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Research Article

Plant species diversity, structure, and regeneration status of Dengago Mountain in Eastern Hararghe Zone, Ethiopia

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Abstract

The study was conducted at Dengago Mountain in Eastern Ethiopia to identify and analyze species' diversity, population structure, and regeneration status along altitudinal gradients. A systematic sampling procedure was employed with 6 transect lines and 45 quadrats established along the transect lines. Data were collected on the tree, shrubs, climbers, and herbaceous plants along altitudinal gradients. The vegetation data were statistically analyzed in one-way ANOVA using R software (version 4.0.5). A total of 49 species within 23 families and 34 genera were identified of which 42.8% were shrubs, 40.8% trees, 10.2% climbers, and 6.1% tree/shrubs. Tiliaceae was the dominant and Lower Altitude had significantly higher plant density than MA and UA. On the other hand, Middle altitude had a significantly higher Shannon's diversity index value and the Jaccard's similarities index showed the highest species similarity between MA and UA. The diameter and height class distribution of the population exhibited an inverted J-shape and the regeneration status of the forest was in fair condition. The study identified the presence of anthropologic disturbances and suggest the conservation the of Dengego mountain.

Keywords: Lower and altitudes, Natural vegetation, Upper altitude

Introduction

Ethiopia has huge floristic species diversity resources due to highly variable topography, climate, ecology, and other physical features such as soil (Admassu Addi et al., 2020; Birhanu et al., 2021; Didita et al., 2010; Zegeye et al., 2006, Gizachew, 2021). The country has about 6000 higher plants of which 10 percent are endemic (Ensermu and Sebsebe, 2014). However, the forest cover of the country has declined from about 40 to 11.4 percent within the past century (Ango et al., 2020; Bessie et al., 2016). Human-induced losses of forest cover such as deforestation, overgrazing, and expansion of farmlands and settlements are among the major factors contributing to the reduction of forest cover in the country (Melese, 2016; Shiferaw & Singh, 2011; Tsegaye, 2019).

The flora of Ethiopia is very heterogeneous and has rich endemic taxa. The country is the fifth-largest floral diversity in tropical Africa (Didita et al., 2010) and I one of the top 25 richest countries in the world (Lemessa & Teka, 2017). According to Badege (2001), the country is one of the few countries in Africa where virtually all major types of natural diversified vegetations are represented, ranging from thorny bushes, and tropical forests to mountain grasslands. However, loss of forest cover and biodiversity due to anthropogenic factors is a growing concern in many parts of the world and Ethiopia is not exception (Meshesha et al., 2012; Senbeta & Teketay, 2003). Information on species composition and diversity of tree species plays a pivotal role not only to understand the structure of a forest community but also in planning and implementing of conservation strategy of the community (Lahiri & Dash, 2021; Malik & Bhatt, 2016). Plant species richness and abundance distribution vary along wide altitudinal gradients (Klanderud & Birks, 2003; Oommen & Shanker, 2005; Pouteau et al., 2016). The decrease in species richness with increasing altitude seems to be a general pattern (Bruun et al., 2006; Rahbek, 1995), the variation of species richness with elevation might be related to reduced temperatures and precipitation, area, mountain slopes and the assumed corresponding reduction in productivity. The study was conducted to investigate the floristic species diversity, structure, and regeneration status of Dengago Mountain. The result of the study will be used for establishing conservation and management strategies in the Dengego Mountain landscape.

Materials and methods

Description of the Study Area

The study was conducted from September to October 2021 at the Dengago Model Tree-Based Restoration Project site in the East Hararghe Zone of Oromia Regional State. situated between 09° 22′ 00″ and 09°31′ N, and 41° 57′ ′ and 41° 58′ E with an elevation ranging between 1556-2284 meters above sea level (Fig. 1).

