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Diversity, Structure and Regeneration Status of Woody Species Along Altitudinal Gradient of Werganbula Forest at Sude District, Arsi Zone, Oromia Region, Ethiopia

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DIVERSITY, STRUCTURE AND REGENERATION STATUS OF WOODY SPECIES ALONG ALTITUDINAL GRADIENT OF WERGANBULA FOREST AT SUDE DISTRICT, ARSI ZONE, OROMIA REGION, ETHIOPIA

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ABSTRACT

The study was conducted with objective to assess species composition, structure and regeneration status of woody species along altitudinal gradient of Werganbula forest at Sude District, Arsi Zone, Oromia Region, Ethiopia. The study area was stratified into lower, middle and upper altitudes. Nine transect lines at 500m interval were laid and nine sample plots were established along each transect line with interval of 200m. A total of 81 plots were established in the study area for vegetation data collection. For the collection of tree related data sample plots with 20m x 20m were laid along transect lines while for shrubs data five sub-plots of 5m x 5m were laid down, four at each corner and one at mid of each main plot. To collect saplings and seedlings data ten sample plots with 2m x 2m were laid down at two corners of each sub-plot. A total of 66 woody plants belonging to 43 families and 58 genera were identified from three altitudes of the forests. Fabaceae and Rosaceae were the most dominant families followed by Asteraceae and Araliaceae families. Out of recorded woody species, five (7.58%) were endemic to Ethiopia. The diversity of woody species in lower, middle and upper altitude were 3.35, 3.26 and 3.21 respectively. The overall density of woody plants species in the study area were 1012.35individuals/ha. The majority of the woody species in the study area were distributed in the lower DBH classes. The total basal area of woody species with DBH ≥2.5cm was 32.07m^2/ha. The density of seedlings was higher than density of sapling and adults and of sapling was greater than adult at three altitudes. This result showed that, there were good regeneration and recruitment potential woody species at three altitudes of the forest. However, the population structure and regeneration status of some woody species in the study area were showed poor regeneration status which need priority conservation in order to ensure the sustainable utilization of the forest resource.

Key words or phrases: Basal area, Environmental gradient, Regeneration, Species diversity

INTRODUCTION

Background and Justification

Biological diversity has been defined as the variability of the living organisms from the all sources that including the inter alia, terrestrial, marine and other aquatic ecosystems (Mace *et al.,* 2012). The diversity of woody plant species is basic to forest biodiversity, because woody plant species provide resources and habitats for the other living organisms (Huange *et al*., 2003). The population growth and the demand for forest resources have more influencing the biodiversity of the world through deforestation and degradation of the forest resource (Kedir Aliyi *et al*., 2015; Getahun Yakob and Anteneh Fekadu, 2016). Therefore, the knowledge of the woody species composition and population structure is very important in order to understand the service and function of any forest ecosystem (Loreau *et al.,* 2001; Muhumuza and Byarugaba, D. 2009: Rahman *et al*., 2011).

Ethiopia is one of countries in the world that endowed with rich biological resources; this is the variation in taltitudes, soil and climate (Abiyou Tilahun *et al*., 2015). Among this biological diversity around 6000 species of the higher plants (10%) are endemic (Ensermu Kelbessa and Sebsebe Demissew, 2014). However, most of these biological resources are removed at alarming rate due to anthropogenic and environmental threats; these affect the capacity of forests to provide different ecosystem function and services (Badege Bishaw, 2001; Demel Teketay, 2001). The major reasons that causing the deforestation and destruction forest in Ethiopia were agricultural land expansion, population growth overgrazing and overexploitation of the forest resources for different purposes (Aukland *et al*., 2003).

The variation in woody species composition and distribution were also occurred due to environmental factors such aspects, altitude, slope, nutrient content of the soil and climate (Feyera Senbeta and Manfred Denich, 2006; Fantaw Yimer *et al.,* 2006; Fontaine *et al.,* 2007; Tadesse Woldemariam *et al.,* 2008). This factor has a significant effect on different types of vegetation and woody species diversity. There are different factors that determine the woody species composition and population structure (Kessler, 2001). Therefore, the assessment on woody species composition and structure are essential to provide important information regarding forest ecology (Pappoe *et al*., 2010). It is also useful in identifying ecologically and economically important woody species (Addo-Fordjour *et al*., 2009).

The information on population structure can provide an insight whether a particular population in the forest has a stable distribution or not (Getachew Tesfaye *et al.,* 2010)

The distribution patterns of woody vegetation some part of mountains area in the world were changed along elevational gradients (Zhang *et al.,* 2013).

Werganbula forest is one of the remained natural forests in Southeastern part of the country that contains high number of woody species. In Ethiopia several studies have been reported on dry afromontane forest regarding to woody species composition, structure and regeneration status of forest (Birhanu Nesibu Yahya; *et al.,* 2019; Mehari Alebachew *et al*., 2019; Zelalem Teshager, 2017).However, the assessment of woody species composition, structure, regeneration status and their response to environmental altitudinal gradient has not been so far studied on the Werganbula dry afromontane forest. Therefore, the present study intends to provide the important information on the woody species diversity, structure and regeneration status of along altitudinal gradient of Werganbula forest for the development of appropriate management and conservation plans.

MATERIALS AND METHODS

Description of the Study Area

This study was conducted in Werganbula Dry Evergreen Afromontane forest which is located in Sude Distric, Arsi Zone, Oromia Region, Ethiopia. The Sude District is situated between 7°50'24"N to 8°9'36"N latitude and 39°36'E to 40°3'E longitude (Figure 1). It is situated at a distance of about 250 km South East of Addis Ababa. The altitude of the study area was ranges from 1612-2986m above sea level and it consists of mountains, deep gorges, rugged and escarpments topographical features. The mean annual temperature of the study area is about 18.4^{0}C. The monthly minimum and maximum temperature of the study area is 12.6°C and 24.3°C respectively. Then the hottest month is June with a maximum temperature of 28.5°C and the coldest month is December (12.72°C). The mean annual rainfall was estimated to be 900mm and the maximum rain fall range from June to September. Although there is some rain throughout the year, its general pattern is bimodal, with unreliable minor rainy season from March to May and a major rainy season from July to September (SWANRO, 2017). The total forest area of Werganbula forest is 3200 hectares which is under the management of Oromia Forest and Wildlife Enterprise (SWANO, 2017). This forest largely dominated by *Juniperus procera, Afrocarpus falcatus, Croton macrostachys, Olea europaea,* *Cordia africana, Hagenia abyssinica, Nuxia congesta, Teclea nobilis, Myrsine africana* and *Maytenus obscura.* The agricultural land expansions, fire wood, charcoal, timber production and overgrazing were the major factors that influencing Werganbula forest. According to SWANRO (2017) report, the soils of the study area are divided into different types. The major soil texture in the study area is clay (3.4%), sandy (26%) and loam (36.6%).

Agriculture is the principal source of livelihood for most of the communities of the study area. It is characterized by mixed farming system, where rainfall dependent and traditional farming system coexisted with livestock production. Some of the communities of the study area depend on natural forest for fuel wood, timber and construction materials through illegal logging (SWANRO 2017).

Methods

Reconnaissance survey and Sampling methods

Reconnaissance survey was conducted in study area on the first week January, 2019. The survey was conducted across forest area in order to gather relevant information that concerning to site condition, woody species and accessibility of the site. Then, the sampling methods, elevation range, transect number and transect direction of the forest were determined.The stratified systematic sampling method was employed to collect woody vegetation data of the study area. The stratification of the study area was done in order to take appropriate data and to maintain the homogeneity of the area. Altitude is one of the major parameter that used to stratify the study area following (Nesibu Yahya; *et al.,* 2019; Yangchenla Bhutia *et al*., 2019; Zelalem Teshager, 2017; Nesru Hassen, 2017).

Based on the altitudinal variation the study area was stratified into three altitudinal gradients as lower altitude (1612-2070m a.s.l), middle altitude (2071-2528 m a.s.l) and Upper altitude (2529-2986m a.s.l) relatively. In this study, the lower altitude was indicated as 1612-2070m a.s.l due to the fact that lower elevation of the forest start at 1612m a.s.l and the upper elevation limit of the forest are at 2986m a.s.l.

For the collection of woody species data nine transect lines (three for each altitudes) at 500m interval were laid down in the study area and also nine plots were established at 200m interval along each transect line. A total of 81 sample plots were taken from three areas. For the collection of tree and climber related data 20 m X 20 m (400m^2) sample plots were established along each transect line. To collect of shrub data five sub-plots of 5m x 5m were laid down, four at each corner and one at mid of each main plot whereas while ten 2m x 2m plots were laid down at two corners of each sub-plot to collect seedlings and saplings related data (Tesfaye Bogale, 2017; Kflay Gebrehiwot and Kitessaa Hundera, 2014; Abyot Dibaba *et al.,* 2014; Shambel Bantiwalu, 2010; Tiwari *et al*., 2010; Mehari Alebachew *et al*., 2018). In order to reduce the edge or boarder effect on the woody species 50 m boarder effect were left.

Vegetation data collection

Woody plant species data was collected in March, 2019. All woody species encountered in each sampling plot was recorded and coded using local name. The trees with DBH >2.5cm and height >2m were measured and recorded in each sample plot. The DBH of tree was taken at 1.3m above ground level while DSH of shrubs was taken at 30cm above ground level. The seedlings and saplings found in each sub-sub-plots sample plots were measured, counted and recorded. Saplings include woody species with diameter 1-2.5cm and height 1 - 2m while seedlings include woody species with collar diameters < 1cm and height < 1m (Shambel Alemu,2011). DBH of trees and shrubs were measured using diameter tape and caliper while the height was measured using clinometer. Environmental variables such as altitude and slope were recorded for each sampling plots by using of GPS and slope was measured by clinometer. Woody species which are common and well known were identified by researcher and local informants at the field. For those species difficult to identify at the field, voucher specimens were collected and pressed for identification and brought to the National Herbarium, Addis Ababa University, where there was properly identified to species and family level. The species scientific nomenclature was carried out by using of the published volumes Flora of Ethiopia and Eritrea (Sebsebe Demissew, 1997), Useful Trees and Shrubs of Ethiopia (Azene Bekele, 2007;) and Natural Database for Africa (NDA) Version 2 (Ermias Dagne, 2011)

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Data Analysis

Species diversity, structure and regeneration status of woody species were analyzed. One-Way ANOVA (T-test, Pearson correlation and multivariate analysis) was used in order to test the variation in woody species along altitudinal gradients. Data was analyzed by using Microsoft Excel, SPSS software version 16.0 and R- Software Package.

