Article

Woody species diversity, composition, and regeneration status across vegetation types and elevation gradients in Jorgo-Wato Natural Forest, West Wollega Zone, Ethiopia

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Abstract
The present study was conducted to assess woody species diversity, composition and natural regeneration status of Jorgo Wato Natural Forest across different vegetation types and altitudinal gradients. A forest was stratified into three vegetation categories including Tree grass land (TGL), High forest (HF) and Dense wood land (DWL). The altitudinal gradients in each vegetation type were classified in to three ranges from the bottom to the top of the forest. A three parallel transect lines were laid down vertically in each vegetation type along altitudinal gradients. A total of 36 nested quadrats having 20 m x 20 m and 1 m x 1 m sub-plots were laid down following altitudinal gradients along the transect lines to collect vegetation data, parameters like diameter at breast height (DBH) and tree height (H) and counting seedlings. The finding of the present study identified a total of 39 woody species that belong to 35 genera and 30 families in the forest. The total number of woody species recorded from the three vegetation types (TGL, HF and DWL) was found to be 26, 26 and 21 in the respective order. The overall mean stem density/ha, species richness/plot, Shannon-Wiener Diversity Index (H’) and evenness (J) were 1087.5 plants/ha, 8.09, 1.715 and 0.81, respectively.The lower diversity index value of woody species (1.715), show that the woody species diversity among vegetation types was not significantly different. The species richness, Shannon-Wiener Diversity Index and evenness significantly varied ($p<0.05$) along elevation gradient but statistically did not show significant different ($p>0.05$) among vegetation type. Therefore, the best way and design to protect forest regarding natural vegetation categories need to be applied to enhance and expand the benefits of ecosystem services, mainly the potential of carbon storage in climate change mitigation.

Keywords altitudinal gradients; natural regeneration; vegetation; woody species diversity.

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1 Introduction

Ethiopia has great cultural and natural diversity with a variety of climates due to its topographical position and latitude. There is a large difference in altitude from 116 m below sea level at Dalol to 4620 m above sea level at Semien.These differences, together with soil variations, form the basis of the country's vast biodiversity (CBD, 2009). There are about 6,500 to 7,000 species of higher plants, of which about 12% are endemic to Ethiopia (Hedberg et al., 2009).

Forests play an important role in providing various ecosystem services. The environment and economic development of many countries are strongly influenced by ecosystem-derived forest resources (Agrawal et al., 2013). The density of woody species could be changed by several factors. Particularly, the types of vegetation and elevation effects could change the capacity of species density of Ethiopian forests in general and moist evergreen in particular (Kendie et al., 2021). The change in woody species density is associated with changes in altitude, the forests past, and its current distance from the forest's edge (Shumi et al., 2019). These modifications enhance the dynamics of species diversity across the forest landscapes (Dimobe and Kuyah, 2019).

At the moment, most of the remaining forests of the country are confined to south, south–western and western parts of the country. The montane moist forest ecosystems comprise the high forests of the country and are found mostly on the south-western plateau, with an altitudinal range between 800 - 2,500 m.a.s.l. The forests are the main remnant forests in the country which is providing the role in woody species diversity (Binyam et al., 2015). Basically, forest in the southwest of Ethiopia has relatively high forest cover as compared to other parts of the country, about 56% of the country’s forest cover (Senbeta et al., 2014). In terms of the woody plant diversity, more than 160 species are recorded from the south-western plateau. However, the deforestation associated with poor forest management has led to major changes in these forests, with major impacts on plant species. Due to the increase in human population, the majority of the forests have been damaged by various anthropogenic activities (Geeraert et al., 2019). The most striking change in the montane moist forest ecosystems is caused by human activities in the form of timber extraction, coffee and tea plantations, agricultural expansion, human settlement and fire hazards. As a result of the selective felling of trees for timber, few species are targeted and those that are of low commercial value are remaining with very few over-matured individuals of quality timber species (CBD, 2009).

Jorgo-Wato Natural Forest (JWNF) is one of the remnants of moist Afromontane evergreen forests in Ethiopia found in western country and is home to a variety of woody species that could provide a wide range of ecosystem services (Balemi et al., 2022). However, forest had been converted to crop farming and other agricultural land due to a lack of long-term conservation strategies and management plan (Mosissa et al., 2019). This suggests that the forest's cover has been shrinking year after year. The majority of the species were also reported to have low significance value score, implying that species diversity is becoming increasingly rare owing to anthropogenic disruptions (Balemi et al., 2022).

Even though some studies have been conducted on forest, no study has been conducted on woody species diversity, composition and natural regeneration status across different vegetation types and altitudinal gradient on the study forest. The current study was, therefore, designed to fill the data gap with respect assessing the dynamics of woody species diversity, composition and natural regeneration of Jorgo-Wato Natural Forest under different vegetation types along altitudinal gradients. Quantifying the diversity of woody species and the carbon stock across various vegetation types is very critical for future carbon trade and forest biodiversity conservation issues. The study was initiated to pave the way on how to design and implement forest management plan that will in turn lead to conservation of forest species.

2 Methods

2.1 Description of the study area

Jorgo-Wato Natural Forest is located between Nole Kaba district (West Wollega Zone) and Meko district (Ilubabor Zone) with much of the forest area is in the Nole Kaba district, Western Oromia, Ethiopia. Its location is from 8°43′30″ N -8°47′30″ N latitude and 35°49′30″ E -35°57′30″ E longitude (Fig. 1), and its altitude ranges from 1950 to 2584 m a.s.l. The total concession area of the forest is 8439.867 ha of which 943.78 ha and 7496.087 ha are covered by plantation and natural forest components respectively (OFWE, 2021). Jorgo-Wato Forest is situated within altitudinal ranges from 1950 to 2584 m a.s.l. The surrounding area, including the forest, has a warm climate. It has a subtropical (Woina Dega) climate and has a uniformly distributed annual rainfall (Mosissa et al.2019). While the dry season spans from November to March, the wet season runs from April to October, with the heaviest rainfall occurring between June and September. According to NASA (2022) report, the mean annual rainfall of the area from 1999 to 2020 was 1700 mm with the highest mean monthly rainfall (280 mm) was recorded in July while the lowest (14 mm) was recorded in January.

