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Effect of environmental gradients on diversity and plant community distribution in remnant dry Afromontane forest of Mount Duro, Nagelle Arsi, Ethiopia

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Abstract. For forest ecosystem management to be effective, explicit understanding of the species diversity-environmental relationship along elevation gradient is crucial. This study aimed at identifying and describing plant communities and also documenting their species diversity. Evaluation of relationships between selected environmental variables and species diversity was another objective of this study. Systematic sampling techniques were used to collect vegetation data in a total of forty two sample plots (size=20×20 m). Within main plots, four sub-plots of 5×5 m were established at four corners and – one sub-plot of the same size in the center. These plots were used for shrub and herb diversity assessment. Within each sample plot, all plant species were documented and their scientific names were identified. Environmental variables, such as: elevation, aspect and slope, were also recorded for each main plot. Species diversity was determined using Shannon-Wiener diversity index and evenness in R statistical software. Agglomerative hierarchical clustering method was used for plant community classification. The total of 44 plant species belonging to 30 families was documented. Four plant community types were identified with different diversity, evenness and species richness. These plant communities were: *Afrocurpus falcatus-Ficus sur, Maesa lanceolata-Bersama abyssinica, Vernonia myriantha-Urera hypselodendron* and *Croton machrostachus-Tecleanobilis* occurring at average elevation of 2521, 2429, 2329, and 2364 m asl, respectively. *Maesa lanceolata-Bersama abyssinica* community type exhibited the highest species diversity and evenness followed by *Croton machrostachus-Teclea nobilis* community type showing the fact that median elevation ranges were rich in species. Elevation and slope gradient explained significant variation in species richness in the studied forest. For effective conservation of biodiversity and sustainable management of the forest ecosystem, further research on the impacts of anthropogenic disturbances and soil properties is recommended as a result of this study.

Key words: woody species, species composition, herbaceous species, altitudinal gradient

1. Introduction

Ethiopia is characterized by a wide range of ecological, edaphic and climate conditions that account for the wide diversity of its biological resources, both in terms of flora and fauna wealth; between 6500 and 7000 higher plant species, out of which about 10 percent are endemic to Ethiopia (IBC 2009). Therefore, due to its wide ranges of elevation, its great geographical diversity with high and rugged mountains, flat-topped plateaus and deep gorges, incised river valleys and rolling plains Ethiopia is an important regional center for biological diversity (Kebede 2010; Alemu *et al.* 2015; Gurmessa *et al.* 2013).

Ethiopian highlands contribute more than 50% of the total land area covered by Afromontane forest, of which dry evergreen Afromontane forests extend over half of the total area cover (Teketay & Bekele 1995; Kebede *et al.* 2013). Forest resources in Ethiopia have been facing intense degradation and deforestation (Berihu *et al.* 2017; Gebeyehu *et al.* 2019). Expansion of agricultural land, over exploitation of forest resources, overgrazing and establishment of new settlements into forested land coupled with increasing population

ECOLOGY

pressure are main driving forces of deforestation (Senbeta & Denich 2006; IBC 2009; Kebede *et al.* 2013; Mekonnen & Nigatu 2013).

Topographic and elevation variation in Ethiopian landscapes has affected the existence of different vegetation types and species diversity patterns. Various scholars reported that there is a correlation between floristic composition and diversity and environmental gradients, such as elevation, slope and aspect (Fisaha *et al.* 2013; Kebede *et al.* 2013; Berhanu *et al.* 2016; Tura *et al.* 2017; Hailemariam *et al.* 2018). Some studies proved that elevation is the most important factor in determining plant diversity and community distribution, because it strongly influences the length of growing season associated with temperature (Austin 2005; Soromessa *et al.* 2004; Adamu *et al.* 2012). Slope and aspect gradient also exerts a significant influence on plant diversity and community distribution (Tadesse *et al.* 2008; Gurmessa *et al.* 2013) in highland ecosystems. This is because changes in slope and aspects lead to changes in hours of sunshine, humidity, and temperature, contributing to changes in species diversity and community distribution (Wu 1980). For example, a variety of plant species composition and community assembly, long term operating soil weathering, and erosion processes are always accelerated on south facing slopes (Rech *et al.* 2001), resulting in different soil properties of north and south faced slopes (Bochet & García-Fayo 2004). Elevation gradient is known to be one of important factors changing spatial patterns of vegetation and species diversity (Zhang *et al.* 2006). The relationship of community structure, composition, and species diversity of natural forests with elevation gradient and other environmental variables developed as a key issue in ecological and environmental research (Ojeda *et al.* 2000; Austrheim 2002).

Patterns of species and community diversity along elevation gradient have been well studied (Lomolino 2001; Zhang *et al.* 2006; Kebede *et al.* 2013; Kuma 2016). The most commonly reported pattern is a maximum diversity at intermediate elevation level (Kessler 2001) and then it decreases. However, there are still a number of exceptions to this pattern. Some scholars debated that whether the species diversity would increase or decrease with increasing elevation or peak at intermediate elevation depended largely on specific patterns of interactions among plant communities, species, and environmental gradients (Lomolino 2001; Meng *et al.* 2012).