Woody species diversity analysis

The woody species diversity, evenness and richness were analyzed using different diversity indices. The most widely used species diversity indices are Simpson's index, Shannon-Weiner index and Sorenson index of similarity (Mueller-Dombois and Ellenberg, 1974). Shannon-Wiener Diversity Index (H'), Richness(S) and Evenness or Equitability Index (E) were used to estimate the diversity of woody species in the forests. Shannon Weiner diversity index was calculated as following (Kent and Cocker, 1992; Krebs, 1999; Magurran and Gill, 2011).

i) Shannon-wiener diversity index (H') was calculated as:-

$$H' = -\sum_{i=1}^{S} pi \ln pi$$

Where H', is Shannon-Wiener Diversity Index

S = is the number of species

Pi=n/N is the proportion of individuals found in the i^{th} species

n=number of individuals of a given species

N=total number of individuals found

ii) Simpson's Diversity Indices

It is measures the probability that two individuals randomly selected from a sample will belong to the same species (or some category other than species). The value of this index also ranges between 0 and 1. Simpson's Index gives more weight to the more abundant species in a sample

$$D = 1 - \left(\frac{\Sigma\, n(n-1)}{N(N-1)} \right)$$

n = the total number of organisms of a particular species

N = the total number of organisms of all species

Simpson's Index of Diversity = 1 - D

iii) Evenness (E)

The measure of evenness (E) which is the ratio of observed diversity to maximum diversity was calculated following (Magurran and Gill, 2011*)*

E= Σ pi lnpi / lnS = H'/lnS = H'/ H_{max}

E = is species evenness

H'= is Shannon-Wiener Diversity Index

S= is the number of species found when all sample plots are united

Pi =is the proportion of total individuals in the i^{th} species

lnS = is the natural logarithm of the total number of species.

iii) Species richness (S) is calculated by:

$$S = \boldsymbol{\Sigma n}$$

Where, *n* is the number of species

Sorensen coefficient of similarity (Ss) index

The similarity of woody species composition between altitudinal gradient were computed by using of Sorensen coefficient of similarity (Ss) index (Kent and Coker,1992).

Ss **= 2a/2a+b+c** Where; **a** = Number of species common to both samples;

b = Number of species in sample one only;

c = Number of species in sample two only.

Structural analysis

The structures of the woody species were described based on the analysis of density, frequency, dominant, important value Index (IVI), diameter, height and basal area (Kent and Coker, 1992). Density and basal area values were computed on hectare basis.

Frequency (F): The probability or chance of finding a species in a given sample area or quadrat.

$$\text{Frequency} = \frac{\text{Number of plots in which a species occur}}{\text{Total number of plots sampled in the study site}} X100$$

$$\text{Relative frequency (\%)} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \text{X100}$$

Density of a species = is a count of the numbers of individuals of a species within the quadrat (Kent and Coker, 1992). It is closely related to abundance but more useful in estimating the importance of a species. Counting is usually done in plots placed several times in the plant communities under study. Afterwards, the sum of individuals per species is calculated in terms of species density per convenient area unit such as a hectare.

$$\text{Density} = \frac{\text{Number of indiviguals of a woody species}}{\text{Sum of samlped area}}$$

$$\text{Relative density} = \frac{\text{Total number of individuals of a species}}{\text{Total number of individuals of all species}} \text{X 100}$$

Basal area (BA): It is the cross-section area of a tree at breast height and expressed in square m/hectare. It was measured through diameter, usually at breast height (DBH) that is 1.3 m above ground level. Its area is also used to calculate the dominance of species. It can be expressed in square meter/hectare (Mueller-Dombois and Ellenberg, 1974; Hutchings, 1986).

$BA = \frac{\pi d^2}{4}$ Where, BA = Basal Area in m^2 per hectare. Where: d = diameter at breast height in meter, $\pi = 3.14$

Dominance (DO) = Basal area individual per sampled area

$$\text{Relativedominance(RDO)} = \frac{\text{Basal area of a species}}{\text{Total Basal area of a species}} \text{X } 100$$

Importance value index (IVI):- Importance value index combines data from three parameters (relative density, relative frequency, and relative dominance) used to compare the ecological significance of species. It reflects the extent of the dominance, occurrence and abundance of a given species in relation to other associated species in an area (Kent and Coker, 1992; Simon Shibru and Girma Balcha, 2004). Therefore, it is a good index for summarizing vegetation characteristics and ranking species for management and conservation practices.

IVI = Relative density + Relative frequency + Relative dominance

Diameter at Breast Height (DBH): Diameter at breast height (DBH) was classified into ten classes and the percentage distribution of each species was then computed. (i.e. 1) 2.5-5cm, 2) 5.1-10, 3) 10.1-15cm, 4) 15.1-20cm, 5) 20.1-25cm, 6) 25.1- 30cm, 7) 30.1-35, 8) 35.1-40, 9) 40.1-45, 10) >45cm) .

Height**:** Individual trees and shrubs having height greater than 2 m within sampling plots were collected and analyzed by classifying into nine classes 1) 2-5 2) 5-10m, 3) 10-15m, 4) 15- 20 m, 5) 20-25m 6) 25-30m 7) 30-35 8) 8) 35 - 40m 9) >40m (Kitessa Hundera *et al*., 2007).

Regeneration data analysis

The regeneration status of woody plant species in the forest were analyzed by comparing number of seedling with number of sapling and number of sapling with number of matured woody species (Shankar, 2001; Dhaulkhandi *et al*., 2008; Tiwari *et al*., 2010; Keflay Gebrehiwot and Kitessa Hundera, 2014) as the following categories; that is, the status was good regeneration, if present in seedlings > saplings > adults; the status was fair regeneration, if present in seedlings > or≤ saplings ≤ adults; the status was poor regeneration, if a species survives only in the sapling stage, but not as seedlings (saplings may be ≤ or ≥ adults); the status was none regeneration, if a species is absent both in saplings and seedlings stages, but present as adult stage and the status was new regeneration , if a species has no mature, but present only in sapling and/or seedling stages (Kitessaa Hundera *et al*., 2007).

RESULTS AND DISCUSSION

Woody Species Composition

A total of 66 woody species belonging to 43 families and 58 genera identified and recorded from lower, middle and upper altitude of the forest (Table 1). Fabaceae and Rosaceae were the dominant families each represented by four (6.06%) species followed by Asteraceae, and Araliaceae families each represented by three (4.55%) species. The remaining 13 families each represented by two (3.03%) species and 26 families each represented by a single species (Table 1). Seventeen families that comprising of 4, 3 and 2 species were together constituted 60.61% of the total species while 26 families that represented by only single species together constituted 39.39% of the total species (Table 1). The Fabaceae and Rosaceae were the dominant families at lower, middle and upper altitude of the forest. This might be showed the higher adaptation and survival mechanism of this species with the environment condition in the study area. Ensermu Kelbessa and Teshome Soromessa (2008) also stated that the dominance of Fabaceae and Rosaceae could be attributed due to their efficient and successful dispersal mechanisms and adaptation to a wide range of ecological conditions. Other studies also indicated that Fabaceae and Rosaceae families were the dominant in the early successional development as many pioneer species may establish and grow together in high density until they reach the climax stage where many individuals were eliminated due to competition (Tesfaye Bekele, 2000).

The woody species that were recorded in the lower, middle and upper altitude of the forest were 59, 53 and 46 species respectively. This result indicated that, the highest number of woody species was occurred in the lower altitude of the forest than those of middle and upper altitude of the forest. The reason for the highest woody species diversity and richness were recorded in the lower altitude of the forest might be due to less altitudinal influences on woody species were pronounced at lower altitude of the forest. The altitude and slope were the major environmental factors causing the variation in number of woody species. In comparison, the total woody species recorded in this study was higher than woody species reported on Chilimo Dry Afromontane forest (31species) (Mehari Alebachew *et al*., 2018), Weiramba forest (32 species) (Zelalem Teshager, 2017) and Yemrehane Kirstos Church forest (39 species) (Amanuel Ayanaw and Gemedo Dalle, 2018). The variation in woody species among werganbula forest and other forest mentioned above might be due to differences in altitudinal ranges, climatic conditions and level of disturbances.

The woody species collected from the study area were consisting about three major forms of growing habit (Figure 4). Those are tree, shrub and woody climber with the recorded value of 27 (40.48%), 32 (48.91%) and 7 (10.61%) respectively. Out of these 13 trees, 22 shrubs and 3 woody climbers were found in three altitudes of the forest in common. *Juniperus procera, Afrocarpus falcatus, Olea europaea*, *Ekebergia capensis, Schefflera abyssinica* and *Teclea nobilis* were among the trees species that common to three altitudes of the forests. *Acanthus sennii, Calpurnia aurea*, *Dovyalis abyssinica, Dombeya torrid, Maytenus arbutifolia and Vernonia auriculifera* were among the shrubs species that common to three altitudes while *Tacazzea conferta* and *clematis simensis* were among the climber species that were common to three altitudes of the forest. The result obtained indicated that, the study area consist high number of shrubs followed by trees woody species and shrubs (Figure 4). The variation in woody species composition among three altitudes of the forest was occurred due to the effect of elevation and slope on woody species.

Shannon Wiener diversity, richness and evenness of woody species

The highest species diversity, Simpson, evenness and species richness were recorded in the lower altitudes followed by middle and upper altitudes of the forest (Table 2). The variation in species diversity, Simpson, richness and evenness in the three altitudes of the forests were attributed due the effect of altitude and slope on the woody species composition. The environmental and anthropogenic factors are major the parameter that determining the survival and dispersals of the plant species in the forest (Colwell and Lees, 2000).