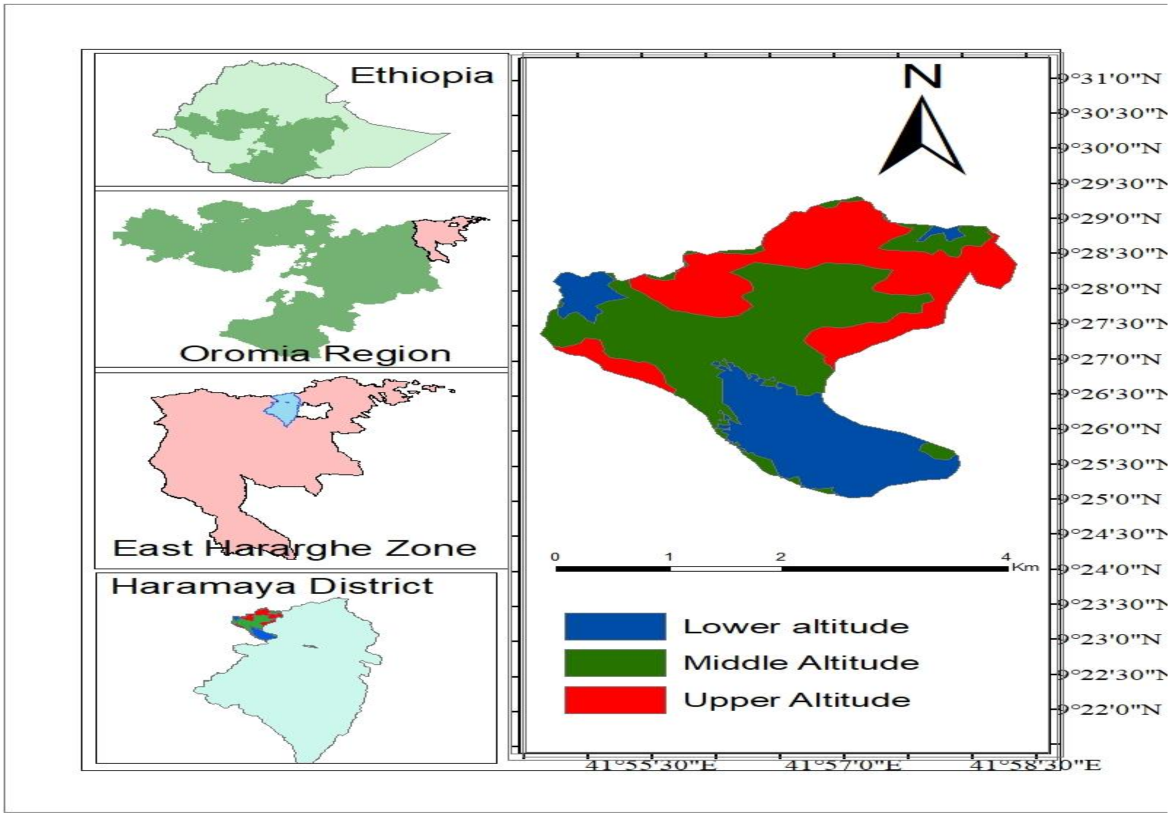

Figure 1. Location map of the study area

Delineation and Stratification of the Study Area

A preliminary survey was made to get an impression of the site conditions, identify the possible sampling sites and determine sampling methods to be used for vegetation data collection. The boundary of the study area was delineated using GPS. Then after, the study site was classified into three altitudinal gradients [i.e., Lower altitude (LA: ≤1800 m.a.s.l); Middle altitude (MA: 1800-2000m.a.s.l) and Upper altitude (UA; ≥2000 m.a.s.l)]. A systematic transect line sampling by elevation segments was used since the area had altitudinal differences that help to determine the variations in elevation as a predictor variable and relate to species diversity and population structure. In each altitudinal class, two parallel transect lines 1000 m in length and 500 m apart were laid along the slope. The first transect line was established at 50m inside from the border to avoid the edge effect. In each altitudinal gradient and along the transect lines six nested plots of 20m x 20m, 5m x 5m, and 2mx2m were systematically set at a distance of 200m between quadrates.

Data Collection and measurement

In all quadrats, species identity, frequency, diameter at breast height, and total plant height were recorded from trees, tree/shrub, climbers, and shrub species for floristic composition and diversity assessment. Diameter at breast height (DBH) and height were measured using a caliper and hypsometer respectively. All plants touching the boundary ‘in’ along two adjacent sides of the plot and ‘out’ along the other two adjacent sides were counted to avoid the edge effect (Elzinga and Salzer, 1998).

The undergrowth woody species with a height of fewer than 1m were considered as seedlings, those greater than or equal to 1m - 2m were considered as a sapling, and woody species greater than 2 m were considered as trees and shrubs (Ayanaw & Dalle, 2018). For tree species forked below 1.3 m, individual stems were separately measured and treated as a single tree (Nord-Larsen & Cao, 2006). In the case of multi-stemmed shrubs, each stem was measured and the diameter equivalent of the plant was calculated using the following formula (Magarik et al., 2020).

$$d= \sum_{i=1}^{n} \sqrt{di^2} \qquad \text{(eq. 1)}$$

Where: d = diameter equivalent height, di = diameter of the ith estimate of the measured height.

Scientific nomenclature was carried out using published volumes of “Flora of Ethiopia and Eritrea” (Sebsebe, 1997), Useful Trees and Shrubs of Ethiopia (Bekele and Tengnäs, 2007) and Natural Database for Africa (NDA) Version 2 (Bultum et al., 2019). For species that were difficult to identify at field level, plant specimens were collected, pressed, dried, and brought to Haramaya University Herbarium for taxonomic identification and nomenclature. These were decided by comparison with authenticated specimens kept at the herbarium. The population size of seedlings and saplings were used to determine the species' regeneration status (Maua et al. 2020; Paul, Khan, and Das 2019; Pradhan, Ormsby, and Behera 2019) .

Vegetation data analysis

Species richness: The term "species richness" mentions the number of diverse species found in a quadrat, area, or community. The variety of species available observed across the entire sample quadrat of each land use type was employed as a reflection of the richness of species in this case. Quadrat species richness, on the other hand, is used to compare the richness of species amid the land use types.

Shannon diversity index (H’) ‘;’ It's vital to choose an index that's more sensitive to richness when comparing diversity among samples and environments. Therefore, the species diversity across land-use types was estimated using Shannon diversity index as follows:

$$H' = -\sum_{1}^{s} pi \ln pi \qquad \text{(eq 2)}$$

where H’ = Shannon index of diversity

Pi = the fraction of species.

Evenness: The Shannon evenness index is the furthermost often used indicator for approximating evenness diversity.

$$E = \frac{H'}{H'max} \qquad \text{(eq 3)}$$

where E = Shannon index of evenness;

H’ = Shannon index of diversity;

H’max = lnS, and

S = total species number.

