered and counted as sapling. In each main plot a woody individual with a DBH ≥ 2.5 cm and a height >2.5 m was counted and recorded as matured tree. In order to collect vegetation structural data of the forest, the density, frequency, basal area, dominance, and IVI were calculated after individual woody plant species data were measured and counted.

Physiographic variables such as altitude of each quadrate were recorded by using Global Position System (GPS) and geographical coordinates were measured using Magellan GPS 315. The types of disturbance were also visually evaluated and recorded for each plot then the conservation status of the forest was justified. Disturbance indicators could be grazing, firewood collection, charcoal making, cutting, building, and agricultural expansion.

## Data analysis

The species diversity was determined by using Shannon and Weiner diversity index. This analysis has two components that are species evenness and richness. The structure of vegetation would be described based on the analysis of species density, DBH, height, basal area, frequency and Important Value Index (IVI). The regeneration status of woody species of forests was determined by computing density ratios between seedlings and mature individuals, seedlings and saplings, and sapling and mature individuals.

The Diameter at Breast Height (DBH) and tree height were classified into DBH classes and height classes. The percentage frequency distribution of individuals in each class was calculated. Tree or shrub density and basal area, values were computed on a hectare basis. Cover abundance and frequency data were used to classify vegetation into plant community types based on hierarchical cluster analysis using SPSS version 20 software.

The evenness and diversity of woody plants were analyzed using the Evenness (E) and Shannon-Wiener diversity index (H'). The Shannon-Wiener diversity index (H') was calculated using the following formula:

$$H' = -\sum_{n=1}^{s}(\mathbf{piln(pi)})$$

Where: S=total number of species; Pi=is the proportion of each species in the sample; ln=log base n.

Shannon's equitability (J) or Evenness is calculated as follows:

$$J = \frac{H'}{H'max} = \frac{H'}{lns}$$

Where: E=Evenness; H'=Shannon-Wiener diversity index; H'max=lnS; S=total number of species in the sample plot.

Frequency: It is computed as the proportion of the number of plots in which a given species is found to the total number of plots sampled and calculated as follows.

$$\text{Frequency} = \frac{the\ number\ of\ plots\ in\ which\ that\ spp\ occures}{total\ number\ of\ plots} x100$$

$$\text{Relative frequency} = \frac{frequency\ of\ a\ single\ spp}{total\ frequency\ of\ all\ spp} x100$$

**Density:** The density of woody plants is calculated as the number of individuals of species per area of samples in hectare.

$$\text{Density of species} = \frac{Number\ of\ individual\ spp}{area\ (ha)};\ \text{Relative Dnsity} = \frac{densityofaspp}{totaldensityallspp} x\ 100$$

**DBH (Diameter at Breast Height):** It is computed by dividing the circumference of each tree documented in the plot by π (3.14).

**Basal area:** It is used to explain the crowdedness of a stand of forests and to calculate the dominance of species expressed in m2/ha.

$$\text{Basalarea(BA)} = \frac{\pi d^2}{4}$$

Where: BA=Basal area in $m^2ha^{-1}$, d=diameter at breast height (m), and π =3.14.

$$\text{Relative dominance (RDO)} = \frac{baasalareaofaspecies}{totalbasalareaofallspp} x\ 100$$

Dominance is a mean basal area per species times the number of species.

**Important Value Index (IVI):** It is used to determine and compare the dominance and abundance of a given species in relation to other associated species in an area. It was calculated as the sum of Relative Dominance (RDO), Relative Density (RD) and Relative Frequency (RF).

**Regeneration status:** The regeneration status of the forest was determined by comparing the density values of seedlings, saplings, and matured woody plants within the forest. According to the regeneration status is good regeneration, if Seedling>Sapling>Matured woody plants; fair regeneration, if seedling ≤ sapling ≥ Matured woody plants, and the status is low in regeneration, if Seedling<Sapling<Matured woody plants. If the species survives only in the sapling stage, and if a species is present only in an adult form (no sapling no seedling) then, the forest is considered as not regenerating.

RESULTS AND DISCUSSION

## Floristic composition

A total of 64 woody species belonging to 51 genera and 31 families were found in Nacho mountain restoration forest. Out of the identified families, Fabaceae was the most dominant family comprising 11 species followed by *Moraceae, Rutaceae, Euphorbiaceae*, and *Asteraceae* each composed of 4 species, and then followed by *Rubiaceae, Oleaceae, Myrtaceae* with 3 species and *Rosaceae, Acanthaceae, Verbenaceae, Cupersaceae*, with 2 species each. This restoration forest's species composition was less than a monastery (Taragedam) with 113 woody species and 73 woody species in Dangilachurch forests but, higher than 54 and 57 woody species in Lammo, and Amoro natural forest respectively.