In comparison, the Shannon Weiner diversity and evenness recorded in the three altitudinal gradients of Werganbula forest were higher than those reported from other forest in Ethiopia. For instance it is higher than Shannon Weiner diversity of woody species reported on Yerer Mountain forest (H'= 2.3) (Nesibu Yahya *et al.*, 2019), Tara Gedam forest (H'=2.98) (Haileab Zegeye *et al*., 2011) and Chilimo forest (H' 2.72) (Taddese Woldemariam et *al.,* 2000).

The reason for the Shannon Wiener diversity of Werganbula forest higher than the forest mentioned in the above might be due to the evenly distribution of the individuals woody species in the forest. Higher Shannon Weiner diversity is an indication of the balance distribution of the individual plant species in the forest (Kent and Coker, 1992).

The species diversity, richness and evenness were decreased from lower to higher altitudes of the forest in the study area. Similar result was reported on Gergeda and Anbessa forests which were stated that, altitude and slope had a significant effect on the woody species diversity, richness and evenness (Tamene Yohannes, 2016).

Sorenson's similarity index

Sorenson similarity coefficient was analyzed in order to investigating the similarities between woody species in the three altitudinal gradients of the forest. Accordingly, the forest in lower and middle altitude had the highest similarity 89.01% followed by middle and upper altitude of the forest 86.87%. The least similarity was recorded in the lower and upper altitudes of the forest 74.29%. The similarity between the altitudes showed that, there was overlapping of woody species. In this study, the similarities decreased as the increasing of the elevation from lower to higher altitudes of the forest. The variations in woody species between the three altitudes of the forest were attributed due to variation in altitudes and slopes. The similarity coefficient recorded between three altitudes of Werganbula forests was higher than the similarity coefficient reported on Keja Araba and Tula forest (46% of similarity coefficient) (Getahun Yakob and Anteneh Fekadu, 2016).The variation between these forests might be due to location, altitudinal differences, species composition, climatic conditions and levels of anthropogenic disturbances.

Endemic woody species

Werganbula forest contains some wood species that are endemic to Ethiopia. Accordingly, five endemic woody species (7.58%) were identified which some of them were, recorded in the IUCN Red List categories. In comparison the endemic woody species recorded in the study area with other forest in Ethiopia it was lower than Chato natural forest (12 species) (Feyera Abdena, 2010), Gera forest (9 species) (bruk bedore, 2015). However, it was higher than endemic plants species reported on woody vegetation of Eastern escarpment of Wello, Ethiopia (3 species) (Getachew Tena *et al*., 2008) while it related with Aba Asrat Monestary forest (6 species) (Gojjam Bayeh, 2013). The variation in endemic woody plant species might be attributed to the adaption of woody species different climatic and altitudinal variation among the forest areas.

Vegetation Structure of the Forest

Density of woody species in Werganbula forest

The overall density of woody species recorded from the three forest area was 1012.35 individuals/ ha. Of these, 39.31%, 33.16 % and 27.53% were contributed by lower, middle and upper altitudes of the forests respectively (Table 4). The highest densities of woody species were recorded in the lower altitude of the forest. *Juniperus procera* was the dominant woody species in three altitudes of the forest. The overall density of Werganbula forest with other density of the forests in Ethiopia was compared. Hence, it was found to be higher than density reported from Wof Washa forerst (698.8 individuals/ha) (Gebremicael Fisaha *et al*., 2013), Adelle forest (898 individuals/ha) (Haile Yineger *et al*., 2008) and Boditi forest (498 individuals/ha) (HaileYineger *et al*., 2008). However, it was lower than density of woody species reported from Hugumburda forest (1218 individuals/ha) (Ermias Aynekulu, 2011).

Frequency of woody species in Werganbula forest

The frequency of the woody species recorded in all plots of three altitudes of Werganbula forest was computed. Among the recorded woody species *Juniperus procera* was the most frequently occurred species in the lower, middle and upper altitudes of the forest with recorded value of 96%, 92% and 85% respectively. Other species such as, *Maytenus obscura, Olea europaea, Teclea nobilis* and *Afrocarpus falcatus* frequently occurred at the three altitudes of the forest (Table 5). Whereas *Allophylus abyssinicus, Combretum molle, Landolphia buchanani, Celtis africana, Rubus volkensii* and *Solanum incanum* were the species least frequently occurred in the study area (Appendix 3).

Based on the percentage frequency, the frequency of woody species was classified into six frequency classes (Figure 5). The higher numbers of woody species were recorded in the first frequency classes while lower numbers of woody species were recorded in the last frequency classes at the three altitudinal gradients of the forest. This result indicated that, high heterogeneity of woody species in the study area. The highest number of woody species was recorded in the lower altitude frequency classes of the woody species followed by middle and upper altitudes frequency classes of the woody species. The Variation in frequency of woody species among three altitudinal gradient were might be due to habitat preferences of the species, environmental effect (slope, altitude), species characteristics for adaptation, degree of disturbance and availability of suitable conditions for regeneration (Figure 5). Similar studies reported on Gergeda and Anbessa forests indicated that, high number of individual woody species in the lower frequency classes and lower number of individual woody species in the higher frequency classes indicate high degree of heterogeneity of species while high number of individual woody species in the higher frequency classes and lower in number of individuals woody species in the lower frequency classes indicated the homogeneity of species (Tamene Yohannes, 2013). Also, the result obtained in the study area was agree with the result reported on Yemrehane Kirstos Church forest (Amanuel Ayanaw and Gemedo Dalle, 2018) and Yegof Dry Afromontane forest (Mesfin Woldearegay *et al,* 2018) which indicated the heterogeneity of the woody plants.

Importance Value Index (IVI) of woody species

Importance value index of Werganbula forest was analyzed to compare the ecological significance of woody species. Accordingly, result of IVI obtained was showed that *Juniperus procera, Afrocarpus falcatus, Olea europaea, Teclea nobilis* and *Maytenus obscura* were the most dominant and ecologically important woody species at three altitudes of the forest (Table 6). These species had higher relative density, relative frequency and relative abundance, due to this they have higher importance value index in relative to another species in the altitudes of the forest. Similar studies reported on Arero Dry Afromontane forest indicated that, the species with the highest importance value index were the most dominant in the forest while the species with lower IVI value were least dominant in the forest (Wakshum Shiferaw *et al*., 2018). The result of IVI obtained from study forest was also in line with the result reported on Gole natural forest **(**Mesfin Belete and Tamiru Demsis., 2018) and Sanka Meda forest (Shambel Bantiwalu, 2010)**.**

Diameter class distribution

The diameter class distributions of woody species in the study area were analyzed and classified into ten DBH classes (Table 7). Accordingly, the highest density of woody species was recorded in the lower DBH classes while the lowest density was recorded in higher DBH classes in the three altitudes of the forest. The pattern of diameter class distribution is an indication of the general trends of population dynamics and recruitment processes of a given species (Steininger, 2000). The result obtained from the analysis of DBH classes in the study area was showed that as the increasing of DBH classes the density of woody species occurred in each DBH classes were decreased (Table 7). This indicated that, there was high number of small sized individuals in the lower DBH classes of woody species which used as a reserve to replacing the losses of large sized individuals. The density of large size of individuals might be lower due to senesce or selective cutting. This result in line with the result reported on Menagesha Amba Mariam Forest (Abiyou Tilahun *et al.*, 2015), Sire Beggo forest (Abyot Dibaba *et al.,* 2014) and Gedo Dry Evergreen Afromontane forest (Birhanu Kebede *et al*., 2014).

The population structures of woody species in the three altitudes were analyzed based the diameter classes distribution. The result obtained from DBH class distribution were indicated that the forest had good regeneration and recruitment potential due to the presences of high number of small sized individuals in the forest(Table 7). The population structure some individuals woody species in the study area analyzed and the result obtained was indicated five general patterns of population structure (Figure 6).

The first pattern was represented by *Juniperus procera* (Figure 6a) for lower, middle and upper altitudes forest. The patterns of these species were represented by an inverted J-shaped which shows that, the presence of highest density in the lower DBH classes with gradual decrease in density towards the higher diameter classes. Such pattern indicated the forest was healthy or normal population structure, good regeneration and recruitment potential of the forest. Similar studies were reported on Denkoro forest (Abate Ayalew *et al*., 2006)

The second pattern was represented by *Olea europaea* (Figure 6b) for lower, middle and upper altitudes of the forest. The patterns of these species were represented by U-shaped pattern of distribution which showed that, there were lower numbers of individual in the medium DBH classes. Such pattern indicated that, good reproduction but discontinuous of the recruitment. The absence of the middle DBH classes in the forest might due to that the selective cutting of individuals of preferred size by local people that surrounding the forest similar studies were reported on Dry Afromontane forest at Bale Mountains (Haile Yineger *et al*., 2008).

The third pattern was represented by *Osyris quadripartita* (Figure 6c) for lower, middle and upper altitudes of the forest. The patterns of these species were represented by Bell-shaped pattern of distribution which shows that, the higher number of middle sized individuals and lower number of small sized and large sized of the individuals in the forest. This pattern indicated that was poor generation and recruitment of the species which might be related with the high competition among woody species, harvesting of the individuals trees which bearing seed in the forest. This result agrees with the result reported on Angada forest (Shambel Alemu, 2011) and Komto forest (Fikedu Gurmessaa, 2010).

The fourth pattern was represented by *Prunus africana* Figure 6 d) for lower, middle and upper altitudes. The patterns of these species were represented by J-shaped pattern of distribution which indicated there was lower number of small sized individual in the lower DBH classes which showed that there was poor regeneration status in the forest.