Many studies on Ethiopian plant communities (e.g., Assefa *et al.* 2013; Kebede *et al.* 2013; Kuma 2016; Tura *et al.* 2017) showed variations of plant community distribution with environmental gradients. Understanding community distribution, diversity of species and their habitats, and comparison with similar other habitats (Afromontane forests), is important to estimate the level of adaptation to the environment. Information on species composition of plant community, diversity and their relationship with their environment is essential in understanding forest dynamics. Sustainable management and conservation of forest resources also requires data on plant species diversity, spatial distribution and forest community types in order to identify and undertake necessary actions aiming at restoring and rehabilitating degraded forest.

In the face of the alarming rate of deforestation and forest degradation, it is crucial to generate information and assist national and regional action towards maintenance of this forest. The effect of topographic factors and elevation on diversity and plant community distribution in the Duro Natural Forest has not been studied so far.

Given this background, in order to evaluate the effect of environmental factors (i.e. elevation, slope and aspects) on species diversity, we assessed vegetation data and environmental variation in remnant dry Afromontane forest of Mount Duro. Therefore, the objective of this study was: (*i*) to identify diversity and plant community types in a remnant dry Afromontane forest of Mount Duro; (*ii*) to evaluate relationships between selected environmental variables and species diversity richness.

2. Materials and methods

2.1. Site description

The study was conducted in Nagelle Arsi District Mount Duro Natural forest around Lepis, near the Oromia Forest and Wildlife Enterprise, Gambo district of Arsi Branch. The study sites lie between 7°16'0"N-7°18'0"N latitude and 38º48'0"E-38º0'0"E longitude. The area is located about 240 km southeast of Addis Ababa (Fig. 1).

The natural forest around Lephis (i.e. Mount Duro natural forest) is a tropical dry Afromontane forest that covered the highlands of Ethiopia with area coverage of 1583 hectares. Soil type of the study area was classified as Mollic Andosol (FAO 1998). The rainfall in the area is characterized by a bimodal distribution. The short rainy season extends between March and June and the major rainy season occurs between July and October. The mean annual rainfall was 1200 mm and the annual mean temperature – about 20^{0}C (Abebe 1998).

The total area of the district was about 1396 km^2 of which 52% was identified as arable, 30% water bodies, 5% forest and 13% grazing. Nagelle Arsi District is characterized by crop-livestock based farming systems (Lemenih *et al.* 2004). The district had a total population of 260,129 in 2007. The population density of the district is 185.7 persons per km^2 (CSA 2007).