The vegetation life form of the study site has 33 (51%) Shrubs, 24 (38%) Trees, 6 (9%) individuals were trees or shrubs, and 1 (2%) individual was a climber. The result showed that, the vegetation life form of this restoration forest wasmore shrubs' than trees. It also indicated that the local community interferes with trees by selective cutting for different purposes like timber production, construction, charcoal, and marketing values. Due to this trees' density was relatively less than shrubs' density.

## Plant community classification of the forest

Four plant community types were identified in Nacho mountain restoration forest (Figure 3). Vegetation community types were given names after one or two dominant and/or characteristic species from 30 plots. However, quadrants 4, 24, 27 and 30 were excluded as outliers during community-type classification (Table 1).

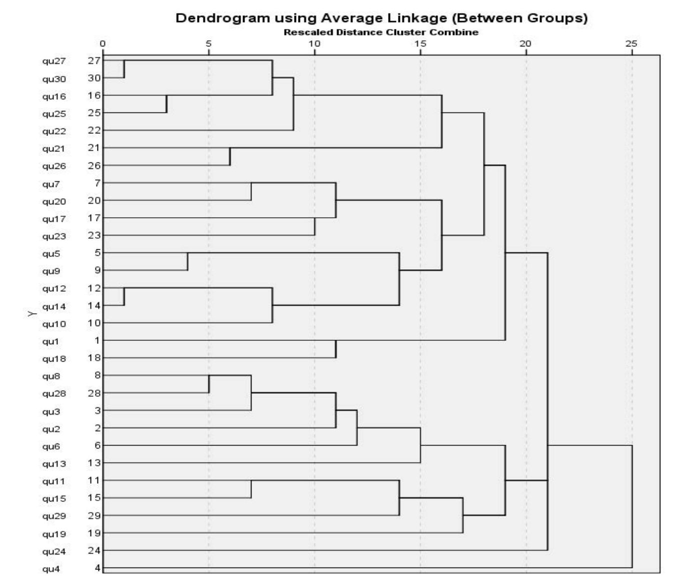


**Figure 3)** *Dendrogram of the vegetation data obtained from hierarchical cluster analysis of Nacho mountain restoration forest*

TABLE 1
**Communities type and the distribution of communities in sample plot**

| Community type | Plots where communities occur | Total plot | Altitude range |
|---|---|---|---|
| C1 | 16,21,22,25,26. | 5 | 1994 to 2022 |
| C2 | 5,7,9,10,12,14,17,20,23. | 9 | 2009 to 2081 |
| C3 | 1,18. | 2 | 2003 to 2011 |
| C4 | 2,3,6,8,11,13,15,19,28,29. | 10 | 1982 to 2082 |

## Albizia schimperiana-*Croton macrostachyus* community type

This community is located between the altitudinal ranges of 1994 to 2022 in the forest. It was dominated by tree and represented by 5 plots and 26 species, along with the dominant species used in the naming of the community, *Croton macrostachyus*, *Albizia schimperiana*, *Juniperus procera*, and *Syzygium guineenes*, were the dominant tree species in the the community. Rhamnusprinoides, Ocimumlamiifolium, and Rosa abyssinica were important species in the shrub layer. The common climber in this community was *Jusminium abyssinica*. *Albizia schimperiana* is the characterstics species of this community.

## *Vernonia auriculifera* community type

This community was represented by 9 plots and 35 plant species and dominated by shrubs. It was found at altitudinal range of 2009 to 2081. *Vernonia auriculifera*, and *Carissa spinarum* are the dominant shrub species in this community. Acacia abyssinica was the dominant tree species. In line with this, *Rosa abyssinica* was the characterstics species.

## *Milletia ferruginea* community type

This community is situated at altitude between 2003 to 2011. It comprises 2 plots and 16 species belong to the group and dominated by tree species. *Millettia ferruginea*, *Ficusvasta*, *Acacia abyssinica*, and *Maytenus obscura* were the dominant species of the tree layer of the community. The shrub layer was dominated by *Osyris quadripartita*, *Carissa spinarum*, *Grewa ferruginea*, and *Rhus glutinosa*. *Vernonia amygdalina* is the charactrestics species of the community.