The fifth pattern was represented by *Nuxia congesta* (Figure 6e) for lower, middle and upper altitudes of the forest. The patterns of these species were represented by irregular-shaped pattern of distribution. This type of patterns has good regeneration but irregular recruitment due to selective cutting of preferred sizes of the individuals in the forest. This result in line with the result reported on Yemrehane Kirstos Church forest (Amanuel Ayanaw, 2016), Keja Araba and Tula forest (Getahun Yakob and Anteneh Fekadu, 2016) and Angada forest (Shamble Alemu, 2011).

Basal area of woody species

The overall basal area of woody species in the three attitudes of the forest computed from the recorded DBH data. Accordingly, the overall basal area of woody species recorded in the study area was 32.07m^2/ha (Table 9). The occurrence high basal area in the lower altitude was due to the availability of large trees with large diameters which contributing high basal area relatively. *Juniperus procera* was contributing highest basal area to total basal area of woody species in the three altitudes of the forest. The species with the largest basal area can be considered the most important woody species in the forest. In comparison, the total basal area of woody species in the study area with other forest found in Ethiopia to be less than total basal area of woody species reported on Menagesha Amba Mariam forest 84.17 m^2/ha (Abiyou Tilahun, 2009), Wof-Washa forest 64.32 m^2/ha (Gebremicael Fisaha, 2013), Menna Angetu forest 94.22 m^2/ha (Ermias Lulekal et al., 2008), Masha Anderacha forest 81.9 m^2/ha (Kumelachew Yeshitela and Taye Bekele, 2003) and Bibita forest 69.9 m^2/ha (Dereje Denu, 2007) and Senka Meda forest 34.7 m^2 /ha (Shambel Bantiwalu, 2010). The possible reason for the above mentioned forest had higher basal area than Werganbula forest might be due to the forests consist high number of trees with a large diameter which contributing the high basal area in the forests. In Werganbula forest was dominated by shrubs woody species with consist less diameter which contributing less basal area in the forest.

Height class distribution

The heights of individual woody species in the study area were recorded and classified into nine classes (Table 8). The result showed that, the highest number and density of woody species recorded in the lower height classes while lowest number and density of woody species were recorded in the higher height classes in each three altitudes of the forest in the study area. The highest density of woody species contributed by first height classes with the recorded value of 71.30 individuals/ha, 56.48 individuals/ha and 50 individuals/ha in lower, middle and upper altitudes of the forest, respectively (Figure 6). As the increasing of height classes the number and density of the individual woody species were decreased which indicated that, there was the dominance of small sized individuals in the forest. Similar studies were reported which that, the density and number of woody species were decreased as the increasing of the height classes which showed the characteristic of normal forest (Bogale Tesfaye *et al*., 2002). The highest density species were recorded in the first height class distribution of woody species at lower altitude of the forest. Similar studies were reported on Yerer forest (Nesibu Yahya *et al.,* 2019) and Menagesha Amba Mariam Forest (Abiyou Tilahun, 2009).

In the three altitudinal gradient of Werganbula forest altitudes had a significant effect on the DBH, basal area and height of the woody species while the slope had a significant effect on the height but not on DBH and basal area of the species at $p<0.05$ (Table 10). The diameter, height and basal area of woody species were decrease with increase of altitudes which showed that, altitude had significant effect on the population structure (Table 10). The effect of altitude and slope on the DBH, height and basal area of woody species were might be associated with the environmental factors which influencing the growth of the species. The finding reported on Oda forest was indicated that, as increasing of the altitudes had great influence on the population structure of woody species (Markos Kuma and Simon Shibru, 2015). The growth and population structures of the woody species were mainly influenced by altitude, slope, aspects, latitudes, light, soil moisture, runoff and other anthropogenic factors (Lacoul and Freedman, 2006; Rohollah and Hamid 2015; Tavankar and Mehrzad, 2014; Teshome Soromessa *et al*., 2004; Kumelachew Yeshitela and Tamrat Bekele, 2002).

Vertical structure

The vertical structures of woody species were classified into three vertical layers. The classification of vertical structure of woody species in study area was following the International Union for Forestry Research Organization (IUFRO) classification scheme. According IUFRO, woody species were classified into upper storey (tree height >2/3 of top height), middle storey (tree height between 1/3 and 2/3 of top height) and lower storey (<1/3 of top height) for each altitudinal gradient. The tallest tree recorded from three study area were *Juniperus procera* and *Afrocarpus falcatus* with 45m height, then the heights were classified into three storey with those height range < 15 m, 15-30 m and >30 m respectively. The highest density of woody species in lower, middle and upper altitudes forest area were found in the lower storey with the recorded value of 181.48 (54.51%) individuals/ha, 154.63 (52.61%) individuals/ha and 130.56 (55.16%) individuals/ha respectively. The density of woody species recorded from middle storey of lower, middle and upper altitudes of the forest were 120.37 (32.94%) individuals/ha, 92.79 (36.60%) individuals/ha, and 80.56 (34.19%) individuals/ha respectively. The density of woody species recorded at the upper storey were 51.85 (12.55%) individuals/ha, 52.78 (12.80%) individuals/ha and 41.17 (10.65%) individuals /ha in lower, middle and upper altitudes of the forest respectively. The highest density of woody species were recorded at lower storey of forest was indicated the high number of woody species were found in lower storey than middle and upper storey of the forest. The percentage of density of woody species recorded in the three altitudes of the forest were lower than the density reported on lower storey of Gedo forest (86.7%) (Birhanu Kebede *et a*l., 2014) and Masha Anderacha forest (92.5%) (Kumilachew Yeshitela and Taye Bekele, 2003). However, the density recorded at middle and upper storey of three altitudes were greater than of Gedo forest 11.5% and 1.7% and Masha Anderacha forest 6.5% and 0.9% respectively.

Regeneration Status of Werganbula Forest

The density of seedlings, saplings and adults woody species that recorded in the lower, middle and upper altitudes of the forest were analyzed in order to investigating the regeneration potential of the forest. Accordingly, the density of seedlings, saplings and adults recorded in the lower altitudes of the forest were 480.56 (40.26%) individuals/ha, 358.33 (30.02%) individuals/ha and 354.63(29.72%) individuals/ha, respectively. The density of seedlings, saplings and adults species recorded in the middle altitude of the forest were 402.85 (39.89%) individuals/ha, 304.63(30.24%) individuals/ha and 300.93 (29.87%) individuals/ha, respectively. Moreover, the density of seedlings, saplings and adults species recorded in the upper altitudes of the forest were 323.15 (38.65%) individuals/ha, 259.26(31.01%) individuals/ha and 253.7 (30.34%) individuals/ha, respectively (Figure 8). The density of seedling recorded in the three altitudes of the forest was higher than density of saplings and adults and of saplings was higher than adults. This indicated that there were good regeneration and recruitment potential of woody species in the forest. Similar studies indicated that, high density of seedlings followed by saplings and adults in the forest were indicated good regeneration potential the forest and suitability of the species to the environment condition (Dhaulkhandi, M., *et al.,* 2008; Saikia & Khan, 2013 and Tiwari *et al*., 2010). Also the result was in line with the findings reported on Dry Afromontane forests of in Awi Zone (Getaneh Gebeye *et al*., 2019).

The highest density of seedlings, saplings and adults were recorded at lower altitudes of the forest which might be attributed due to the less influences of environmental factors on woody species at lower altitudes of the forest than middle and upper altitudes. This result was agree with the result reported by Ademoh, Muoghalu, and Onwumere (2010) which indicated the density of adult tree, seedling and sapling varied due to topographical variations and levels of disturbances.

The regeneration status of the woody species were categorized as good, fair, poor, new and none regeneration status based on the number of seedlings, saplings and adults recorded in the three altitudes of the forest. Those were Accordingly, out of 66 total woody species recorded from three altitudes of the forest the regeneration status of 34 (51.52%) species were good, 13 (19.7%) species were fair, 4 (6.06%) species were poor, 3 (4.55 %) species were new and 12 (18.18 %) species were none regeneration status (Appendix 4, Figure 7). This result indicated that, the most of woody species in the study area was categorized under good regeneration status. However, some individual of woody species in the study area was not represented in the seedlings and/or saplings stage. For instance, woody species such Ficus *sur, Cordia africana, Schefflera volkensii, Clerodendrum myricoides, Syzygium guineense, Schefflera abyssinica, Albizia gummifera, Cussonia arborea, Euphorbia abysinica*and *Urera hypselodendron* were not represented in the seedling and sapling stage at three altitudes of the forest Whereas, *Croton macrostachyus, Prunus africana, Rytigynia neglecta* and *Allophylus abyssinicus* were not represented in the seedling stage at three altitudes of forest. Also woody species such as *Dovyalis verrucosa, Solanum indicum and Embelia schimperi* were not represented by adult stage at three altitudes of the forest (Appendix 4**).** Possible reasons for the absence of individuals woody species from the forest at certain age might be due to biotic factors (seed dormancy, overgrazing) and abiotic (altitudes, slopes, aspects, soli) factors. Similar result was reported which indicated the environmental and anthropogenic factors may cause the absence of from the forest at certain ages (Getachew Tesfaye et al., 2002). In addition, similar result was also reported on Sire Beggo forest (Abyot Dibaba *et al.,* 2014) and Wof-Washa natural forest which showed that the absence of some individual of woody species from the forest at certain age (Gebremicael Fisaha *et al*., 2013).

This absence of seedlings and saplings in the forest indicates the discontinuous population structures. Therefore it requires the urgent forest management and conservation plan to enhance natural regeneration status of that individual species. (Girma Adane, 2012).

Juniperus procera was most dominant woody species that contributing high density to the total density of seedlings, sapling and adults woody species in at three altitudes of werganbula forest followed by *Afrocarpus falcatus, Olea europaea, Teclea nobilis and Maytenus obscura* (Appendix4).

The result of independent t-test indicated that, there was a significance difference in the mean density of the seedling, sapling and adult at three altitudes of the forest ($P<0.05$) (Table 12).

Both altitude and slope has significant effect on regeneration status of seedlings, saplings and adults species in at three altitudes of the forest ($P < 0.05$) (Table 11). This showed that, the regeneration of woody species was negatively correlated with altitudes and slopes that recorded in the study area. The result also showed that, as the increasing of the altitude and slope the regeneration of woody species were decreased.