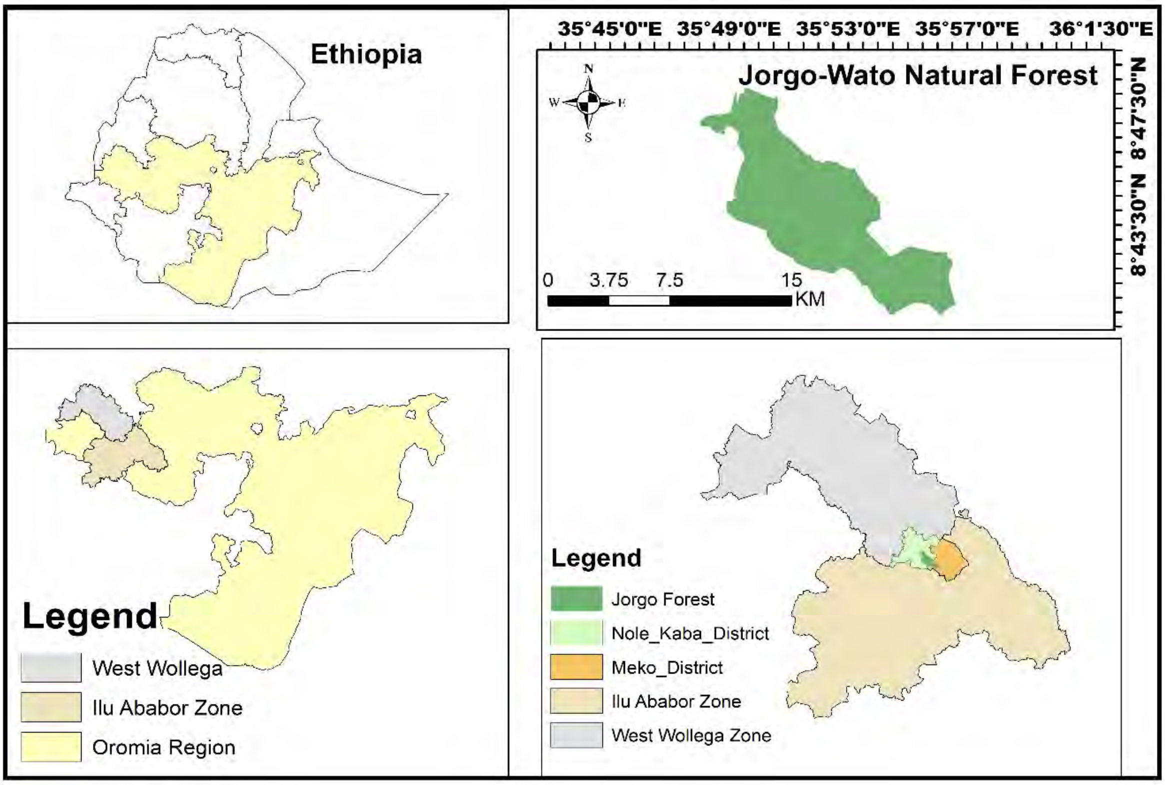


Fig. 1 Geographical location of Jorgo-Wato Natural Forest.

Regarding temperature, the mean monthly maximum (28°C) was recorded in February and March whereas the mean monthly minimum (12°C) was recorded in July and August. According to the report of Nole Woreda Agricultural Office (2022), the soils are well drained, strong to moderately acidic, deep, and reddish-brown in color. The forest is characterized under Moist Evergreen Afromontane Forest since its altitude is ranged from 1950 to 2584 m a.s.l. (Friis et al., 2010).

Jorgo-Wato Forest enriched withendemic trees and could be considered as one of the country's centers of plant diversity (Balemi et al., 2022). It mostly comprises of natural and plantation forests with evergreen trees, shrubs and grasses (OFWE, 2021). In terms of living forms, the vegetation area can be categorized into various classes such as high natural forest, dense woodlands, and Tree grasslands. The forest contains some woody species which could store more carbon and could be recommended as one of the future carbon trade center in the country (Mosissa et al., 2019).

2.2 Data types and sources

To achieve the objectives of the study, both primary and secondary data were used. Primary data was obtained from field vegetation survey, whereas secondary data was obtained from recently published scientific articles, journals and project reports on biomass assessment of evergreen moist Afromontane forests in Ethiopia.

2.3 Sampling design and data collection methods

2.3.1 Reconnaissance survey

Reconnaissance survey was conducted in August 2022 in order to gain a general understanding of the forest, to gather sufficient data regarding the vegetation composition and topographical condition of the forest, as well as to identify appropriate sampling points. Accordingly, sites that represent different features of natural vegetation were surveyed and identified mainly through physical observation with the support of local people and the respective Woreda experts.

2.3.2 Stratification of study area

The Natural vegetation of the forest was stratified in to three different vegetation categories, namely, High Forest (HF), Tree Grass Land (TGL) and Dense Woodland (DWL) following the method employed by Breuer (2012) and according to the guideline suggested in Pearson et al. (2005). Since stratifying forests is necessary to capture the differences on C stocks in different pools (IPCC, 2008), the forest was divided into different categories. The stratification process took into account the stand feature, vegetation composition and characteristics of the forest across different landscapes.

Table 1 Description of the vegetation determined through stratification in the forest.

Vegetation Type	Symbol	General Description Adopted
High Forest	HF	A relatively continuous cover of trees, which are evergreen or semi-deciduous, only being leafless for a short period, and then not simultaneously for all species. The canopy should preferably have more than one story (EFCCC, 2017).
Dense Woodland	DWL	A continuous stand of trees with a crown density of between 20 - 80%. Mature trees are usually single storied, although there may be layered under-stories of immature trees, and of bushes, shrubs and grasses/forbs (EFCCC, 2017).
Tree Grass Land	TGL	Grasslands with scattered or assemblies of trees, with a canopy cover lower than 20% of the total surface. The land is covered by some grasses with scattered patterns of trees (Hanan and Hill, 2012).

Source: The vegetation stratification modified from Breuer (2012).

2.3.3 Sampling design and data collection

The altitudinal ranges of each vegetation type were determined from the GPS reading points. The altitude of each vegetation type were classified into three elevation ranges including 1950-2161 m.a.s.l (LA), 2162-2373 m.a.s.l (MA) and 2374-2584 m.a.s.l (HA) based on the elevation ranges of the forest following the method employed by Dibaba et al. (2020). In other words, an altitudinal difference of (211 m) was maintained between the lower-middle and (210 m) was maintained between middle-upper elevations in each vegetation type.

Three parallel transect lines were systematically established in each vegetation type along the altitudinal gradient, going from the lowest to the highest altitude. There were distances of 300 m between adjacent transect lines. In order to collectvegetation data, nested sampling plots were set up systematically at every 300 m distances; following altitudinal gradients in each transect line. To completely eliminate the impact of edge effects, all plots were placed at least 150m away from the closest roads and other biophysical factors (Hairiahet al., 2001). Following the techniques used by Yohannes (2016), Ayalew et al. (2018), Mewded and Lemessa (2020) and Asfawet al. (2019), a total of 36 nested plots having 20 m x 20 m (400 m^2) were set up along altitudinal gradientstocollect data. On other hand, 12 nested quadrats were laid downsystematically in each vegetation type following altitudinal gradients.The five sub-plots within the main plot were used to count the number of seedling of woody plants (less than 1.5 m) for estimation of natural regeneration (Chauhan et al., 2008).