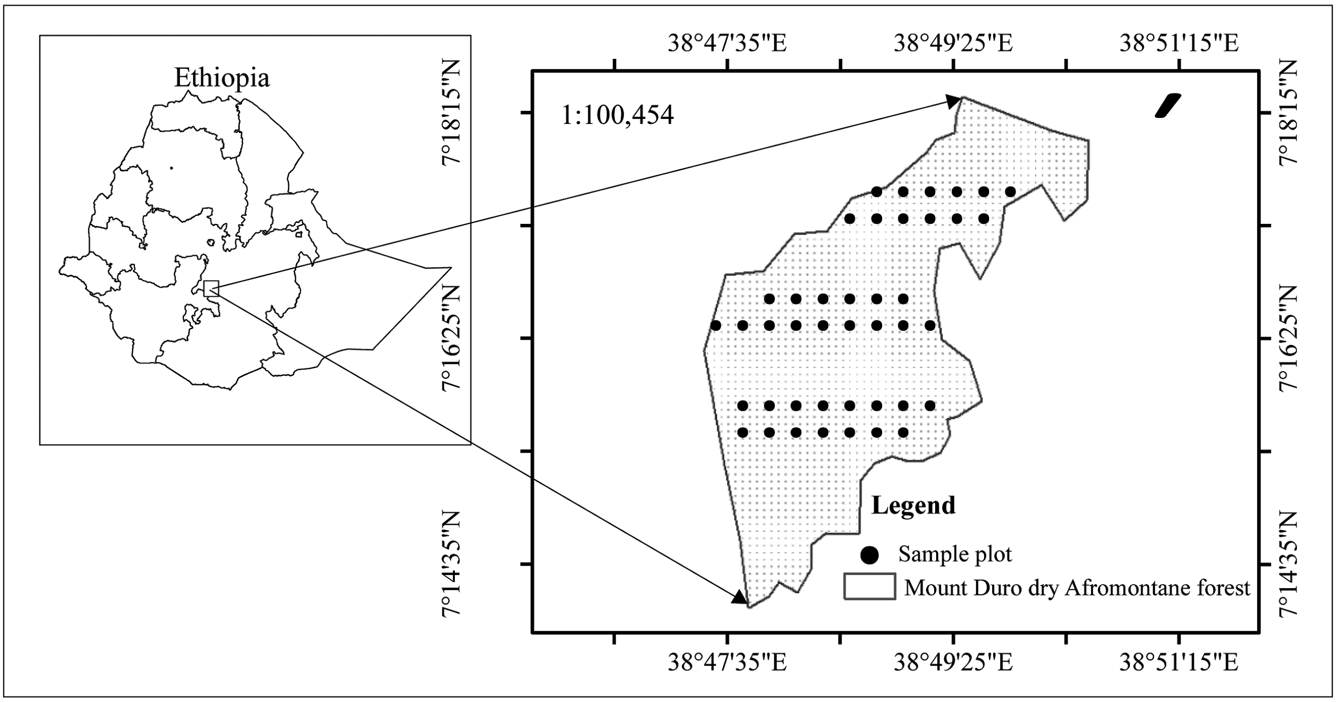

Fig. 1. Map of the study area

2.2. Vegetation data collection

Systematic sampling design was used to collect vegetation data (woody and herb species) following Muller-Dombois and Ellenberg (1974) and Kent and Coker (1992). Plot size of 20×20 m (400 m^2) was used for collecting data on trees, whereas within each 400 m^2 plot, a 5×5 m subplot was used for recording shrubs and herbaceous species. A total of 42 plots was used, where 15 plots were from a forest patch of Bombasa Rejji, 15 plots from Lephis and 12 plots from Ashoka (Fig. 2).

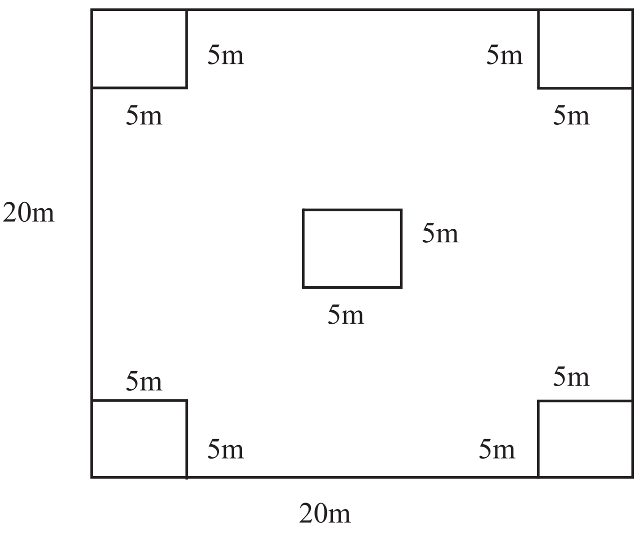

Fig. 2. Sample plot layout

The transect lines were established parallel to each other at the interval of 300 m in each forest patch starting from the top ridge to valley bottom. Transects were fixed on both sides of the ridge). Sample plots were adjusted at a distance of 200 m along line transects. Environmental variables (i.e. slope, elevation and aspect) were recorded for each main plot to characterize the association of species along elevation gradient. Aspect refers to a facing direction of sample plot. Elevation and locations of plots were marked using Global Positioning System (GPS) Garmin. Sunto clinometer was used for slope measurement.

Complete lists of all plant species were made for each sample plot throughout the entire area under study and recorded using local names (Afaan oromoo). Specimens were collected, pressed and dried properly in the field. Specimen identification and documentation were made at the National Herbarium of (ETH), Addis Ababa University.

2.3. Data analysis

2.3.1. Plant community classification and ordination

Plant community classification was explained and identified by agglomerative hierarchical clustering using single clustering methods (Borcard *et al.* 2018). Next, association of species and sample plots was described by indicator species (De Caceres & Legendre 2009). Species diversity was estimated using species richness, Shannon-Wiener diversity index, dominance and evenness in R statistical software. Shannon-Wiener diversity index and evenness were computed for plant communities. Species richness is the total number of species in the community (Magurran 1988; Krebs 1999).

Ordination was computed using a Nonmetric Multidimensional Scaling. Species abundance and environmental variables such as elevation (meters asl), slope (%), and aspect (degree) were used for the ordination. Data analysis was based on Nonmetric Multidimensional Scaling (NMDS) technique using Euclidian distance measure in R. Advantages of using NMDS include: (*i*) it avoids the assumption of linear relationship among variables; (*ii*) its use of ranked distances tends to linearize the relationship between distances measured in species space and distances in environmental space; (*iii*) it allows the use of any distance measure.