Importance value index‘;’ To measure the relevance of all species to the study area, the IVI, relative frequency, frequency and abundance were estimated using the method of (Kent and Coker, 1992a).

$$\text{IVI} = \text{Relative Frequency} + \text{Relative Dominance} + \text{Relative Density} \qquad \text{(eq 4)}$$

$$\text{Relative Frequency (\%)} = \frac{\text{Frequency of any species}}{\text{Total frequency of all species}} \times 100 \qquad \text{(eq 5)}$$

$$\text{Relative Density (\%)} = \frac{Number\ of\ individual\ of\ each\ species\ per\ ha}{Total\ number\ of\ individuals\ of\ all\ species\ per\ ha} \times 100 \qquad \text{(eq 6)}$$

$$Realtive\ Dominance = \frac{Basal\ area\ of\ each\ species}{Total\ Basal\ area\ of\ all\ species} * 100 \qquad \text{(eq 7)}$$

$$\text{Basal area(BA) (\%)} = \frac{\pi d^2}{4}, d = \text{Diameter at breast height} \qquad \text{(eq 8)}$$

The BA is a measurement of domination and is used to elucidate the cross-section the tree stand. It is derived using the method below (Kent and Coker, 1992):

$$\text{BA} = \frac{\pi d^2}{4}) \qquad \text{(eq 9)}$$

Where; BA = Basal area, d = DBH/DSH, and π= 3.14

The Jaccard similarity index was used to calculate the coefficient of similarity between land use types (Chidumayo, 1997).

$$J = \frac{a}{a+b+c} \qquad \text{(eq 10)}$$

J = Jaccard coefficient of similarity, a= Species Number shared to both samples, b= species number present in the first site only and, c= species number found only in the second area.

Statistical analyses

Following the requisite data collection, both qualitative and quantitative statistics were carried out. Percentages, figures, and means were used to present descriptive analyses of population structure. One-way analysis of variance is an example of inferential statistics were used for diversity indices (evenness and Shannon Weiner diversity index) and species richness. Each and every statistical analysis were carried out using R software (version 4.1.2) using lattice, vegan, permute and biodiversity R package (Core Team, 2013) at the 5% level of significance.

Results

Species Composition

A total of 49 floristic species representing 23 families and 34 genera were recorded at Dengago Mountain. The number of families recorded in UA and MA sites of the study area were high (n=14) compared to smaller family size of LA (n=13). Tiliaceae was found the most species-rich family consisting of 12 (16%) species, of which 5, 4 and 3 species were found in UA, LA and MA gradients respectively. It was followed by Fabaceae and Euphorbiaceae with 14% and 11% species.

Table 1. Plant species composition in Dengago Mountain

Strata	Tree species		Shrub species		T/Sh		Climber species		Total	
	Number	%	Number	%	Number	%	Number	%	Number	%
LA	7	35	11	55	2	10	0	10	20	100
MA	18	52.94	12	35.29	2	5.88	2	5.88	34	100
UA	14	40.00	13	37.14	3	8.57	5	14.29	35	100
Overall	20	40.82	21	42.86	3	6.12	5	10.20	49	100

Among the total tree species, 8.16%, 12.24%, 7%, and 16.33% of species were observed only in MA, UA, and LA respectively, while 18.37% of plant species were observed in all altitudinal gradients (Fig. 1).

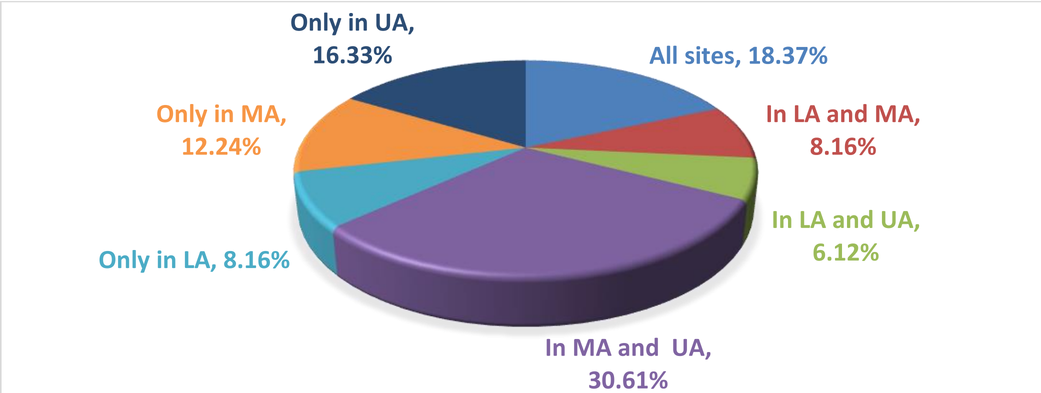

Figure 2. Percentages of species distribution across three altitudinal gradients (LA=lower altitude, MA=middle altitude land, and UA=upper altitude)

Density and Frequency of Woody Species

Density

The overall average density of Dengago floristic species was estimated as 152.17 individuals per hectare. The total density of woody species with DBH > 2.5cm recorded were1675.48, 1554.58, and 1273.16 individuals per hectare for UA, LA, and MA respectively. The upper altitude had a relatively higher density (1675.48) followed by LA (1554.58) and and MA (1273.16). The highest density of species recorded were for *Cadia purpurea and Jasminum abyssinicum,* and *Agave sisalana* with 133,800 and 7200 individuals/ha at MA, UA and LA respectively. The second-highest density was contributed by *Cadia purpurea* (300 individuals/ha), *Solanum nigrum* (150 individuals/ha), and *Opuntia stricta* (166 individuals/ha) in LA, UA, and MA respectively. On the other hand, the lowest density value was recorded in LA for *Ficus vasta* and *Grewia ferruginea* with 25 individuals/ha each. Similarly, *Ficus vasta* and *Jasminum abyssinicum* had the lowest density value in MA with 25 individuals/ha while *Acacia nilotica*, *Acacia bussei*, and *Acacia brevispica* were also exhibited lower density (37.5) in the UA.

