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Plant diversity and communities along environmental, harvesting and grazing gradients in dry Afromontane forests of Awi Zone, northwestern Ethiopia

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ABSTRACT: Afromontane forests support diverse species and provide numerous ecosystem goods and services. There are few studies examining the role of dry Afromontane forests in biodiversity conservation, thus motivating our assessment of plant diversity and communities in five dry Afromontane forests. The objective of the study was to determine plant diversity and communities along environmental, harvesting and grazing gradients. Vegetation data were collected systematically in 80 quadrats (400 m^2) with subplots for shrubs and herbaceous species. Biodiversity models and multivariate analyses were employed to determine diversity and community types. Cluster and Redundancy Analyses (RDA) were employed for classification and ordination. The result showed that the forests contained 153 species belonging to 63 families of which six species were endemic. Shannon-Weiner index (H') and its effective number of species in five forests were 2.4 and 11.11, respectively. Modeling diversity and evenness exhibited a declining trend along with an increase in elevation. The harvesting index and grazing intensity correlated negatively with richness and diversity. A cluster analysis coupled with indicator species resulted in four community types. RDA showed that the cumulative variance explained by the first four axes accounted for 14.4% of the species variation. The environmental factors that contributed most to explaining species-environment variation included elevation (37.3%), total nitrogen (13.3%), soil pH (12.2%) and grazing intensity (11.8%). In conclusion, dry Afromontane forests contained considerable endemic species, diversity and community types. However, environmental factors, harvesting and grazing intensity showed significant impacts on diversity and community types. Therefore, an effective management plan is needed for the conservation of biodiversity in the forests.

KEY WORDS: Dry Afromontane forests, Diversity index, Environmental factors, Ethiopia, Plant community, Redundancy analysis.

INTRODUCTION

The Afromontane zone is in the Afrotropic subregion and its plant species are common to the mountains of Africa and the southern Arabian Peninsula. Tropical Afromontane forests support diverse species and provide numerous ecosystem goods and services, but they have experienced major anthropogenic impacts, particularly the conversion from forest to agricultural land, which is a key driver in the loss of species diversity at local and regional scales. Consequently, tropical forests have become heavily disturbed, exploited, fragmented and threatened (Miles *et al.* 2006). Tropical forests and forest resources are either vanishing or being degraded rapidly due to accelerated growth of human populations, resulting in the conversion of forested land to agriculture, overgrazing and excessive exploitation of forests for fuelwood, construction material and timber for export. The challenge generated by the reduction and degradation of forest cover can be adequately met only if serious efforts are made to maintain the remaining forests and to restore deforested and degraded areas (Teketay 2005).

Topography and edaphic factors are key drivers that determine the pattern of plant diversity and composition on the spatial and temporal scales (Zhang *et al.* 2016; Dattaraja *et al.* 2018). Climate plays an important role in relation to plant community responses at regional and global scales (Liu *et al.* 2007) while topographic and edaphic factors play critical roles at the local level (Aerts *et al.* 2006; Moeslund *et al.* 2013; Zhang *et al.* 2016). Several scientific studies (Zhang *et al.* 2013; Lee and Chun 2016) have found that different diversity patterns relate with increasing elevation, and the majority of diversity occurs at intermediate elevations (Rahbek 2005). However, scientists still debate over the generality of patterns found due to the complexity of the observed variation in plant characteristics along elevation gradients (Körner *et al.* 2007).

Anthropogenic disturbance influences processes that can either augment or erode the forest community and diversity. It has been emphasized that land use effects result in dramatic changes in structure, composition and plant diversity in Afromontane forests (Deichert *et al.* 2014). Several studies have also quantified human disturbances and developed disturbance indices on the basis of the ratio of the number of trees that have been cut and the total number of individuals within a plot (Pandey and Shukla 2003; Sagar *et al.* 2003) and considering canopy cover (Kumar and Ram 2005). These type of disturbances (severity and intensity) also affect diversity and composition of plant communities in tropical forests (Flynn *et al.* 2009). Therefore, understanding the response