## *Dodonaea angustifolia* community type

This community contains 10 plots. There are 38 species that are associated with this community and dominated by shrub. It occurs in the altitudinal range of 1982 to 2082m.a.s.l. *Dodonaea angustifolia*, *Grewia ferruginea*, *Hypericum revolutum*, *Bridelia micrantha*, *Clausena anisata*, *Premna schimperi*, *Rhus glutinosa* and *Calpurnia aureawere* the common shrub species of this community. *Croton macrostachyus*, *Acacia abyssinica*, *Millettia ferruginea*, *Ficus sur*, are the most common tree species in this community. Jusminium abyssinica was the common climber species in this community. Carissa spinarum is the charactrestics species in this community.

## Species diversity and evenness analysis

Based on the result of the study, the Shannon-Weiner diversity and evenness of woody plant species of the study forest were 3.6 and 0.9 respectively. This restoration forest has a relatively high value of species diversity and evenness. The diversity and evenness of woody species in this forest are higher than the nearby church forests of Dangila town which were 3.5 and 0.82 respectively. This result is also far higher than the diversity and evenness of Weiramba forest of North Ethiopia which were 2.3 and 0.66, respectively, diversity and evenness of a sacred forest Tara Gedam forest 2.98 and 0.65, respectively. According to diversity and evenness increases, as the species are rich and evenly distributed.

Higher species diversity generally indicates a more complex and healthier community because of the variety of species tolerable for more climatic difference; hence it helps to have a greater system of stability by making good environmental conditions. A forest is said to have high species diversity, with many woody species nearly equally abundant. The species evenness value ranges between 0 and 1. When it is 0, the area is dominated by single species and when it is 1, the species are evenly distributed in the area. This indicates that the species in the study forest were evenly distributed. The studied forest has also a higher value of species diversity and evenness compared with Kurib Forest with average values of 1.81 and 0.81 respectively. This higher value of species diversity and evenness in this restoration forest is achieved due to the unlimited protective efforts of the district agricultural sector experts and the local community by itself.

## Vegetation structure

The percentage frequency and relative frequency values of each woody species in Nacho mountain restoration forest were determined. According to the result, it was found that *Vernonia auriculifera* and *Croton macrostachyus* were the most frequent woody plant species occurring in 43.3% of the quadrats followed by *Albizia schimperiana, Carissa spinarum, Acacia abyssinica*, and *Rosa abyssinica*, which accounted 36.7%of the sample plot. Whereas *Ficus sur, Ficu sthonningii, Embelia schimperi, Catha edulis,* and *Olea europaea* were the least frequent species with 3.3% of the total sample quadrat in the study forest (Table 2).

TABLE 2
**Frequency of woody species (%) in descending order**

| Species name | No of quadrants the spp. occure | %Frequency | Relative frequency |
|---|---|---|---|
| *Vernonia auriculifera* | 13 | 43.3 | 4.7 |
| *Croton macrostachyus* | 13 | 43.3 | 4.7 |
| *Albizia schimperiana* | 11 | 36.7 | 3.78 |
| *Carissa spinarum* | 11 | 36.7 | 3.78 |
| *Acacia abyssinica* | 11 | 36.7 | 3.78 |
| *Rosa abyssinica* | 11 | 36.7 | 3.78 |
| *Ficus sur* | 1 | 3.3 | 0.343 |
| *Catha edulis* | 1 | 3.3 | 0.343 |

| | | | |
|---|---|---|---|
| *Ficu sthonningii* | 1 | 3.3 | 0.343 |
| *Embelia schimperi* | 1 | 3.3 | 0.343 |
| *Olea europaea* | 1 | 3.3 | 0.343 |

## Density of woody species

According to the result, the density of trees in the study forest with DBH ≥ 2.5 cm was 419 individual's ha-1, those with DBH ≥ 10 cm was 115 individual's $ha^{-1}$ and those with DBH ≥ 20 cm was 111 individual's ha-1. Similarly, this forest edge density was 289, 85, and 78 individual's $ha^{-1}$ respectively based on the above-listed DBH ranges. This confirmed that the inner restoration forest density was much higher than the edge of this forest. According to the result of individual tree density, *Vernonia auriculifera* is the densest shrub followed by *Carissa spinarum*, *Croton macrostachyus*, *Acacia abyssinica*, *Milletia ferruginea* respectively.