Gradient analyses were done by using R version 3.6.0. NMDS was run on the log-transformed abundance data using Euclidean distance measure. To test for concordance between environmental variables and the NMDS dimension, Spearman rank correlation coefficients were calculated. Monte Carlo test was performed to evaluate whether NMDS extracted

Table 1. Woody (trees and shrubs) and climber species recorded from remnant dry Afromontane forest of Mount Duro, Nagelle Arsi, Ethiopia

Scientific name	Families	Vernacular name
Afrocarpus falcatus (Thunb.) C. N.	Podocarpaceae	Birbirsa
Allophylus abyssinicus (Hochst.) Radlk.	Sapindaceae	Hirqammuu
Apodytes dimidiata E. Mey. ex Arn.	Icacinaceae	Odaa baddaa
Bersama abyssinica Fresen.	Melianthaceae	Waraqqaa
Calpurnia aurea (Ait.) Benth.	Fabaceae	Ceekataa
Canthium oligocarpum Hiern	Rubiaceae	Xiilloo
Carissa spinarum L.	Apocynaceae	Agamsa
Celtis africana Burm. f.	Ulmaceae	Amallaqaa
Clematis longicauda Steud. ex A. Rich.	Ranunculaceae	Ciroontaa
Croton machrostachys Del.	Euphorbiaceae	Bakkanniisaa
Dovyalis abyssinica (A. Rich.) Warb.	Flacourtiaceae	Qamoo
Dregea schimperi (Decne.) Bullock	Asclepiadaceae	Gaalee dikii
Ekebergia capensis Sparrm.	Meliaceae	Onoonnuu
Euclea divinorum Hiern	Ebenaceae	Mi'eessaa
Fagaropsis angolensis (Engl.) Dale	Rutaceae	Qarcaccee
Ficus sur Forssk.	Moraceae	Odaa nyaataa
Hagenia abyssinica (Bruce) J. F. Gmel.	Rosaceae	Heexoo
Hibiscus micranthus L. f.	Malvaceae	Incinnii
Juniperus excelsa Hochst. ex. Endl.	Cupressaceae	Hindheessaa
Maesa lanceolata Forssk.	Myrsinaceae	Abbayyii
Maytenus sp.	Celestraceae	Kombolcha
Mikaniopsis clematoides (Sch. Bip. ex A. Rich.) Milne-Redh.	Asteraceae	Gaalee fiitii/korma
Millettia ferruginea (Ho & Hst.) Bak	Fabaceae	Dhaadhaatuu
Myrsine melanophloeos (L.) R. Br.	Myrsinaceae	Unidentified
Not identified	Not identified	Ancootee
Not identified	Not identified	Haadhamanee
Not identified	Not identified	Hadhooftuu
Nuxia congesta R. Br. ex Fresen.	Loganiaceae	Buchaanaa
Pentas sp.	Rubiaceae	Unidentified
Periploca linearifolia Quart.-Dill. & A. Rich.	Asclepiadaceae	Gaalee Aannannoo
Phytolacca dodecandra L 'Herit.	Phytolaccaceae	Andoodee
Polyscias fulva (Hiern) Harms	Araliaceae	Warqichoo jaldeessaa
Prunus africana (Hook. f.) Kalkman	Rosaceae	Sukkee
Ricinus communis L.	Euphorbiaceae	Qobboo
Rubus apetalus Poir.	Rosaceae	Goraa
Rumex nervosus Vahl	Polygonaceae	Dhangaggoo
Schefflera abyssinica (Hochst. ex. A. Rich.)	Araliaceae	Gatamee
Teclea nobilis Del.	Rutaceae	Hadheessaa
Urera hypselodendron (A. Rich.) Wedd.	Urticaceae	Gaalee haliillaa
Vangueria madagascariensis Gmel.	Rubiaceae	Gaalloo
Vernonia myriantha Hook. J.	Asteraceae	Reejjii

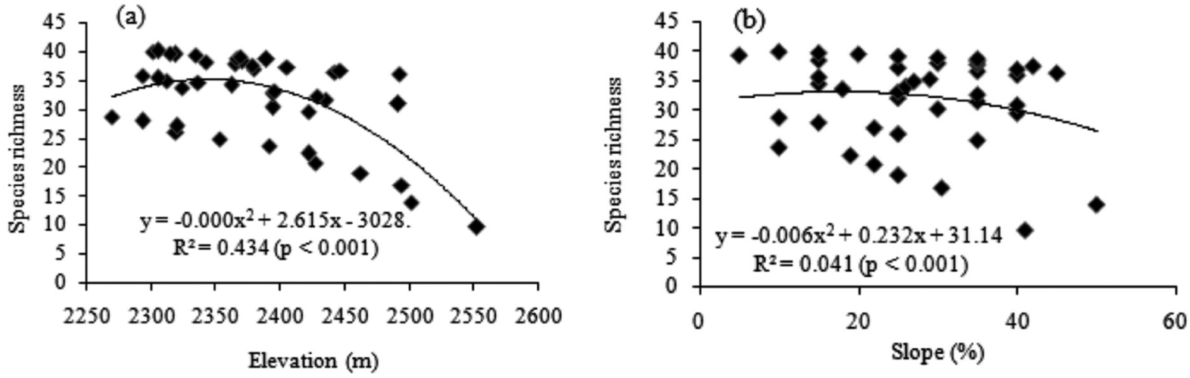

Fig. 3. Relationship between elevation (a), slope (b) and species richness of the Mount Duro dry Afromontane forest

stronger axes than expected by chance. To check for the effect of polynomial regression of environmental gradient on species richness R statistical software was used, whilst Spearman critical value was considered to check the significance level.