Relationship between Woody Species and Environmental Factors

The regression analysis showed that, species richness and abundance were negatively related with altitude in the study area (Figure 9). Also the slope was negatively related with species richness and abundances (Figure 10). This result indicated the altitude and slope had a great influence on growth and development of woody species. The variation in woody species composition as increasing of altitude and slope showed the negative effect of altitude and slope on woody species composition.

The R-square result obtained indicated that, effect of altitudes on the species richness and abundances in the study area with the recorded value of 56% and 47% respectively at $P< 0.01$ (Figure 9). The effect of altitude on species richness and abundances were highly pronounced at upper altitude than by middle and lower altitudes of the forest. The possible reason for the altitude influencing the species richness and abundance were might be due to the altitudes affecting different microclimates such as light, temperature and moisture which are important for the growth of woody species. Similar studies was reported, which stated that, altitude was an important environmental factors that influencing the growth, development and distribution of woody species by affecting the temperature, moisture, radiation atmospheric pressure which important for plants (Hatfield *et al*., 2015).

Slope was also one of the environmental factors that influencing species richness and abundances in the three altitudes of the forest. The R-square value obtained from the regression analysis was indicated the slope had significant effect on species richness and abundances with recorded values of 23% and 20.7% respectively ($P< 0.05$). This result also showed that, as the increasing of the slope the species richness and abundance of woody species were decreased (Figure 10. This result was agree with the result reported on Dry Afromontane forest in Bale (Kitessa Hundera *et al.,* 2007).

CONCLUSION AND RECOMMENDATION

Conclusion

The study conducted in Werganbula forest indicated that, the forest was still rich in species diversity as compared with other similar forest in the country. The woody species diversity, structure and regeneration status in Werganbula forest have been studied. The result was indicated that the forest has high number of species diversity that was, 66 woody species that belonging to 58 genera and 43 families were recorded. Fabaceae and Rosaceae were the dominant families followed by Asteraceae and Araliaceae families. The result indicated that the altitude and slope were the major environmental factors that attributing the variation in woody species composition, structure and regeneration along altitudinal gradient of the forest. From the structural analysis, the density of woody species in three altitudes of the forest were decreases with the increasing of DBH and height classes, which indicated the predominance of small-sized individuals in the lower classes than in the higher classes in the three altitudes of the of forest. The occurrence of high number of woody species in the lower frequency classes in the three altitudes of the forest were indicated the heterogeneity of the forest. *Juniperus procera, Afrocarpus falcatus and Olea europaea* were the most dominant woody species in Werganbula forest. The analysis of woody species data for regeneration was indicated that, most of the woody species in the study area had enough seedling and sapling which showed good regeneration status of the species while few of them had not seedling or/and sapling which indicated poor or none regeneration status of the species in the forest.

Generally, the result obtained from the study was showed that, woody species composition, structure and regeneration status were negatively correlated with altitude and slope in the three altitudinal gradients of Werganbula forest.

Recommendation

In order to ensure appropriate management and sustainable utilization of the forest resources, the following recommendations were suggested based on the findings in the study area:

- The priority of conservation should be given for the endemic woody species and for woody species that have no seedlings and saplings in the forest area.
- The present study was limited to diversity, structure and regeneration status of woody species thus, further studies on herbaceous plants, soil seed bank, seed physiology and land use management system in the area are recommended
- The government and its institutions should be planting the indigenous woody specie that adapting the altitudinal gradient of the forest area and establishing the management and conservation plans are recommended.
- The more protection are required for the woody species that have low impotence value index in the three altitudes of the forest.

DECLARATION

TITLE: DIVERSITY, STRUCTURE AND REGENERATION STATUS OF WOODY SPECIES ALONG ALTITUDINAL GRADIENT OF WERGANBULA FOREST AT SUDE DISTRICT, ARSI ZONE, OROMIA REGION, ETHIOPIA

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- I confirm that I have read, understand, and agreed to the submission guidelines, policies, and submission declaration of the journal.
- I confirm that all authors of the manuscript have no conflict of interests to declare.
- I confirm that the manuscript is the authors' original work and the manuscript has not received prior publication and is not under consideration for publication elsewhere.
- On behalf of all Co-Authors, I shall bear full responsibility for the submission.
- I confirm that all authors listed on the title page have contributed significantly to the work, have read the manuscript, attest to the validity and legitimacy of the data and its interpretation, and agree to its submission.
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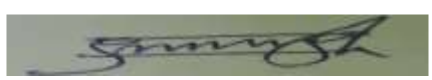

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

AUTHOR CONTRIBUTION

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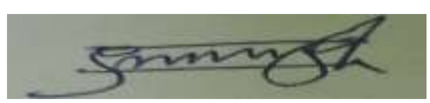
Type of contribution	**Description**	**Contributors**
Conception	constructing an idea or hypothesis for research and/or manuscript	corresponding author
Design	planning methodology to reach the conclusion	corresponding author
Supervision	organizing and supervising the course of the project or the article and taking the responsibility	co-author
Founding’s	providing personnel, environmental and financial supportand tools and instruments that are vital for the project	corresponding author
Materials	all materials used for data collection was covered	corresponding author
Data collection and/or processing	taking responsibility in execution of the experiments, data management and reporting	corresponding author
Analysis and/or interpretation	taking responsibility in logical interpretation and presentation of the results	corresponding author and co-author
Literature review	taking responsibility in this necessary function	corresponding author
Writer	taking responsibility in the construction of the whole or body of the manuscript	corresponding author and co-author
Critical review	Reviewing the article before submission not only for spelling and grammar but also for its intellectual content.	corresponding author and co-author



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Figures

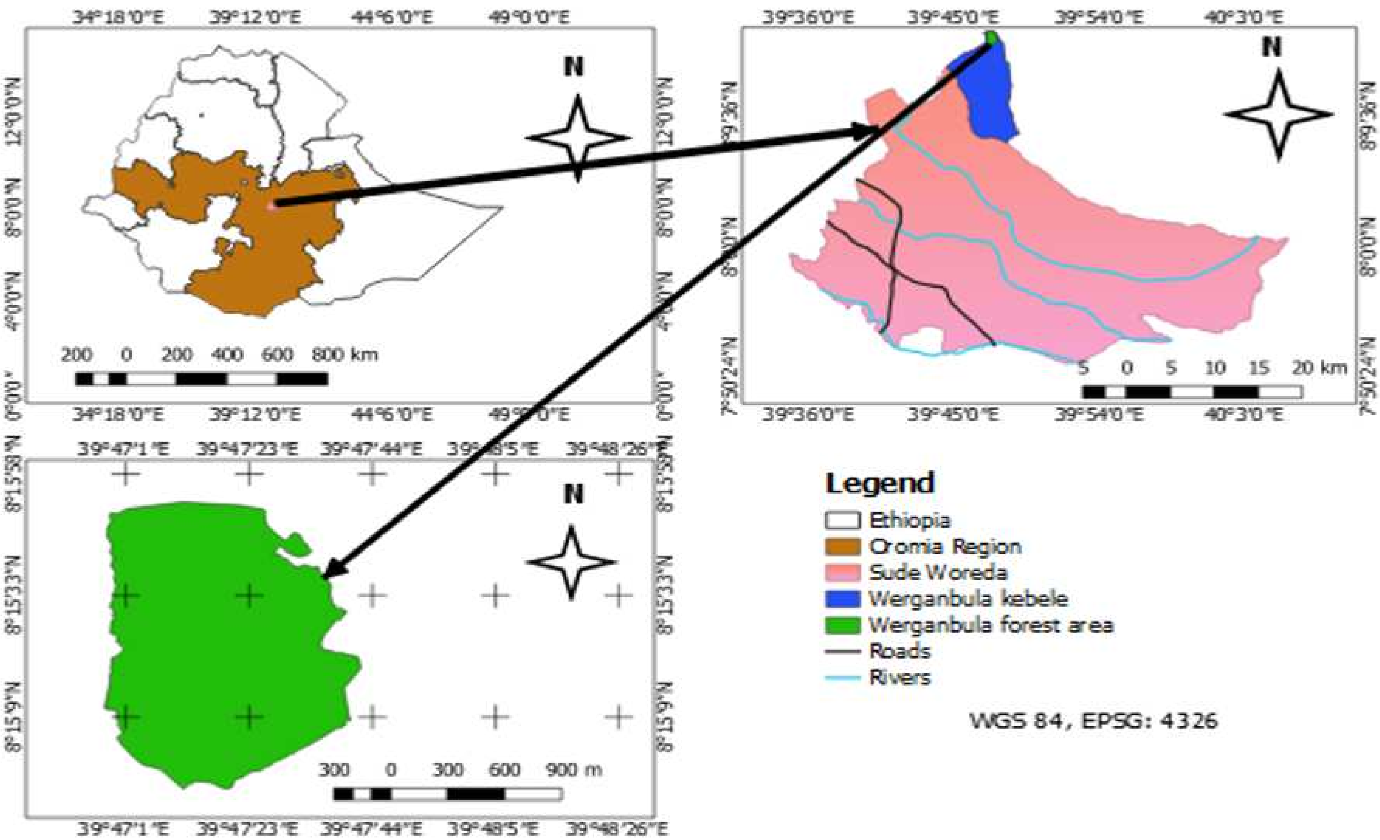


Figure 1

Map ofthe study area

Figure 2

The anthropogenic disturbance in the study area (by Geta Sileshi, 2019)