Table 2. Species density, frequency, and basal area of Dengago Mountain (mean ± SD)

Altitudinal range	Density	Frequency	BA
LA	727.7^{a}	$38.6^{a} \pm 22.6$	94.8^{ab}
MA	284.5^{b}	$36.2^{a} \pm 18.6$	177.4^{b}

UA	521.1 ^{ab}	30.2 ^{a} ±15.5	58.7 ^{a}
P-value	0.03*	0.22 *	0.00*

Frequency

For frequency analysis, species were grouped into four major classes: ≥76(D), 51–75(C), 26 – 50(B), and≤25(A).

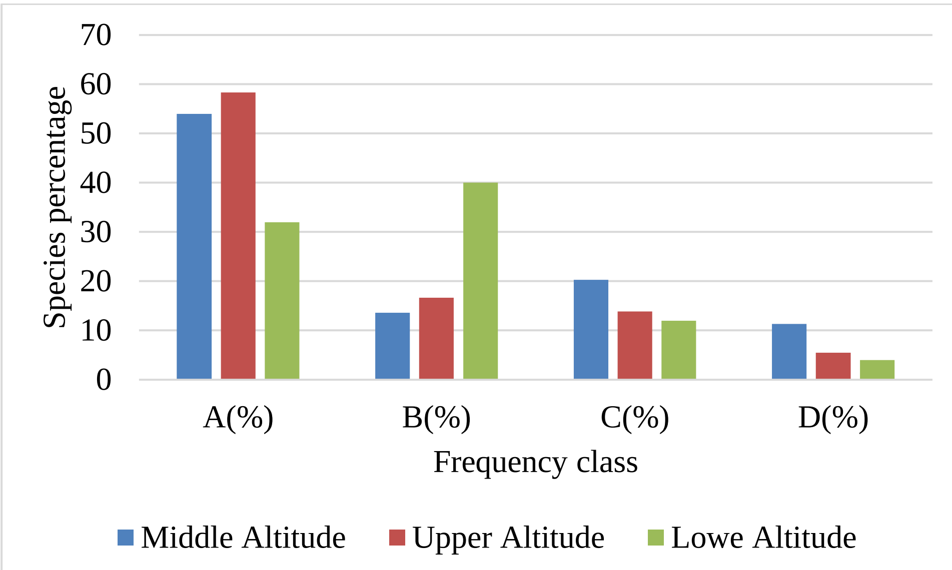

Figure 3. Distribution of species in frequency classes and altitudinal gradients (A = ≤25, B= 26 – 50, C= 51–75 and D= ≥76)

The highest frequency percentage was obtained for *Cupressus lusitanica* (88.89%), *Acacia brevispica (*81.57%) *and Grewia schweinfurthii (86.72%)* in LA. The reason for lack of perfectly frequent species might be due to human interference and animal grazing in the gradient since it is relatively closer to the residency area and minimal protection from the authorities.

Basal Area

The total mean basal area coverage of natural vegetation of the study area was 114.08m^2/ha. The mean basal area for MA, LA and UA were 177.4 ±168.1m^2/ha, 94.8 ±143.5m^2/ha, and 58.7 ±87.9m^2/ha respectively (Table 2).

The highest species wise proportion of basal area was recorded for *Bridelia micrantha* (283.3m^2/ha), *Acacia seyal* (346.1m^2/ha) and *Acacia brevispica* (706.5m^2/ha) in LA, UA and MA respectively. While, the species with lower basal area were *Dregea rubicunda* (0.7m^2/ha), *Grewia velutina* (5.3m^2/ha) and *Grewia schweinfurthii* (7.6m^2/ha) in UA, LA and MA respectively.

Importance Value Index

The results of the important value index (Table 3) showed that *Junipers procera (36.14%)*, *Acacia nilotica* (27.9%) and *Grewia schweinfurthii* (25.7%) were the three species with higher important value index in LA. On the other hand, *Acacia brevispica* was the most frequently found species with high RF (6.66%). *Acacia nilotica and Juniperers procera were* the most densely found species with high RD (19.62%) and most dominant species with the highest value of relative dominance (11.50%) respectively. Contrary to this, *Jasminum abyssinicum*, *Jasminum schimperi* and *Jasminum grandiflorum* had the lowest value of IVI.

Table 3. Importance value index of some floristic species in LA gradient of Dengago Mountain

Species name	**RF**	**RD**	**RDO**	**IVI**
Junipererersprocera	6.21	18.43	11.50	36.14
Acacia nilotica	6.19	19.62	2.17	27.9
Grewiaschweinfurthii	6.19	19.10	0.48	25.7
Olea europaea	5.23	10.8	0.27	16.3
Acacia tortilis	4.28	0.28	10.3	14.9
Euphorbia adjurana	1.42	1.57	8.68	11.6
Acacia brevispica	6.66	1.23	3.07	10.9
Acacia bussei	5.23	0.46	5.18	10.8
Acalypha fruticose	3.33	1.56	5.81	10.7
Agave sisalana	4.76	5.95	0.06	10.7

RD-Relative Density; RF-Relative Frequency; Rdom- Relative Dominance and IVI- Importance Value Index

In MA, species with the highest IVI values were *Acacia brevispica* (19.5%), *Acacia nilotica* (19%) and *Acalyph afruticosa* (17.8%). *Cupressus lusitanica*, *Acacia nilotica*, and *Acacia brevispica* had high RF (7.12%), RD (12.1%) and RDO (11.4%) respectively. In this altitudinal gradient species with the lowest IVI value were *Grewia velutina*, *Jasminum grandiflorum*, and *Berchemia discolor* with 1.01%, 0.80%, and 0.75% values, respectively.