2.4 Data analysis

2.4.1 Woody species diversity analysis

Species diversity was calculated using the Shannon–diversity index. Shannon–diversity index provides an account of both the abundance and evenness without disproportionately favoring any species as it counts all the species according to their frequency.

Species richness, Shannon–Wiener diversity index and evenness were computed following Maguran (1988) and Krebs (1999) formula.

Species diversity was calculated using the Shannon–Wiener diversity index, H′, as

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

where H′ is Shannon diversity index, *s* is the number of woody species and *pi* is the proportion of individuals or the abundance of the i^{th} species expressed as a proportion of the total and ln is the logarithm to base e(ln = log base).

Shannon's evenness, *J*, was calculated as the ratio of observed diversity, H′, to the maximum diversity, Hmax, using the following equation:

$$J = \frac{H'}{\ln(s)} \qquad (2)$$

where, ln(s) is the natural logarithm of the total number of species evenness (a measure of species abundance). A value of evenness approaching zero reflects larger difference in abundance of species, whereas the higher evenness value means all species are equally abundant or even their distribution within the sample quadrant (Mebrat et al., 2014). DBH, tree height, basal area, relative dominance, relative density, relative frequency and importance value index were determined to describe the vegetation structure and woody species diversity of the forest.

Species richness(S): is the total number of species present within a plot.

Density (D): is the total number of individuals of a species per sample area (ha^{-1}).

Frequency (F): is the percentage of the number of plots where a species occur per total number of plots.

$$\text{Basal area (Ba)} = \frac{\pi * (DBH)^2}{4} \qquad (3)$$

where, π = 3.14; Ba is basal area; DBH is diameter at breast height.

Relative density (RD), relative frequency (RF), and relative dominance (RDO) were computed for each species using the following formulas:

$$RD = \frac{di}{dt} \times 100 \qquad (4)$$

where, RD is relative density, di is density of the i^{th} species (number of individuals of species) per the $d_t$the total density of all species in the sample (total number of individuals of all species).

$$\mathrm{RF} = \frac{fi}{ft} x100 \quad (5)$$

where, RF is relative frequency, f_i is the frequency of the i^{th} species, and f_t is the total frequency of all species in the sample.

$$\mathrm{RDO} = \frac{\text{Basal area of a single species}}{\text{Total basal area of all species}} \mathrm{X}100 \quad (6)$$

where RDO is relative dominance.

Importance Value Index (IVI) for each species was determined by adding the relative values of density, frequency and dominance following Mueller-Dombois and Ellenberg (1974) formula:

IVI=RDO+RD+RF (7)

2.4.2 Regeneration data analysis

The mean of seedlings densities per hectare was determined. Regeneration status of the forest was analyzed by comparing mean seedlings density with the matured trees (Shankar, 2001).

All data were organized by excel 2010 and analyzed using SAS software, version 9.4 M7. The analysis results subjected to two-way ANOVA. Treatment means comparison was determined using the least significant difference (LSD) at 0.05 levels of significances.

In each plot, individual tree species were identified and recorded primarily using local names with the aid of local people. Later, scientific names of the species together with their family were determined using the different volumes of Flora of Ethiopia and Eritrea (Volume 1-8) and the book Useful Trees and Shrubs for Ethiopia (Bekele et al., 2007).

3 Results and Discussion

3.1 Density and population structure of woody species

3.1.1 Density of woody species

A total density of woody species of Jorgo-Wato Forest was found to be 1087.5 stems ha^{-1}. The highest density of individual woody species (269.44/ha, 24.77%) was exhibited by *Syzygium guineense* which followed by *Macaranga capensis* (184.027/ha, 16.92%) while lowest was by *Olea europaea* (0.69/ha, 0.063%). Table 2 gives density and relative density of the top 7 abundant woody species of the forest.

Table 2 Density and relative density (RD) of the most abundance woody species in JWF.

Species name	Density ha^{-1}	Relative density (%)
Syzygium guineense	269.44	24.77
Macaranga capensis	184.027	16.92
Olea capensis	90.27	8.30
Croton macrostachyus	88.88	8.17
Maytenus gracilipes	84.72	7.79
Albizia grandibracteata	62.5	5.74
Olea welwitschi	54.16	4.98
Others	253.47	23.3

The study results revealed that there is variation in density of woody species in Jorgo-Wato Forest. Some woody species were recorded with the highest density value while others had lower value in density per hectare. This might be associated with the anthropogenic disturbances, management status and competition among species. The variation of soil characteristic, landscapes and altitude could also be the factors for stems density variation among woody species. According to Zhang et al. (2013) and Muhammed and Elias et al. (2020), the variation might be related to environmental factors, including elevation, disturbance intensity, litter thickness, slope, and aspect, among which elevation and disturbance are the most important for the distribution and richness of the species.

The total density value reported in this study (1087.5 stems ha^{-1}) was comparable to the woody species density of Ankober District (1138 stems ha^{-1}) (Aynekulu et al., 2014) while lower than of Gera Forest (1778/ha) (Mulugeta et al., 2015).The reasons for the difference might be associated with the disturbance, competition, and site productivity, size of the studied forests as well as topographic, edaphic and climatic factors.For example, several studies have reported that stem density decreases as the intensity of the disturbance increases (Senbeta et al., 2014; Gogoi and Sahoo, 2018).

3.1.2 Population structure of woody species

Diameter at Breast Height (DBH)

All woody species with a DBH≥2.5 cm were assessed in each vegetation type. In TGL, the woody species recorded with the minimum DBH was *Bersama abyssinica* (2.5 cm), while the maximum of DBH was *Ekebergia capensis* (124 cm). In HF, the minimum DBH recorded was *Apodytes dimidiate* (2.5 cm) while the maximum was *Croton macrostachyus* (122 cm). In DWL, the minimum DBH recorded was *Maytenus gracilipes* (2.5 cm) *while* the maximum was *Ficus sur* (101 cm). Furthermore, existence of difference in size of the DBH among vegetation types was determined. The average DBH of each vegetation type was 19.4 cm, 22.1 cm and 21.2 cm in TGL, HF and DWL respectively. The overall average DBH value of the vegetation in Jorgo-Wato Forest was found to be 20.93 cm.

Regarding the frequency occurrence of woody species, the highest frequency of woody species was recorded at the lower DBH (2.5-15 cm) class in all vegetation types. This on other hand reflects the number of stems decreases with increasing their diameter class (Fig. 2). This indicates that the majority of individual species is represented in smaller diameter class in all vegetation types and show prevalence of selective tree cutting on the mature trees. Although the general pattern of DBH class distribution of the forest showed an inverted J-shaped distribution showing normal distribution, matured trees were continuously removed due to anthropogenic activities. This goes in agreement with what Muhammed and Elias (2020) asserted that selective cutting of medium and larger sized of woody species for various purposes could lead to the degradation of larger trees leading to the diminishing of the larger DBH class.