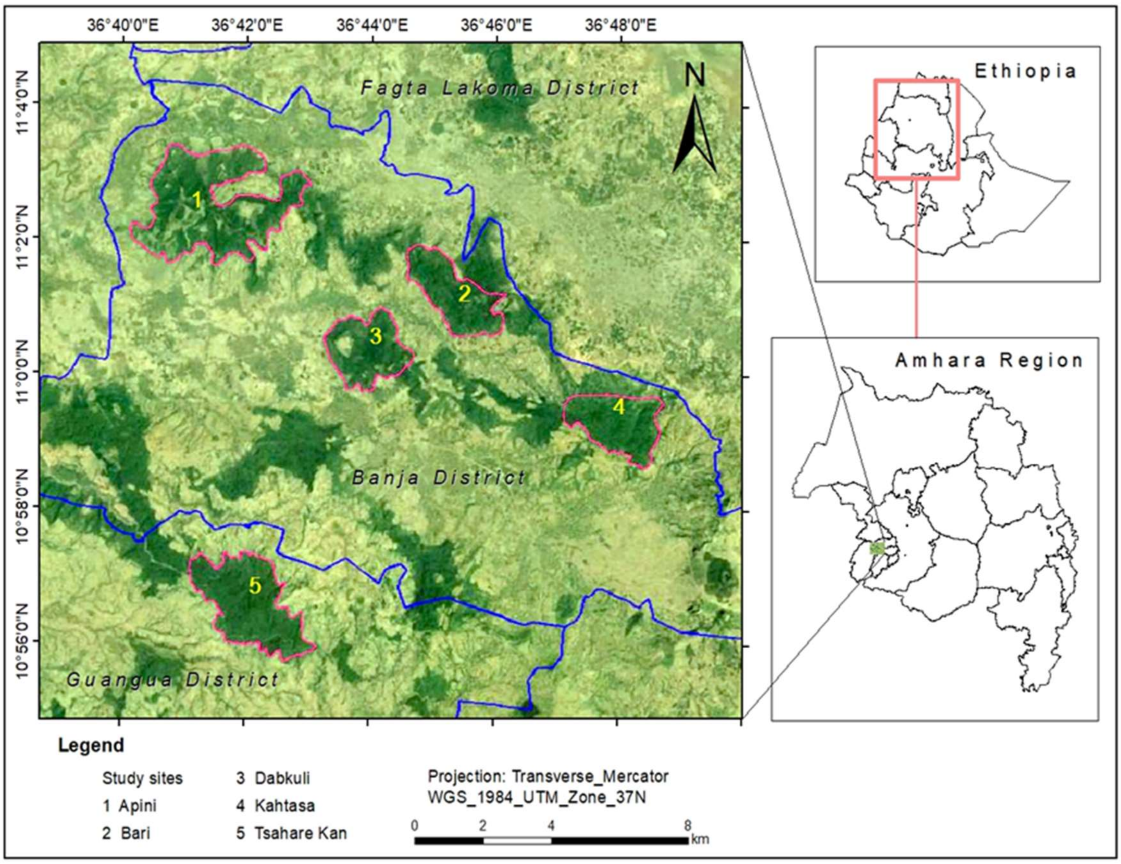

Fig. 1. Map showing the study area.

the response of plant diversity to disturbance gradients would be important to improve the role of dry Afromontane forests in biodiversity conservation.

Previous studies have reported the association of plant community distributions with variation in environmental gradients in protected forests (Soromessa *et al.* 2004), fragmented forests (Aerts *et al.* 2006) and community-managed forests of Ethiopia (Abiyu *et al.* 2011). However, the effects of anthropogenic disturbances and environmental factors on dry Afromontane forests and the roles of these forests in biodiversity conservation have not been well-studied in Ethiopia in general and the Awi Zone of northwestern Ethiopia in particular. Therefore, the objective of this study was to assess and determine plant diversity as well as classify plant communities in response to environmental, harvesting and grazing gradients in five dry Afromontane forests in the study areas.