Table 4. Important value index of some woody species in MA gradient of Dengago Mountain

Species name	RF	RD	RDO	IVI2
Acacia brevispica	6.93	1.14	11.4	19.5
Acacia nilotica	6.43	12.1	0.43	19.0
Acalypha fruticose	5.94	0.93	10.9	17.8
Cupressus lusitanica	**7.12**	4.54	5.67	17.33
Olea europaea	6.93	9.39	0.20	16.5
Acacia seyal	5.44	10.9	0.19	16.5
Acacia tortilis	4.95	0.44	9.91	15.3
Acacia etbaica	5.44	9.39	0.37	15.2
Barbeyaoleoides	4.45	9.14	0.61	14.2

RD-Relative Density; RF-Relative Frequency; Rdom- Relative Dominance and IVI- Importance Value Index

Grewia schweinfurthii (24.9%), *Acacia nilotica* (23.2%) and *Acacia etbaica* (22%) were the top three ecologically important species having higher IVI values (Table 5). *Acacia nilotica* was found the three-altitudinal gradients and had high IVI. The least ecologically significant species were *Grewia villosa (1.56%), Ziziphus mauritiana* (1.49%) and *Dracaena ombet (0.89%)*.

Table 5. Important value index of some woody species in UA gradient of Dengago Mountain

Species name	**RF**	**RD**	**RDO**	**IVI3**
Grewiaschweinfurthii	10.8	13.8	0.31	24.9
Acacia nilotica	4.16	5.27	13.8	23.2
Acacia etbaica	5.83	11.2	4.98	22.0
Acacia brevispica	7.52	0.98	11.2	19.7
Olea europaea	6.66	12.5	0.16	19.3
Agave sisalana	7.50	11.2	0.37	19.0
Acacia bussei	7.52	0.53	7.78	15.8
Solanum nigrum	3.33	3.95	6.78	14.0

RD-Relative Density; RF-Relative Frequency; Rdom- Relative Dominance and IVI- Importance Value Index

Woody Species Diversity, Richness, and Evenness

The average overall vegetation species diversity and evenness were 3.1 and 0.8 respectively.

Table 6. Mean ± SD of species diversity, richness, and evenness of Dangago Mountain

Land use types	Shannon diversity index (H')	Evenness(H′/Hmax)	Species richness
LA	2.8[c]±0.8	0.88 [a] ±0.023	17.3[a]±7.50
MA	3.3[a] ±0.7	0.84 [a]±0.03	21.6 [a] ±8.63
UA	3.1[b]±1.3	0.83 [a]±0.06	26.2 [a] ±9.83
P-value	0.03*	0.06	0.08

Jaccard Coefficient of Species Similarity

Table 7. The similarity of species between three altitudinal sites

Forest type	LA	MA	UA
LA	1		
MA	0.67	1	
UA	0.53	0.72	1

Density against DBH class

Highest frequency in low diameter classes found in 69.3%, 58.3%, and 56.6% of total DBH frequency lie between the first three diameter classes in LA, MA, and UA respectively.

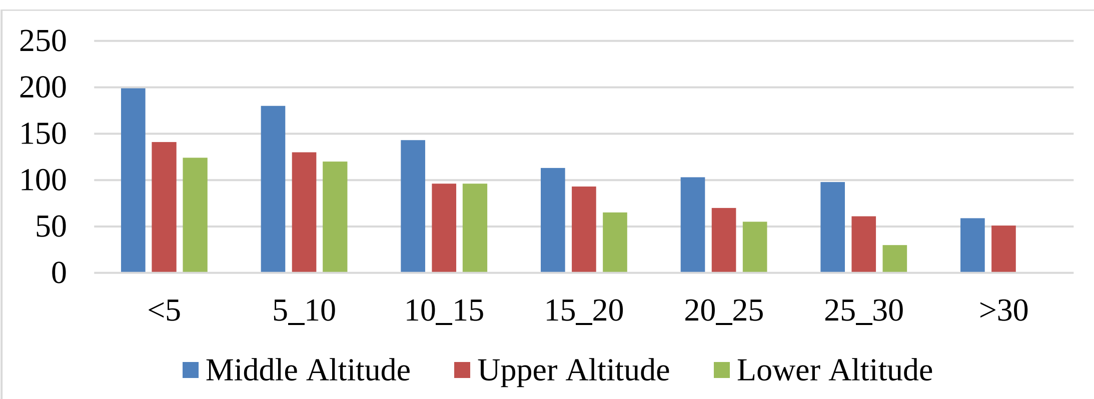

Figure 4. Diameter distribution of species in three altitudinal gradients

Height Distribution

Height class distribution had reversed J-shape pattern. Most species attained the medium canopy layer class (5-10 and 10-15m) and decreased towards the lower and higher height classes in MA.

The species in the medium canopy class (5-10m) contribute 31.6%, 28.3%, and 23.4% of the totally selected individuals of woody species in LA, UA, and MA gradients (Fig. 7). Only 14.5% and 10.9% of trees were in the higher height class distribution for MA and UA.