In addition, uncontrolled forest consumption by the local community did cause the forest's normal DBH class distribution (Ayanaw and Dalle, 2018). Similarly, Tesfaye et al. (2019) and Boz and Maryo (2020) reported that the possible reason for missing the highest DBH class of woody species in the forest could be due to illegal selective cutting of matured trees for various purposes, including household tool making in rural and urban areas. Additionally, Teshager et al. (2018) reported that the variation in the distribution of the DBH classes of the forest could be due to the heavy degradation of the forest that resulted from the human disturbance, livestock trampling or browsing, and some other biotic and abiotic impairment that can reduce the normal recruitment potential of woody species.

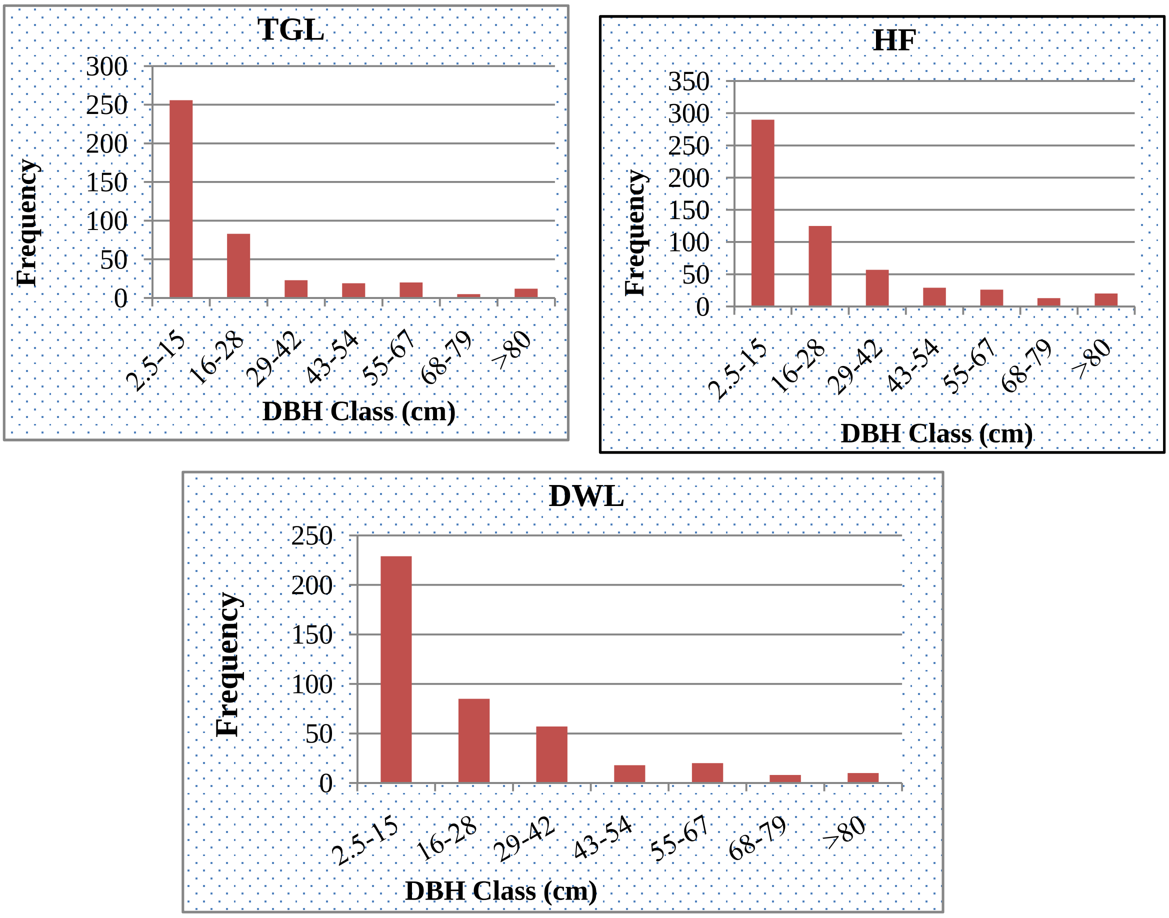
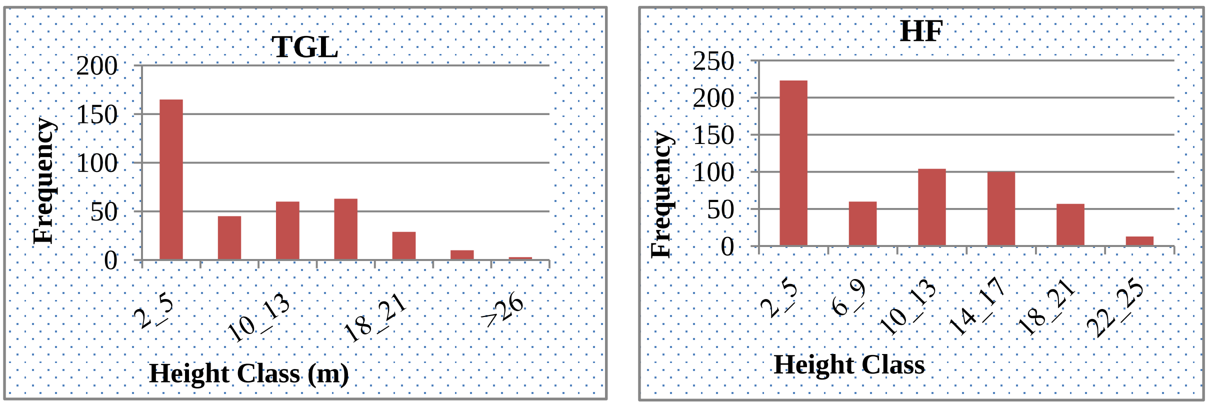


Fig. 2 DBH class distribution of woody species in JWF (HF: High Forest, DWL: Dense Woodland, TGL: Tree Grass Land).

Height class Distribution

The heights of all woody species with DBH≥2.5cm were assessed in each vegetation types. In TGL, the woody species that recorded with the minimum height was *Maytenus gracilipes* (2 m), while the maximum height was *Pouteria adolfi-friederici* (30 m). In HF, the minimum height recorded was *M. gracilipes* (2 m), while the maximum height was *Syzygium guineense* (24.5 m). In DWL, the minimum height recorded was *Maytenus addat* (2 m), while the maximum was *P. adolfi-friederici* (26 m). The average tree height for each vegetation type were 9.26 m, 9.43 m and 9.65 m in TGL, HF and DWL respectively. The overall average tree height in Jorgo Wato Forest was found to be 9.44 m. The majority of individuals of woody species are concentrated with in the lower height class in all vegetation types (Fig. 3).