The analysis result showed that the majority of woody plant species were distributed in DBH class ≥ 2.5 cm and the least woody plant species were distributed in DBH class ≥ 20 cm. This indicates that there were a high proportion of shrubs and small-sized individual tree species within the forest. The proportion of density of woody plants with DBH class ≥ 10 cm to DBH class ≥ 20 cm for the present study forest is 1.04. This density ratio is higher than the density ratio of Kurib forest which was 0.469. This indicates that there are large number of shrubs and small-sized individual trees in the study forest. The result indicated that there is a selective cutting of large trees for firewood, charcoal, timber production, and building by local communities. From the result, the density of this restoration forest in the town of Merawi was less than the density of trees of Gedo and Amoro natural forests with the density of 781.9 and 2860.5 individual's ha-1 respectively for DBH class ≥ 2.5 cm.

## Height of trees in the forest

Individual trees recorded in the study area were classified into eight height classes, 1) <5 m, 2) 5.01-10 m, 3) 10.01-15 m, 4) 15.01-20 m, 5) 20.01-25 m, 6) 25.01-30 m, 7) 30.01-35 m and 8) > 35 m. There were a higher number of shrubs and tree individuals in the height (class1) which accounts for 2140 individuals with 1783.3 (89.2%) of the total height classes. The species that contribute to the values in the lowest height class were *Rumex nervosus, Rubus apetalus, Psidium guajava, Vernonia auriculifera, Justicia schimperiana, Acanthus pubescens, Bridelia micrantha, Osyris quadripartite, Clausena anisata, Carissa spinarumetc*. The percentages of trees in height class 2 (5.01-10 m) is 180 individual with 150 (7.4%) class 3 (10.01-15 m), 34 individual with 28.3 (1.4%) class 4 (15.01-20 m), 40 individual with 33.3 with (1.7%), class 5 (20.01-25 m), 11 individual with 9.2 (0.5%), class 6 (25.01-30 m), 9 individual with 7.5 (0.4%), class 7 (30.01-35 m), 7 individual with 5.8 (0.3%) and 8 (>35 m), 2 individual with 1.7 (0.08%) contributed the cumulative height classes in the forest respectively. From the analysis, tree species distributed in height classes 7 (30.01-35 m) and 8 (>35 m) dominated the upper covering of the forest, these were *Ficus vasta, Ficus thonningii, Croton macrostachyus, Cordina africana, Albizia schimperiana, Cupressus lusitanica, Ficus sur, Maytenus obscura*, and *Syzygium guineenes*, were the growing tree which grows above all the canopies of trees in the forest due to their average height. The individual tree distribution value from lower class to highest was absolutely decreasing.

## Diameter at Breast Height (DBH)

The DBH were classified into five classes 1 (2.5-10 cm), 2 (11-20 cm), 3 (21-30 cm), 4 (31-40 cm) and 5 (>40 cm). The woody plants' DBH distribution result showed that the majority of woody plant species distributed in the first class (2.5-10 cm) which has a total of 420 individuals with 350 (65.2%) individuals per hectare. The least woody plant species distributed in DBH class 5 (>40 cm) has a total of 15 individuals with 12.5 (2.3%) $ha^{-1}$, and also DBH class 2 (11-20), class 3 (21-30), and class 4 (31-40) have a percentage of 18.2%, 7.8%, 6.5% individual per hectare respectively (Figure 4). Generally, the result showed as the DBH class increased distribution of individual trees decreased in different size classes as a result the distribution of total individuals showed an inverted J-shaped (Figure 4). This distribution pattern implies that the forest is on the status of good regeneration and recruitment potential. Similar to this finding and also found an inverted J-shaped pattern of DBH structure.