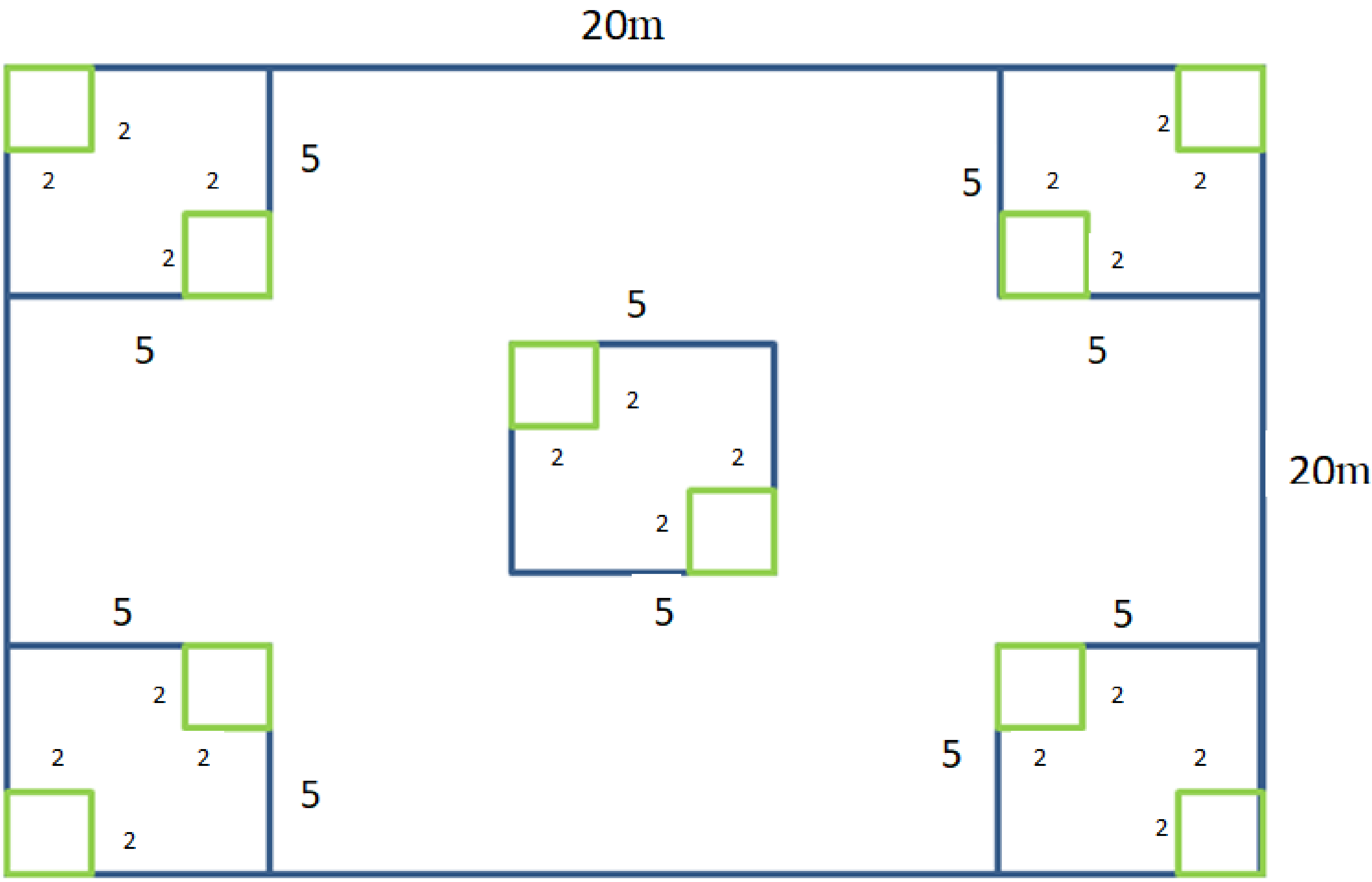


Figure 3

Sampling design of plots of the study area.

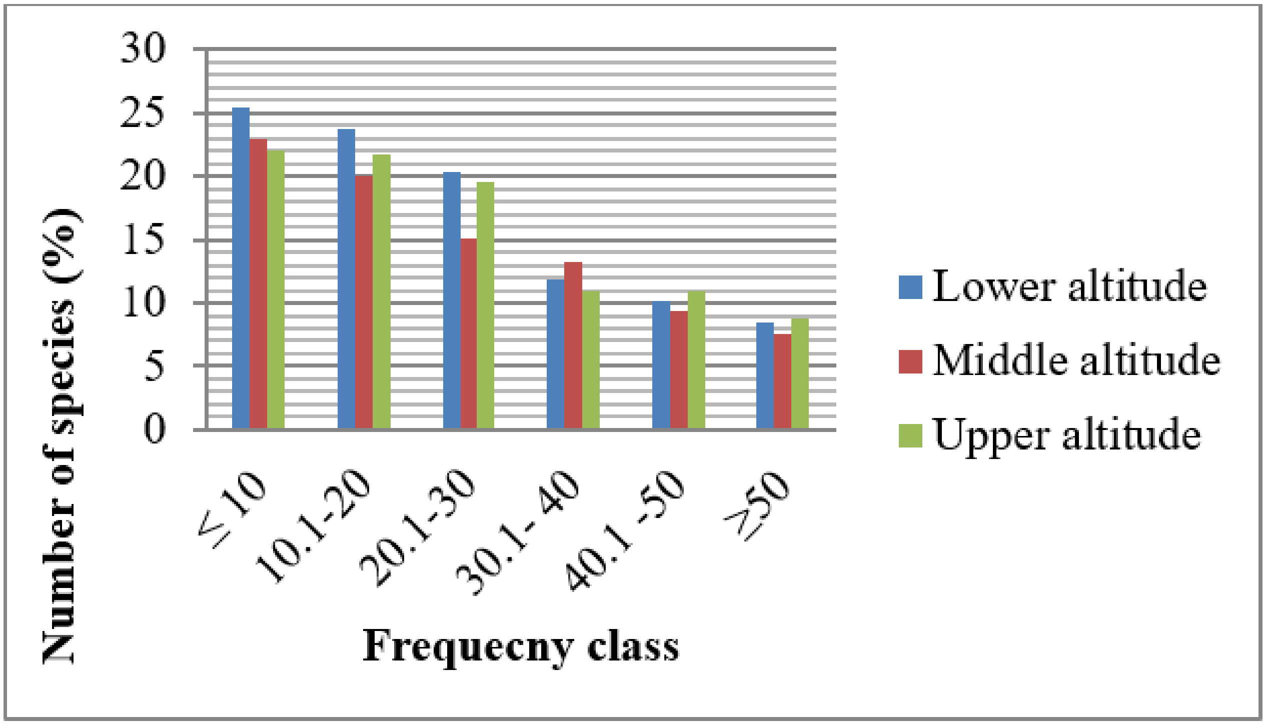


Figure 4

Frequency class distributions of woody species in the three altitudes of the forest

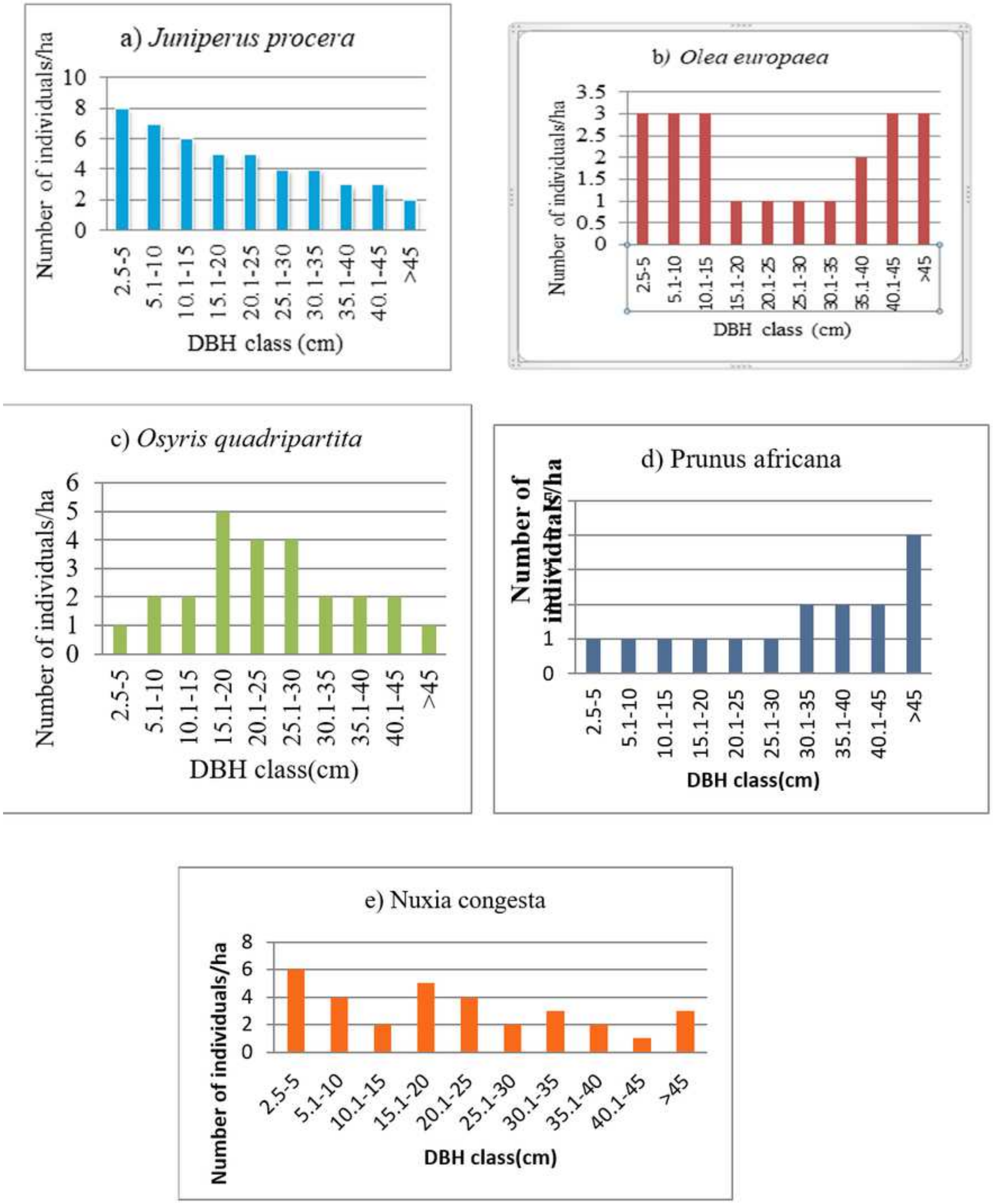


Figure 5

Diameter class distribution of wood species selected from three altitudes of forest