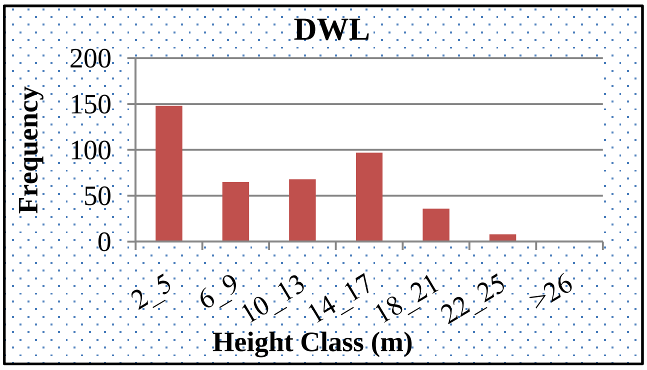


Fig. 3 Height class distribution of Woody species of JWNF (HF: High Forest, DWL: Dense Woodland, TGL: Tree Grass Land).

The height distribution of individuals of all woody species in different height classes showed an irregular distribution pattern. That means there is an increase in the frequency of medium sized diameter trees with the progressive decline of woody species individuals at the highest individual class. This may be attributed to the nature of woody species type because some woody have shorter in height. The variation in height size class might also be associated with difference in the level of management and expansion of coffee (Schmitt et al., 2010). The irregular opening of the upper canopy layer after human disturbance and natural death, opening the door to light and facilitating the natural regeneration of long-lived, shade-tolerant seedlings, could be the reason for the increase in medium sized trees and decrease in taller tree (Seyoum et al., 2022). The presence of large scale timber exploitation of matured trees is an evidence for the suggested human interference contributing to the decrease of taller tree in the vegetation. This argument is supported by Ayanaw and Dalle (2018) who asserted that the highest tree distribution in the lowest class height implies that the forest has been heavily influenced by the local anthropogenic activities including selective cutting for fuel wood, construction and illegal wood harvest for timber production.

Basal Area

The total average basal area of woody species in JWNF was 70.3 m^2. The total basal area for each vegetation types was 57.57 $m^2 ha^{-1}$, 93.32 $m^2 ha^{-1}$ and 59.99 $m^2 ha^{-1}$ in TGL, HF and DWL respectively. This indicates that there is a difference in average basal area among vegetation types. The highest basal area was recorded in HF while the lowest was recorded in TGL. For each vegetation type, the individual woody species acquiring the largest basal areas was *Syzygium guineense* (7.06 $m^2 ha^{-1}$) followed by *Macaranga capensis* (5.4 $m^2 ha^{-1}$), *Olea welwitschi* (2.787 $m^2 ha^{-1}$) and *C. macrostachyus* (2.711 $m^2 ha^{-1}$).

The present result revealed that different values of basal area were recorded among vegetation types in the forest. Various reasons can be given for the differences in basal area among each vegetation type in the forests. Density and DBH size (age) of woody species and type of woody species can be associated with the dynamics of trees basal area. According to Sagar and Singh (2006), the vegetation types with high density value may have high basal area. In addition, increasing competition for resource among species type can limit and cause variation in basal area (Tenzin et al., 2017). Anthropogenic disturbances including selective tree cutting and uncontrolled degradation could also be the cause for basal area dynamics among vegetation types.

The basal areas of woody species value determined for Jorgo-Wato was found to differ to those reported for other moist Afromontane forests. Accordingly, the basal area of the current study was lower when compared to the basal area reported by Bogale et al. (2017) for Berbere moist Afromontane Forest and Belete moist Afromontane Forest (Gebrehiwot and Hundera, 2014) which were 87.49 $m^2 ha^{-1}$ and 103.5 $m^2 ha^{-1}$ respectively. However, it was larger than the basal area of Wanzaye dry afromontane natural forest (23.3 m^2

ha^{-1}) (Getnet, 2018). This variation might be due to the management efforts, anthropogenic disturbances, agro ecology, soil type and competition among woody species for resource. Since the result of anthropogenic disturbance is the removal of larger or old trees, it could directly affect the overall basal area because clear cutting of larger trees with larger DBH class can result in a reduction of basal area. Competition for resources (light, water, nutrients, etc.) could also limit the size and abundance of live trees that reduce the growing capacity of the tree (Neumann and Hasenauer, 2021).

Frequency

The present study revealed that high number of woody species in lower frequency classes and relatively lowers number of species in high frequency classes (Fig. 5). This shows that there was a high degree of floristic heterogeneity in the forest since lower frequency may reflect clumped distribution of species while higher frequency indicates a wide distribution of species (Boz and Maryo, 2020). The finding obtained through this study is identical to what was reported by Yigeremu and Woldearegay (2022) from their study on Abbo Sacred Forest, Southern Ethiopia. The most frequently observed woody species in JWNF was *Syzygium guineense* (100%) which occurred in all quadrats followed by *Macaranga capensis* (72.2%) and *Olea welwitschi* (72.2%). Woody species with the highest frequency might have a wide range of seed dispersal mechanisms like by wind, livestock, wild animal, birds and the like and could live in all agroclimatic zones. According to Bekele (2007), *Syzygium guineense* does very well in moist and wet Kolla and Woyna Dega agroclimatic zones of all regions in the country at an altitude of 1200–2600 m and its ubiquity in the study site must have arisen from the suitability of environmental conditions for its growth.

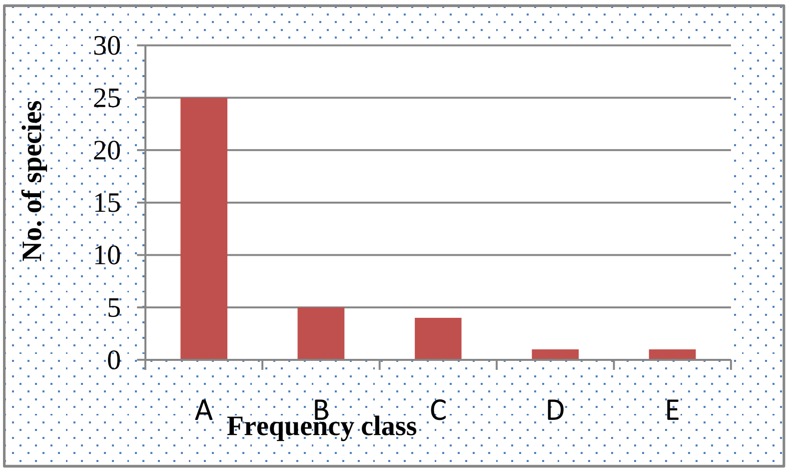


Fig. 4 Frequency class distributions of woody species in JWF (Frequency class: A: 1-20%, B: 21-40%, C: 41-60%, D: 61-80%, E: 81-100%).