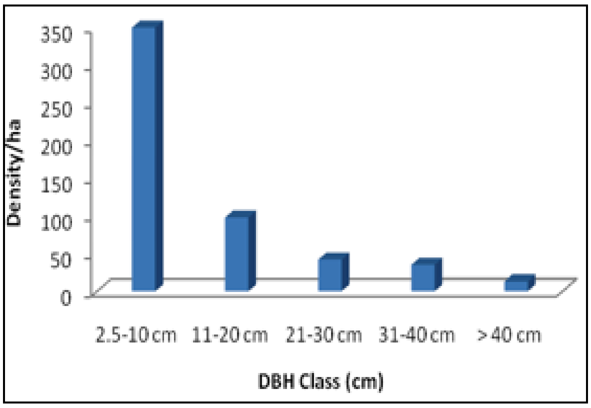


**Figure 4)** *DBH classes and numbers of individuals per hectare*

## Basal area of woody species

The cumulative basal area of woody species in the forest was 206.6 $m^2ha^{-1}$. Although few species contributed to the higher basal area classes on the other hand most species have small basal areas (Table 3). According to the result, *Acacia abyssinica*, *Albizia schimperiana*, *Milletia ferruginea*, *Croton macrostachyus*, *Eucalyptus camaldulensis*, and *Stereospermum kunthianun* were the major tree species contributed to the higher basal area in the forest. Species that contributed to the least basal area in the study forest were *Maytenus obscura*, *Acanthus pubescens*, *Pavetta abyssinica*, *Clausena anisata*, etc. (Table 3). The basal area of Nacho mountain restoration forest was higher as compared with the basal areas of other forests such as Gedo forest 35.45 $m^2ha^{-1}$, Alemsaga 75.3 $m^2ha^{-1}$, Taragedam 115.4 $m^2ha^{-1}$, Kurib forest 105.7 $m^2h^{-1}$, and Angada forest 78.8 $m^2h^{-1}$. This revealed that Nacho forest has relatively the highest DBH value that is, a high number of mature species, as copared with other mountain forests of Ethiopia.

**TABLE 3**
**Basal area of woody species in descending order $m^2ha^{-1}$**

| S. no | Species name | Basal area | Relative basal area | Rank |
|---|---|---|---|---|
| 1 | *Acacia abyssinica* | 76.9 | 33.9 | 1 |

| | | | | |
|---|---|---|---|---|
| 2 | *Albizia schimperiana* | 42.9 | 18.9 | 2 |
| 3 | *Croton macrostachyus* | 28.26 | 12.5 | 3 |
| 4 | *Milletia ferruginea* | 11.9 | 5.25 | 4 |
| 5 | *Eucalyptus camaldulensis* | 4.5 | 1.98 | 5 |
| 6 | *Stereospermum kunthianun* | 3.56 | 1.6 | 6 |
| 7 | *Maytenus obscura* | 0.13 | 0.06 | 7 |
| 8 | *Acanthus pubescens* | 0.12 | 0.05 | 8 |
| 9 | *Pavetta abyssinica* | 0.07 | 0.03 | 9 |
| 10 | *Clausena anisata* | 0.01 | 0.004 | 10 |

## Important Value Index (IVI) of woody species in nacho forest

The Importance Value Index (IVI) indicates the structural importance of a species and it is calculated by the sum of Relative Dominance (RDO), Relative Density (RD), and Relative Frequency (RF) of species in the study area. IVI gives a more realistic figure of dominance from a structural point of view. It is useful to compare the ecological significance of species. The species with the greatest importance value are the most dominant of particular vegetation.

**TABLE 4**
**Importance Value index of woody plant species in descending order**

| S. no | Species name | RF | RD | RDO | IVI | Rank |
|---|---|---|---|---|---|---|
| 1 | *Acacia abyssinica* | 3.78 | 4.9 | 27.5 | 36.6 | 1 |
| 2 | *Albizia schimperiana* | 3.78 | 3.3 | 18.9 | 26 | 2 |
| 3 | *Carissa spinarum* | 4.12 | 3 | 8.6 | 15.7 | 3 |
| 4 | *Croton macrostachyus* | 4.46 | 5.5 | 12.5 | 22.5 | 4 |
| 5 | *Vernonia auriculifera* | 4.46 | 8 | 1.1 | 13.6 | 5 |
| 6 | *Catha edulis* | 0.343 | 0.08 | 0.0088 | 0.43 | 50 |
| 7 | *Ficus sur* | 0.343 | 0.2 | 0.16 | 0.7 | 51 |
| 8 | *Olea europaea* | 0.343 | 0.2 | 0.017 | 0.6 | 52 |
| 9 | *Psidium guajava* | 0.343 | 0.2 | 0.0013 | 0.5 | 53 |
| 10 | *Rubus apetalus* | 0.343 | 0.2 | 0.002 | 0.5 | 54 |

Based on the result *Acacia abyssinica, Albizia schimperiana, Croton macrostachyus* and *Vernonia auriculifera* were the most dominant woody species (Table 4). These species are well adapted to high-pressure disturbance, natural and environmental factors. Whereas *Catha edulis, Ficus sur, Olea europaea, Psidium guajava,* and *Rubus apetalus* are species among the lowest relative IVI values species (Table 4).