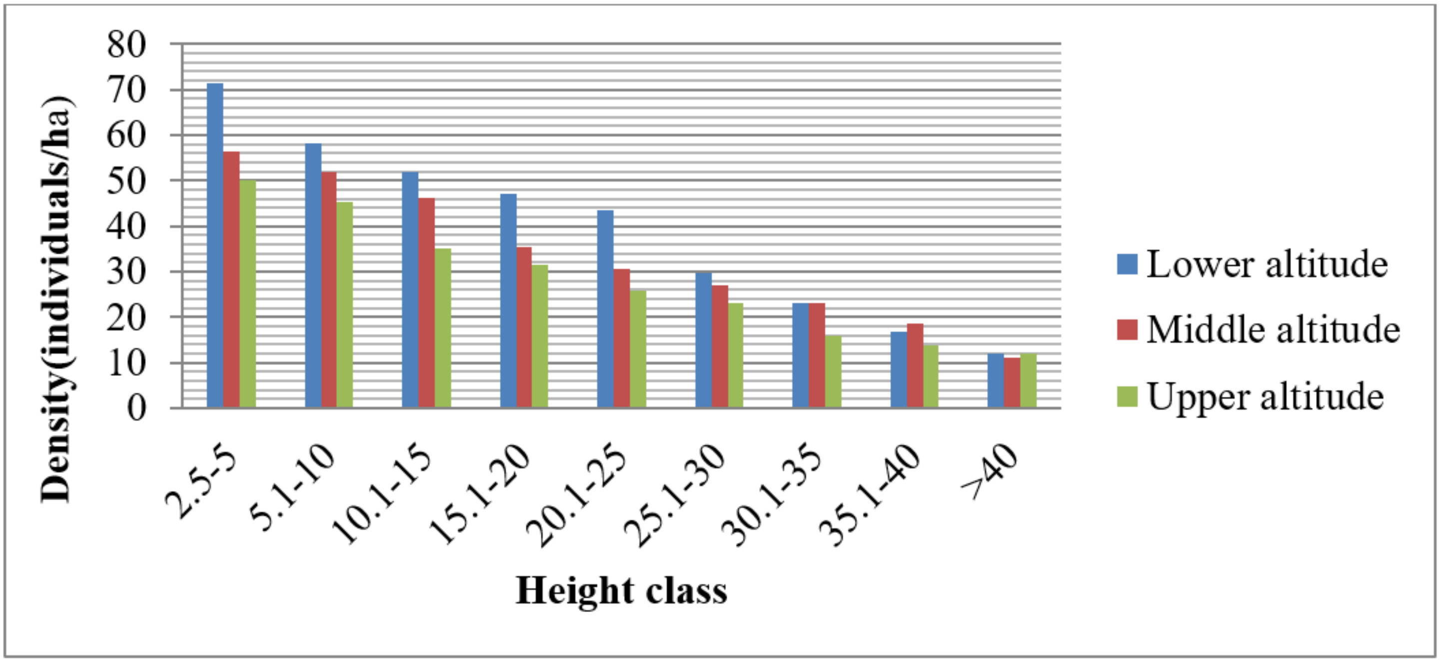


Figure 6

Height classes and density of woody species in the lower, middle and upper altitudes of the forest

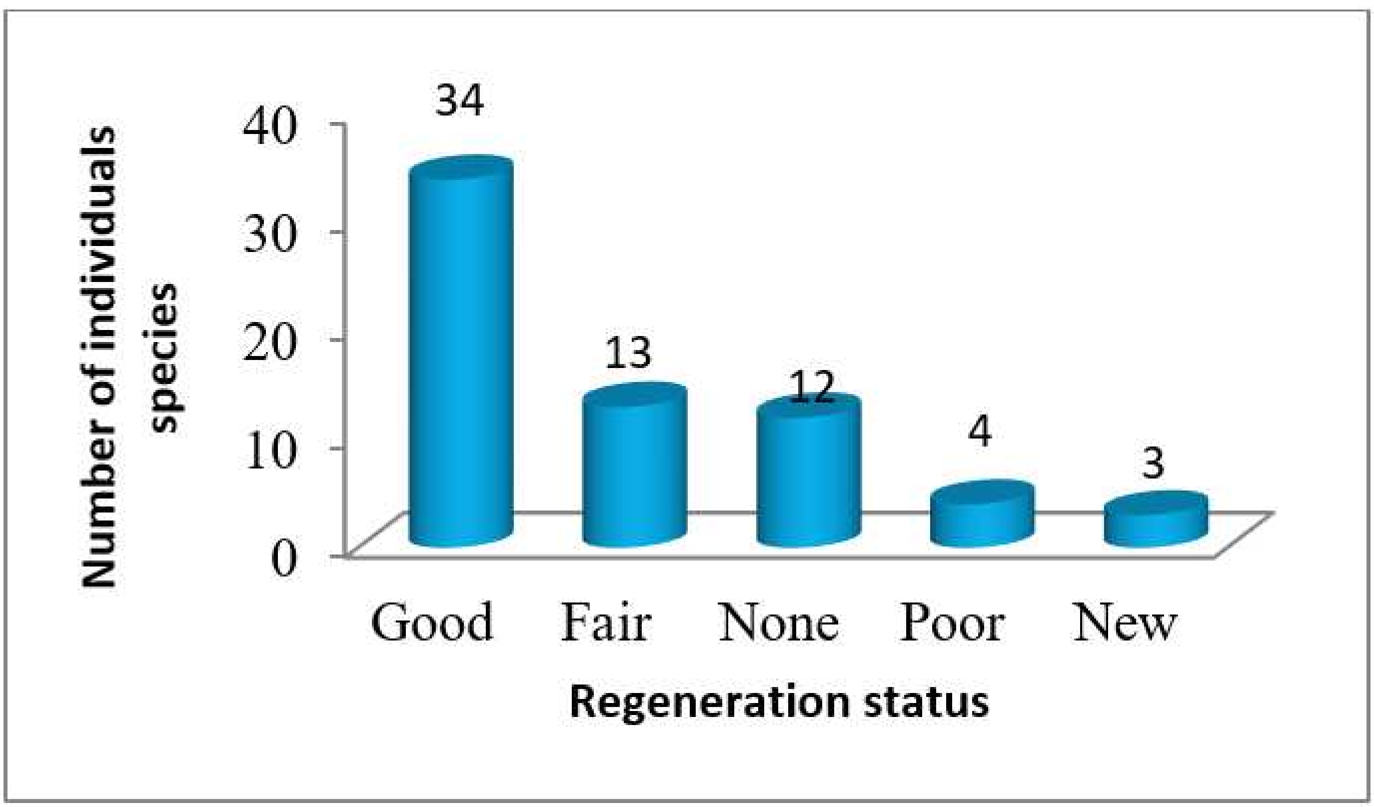


Figure 7

overall regeneration status of woody plant species in the three study area forest