3. Results

3.1. Floristic composition and plant diversity

The total of 44 plant species belonging to 30 families were documented from the study area. Trees and shrubs were dominant (32 species) followed by herbaceous species (2 species) and climbers (10 species). Five dominant families in the area included: Euphorbiaceae, Asteraceae, Melianthaceae, Podocarpaceae, and Rutaceae) (Table 1).

3.2. The relationships of environmental variables with species richness

Species richness (r^2 =0.43, $P < 0.001$) showed significantly negative correlation with elevation (Fig. 3a). In a similar way, slope was correlated with species richness (r^2 = 0.041, $P < 0.001$) (Fig. 3b).

3.3. Plant community type along elevation gradient

Four plant communities were identified and described from agglomerative hierarchical cluster analysis (Fig. 4). Plant community types were named after two most dominant species based on the abundance of species that

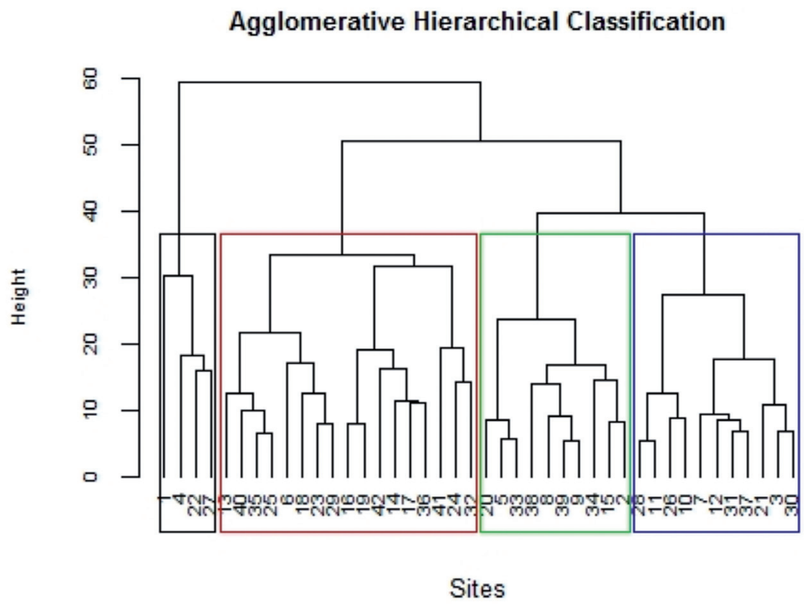

Fig. 4. Plant communities along the elevation gradient. Height indicates dissimilarity; sites are indicated by plot numbers. Rectangular boxes in black, red, green and blue colors indicate plant communities: 1,4,2, and 3, respectively

occurred within the community (Table 2). Accordingly, four plant community types: *Afrocarpus falcatus-Ficus sur; Maesa lanceolata-Bersama abyssinica; Vernonia myriantha-Urera hypselodendron* and *Croton machrostachys-Teclea nobilis* were identified (Fig. 4).

(1) ***Afrocurpus falcatus-Ficus sur* community**

This community occurs at average elevation of 2521m asl. It comprises a smaller number of plots than the rest community types and is represented by 4 plots and 21 species. It is dominated by *Afrocurpus falcatus* and *Ficus sur* (Table 2). Other woody species (trees and/or shrubs) associated with this community are Maytenus sp., *Euclea divinorum*, *Apodytes dimidiate*, *Allophylus abyssinicus*, *Rumex nervosus*, *Vangueria madagascariensis*, *Maesa lanceolata*, *Carissa spinarum*, *Myrsine melanophloeos*, *Ekebergia capensis*, *Hagenia abyssinica*, *Bersama abyssinica*, *Croton machrostachus*, *Juniperus excelsa*, *Dovyalis*