## Population structure of selected woody species in Nacho forest

According to the result of the study, four general patterns of population structure were recognized. The population structure of some selected tree and shrub species in Nacho mountain restoration forest was determined using their density at the various DBH classes. These population structures were described using four representative species (Figure 5).

The first pattern is represented by *Osyris quadripartite* (Figure 5A). This pattern indicates the presence of the highest density in the lower DBH classes with a gradual decrease in density towards the larger classes. It represents an inverted J-shaped curve and it suggests good reproduction and recruitment. The result is similar in Gedo forests; Saleda Yohans Church Forest and Wonjeta forest.

The second pattern was represented by *Juniperus procera* (Figure 5B). This species has the highest density in higher DBH classes and low density in the middle DBH classes and slightly increase in the lower DBH classes. The species with this type of pattern (U-shaped) have large individuals that are less competent to reproduce and in a weak position of regeneration status.

The third population structural pattern consists of a species in the higher DBH classes and absent from the lower and middle DHB classes. This pattern was represented by *Ficus vasta* (Figure 5C). All The other Muraceae family was shown these types of pattern in the study forest.

The fourth pattern was zigzag or irregular- represented by *Milletia ferruginea* (Figure 5D). In this pattern, the lowest DBH classes have lower densities followed by an increase in the number of individuals towards the middle classes and then a progressive decrease towards the higher DBH classes and finally terminate by a slight increase for DBH classes seven and eight. Species with such a distribution pattern indicate poor reproduction and recruitment which may be associated with different factors that inhibit reproduction or the presence of only a few seed-bearing individuals. Many changes in land use and land cover patterns and change with the elevation gradient highly determined the dynamics of vegetation population structural patterns.

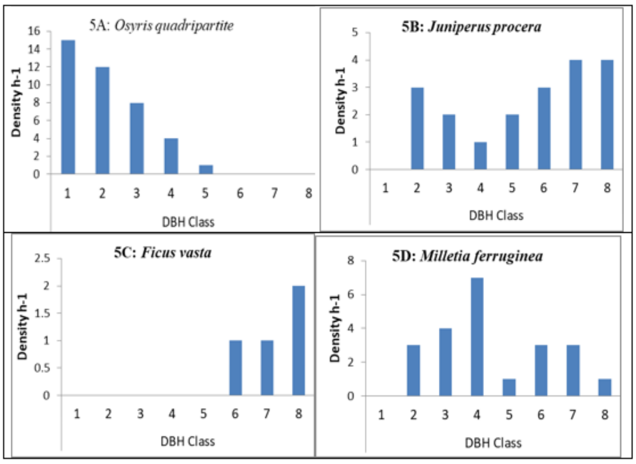


**Figure 5)** *Population structure pattern of selected woody species within 8 DBH class for, Osyris quadripartite (5A), Juniperus procera (5B), Ficus vasta (5C), and Milletia ferruginea (5D)*

## Regeneration of woody species in Nacho restoration mountain forest

The population structure of a species in a forest can suggest its regeneration performance. The population structure characterized by the presence of a sufficient population of seedlings, saplings, and adults indicate successful regeneration of forest species and the presence of saplings under the canopies of adult trees indicates the future composition of a community and healthy. The density of seedlings, saplings, and mature trees comprised 1125 individuals with 937.5 $h^{-1}$ (47.2%), 646 individuals with 538.3 $h^{-1}$ (27%), and 617 individuals with 514.2 $h^{-1}$ (25.8%) respectively. According to the result, the ratio of seedlings and saplings to mature individuals was 1.74:1 and 1.04:1 respectively. The result revealed that the distribution of seedling individuals was greater than sapling, and sapling was greater than mature individuals. Based on this comparison and according and it is indicated that the regeneration status of the forest is in good and healthy condition. The presence of good regeneration potential shows the stability of the species in the environment. Climatic factors and biotic interferences influence the regeneration of different species in the area. Similar results were found in church forests of Saleda Yohanes Church forest and Wonjeta St Michael Church Forest.