Importance Value Index

The IVIs of all sampled woody species of JWNF (DBH ≥2.5 cm) varied from 0.424 to 60.17 (Table 3). The eight most ecologically significant woody species in terms of their IVI value (>10) in JWNF were *Syzygium guineense* (60.17), *Macaranga capensis* (43.43), *Croton macrostachyus* (25.5), *Olea welwitschi* (22.9), *Maytenus gracilipes* (16.31), *Albizia gummifera* (13.93), *Olea capensis* (12.84) and *Albizia grandibracteata* (10.16) (Table 3) while the less dominant woody species in terms of their IVI were *Ritchiea albersii* (0.424), *Olea europaea* (0.48), *Oncoba spinosa* (0.517), *Pittosporum viridiflorum* (0.57), *Euclea racemose* (0.62) *and Warburgia ugandensis* (0.65).

Table 3 Ecologically the most important woody species in JWNF (RD: Relative Density, RDO: Relative Dominance, RF: Relative Frequency and IVI: Importance Value Index).

Scientific name	RF	RD	RDO	IVI
Syzygium guineense	12.08	24.77	23.31	60.17
Macaranga capensis	8.72	16.92	17.784	43.43
Croton macrostachyus	8.39	8.17	8.94	25.50
Olea welwitschi	8.72	4.98	9.196	22.90
Maytenus gracilipes	8.05	7.79	0.47	16.31
Albizia gummifera	4.36	1.85	7.71	13.93
Olea capensis	4.02	8.30	0.51	12.84
Albizia grandibracteata	2.01	5.74	2.40	10.16

Different letters shows that the difference is significant at p≤0.05. DWL: Dense Woodland, HF: High forest, HA: Higher altitude, LA: Lower altitude MA: Middle altitude and TGL: Tree grassland.

It is evident from the present study that the degree of dominance and abundance of a given species were not equal in terms of their IVI value. Some woody species were dominant and could be considered as the ecologically most important species in the forest (Amanuel et al., 2018), while others with a lower IVI value are rare species. The species identified as ecologically dominant might be associated with their regeneration potential, adaptation potential and ability to grow in stress environmental conditions. On the other hand, the species with the lower IVI value recorded could be associated with anthropogenic activities, including selective logging and coffee expansion. According to Negash et al. (2013), the species with low IVI value could be seen as overexploited or improperly managed woody plants in the forest. Similarly, Mekonen et al. (2015) reported that the lower woody species in terms of their IVI value indicate that they are being threatened and need immediate conservation measures.

3.2 Woody species richness

A total of 1566 woody plants (DBH ≥2.5 cm) were assessed in Jorgo-Wato Forest. A total of 39 woody species belonging to 35 genera and 30 families were identified. The total number of woody species recorded from the three vegetation types (TGL, HF and DWL) was found to be 26, 26 and 21 in the respective order. The mean richness of woody species per vegetation in this case was 24.33.

Table 4 Woody species richness/plot of each vegetation type.

	Vegetation Types		
Elevation	TGL	HF	DWL
HA	7±0.748[a]	7.1±0.87[a]	6±0.87[b]
MA	8.62±0.478[b]	8.65±0.472[b]	7±0.0[b]
LA	10.25±0.5[c]	10.25±0.5[c]	8±0.0[c]
Mean	8.62±1.43[d]	8.66±1.4[d]	7±0.85[e]
LSD (5%)		0.266	
CV (%)		3.906	

Different letters shows that the difference is significant at p≤0.05. DWL: Dense Woodland, HF: High forest, HA: Higher altitude, LA: Lower altitude MA: Middle altitude and TGL: Tree grassland.

The mean richness of woody (species/plot) in the three vegetation types (TGL, HF and DWL) was found to be 8.62, 8.66 and 7 in the respective order (Table 2). The average woody species richness/plot in the three vegetation type was 8.09. Analysis of species richness in the three vegetation types revealed thatthe mean woody species richness/plot in TGL and HF was significantly higher than of the richness in DWL. This could primarily be due to the fact that a greater concentration of woody species is expected in forests with dense trees when compared to other vegetation types (Sintayehu et al., 2020). Secondly, the significant difference might have resulted from the heterogeneity of forest patches, soil type and ability of species type to adapt to the site (Dufour et al., 2006). This assumption originates from earlier generalizations which underlined that patterns of woody species availability could be different across various forest landscapes due to the environmental variables of the forest landscapes (Amare et al., 2023). Jamoneau et al. (2011) also indicated that species assemblage at the local patch of the forest is predominantly controlled by local environmental heterogeneity and agricultural intensity, and this stands in favor of the current argument. The absence of significant difference ($p>0.05$) in species richness between TGL and HF could be associated with the similarity in the soil type, management practices, landscape features and agro ecology that determine distribution of woody species.

As observed on Table 4, the mean woody species richness in each vegetation type at low-altitude was significantly higher ($p<0.05$) than that at middle and higher altitude. This could be due to the stressful environmental variables such as reduction of the suitability of temperature, precipitation, solar radiation at the higher altitude. Das et al. (2020), from their studies in the Great Himalayan National Park, also attributed to the gradual decrease in species richness towards both upper and middle altitudes due to temperatures conditions, soil conditions, degree of disturbances, proportion of geographical area and topographic features. At the middle and lower altitude, there might be suitable conditions like fertile soils, suitable topography and low extent of disturbances that promote the enrichment of woody species. In all three vegetation types, the maximum richness was recorded at the lower altitude and this could be associated with favorable environmental condition that promotes growth of diverse woody species relative to the other two altitudinal categories.

The mean woody species richness per vegetation of Jorgo-Wato natural forest (24.33) was comparable with the species richness of Berbere moist Afromontane evergreen forest (29) (Bogale et al., 2017) while lower than the woody species richness of moist Afromontane Forest of Wondo Genet (72) (Kebede et al., 2013). The might be due to the site characteristics, management approach, socioeconomic issues, and farmers' preferences for tree species (Wade et al., 2010). In addition, the variation is probably due to the diverse physiographic nature of the area, the condition of its mountain slopes, valleys and fluvial landforms made the vegetation unusually diverse (Kebede et al., 2013). Anthropogenic disturbances could also be the cause for species richness dynamics.

3.3 Woody species diversity

The Shannon-Wiener diversity index of woody species was computed for each vegetation type (Table 5).

The overall mean of woody species diversity value (H) of Jorgo-Wato Forest was 1.715. This is a lower diversity index value of woody species when compared to many other moist evergreen forests. This could be due to the pressure of anthropogenic disturbances including selective cutting and deforestation for various purposes. The mean Shannon woody species diversity indexes in each vegetation type were 1.769, 1.643 and 1.73 for TGL, HF and DWL respectively (Table 5). The present study demonstrated that, the woody species diversity among vegetation type were not significantly different. This might be due to the similarity of management practices, agro ecology, ecological conditions and soil types of the forest. The three vegetation categories have 13 (33.33%) species share in common, and the significant similarity on species composition as well as the uniform distribution of woody species in natural forest might be contributed to the similarity in species diversity as suggested by Motuma et al. (2008).