Table 2. Indicator species for the community types

Species	1	2	3	4
Croton machrostachus	0.145	0.069	0.168	**0.508**
Teclea nobilis	0.046	0.103	0.098	**0.355**
Bersama abyssinica	0.177	**0.212**	0.156	0.315
Vangueria madagascariensis	0.262	0.070	0.064	0.261
Polyscias fulva	0.000	0.075	0.143	0.234
Vernonia myriantha	0.070	0.108	**0.554**	0.232
Calpurnia aurea	0.000	0.000	0.000	0.176
Fagaropsis angolensis	0.000	0.000	0.043	0.135
Mikaniopsis clematoides	0.000	0.089	0.130	0.123
Millettia ferruginea	0.000	0.000	0.000	0.118
Urera hypselodendron	0.000	0.055	**0.271**	0.113
Rubus apetalus	0.046	0.117	0.097	0.091
Prunus africana	0.000	0.025	0.000	0.088
Dregea schimperi	0.000	0.000	0.092	0.087
Celtis africana	0.000	0.000	0.040	0.066
Afrocurpus falcatus	**0.762**	0.042	0.067	0.060
Nuxia congesta	0.000	0.000	0.000	0.059
Maytenus sp.	0.640	0.087	0.101	0.052
Maesa lanceolata	0.214	**0.303**	0.187	0.044
Clematis longicauda	0.000	0.044	0.055	0.030
Phytolacca dodecandra	0.000	0.000	0.055	0.023
Kalanchoe lanceolata	0.000	0.063	0.000	0.022
Dovyalis abyssinica	0.096	0.015	0.051	0.021
Periploca linearifolia	0.252	0.010	0.075	0.014
Allophylus abyssinicus	0.335	0.080	0.000	0.007
Rumex nervosus	0.263	0.095	0.009	0.004
Apodytes dimidiata	0.347	0.028	0.023	0.002
Euclea divinorum	0.417	0.019	0.004	0.002
Englerina woodfordioides	0.000	0.000	0.182	0.000
Ricinus communis	0.000	0.000	0.091	0.000
Canthium oligocarpum	0.000	0.052	0.043	0.000
Juniperus excesla	0.130	0.010	0.034	0.000
Carissa spinarum	0.183	0.000	0.024	0.000
Myrsine melanophloeos	0.183	0.000	0.024	0.000
Stephania abyssinica	0.000	0.200	0.000	0.000
Pteridium aquilinum	0.000	0.200	0.000	0.000
Schefflera abyssinica	0.000	0.100	0.000	0.000
Hibiscus micranthus	0.000	0.100	0.000	0.000
Pentas sp.	0.000	0.100	0.000	0.000
Ekebergia capensis	0.179	0.057	0.000	0.000
Hagenia abyssinica	0.179	0.029	0.000	0.000
Ficus sur	**0.750**	0.000	0.000	0.000

Explanations: Indicator value of species is the result of the relative frequency and relative average abundance in communities. Values in bold refer to the species used for naming the community types

Table 3. Diversity indices of plant community types identified from remnant dry Afromontane forest of Mount Duro, Nagelle Arsi, Ethiopia

Community types	Elevation (m a.s.l)	Shannon-Weiner diversity (H')	Richness (S)	Evenness (E)	Dominance (D)
1	2491-2552	2.198 (0.44)	21 (3.6)	0.722 (0.11)	0.264 (0.12)
2	2390-2491	2.506 (0.45)	30 (5.3)	0.737 (0.01)	0.251 (0.12)
3	2269-2389	2.261 (0.42)	30 (5.2)	0.665 (0.12)	0.182 (0.09)
4	2293-2435	2.289 (0.43)	29 (3.6)	0.680 (0.08)	0.221 (0.07)

abyssinica, *Vernonia myriantha* and *Teclea nobilis*. It is also characterized by woody climbers such as *Periploca linearifolia* and *Rubus apetalus. Pteridium aquilinum* is a herbaceous plant characteristic for this community.

(2) ***Maesa lanceolata-Bersama abyssinica* community**

This community type is encountered at average elevation of 2429 m asl in the forest. It comprises 10 plots and 30 species. The average species richness per plot is 3 for this community. Woody species (tree and/or shrubs) associated with this community type include: *Vernonia myriantha*, *Teclea nobilis*, *Schefflera abyssinica*, *Hibiscus micranthus*, *Pentas* sp., *Rumex nervosus*, *Maytenus* sp., *Allophylus abyssinicus*, *Vangueria madagascariensis*, *Croton machrostachus*, and *Ekebergia capensis. Climber species associated with this community are Rubus apetalus, Mikaniopsis clematoides*. *Stephania abyssinica* and *Polyscias fulva* are herbaceous species associated with this community.

(3) ***Vernonia myriantha-Urera hypselodendron* community**

This community type occurs at average elevation of 2329 m asl and comprises 11 plots and 30 species. This community type is highly dominated by *Vernonia myriantha, and Urera hypselodendron* (Table 2). Other woody species associated with this community include: *Maesa lanceolata*, *Croton machrostachus, Bersama abyssinica*, Maytenus sp., *Teclea nobilis*, *Dregea schimperi*, *Ricinus communis*, *Afrocurous falcatus*, *Vangueria madagascariensis*, *Phytolacca dodecandra*, and *Dovyalis abyssinica*. Climber species associated with this community are: *Polyscias fulva*, *Mikaniopsis clematoides*, *Rubus apetalus*, *Periploca linearifolia,* while, *Englerina woodfordioides*, and *Clematis longicauda* are herbaceous species characteristic for this community type.