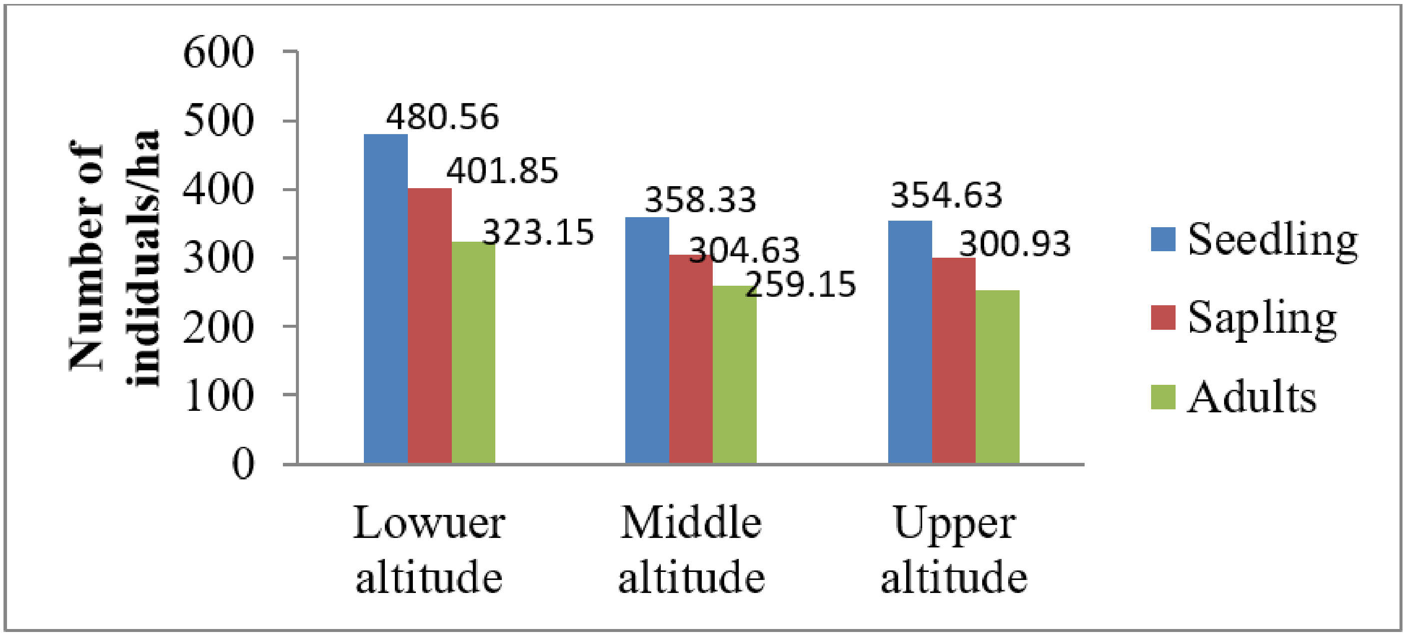
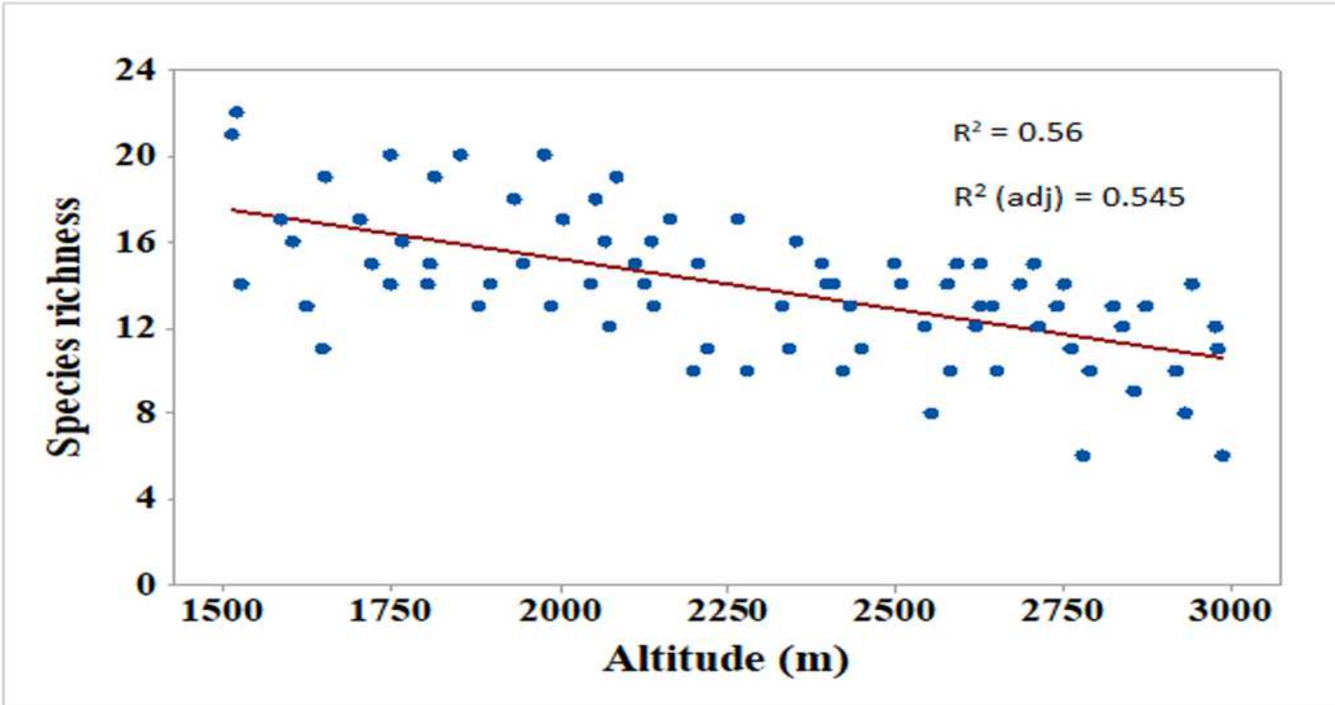


Figure 8

Seedlings, saplings and adults density in percentage in the three forests



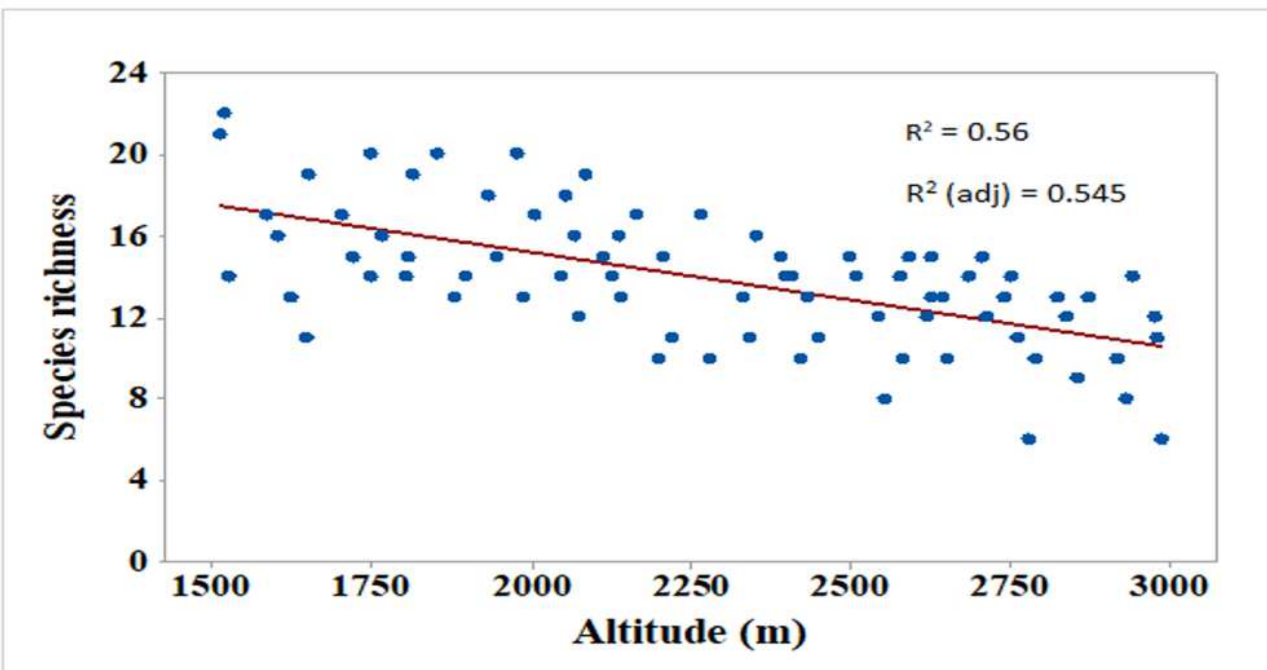


Figure 9

Relationship between species richness and abundance with altitudes of the forest

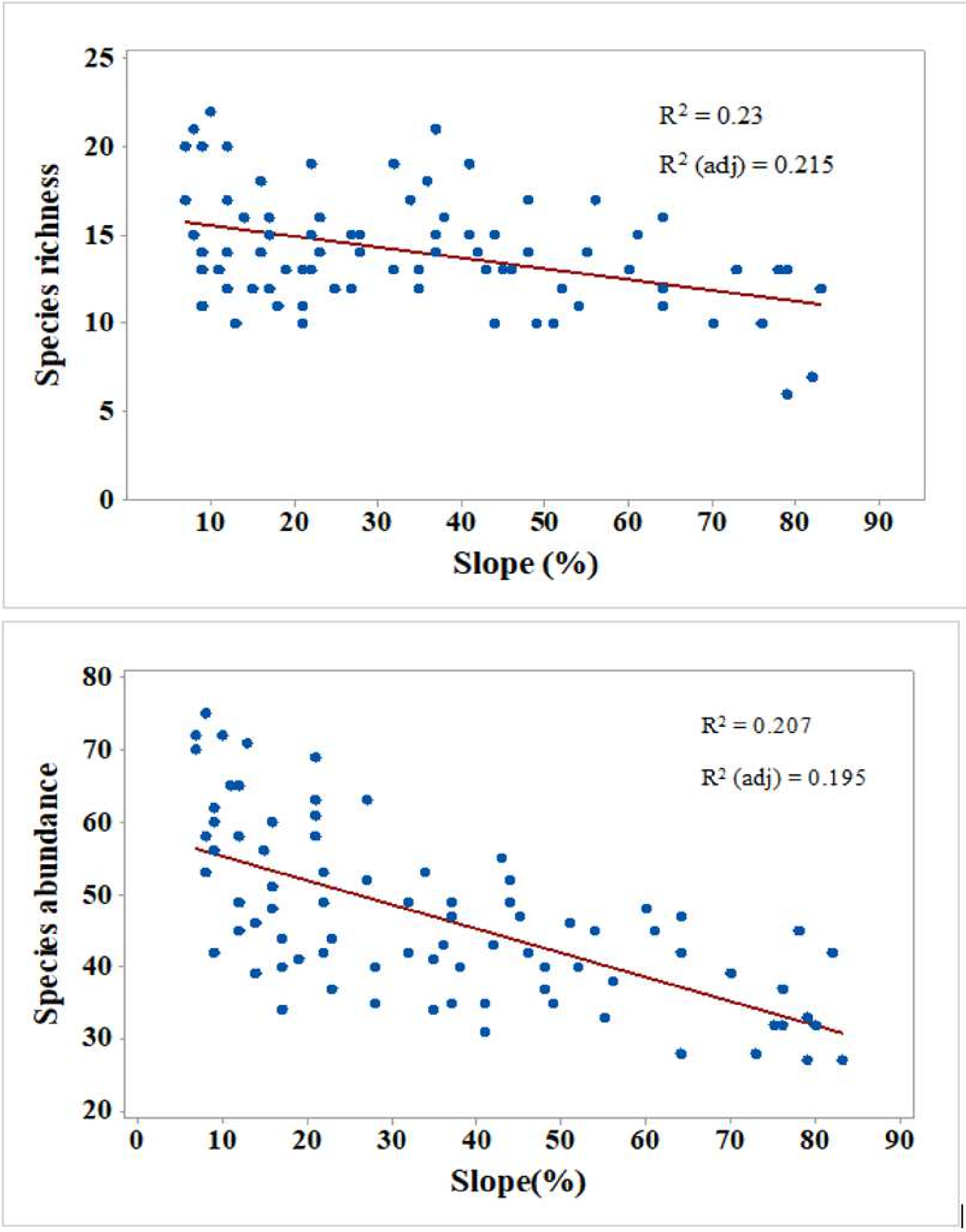


Figure 10

Relationship between species richness and abundance with the slope of the forest

Supplementary Files

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- Appendix1to3.docx