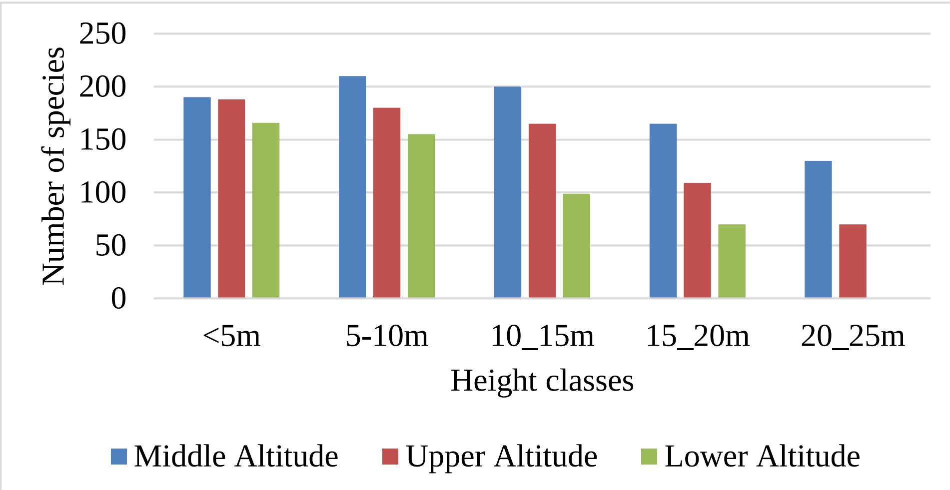

Figure 5. Height class distribution of woody species at the three altitudinal sites

Regeneration status

In the study site 10.68% seedlings, 4.03% saplings and 85.29% of mature floristic species were counted.

Table 8. Regeneration status of species in all altitudinal gradients of Dangago Mountain

Altitudes	Seedling (%)	Sapling (%)	Matured trees (%)
Lower	10.68	4.03	85.29
Middle	11.41	6.92	81.67
Upper	7.65	4.61	87.74

Discussions

Species Composition

In the study site, small sized shrubs were dominating the floristic composition in all sample plots considered. Such domination of shrub species may be due to the different dispersal agents, wide range of dispersal mechanisms and rapid reproduction strategies. Cowling & Kerley, (2002) also suggested that since most of the shrubs produce bird-dispersed fruits, they can recolonize areas successfully. Some of the species in the LA, were due to their resistance to grazing and trampling of humans and cattle (Rad et al., 2009).

Density and Frequency of Woody Species

Density

The lower density of important woody species such as *Acacia nilotica*, *Acacia bussei*, and *Acacia brevispica* were recorded. This lower density might be due to selective exploitation for construction, firewood, charcoal and other domestic uses by local peoples. Tree cutting was mainly associated with expansion of settlements and agriculture, fuel wood for home consumption and sale, raw materials for house and households' utilities construction (Gebreegziabher, 2007; Kull et al., 2011). Similarly, the highest densities of some species like *L. camara* could be due to their unpalatable nature for both wild and domestic animals and wide range of dispersal mechanisms and rapider reproductions strategies (Belayneh and Demissew 2011; Senbeta and Teketay 2003). Statistical analysis of density for each altitudinal gradient indicated significant mean difference between LA and MA, while UA had insignificantly lower mean density than both LA and MA (Table 2). As depicted in table 2, LA had a significant high mean density than MA but not with UA. On the other hand, MA had a significant low mean density, while UA holds the intermediate mean density (Table 2). From this we can conclude that altitude has high impact on species density of the study area. In conclusion woody species density tends to increase with increase in altitude (Cirimwami et al., 2019; Fajardo, 2018; Midolo et al., 2019).

Frequency

The result showed that MA and UA gradients had high value records in lower frequency class ($\leq$ 25%) classes and low values in higher frequency class. This imply that there is high diversity in the two gradients compared to LA. However, in LA there was high value in middle frequency class (26–50), which is because of domination of some planted species like *Junipers* (Fig. 4). Generally, MA and UA of Dengago Mountain had heterogeneous species compositions compared to LA. Similar results were also reported by other authors (Bogale *et al.* 2017; Tegegne andWorkineh 2017). Statistical analysis of frequency in each altitudinal gradient indicates a non-significant mean difference among all the three altitudinal gradients (Fig. 6). However, LA had significantly the highest mean frequency followed by MA and UA. Frequency indicates an approximate homogeneity and heterogeneity of species. The high value in higher frequency and low value in lower frequency classes indicate constant or similar species composition whereas high value in lower frequency classes and low values in higher frequency indicates a high degree of floristic heterogeneity (Wang *et al*. 2003). In other words, it gives an approximate indication of the homogeneity of the stand under consideration (Kent & Coker, 1992a).

Basal Area

Accordingly, there was a significant difference in mean basal area between the MA and UA (p= 0.00). Hence, MA had significantly higher basal area coverage than the other two sites. This witnesses that altitude had significant influence on basal area and dominance of an area by different vegetations. Similar result was also reported by (Fenetahun et al., 2020; Kebede et al., 2013; Wassie et al., 2010). The directly relational trend indicated that the value of basal area starts to increase in middle altitude, which might be due to the presence of relatively higher proportion of larger and aged trees and limited interference by human activities. Atsbha et al., (2019) concluded that the greater difference in basal area between the altitudes could be due to the high number of multi-stemmed trees in undisturbed sites leading to bigger diameters. Gebrewahid & Abrehe (2019); Yilma & Derero (2020) also suggested that altitude with aspect and slope affects dominance, basal area, and distribution of species due to its influence on light radiation, temperature, moisture, runoff, and infiltration, which is optimum in MA.

Bridelia micrantha, *Acacia brevispica* and *Acacia seyal* were species with high relative dominance in LA, MA, and UA. Even though, the local community utilized them for different purposes, they are relatively dominant species in the study area. This is because seedlings and saplings grow fast and have thorns that discourage browsing by a variety of free-grazing domestic animals and wildlife (Mbuya *et al.* 1994).