(4) ***Croton machrostachus-Teclea nobilis* community**

This community is distributed at average elevation of 2364 m asl. This community derived from 17 plots and comprised 29 species. It is the second species rich community type. The most dominant species of this community type are: *Croton machrostachus* and *Tecleanobilis*. Other woody species associated with this community include: *Bersama abyssinica*, *Vangueria madagascariensis*, *Vernonia myriantha*, *Calpurnia aurea, Fagaropsis angolensis*, *Millettia ferruginea, Prunus Africana*, *Celtis Africana*, *Afrocurpus falcatus*, *Nuxia congesta*, *Maesa lanceolata*, *Phytolacca dodecandra*, and *Dovyalis abyssinica*. *Mikaniopsis clematoides*, *Rubus apetalus*, *Kalanchoe lanceolata*, *Urera hypselodendron*, *and Dregea schimperi* are clumbers associated with this community. Herbaceous species associated with this community are: *Polyscias fulva*, *Clematis longicauda*, and *Periploca linearifolia*.

3.4. Species richness and diversity in individual communities

Summary of Shannon-Wiener diversity index and evenness for the studied communities is presented in (Table 3). Plant community types showed variation in their species richness, evenness and Shannon-Wiener diversity. Evenness was moderate and dominance was low in all types. Out of four community types, community type 2 (*Maesa lanceolata-Bersama abyssinica* community) exhibited the highest species diversity and evenness followed by community type 4 (*Croton machrostachus-Teclea nobilis* community) and community type 3 (*Vernonia myriantha-Urera hypselodendron)*. Community type 1 showed the least species diversity (Table 4).The least species diversity of community type 1 may imply dominance of the environment by few species and also this community was found on gentle slope areas. Communities 2 and 3 had the highest species richness followed by community type 4, while community type 1 hadthe lowest species richness (Table 4).

3.5. Ordination

In the NMDS ordination, the greatest reduction in 'stress' obtained was 7.34 with a two dimensional solution. Elevation showed significant correlation with NMDS 2 ($r=0.633$, $P<0.001$) and NMDS 1 ($r=0.774$, $P<0.01$). Slope had significant correlation with NMDS 2 ($r=0.913$, $P<0.001$), and NMDS 1 ($r=0.409$, $P<0.01$). The correlation of aspect with the dimensions was not

Table 4. Correlations of species ordination axes with environmental variables, and percentage variances explained from nonmetric dimensional scaling of the first two axes (NMDS1 and NMDS2)

	NMDS1	NMDS2	r^2	p-value
Elevation	-0.774	0.633	0.644	0.001***
Slope	-0.409	0.913	0.287	0.001***
Aspect	-0.406	0.913	0.070	0.239ns

Explanations: *** – p<0.001, ns=no significant

significant. Elevation explained 64% of variation in species richness. Slope explained 28% of variations in species richness. The percent of variation explained by aspect was 7% of the species richness (Fig. 5, Table 4).

4. Discussion

4.1. Diversity and plant community along environmental gradients

In the dry Afromontane forest of Mount Duro, four plant community types were identified with different diversity, evenness and species richness. Along environmental gradient, classification of natural vegetation into plant community has an immense role in ultimate conservation of natural vegetation (Zhang *et al.* 2013).

In this study, elevation showed a significant effect on species richness and spatial distribution of species. The highest woody species richness (S) was recorded at average elevation of 2429 (30 species). Similarly, species diversity was the highest (Shannon-Wiener diversity index 2.3501) between this elevation range followed by average elevation of 2329 (2.289). These findings are in agreement with many previous reports (e.g. Chawla *et al.* 2008; Gurmessa *et al.* 2013). It is an established fact that species distribution along elevation shows a hump-shaped curve, which may be attributed to the increase in habitat diversity at median ranges and relatively less habitat diversity at higher altitudes (Chawla *et al.* 2008). Concentration of dominance was found to be higher (0.264) for average elevation of 2521 m asl followed by average elevation of 2429 m asl (0.251).

Whereas community types 2 and 3 had the highest species richness followed by community type 4, community type 1 showed the lowest species richness. A possible reason for high species richness of communities 2 and 3 may be an altitudinal factor, because intermediate altitude could be associated with optimal conditions of environmental factors that favor vegetation growth. The least species diversity of community type 1 may imply dominance of the environment by few species and also this community was found on gentle slope areas. In highland areas, increasing altitudes are always related with lower temperatures and higher humidity that influence species diversity and plant community distributions (Solefack *et al.* 2018). For instance, species richness of broad-leaved trees increased with solar radiation, temperature and moisture, while conifer species occurred maximally with low insolation, low moisture deficit and high humidity, intermediate temperatures and impeded drainage (Pausas & Austin 2001). This climatic factor