However, some of the woody species like *Maytenus obscura, Ficus sur, Syzygium guineense, Eucalyptus camaldulensis, Catha edulis, Petrobium stellatum, Jusminum grandiflorum, Ficus vasta, Cordia africana, Rubus apetalus, Rhamnus prinoides, Ficus thonningii, Embelia schimperi* did not show good regeneration status. Similar result was found in Weiramba forest and Taragedam forest. This implies the density of seedlings, saplings, and mature trees are not proportionally increased respectively. So those species need special attention or conservation priority in the forest.

Depending upon the general pattern of the frequency distribution of size classes, the regeneration of all woody species was divided into three regeneration patterns (Figure 6). The first pattern of seedling, sapling, and mature tree distribution (Figure 6A) showed a higher number of seedlings than saplings and the number of saplings is relatively greater than that of mature individuals of trees or shrubs. The pattern has many individuals at the seedling stage and decreasing number of individuals successively at the saplings and adult stages and exhibited a typical inverted J-shape curve. This is because, before ten years the vegetation was highly influenced by the local community for different purposes but currently agricultural experts, the local community, and other concerned bodies relatively protect the study forest. Woody plant species like *Calpurnia aurea, Vernonia auriculifera*, and *Croton macrostachyus* have huge numbers of seedling than sapling and mature trees showed an in inverted J-shape pattern that implies these species have good regeneration potential. Similar result was found.

The second pattern of seedling, sapling and mature trees distribution (Figure 6B) had higher number of seedling and mature individuals than saplings. The regeneration pattern forms U-shape which indicated that there was less number of saplings than adult and seedling individuals in the forest. This may suggest that life span of seedling to sapling was disturbed by environmental factors like moisture content or water availability, organic matter and other factors such as grazing. Species in this pattern includes *Milletia ferruginea, Gardeinia ternifolia, Grewia ferrujinea, and Cassia singueana* etc. This patern of distribution for those woody species also found in Gedo forest and Taragedam forest.

The third pattern of seedling, sapling, and mature tree distribution (Figure 6C) was represented by a zigzag or irregular type of distribution. This pattern may result due to selective cutting by local community for different activities like timber, charcoal, construction, etc. woody species in this pattern includes *Premna schimperi, Olea europae, Lippia adoensis, Acanthus pubescens* etc.

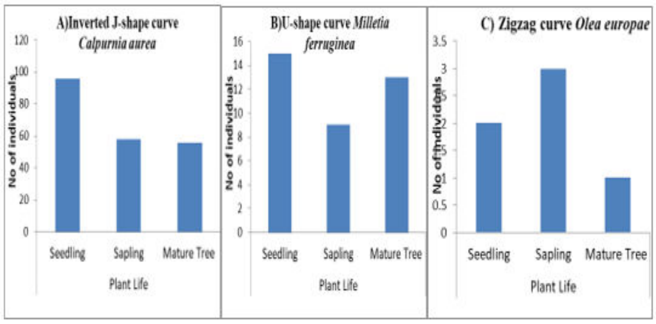


**Figure 6)** *Seedlings, saplings, and mature individual distribution of some selected species as Inverted J-shape curve in Calpurnia aurea (A), U-shape curve in Milletia ferruginea (B), and Zigzag pattern distribution in Olea europae (C)*

## CONCLUSION

This restoration forest in the town of Merawi is rich in woody plant composition and diversity compared to other similar mountain natural forests and even some of sacred groves of the country. Therefore, the Nacho restoration forest has an important role as a reservoir of biodiversity and conservation of threatened plant species as seed source. The higher frequency, diversity, and evenness values of woody species showed the forest has high heterogeneity or diversity of woody species in the study area. The structural result indicated that there was the occurrence of selective cutting of large trees in the forest since the last 10 years. From the result of data analysis of IVI and basal area of woody plants *Albizia schimperiana, Acacia abyssinica*, and *Croton macrostachyus* are the most dominant woody plant species in the forest. The DBH class data also suggests the forest is in a good reproduction and regeneration potential of the vegetation. However, the edge of this restoration forest was very less in composition, density, and diversity since still affected by human influences like agricultural expansion, grazing, and fuel wood collection in the area.

## RECOMMENDATION

Such restoration forest in town provides economic, social, and recreational importance to urban communities living in and around the area. Restoration forest if well maintained can be used as a reservoir of plant biodiversity, recovery of forest structure, and ecological functioning. However, some of the woody plant species in this restored forest with the lowest IVI such as, *Catha edulis, Ficus sur, Olea europaea, Psidium guajava*, and *Rubus apetalus* are highly threatened species that need to have special conservation. In line with this local community and other stakeholders should pay attention and give priority to the conservation of these woody plant species. Sustainable management is recommended in this forest to tackle the present human influence on some selected woody species especially at the edge of the forest. It can also be recommended that it is possible to have forest restoration in such a highly populated town. Restoration of scattered small-sized remnant forests in northern part of Ethiopia is mandatory to save vegetation diversity. Moreover, further research to monitor and evaluate vegetation change, soil-plant relation, and carbon sequestration potential of this restoration forest is recommended.