Importance Value Index

Higher important value index in LA indicated that there were most ecologically important species in LA. Low IVI value might be a sign of over-utilization or low management of species (Negash et al. 2013; Chhetri et al. 2019). Therefore, the vegetation community may loss these species if appropriate management and conservation strategies are not implemented (Muluneh et al., 2021). *Acacia nilotica* was ecologically important species in both LA and MA indicating the suitability of the two gradients for the species. Besides, there could be low anthropogenic disturbance of the species.

Woody Species Diversity, Richness, and Evenness

The three altitudinal gradients had a significantly different values of species diversity and non-significant values for evenness. Middle altitude had a significantly higher Shannon diversity index value than UA and LA. Hence, Dengago Mountain had high Shannon diversity index (Cavalcanti & Larrazábal, 2004). The general pattern of woody species diversity along altitudinal gradient follows a humped shape structure with the peak at the middle altitude. This finding is also in line with Abebe et al. (2019); Bora et al. (2020); Grytnes & Vetaas, (2002); Negese Guluma, (2020). The present study demonstrated that vegetation diversity varies along altitudinal gradients. The lowest Shannon diversity index and evenness registered in LA was due to frequent and intensive interference by humans and livestock (Atsbha et al., 2019) or presence of disturbance and absence of adequate nutrients and moisture (Aynekulu et al., 2016; Rossiter et al., 2017).

In all altitudinal gradients, average evenness decreased insignificantly from LA through MA and UA sites (Table 6). The high evenness value indicates similar adaptation potential of woody species and the lowest value might be due to relatively low sunlight radiation that affects soil productivity and species distribution (Dereje, 2006). A total number of woody species richness follows a humped shape pattern, which indicates higher diversity in the middle that might be related to relatively favorable climatic, environmental conditions and soil characteristics especially soil texture, soil organic matter (Desalegn and Beierkuhnlein, 2010), slope and lower human disturbance (McKinney, 2002).

Jaccard Coefficient of Species Similarity

Even though the three altitudinal gradients are found adjacent to each other, they have different similarity coefficients. The Jaccard's similarities of vegetation species for MA and UA were 72% while it was 67% for LA. However, the similarities between LA and UA were 53% of species, which is the lowest similarity (Table 7). This could be due to excessive exploitation of the same species (Tessema et al., 2012; Yirdaw, 2001).

Density against DBH class

The pattern of dimeter class in the three altitudinal gradients exhibited a reversed J-shaped distribution (Fig. 6). This pattern indicates highest frequency in low diameter classes and a gradual decrease towards the higher class. It was found that 69.3%, 58.3%, and 56.6% of total DBH frequency lie between the first three diameter classes in LA, MA, and UA indicating that woody species with higher diameter were harvested by local people (Getaneh, 2007). Contrarily, the proportion of species in the larger diameter classes were exhibits the presence of larger trees as the altitude increases. The current finding is congruent with the findings of Atsbha et al. (2019); Nord-Larsen & Cao, (2006).

Height Distribution

Trees in medium canopy class (5-10m) category forms the upper canopy of the vegetation and found in the less disturbed forest (Awas, 2007; Rao et al., 1990). This could be due to selective cutting of trees by the local people for construction and firewood, poor regeneration status, and over-harvesting of seed-bearing individuals (Bogale et al., 2017). This pattern is supported by the work of (Singh et al., 2020) that states the direct removal of trees by logging and farming activities was directly responsible for the decrease in height in LA forests.

Regeneration status

The overall regeneration status of Dengago Mountain was found in fair condition. This was observed as the proportion of regenerating seedling > sapling< mature in all altitudinal gradients. This finding indicates faire regeneration status of the forest and corroborated with previous reports (Khaine et al., 2018; Maua et al., 2020; Paul et al., 2019; Pradhan et al., 2019). The future composition of the forests depends on the potential regenerative status of individual species within a forest stand in space and time (Henle et al., 2004). The population structure, characterized by the presence of a sufficient population of seedlings, saplings, and mature woody species indicates successful regeneration of forest species (Bogale et al., 2017).

Conclusion

Understanding the distribution of species along the elevation gradient and factors governing the same is essential for the conservation of biodiversity and prioritizing areas for conservation planning. Dangago is a unique habitat because of its topographic arrangement and location, it lies between Oromia Regional State and Dire Dawa Administration. Thus, conservation of Dangago Mountain has special importance across the two regions. The present study could assist policymakers and local practitioners to devise sound strategies for conservation and sustainable management of the fragile Dengago as well as similar areas in eastern Ethiopia.