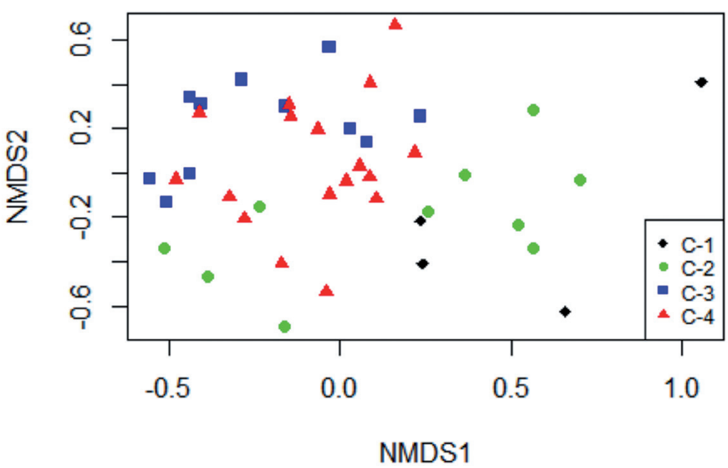

Fig. 5. Ordination based on a Nonmetric Multidimensional Analysis (NMDS) for 44 woody species from 42 plots

change is a stress factor for plants, which affects plant diversity by selecting biological forms capable of living at different altitudinal range (Klimes 2003).

Species diversity of studied forests is an important attribute in community structure and its change was a part of community variation (Olten *et al.* 1993; Ojeda *et al.* 2000). In this study, the diversity variation within the community attributed to variation in environmental factors (i.e. elevation, slope and slope aspects; because there was a significant correlation between species composition of community and environmental gradients. It was also reported that community variation closely related to environmental variables, such as elevation, aspect, and slope (Bochet & García-Fayos 2004).The highest species richness was observed in communities 2 and 3; both communities also showed the highest Shannon-Wiener diversity. A high number of species in these communities may result from their distribution at an intermediate elevation, which favours the species growth. Gurmessa *et al.* (2013) from Komto Afromontane Moist Forest, East Wollega Zone, and western Ethiopia found that intermediate altitude associated with optimal conditions of environmental factors that favor vegetation growth which result in high species richness. Additionally, Soromessa *et al.* (2004) and Yohannes *et al.* (2013) found that the highest species richness is attributed to the optimum environment that supports the species. In turn, community 1 is located in the upper altitude zone of the forest and at very inclined slope areas, which probably explains its lower species richness and Shannon-Wiener diversity. Some studies also confirmed that altitude could affect the growth of species at higher altitude through influencing soil moisture, radiation and soil nutrient (Olten *et al.* 1993; Lomolino 2001; Bochet & García-Fayos 2004). Furthermore, other scholars noted that plant community distribution along geographical gradients are also a manifestation of physical factors, such as soil heterogeneity, micro-climate, biotic response to these physical factors, and historical disturbances (Senbeta 2006; Urban *et al.* 2000). Therefore, in this study, we found that altitude was an important environmental factor determining species composition and diversity variation of plant community in the studied forest. Several authors (e.g. Adamu *et al.* 2012; Gurmessa *et al.* 2013; Senbeta 2006; Hawas 2007; Soromessa & Kelbessa 2013; Yohannes *et al.* 2013) also found that presence of altitudinal variation influenced diversity and plant community distribution in the forest vegetation of Ethiopia. Furthermore, some authors confirmed that elevation variation could play a significant role in determining plant diversity and community variation, because it strongly influences the length of growing season associated with temperature and the availability of soil moisture and nutrients (Senbeta & Denich 2006; Adamu *et al.* 2012; Soromessa & Kelbessa 2013).

In addition to elevation, slope gradient also explained significant variation in species composition of plant communities in remnant dry Afromontane forest of Mount Duro. This finding was consistent with previous studies by Soromessa & Kelbessa (2013) and Zhang *et al.* (2013) who reported that slope gradient strongly affected species diversity and structure of forest vegetation through influence on soil chemical properties, since soils on steeper slopes were influenced by bedrock and tended to be less moist and more acidic. Even within one elevation, the cofactors like topography, aspect, inclination of slope and soil type influenced distribution patterns of plant communities (Bochet & García-Fayos 2004; Senbeta 2006). However, variation in species composition of communities was not significantly explained by slope aspects. This finding is inconsistent with previous studies that reported changes in slope aspects led to changes in hours of sunshine, humidity, and temperature, all of which affect the species composition of a community (Wu 1980; Zhang *et al.* 2013). This difference could be probably due to slope aspects of the studied forest, receiving relatively equal amount of sunlight from solar radiation. Zhang *et al.* (2013) confirmed that the effect of aspect on diversity depends on the amount of sunlight received by vegetation.

5. Conclusions

Plant community composition and diversity is significantly influenced by environmental variables. Elevation and slope gradient are the most significant environmental gradients determining species diversity of study forest. Therefore, for better understanding of environmental effects on biodiversity, further research will be needed on the effect of disturbances and soil properties on species diversity and plant community distribution to elucidate the relationship between these factors and species diversity and plant community variation.

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