Table 5 Mean for Shannon diversity index of woody species under different vegetation types along elevation of JWF.

	Vegetation Types		
Elevation	TGL	HF	DWL
HA	1.53± 0.32[a]	1.68± 0.13[a]	1.84± 0.15[a]
MA	1.83± 0.16[b]	1.69± 0.44[a]	1.56± 0.357[b]
LA	1.941±0.156[b]	1.553± 0.48[a]	1.794± 0.23[ab]
Mean	1.769± 0.274[c]	1.643± 0.356[c]	1.73± 0.268[c]
LSD (5%)		0.239	
CV (%)		16.57	

Different letters shows that the difference is significant at p≤0.05). ab: Means no significant difference at a and b. DWL: Dense Woodland, HF: High forest, HA: Higher altitude, LA: Lower altitude MA: Middle altitude and TGL: Tree grassland.

In tree grass land (TGL), the maximum diversity index was recorded in the lower altitude while the minimum diversity was recorded in higher altitude. Hence, the woody species diversity index of TGL was significantly different ($p<0.05$) between lower and higher altitude. In High forest (HF), the diversity index values did not show significant difference among altitudinal categories. In DWL, the maximum diversity was recorded at higher altitude while the minimum diversity was recorded at middle altitude. Furthermore, the species diversity index value of higher altitude was found to be significantly larger ($p<0.05$) than that of lower altitude. A similar situation was reported from a vegetation study in northern Ethiopia where the diversity of woody species was found to be higher at top altitude (Woldu et al., 2020). This could be associated with the higher frequency of disturbances occurring at the lower elevation. As suggested by Berhanu et al. (2022), settlement and agricultural expansion could be the most common factors that contributed to the decline of woody species diversity at the lower altitude.

The decreasing of woody species diversity with increasing altitude, as in the case of TGL, could be related to the decrease in soil fertility and unsuitable topographic and ecological conditions. The eco-physiological constraints such as low temperature, low growing season, and geographical barriers including soil erosion, rocks and mountains at the steep elevation of the forest could decrease the dominance of woody species (Chawla et al., 2008). Sharma and Kala (2022) also reported that elevation is one of the major abiotic factors in the forest ecosystems that determines the establishment and distribution of woody species diversity because of its impact on soil fertility and condition of temperature.

The mean Shannon diversity index of woody species in JWNF was comparable with Gargeda Moist evergreen forest (1.79) (Yohannes, 2016), protected natural forest in northern Amhara (1.77) (Eshetie et al., 2021) and Afromontane moist evergreen forests in SW Ethiopia (1.84) (Seyoum et al., 2022). However, it was lower than the diversity of woody species in the moist Afromontane Forest of Agama (3.25) (Dibaba et al., 2020) and Bonga Forest (3.17) (Senbeta et al., 2014) and higher than the forest of Northern Ethiopia (1.11) (Yikunoamlak et al., 2019). The variation could be due to the extent of anthropogenic disturbances, and soil type as well as agro ecological conditions of the forest ecosystems. The anthropogenic disturbances including selective tree cutting for various purposes could decrease the diversity of woody species. Overgrazing and the continuous extraction of forest products are important drivers of chronic disturbances that can lead to gradual local extinctions of woody species and changes in vegetation structure (Ribeiro et al., 2015). Similarly, plant diversity decreased with increasing disturbance intensity in the forest.

The overall mean evenness of woody species in Jorgo-Wato Forest was 0.81. The mean evenness of woody species in each vegetation type was 0.81, 0.79 and 0.83 in TGL, HF and DWL respectively (Table 6).

Table 6 Evenness of woody species in Jorgo-Wato Forest.

	Vegetation Types		
Elevation	TGL	HF	DWL
HA	0.748±0.0829[a]	0.876±0.057[a]	0.872±0.054[a]
MA	0.819±0.098[ab]	0.792±0.117[b]	0.755±0.16[b]
LA	0.8620±0.053[b]	0.714±0.135[c]	0.86±0.049[a]
Mean	0.81±0.087[d]	0.79±0.12[d]	0.83±0.108[d]
LSD (5%)		0.0741	
CV (%)		10.82	

Different letters shows that the difference is significant at p≤0.05).ab means that there is no significant difference at a and b. DWL: Dense Woodland, HF: High forest, HA: Higher altitude, LA: Lower altitude MA: Middle altitude and TGL: Tree grassland.

The mean evenness of woody species in the three vegetation types did not show significant difference (p>0.05). This demonstrated that the woody species distribution among vegetation types are more or less in similar situation that may be associated with the similarity in management status, agro ecology and site conditionin the forest. As the study showed, there is a significant difference in mean evenness of woody species in TGL and HF at the three altitudinal levels while only the mean evenness of woody species of DWL at mid altitude differs significantly from that of higher and lower altitude zones. This lays the ground to hypothesize that altitude had significant effect on the evenly distribution and abundance of woody species. The difference in woody species evenness with altitudinal range could be due to the dominance of some individual species that could simply be adapted to the environment and cause stressing on other species. On other hand, Berhanu et al. (2022) indicated that the change in woody species evenness along altitudinal range could be correlated with unsustainable use of the trees that can reduce the distribution of individual species.

Comparison of the evenness result of current study (0.81) was comparable to the evenness of moist evergreen Afromontane Forest in the southern Ethiopia (0.81) (Befikadu et al., 2020) but showed lower value of evenness valuethan in Wurg Forest in South Western Ethiopia (0.90) (Boz and Maryo, 2020). The lower evenness in distribution of woody species in Jorgo-Wato forest might be associated with difference in environmental settings of the forests, the greater dominating tendency of some species (Mebrat et al., 2014), and the level and kinds of anthropogenic interferences (Wasie and Yimer, 2020).

3.4 Natural regeneration of woody plants in Jorgo-Wato Forest

Out of 39 woody species recorded from Jorgo-Wato forest, 27 were found to be represented by seedlings besides adult trees. The woody species recorded with abundant seedlings were *C. macrostachyus, S. guineense, M. capensis, M. gracilipes* and *L. volkensii*. The densities (number of plants per hectare) of seedlings for woody species were determined across all vegetation types. The mean densities of seedlings in each vegetation type recorded per hectare were 3741 (29.2%) plants/ha, 4383 (34.2%) plants/ha and 4683 (36.5%) plants/ha for TGL, HF and DWL respectively (Fig. 5).

The study revealed that there was numerical difference in density of seedlings across vegetation types. The maximum and the minimum mean density of seedlings were recorded in DWL and TGL respectively while that of HF comes in between. This could be due to the different regeneration potential of the trees associated with their different features in adapting to environmental conditions. For example, most of woody species have better ability to regenerate themselves in hazard conditions than others. As a result, the germination ability of seeds of trees could be based on nature of woody species and forest settings. According to Willandet al. (2013), the richness and diversity of non-sown emerging seedling species is different across sites due to soil type and environmental conditions. Canopy coverage of some woody species can also affect the regeneration potential of seedlings based on the composition of woody species (Ayanaw and Dalle, 2018). Hence, the relatively lower density of seedlings of HF, as compared to DWL, might be interpreted due to the greater closeness of the canopy.