## ACKNOWLEDGMENTS

We would like to acknowledge Bahir Dar University, Ethiopia for the financial and technical support of this work. We also express our gratitude to Mecha District agricultural office and regional forestry enterprise for allowing us to access the forest during data collection.


## DATA AVAILABILITY

The data used to support the findings of this study are available from the corresponding author upon request.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

## REFERENCES


1. Mekonen Ab, Gebreegziabher Bg, Wassie Wa, et al. Church forests the green spots of Ethiopian highlands. Asian J For. 2019;3.
2. Kebede B, Soromessa T, Kelbessa E. Structure and regeneration status of gedo dry evergreen montane forest, west shewa zone of oromia national regional state, central Ethiopia. Sci Technol Arts Res J. 2014;3:119-131.
3. Gepts P. Tropical environments, biodiversity, and the origin of crops. 2008;1-20.
4. Senbeta F. Moist Montane Forests of Ethiopia. 2011;103-134.
5. Kindt R, Van Breugel P, Lillesø JP, et al. Potential natural vegetation of eastern Africa (Ethiopia, Kenya). 2014.
6. Cardelús CL, Woods CL, Bitew Mekonnen A, et al. Human disturbance impacts the integrity of sacred church forests, Ethiopia. PLoS One. 2019; 14:e0212430.
7. Woods CL, Bitew Mekonnen A, Baez-Schon M, et al. Tree community composition and dispersal syndrome vary with human disturbance in sacred church forests in Ethiopia. Forests. 2020;11:1082.
8. Klepeis P, Orlowska IA, Kent EF et al. Ethiopian church forests: a hybrid model of protection. Hum Ecol. 2016;44:715-730.
9. Birhanu L, Bekele T, Demissew S. Woody species composition and structure of Amoro forest in west Gojjam zone, north western Ethiopia. J Ecol Nat Environ. 2018;10:53-64.
10. Singh S, Malik ZA, Sharma CM. Tree species richness, diversity, and regeneration status in different oak (*Quercus* spp.) dominated forests of Garhwal Himalaya, India. J Asia-Pac Biodivers. 2016;9:293-300.
11. Abuye F, Haile M, Haile W. Soil fertility status, fertilizer application and nutrient balance in SNNPR, southern Ethiopia in contrasting agro-ecological zones of Ethiopia. Afr J Agric Res. 2021;17:1433-1452.
12. Bekele-Tesemma A, Tengnäs B. Useful trees and shrubs of Ethiopia: identification, propagation, and management for 17 agroclimatic zones. 2007.
13. Hedberg I, Edwards S, Demissew S. Flora of Ethiopia: *Poaceae* (Gramineae). 1989.
14. Hedberg I. Flora of Ethiopia and eritrea. 1996;802-804.
15. CE S. Weaver W. The mathematical theory of communication. Urbana: University of Illinois Press. 1949.
16. Dhaulkhandi M, Dobhal A, Bhatt S, et al. Community structure and regeneration potential of natural forest site in Gangotri, India. J Basic Appl Sci. 2008;4:49-52.
17. Zegeye H, Teketay D, Kelbessa E. Diversity and regeneration status of woody species in Tara Gedam and Abebaye forests, northwestern Ethiopia. J For Res. 2011;22:315-328.
18. Birhanu T, Mohammed AS, Mekonnen AB. Floristic composition, structure and regeneration status of woody plants in church forests of Dangila, Northwestern Ethiopia. Cogent Food Agric. 2021;7:1911438.
19. Hemade MB, Abebe W. Floristic composition and vegetation structure of woody species in Lammo natural forest in tembaro Woreda, kambata-tambaro zone, southern Ethiopia. Am J Agric For. 2016;4:49-55.
20. Teshager Z, Argaw M, Eshete A. Woody species diversity, structure and regeneration status in Weiramba forest of Amhara region, Ethiopia: implications of managing forests for biodiversity conservation. J Nat Sci Res. 2018;8:16-31.