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Appendix table S1

Species name	*LA*				*MA*				*UA*			
	RF	**RD**	**RDO**	**IVI**	**RF**	**RD**	**RDO**	**IVI**	**RF**	**RD**	**RDO**	**IVI**
Acacia brevispica	6.66	1.23	3.07	10.9	6.93	1.14	11.4	19.5	7.52	0.98	11.2	19.7
Acacia bussei	5.23	0.46	5.18	10.8	4.45	0.55	8.02	13.0	7.52	0.53	7.78	15.8
Acacia etbaica	4.28	5.08	0.31	9.68	5.44	9.39	0.37	15.2	5.83	11.2	4.98	22.0
Acacia negrii	4.76	0.36	4.59	9.71	3.96	0.34	8.94	13.2	6.66	0.49	4.98	12.1
Acacia nilotica	6.19	19.62	2.17	27.9	6.43	12.1	0.43	19.0	4.16	5.27	13.8	23.2
Acacia seyal	2.85	2.27	0.25	5.39	5.44	10.9	0.19	16.5	2.54	4.61	2.74	9.8
Acacia tortilis	4.28	0.28	10.3	14.9	4.95	0.44	9.91	15.3	0	0	0	0
Acalyphafruticosa	3.33	1.56	5.81	10.7	5.94	0.93	10.9	17.8	5.83	0.78	6.78	13.3
Agave sisalana	4.76	5.95	0.06	10.7	4.95	7.36	0.20	12.5	7.50	11.2	0.37	19.0
Aloe harlana	0	0	0	0	0	0	0	0	2.50	3.29	0.18	5.98
Balanites glabra	1.42	1.40	0.50	3.33	2.97	3.55	0.50	7.02	0	0	0	0
Barbeyaoleoides	3.80	3.68	0.58	8.07	4.45	9.14	0.61	14.2	0	0	0	0
Berchemia discolor	0	0	0	0	0.49	0.25	0.00	0.75	0	0	0	0
Brideliamicrantha	1.90	0.09	5.18	7.19	0.99	0.06	8.02	9.08	0	0	0	0
Cadiapurpurea	0.95	0.03	4.59	5.57	0.99	0.03	7.58	8.60	0	0	0	0
Clerodendrumcephalanthum	2.85	3.50	0.20	6.56	1.48	2.54	0.22	4.24	3.33	4.61	0.25	8.20
Cupressus lusitanica	6.21	18.43	4.50	29.14	7.12	4.54	5.67	17.33	1.66	2.63	2.50	6.80
Dodonaea angustifolia	3.33	2.97	0.20	6.51	1.98	1.77	1.79	5.54	1.66	1.97	0.63	4.28
Dracaena ombet	0	0	0	0	0	0	0	0	0.83	0.04	0.02	0.89
Dregearubicunda	0.95	0.70	0.05	1.71	0	0	0	0	0	0	0	0
Euphorbia abyssinica	0	0	0	0	0	0	0	0	1.66	0.16	3.32	5.15
Euphorbia adjurana	1.42	1.57	8.68	11.6	1.48	1.77	2.14	5.40	2.50	1.97	2.74	7.21
Euphorbia candelabrum	0.95	0.03	7.54	8.52	1.48	0.07	5.57	7.13	0.83	0.04	11.2	12.0
Euphorbia polyacantha	0.95	0.87	0.07	1.90	0	0	0	0	0	0	0	0
Ficusvasta	1.90	0.09	7.17	9.18	3.96	0.30	7.16	11.4	0	0	0	0
Grewiaerythraea	2.85	3.85	0.08	6.79	1.98	3.04	0.47	5.50	5.00	6.59	0.40	11.9
Grewiaferruginea	0.47	0.35	0.09	0.91	0	0	0	0	1.66	1.97	4.18	7.83
Grewiaschweinfurthii	6.19	19.10	0.48	25.7	4.45	7.36	0.25	12.0	10.8	13.8	0.31	24.9
Grewiatenax	1.90	1.57	0.64	4.12	0	0	0	0	0	0	0	0
Grewiavelutina	0	0	0	0	0.49	0.25	0.26	1.01	0	0	0	0

Grewiavillosa	0.95	0.52	0.18	1.66	0	0	0	0	0.83	0.65	0.06	1.56
Jasminum abyssinicum	0.47	0.17	0.07	0.72	0	0	0	0	0	0	0	0
Jasminum grandiflorum	0.47	0.17	0.02	0.67	0.49	0.25	0.05	0.80	0	0	0	0
Jasminum schimperi	0.47	0.17	0.03	0.68	0	0	0	0	0	0	0	0
Lantana camara	0.47	0.35	0.04	0.86	0.49	0.50	0.06	1.07	0	0	0	0
Olea europaea	5.23	10.8	0.27	16.3	6.93	9.39	0.20	16.5	6.66	12.5	0.16	19.3
Opuntia ficus-indica	0.47	0.01	5.81	6.30	0	0	0	0	0	0	0	0
Opuntia stricta	3.33	3.32	0.15	6.81	1.98	2.28	0.19	4.46	5.83	7.25	0.21	13.30
Pittosporum abyssinicum	2.85	1.92	0.27	5.05	0.99	1.27	0.19	2.45	0	0	0	0
Rhusglutinosa	1.42	1.05	0.36	2.84	1.48	1.01	0.37	2.87	1.66	1.97	5.40	9.05
Rhusnatalensis	0.95	0.35	0.07	1.37	0.99	0.76	0.08	1.83	0	0	0	0
Rhusruspolii	1.42	0.07	6.47	7.98	0.99	0.04	7.16	8.19	0	0	0	0
Rhus vulgaris	1.90	1.22	0.58	3.71	3.46	4.31	0.33	8.12	0	0	0	0
Rumexnervosus	0.47	0.02	7.91	8.41	0	0	0	0	0	0	0	0
Salvadorapersica	0.47	0.03	7.91	8.42	0.49	0.01	4.85	5.36	0.83	0.65	8.85	10.3
Sansevieriaehrenbergii	0	0	0	0	1.48	0.76	0.25	2.50	0	0	0	0
Solanum nigrum	0.95	1.05	0.66	2.67	2.47	4.06	0.69	7.23	3.33	3.95	6.78	14.0
Ziziphusmauritiana	0.95	0.52	0.05	1.53	0	0	0	0	0.83	0.65	0.00	1.49
Ziziphus spina-christi	0.95	0.70	0.41	2.06	0	0	0	0	0	0	0	0