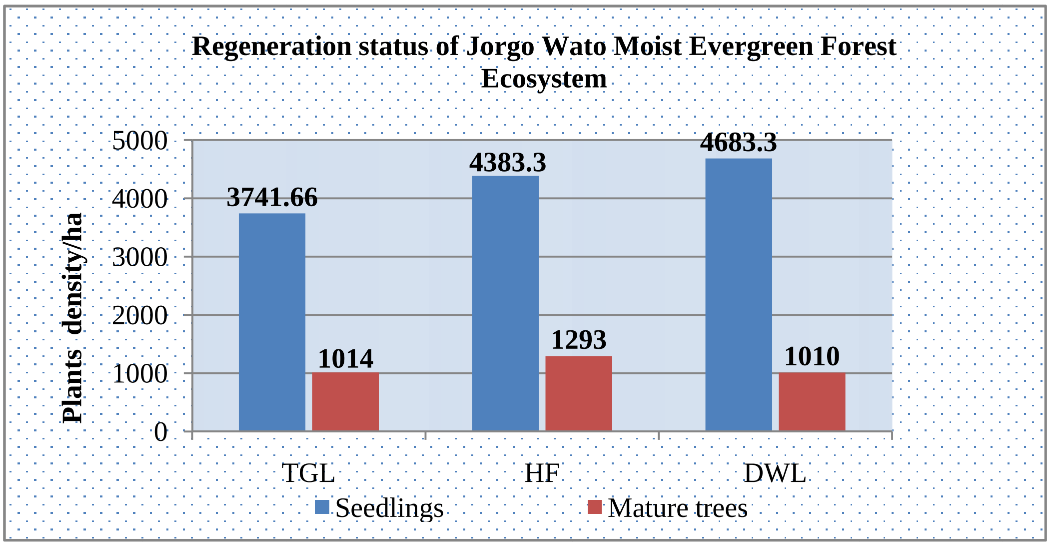


Fig. 5 Mean densities of seedlings and mature trees of woody species of each vegetation type in JWF. (DWL: Dense Woodland, HF: High forest, TGL: Tree grass land).

The total mean density of mature trees was less than density of seedlings in all vegetation types. The mean density of seedlings was higher by 74.1% when compared to the mean density of mature trees. According to the method of Bogale et al. (2017), the regeneration status of the forest was good when the presence of seedling was greater than mature trees. This might simply demonstrate good regeneration status and various natures of woody species for regeneration ability.

The total mean density of regeneration abundances of JWNF (4269 seedlings/ha) was comparable to the regeneration of woody species in Belete moist evergreen Afromontane Forest which was determined as 4,547 seedlings/ha (Gebrehiwot and Hundera, 2014) and Gargeda moist evergreen forest 4583 plants/ha (Akena, 2022). However, it was much higher than the regeneration of tropical moist evergreen forest of Arunachal Pradesh 200 seedlings/ha (Bhuyan et al., 2002), and much lower than the regeneration of tropical forest of Chhattisgarh 39,500 seedlings/ha (Pawar et al., 2012). The differences might be related to the difference in management practices, anthropogenic disturbances, agro ecology, and feature of forest types, feature of soil types and topographical condition of the forest.

4 Conclusion

A total of 1566 individual plants (DBH ≥2.5 cm) were assessed in JWNF. Regarding floristic diversity of the forest, a total of 39 woody species belonging to 35 genera and 30 families were recorded. Out of this, 27 woody species were recorded with seedlings. The mean total density of seedlings (<1.5 m height) recorded was 4269 plants/ha. *C. macrostachyus, S. guineense, M. capensis, M. gracilipes* and *L. volkensii* were the most dominant species recorded with seedlings. The mean density of seedlings (per/ha) was greater than the density of mature trees, demonstrating a good regeneration status in the forest.

The Mean Shannon diversity index, richness and evenness of woody species recorded in JWNF were found to be 1.715, 8.09 and 0.81 respectively. The result of Shannon diversity index was lowest when compared to other tropical forests; and this might be attributed to the pressure of anthropogenic disturbances on the forest due to lack of sustainable forest management. As the study result suggested, altitude had a significant effect on the diversity of woody species in TGL and DWL; and this may be attributed to the variability of soil fertility, topographic features, temperature conditions and extents of disturbances. The vegetation types did not show the significant difference in species diversity and this is evidently linked to the similarity in ecological conditions and soil types of the forest. However, the slight difference in species richness among vegetation types could be associated with the heterogeneity of forest patches and nature of woody species and their distribution.

The overall tree density of JWNF was 1087.5 trees ha-1. The highest density of woody species was exhibited by *S. guineense* (269.44/ha, 24.77%), and *M. capensis* (184.027/ha, 16.92%) while the lowest were *R. albersii* (0.69/ha, 0.086%), *Warburgia ugandensis* (0.694 ha^{-1}, 0.063%), *R. prinoides* (0.69/ha, 0.063%) and *Olea europaea* (0.69/ha, 0.063%). The total basal area of the trees in JWNF was 70.3 m^2 in which four species including, *S. guineense* (7 m^2 ha^{-1}), *M. capensis* (5.4 m^2 ha^{-1}), *O. welwitschi* (2.787 m^2 ha^{-1}) and *C. macrostachyus* (2.711 m^2 ha^{-1}) contributed to the largest basal at a species level. Regarding frequency, the most frequently observed woody species in JWNF was *S. guineense* (100%) which occurred in all quadrats and followed by *M. capensis* (72.2%) and *O. welwitschi* (72.2%) indicating that these woody species are distributed to all area of forest sites. Based on this observation, it is possible to conclude that the woody species with largest basal area, frequency and density are the most dominant woody species in the forest.

The most ecologically important woody species in terms of their IVI in JWNF were *S. guineense* (60.17), *M. capensis* (43.43), *C. macrostachyus* (25.5), *O. welwitschi* (22.9), *M. gracilipes* (16.31), *A. gummifera* (13.93), *O. capensis* (12.84) and *A. grandibracteata* (10.16) while the less dominant woody species in terms of their IVI were *R. albersii* (0.424), *O. europaea* (0.48), *O. spinosa* (0.517), *P. viridiflorum* (0.57), *E. racemose* (0.62) and *W. ugandensis* (0.65). An irregular shape showed in terms of tree height class distribution while an inverted J-shape showed in the DBH class distribution. The irregular shape indicates the extent of human interference on the forest including removal of matured trees through selective logging for different purposes. Therefore, particular attention needs to be paid to the rare woody species and dominant species need to be monitored regularlyand regular assessment needs to be applied to the regeneration status of the forest.

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