MATERIALS AND METHODS

Description of study area

The study was conducted in five dry Afromontane forests in Awi Zone of Amhara National Regional State (ANRS), northwestern Ethiopia (Figure 1). It is located at the coordinates of 10°56' to 11° 4' N and 36° 40' to 36° 48' E. Awi Zone is the site of the second dominant natural forest area (5.5%) next to North Gonder Zone (8.5%) in the ANRS of Ethiopia (Mekonnen *et al.* 2016). Among different administration districts in the Zone, Guangua and Banja districts (Figure 1) were selected for their representativeness of the region's vegetation, and since they are among the least studied natural forest sites. The forests cover a total area of 3,188 ha, varying from 509.79 to 724.03 ha, and they vary with respect to elevation, slope, soil pH and total nitrogen concentration (Table 1). The forests are mainly found on intermediate and steep slopes, and they are isolated from each other by agricultural and grazing lands as well as settlements. The soils of the study forests have been developed from parent materials of volcanic origin. Hence, they are closely related to their parent materials and their degree of weathering, exhibiting mainly reddish or brownish color, medium to heavy texture and free drainage.

Historically, agricultural activities were the main causes of forest cover decline during the Transitional Government of Ethiopia (1991–1994) because local communities depended on the forests to support mixed agricultural activities and rearing of livestock (Awi Zone Agricultural Office, unpublished). After 1994, the forest areas were protected from agricultural activities, and four of the forests were designated as state forests, which

Table 1. Locations and topographic characteristic of forests. (Mean ± Standard error)

Forest	Cover (ha)	Elevation(m)	Slope (%)	Soil pH	TN (%)	Aspect	Geographical location
Tsahare Kan	724.03	2034±12.5	12.94±1.09	6.0±0.06	0.36±0.02	W, N ,SW	10°56' to 10°57'N and 36°40' to 36°42'E
Apini	693.33	2110±12.7	15.93±1.89	5.0±0.08	0.86±0.08	S, SW, W, E	11°01' to 11°02'N and 36°41' to 36°42'E
Dabkuli	509.79	2168±11.96	21.87±3.02	5.8±0.12	0.52±0.06	W, NW, NE, S	10°59' to 11°00'N and 36º43' to 36°44'E
Bari	720.41	2266±19.55	17.5±2.62	5.9±0.12	0.68±0.10	S, SW	11°00' to 11°01'N and 36º45' to 36°45'E
Kahtasa	540.74	2410±10.54	13.44±2.53	5.1±0.06	0.74±0.04	S, N, W	10°58' to 10°59'N and 36º47' to 36°48'E
Total	3,188						

TN = total nitrogen concentration.

are protected and managed by the Government of ANRS. Tsahare Kan forest has been managed by local communities during the last 15 years. Despite these measures, the forests are still under heavy pressure due to free grazing and illegal harvesting of woody species by the local inhabitants.

Data on rainfall and temperature were gathered from two principal weather stations during 1987–2016 (Figure 2). The first weather station is located at Kidamaja town close to the four forests in Banja District. The station is 5.05 km from the nearest Apini forest and 16.69 km away from Kahtasa forest. Kidamaja station shows that the forest receives 2241 mm of the annual rainfall in the area. The annual monthly temperature ranges from 8.1 to 30.5°C with average temperatures of 18.7°C (Figure 2A). The second weather station is located at Chagni town in Guangua District. This weather station is 21.6 km away from Tsahare Kan forest. This station shows that the forest receives the annual rainfall of 1679 mm. The annual monthly temperature ranges from 8.9 to 32.7°C with an average temperature of 20.8°C (Figure 2 B). The study areas have a unimodal rainfall pattern with the maximum occurring from June to October.

Vegetation data collection and identification

Data were collected in the five Afromontane forests from January 2016 to May 2017. A systematic sampling design was established to collect vegetation data (Kent, 2011). A total of 19 parallel transect lines, 500 m apart from each other, were used in each of the forests. The quadrats were also placed 50 m away from the forest margins to avoid edge effects related to degrees of forest management and disturbances. The first quadrat was laid down randomly on each starting of transect, and the subsequent quadrats were established at 50 m intervals along the transect lines. The sizes of quadrats were determined based on the growth forms of plants (Kent, 2011), i.e. 400, 25 and 1m^2 for trees, shrubs and lianas, and herbs, respectively, in a nested plot design. A total of 80 large quadrats were laid down, 16 quadrats in each of the five forests, i.e. 1–16 in 'Dabkuli', 17–32 in 'Apini', 33–48 in 'Bari', 49–64 in 'Kahtasa' and 65–80 in 'Tsahare Kan' forests.

In the 80 quadrats (400 m2), the identities of all tree species, with diameters (dbh) of ≥ 5 cm, were determined and their number of stems were counted and recorded.

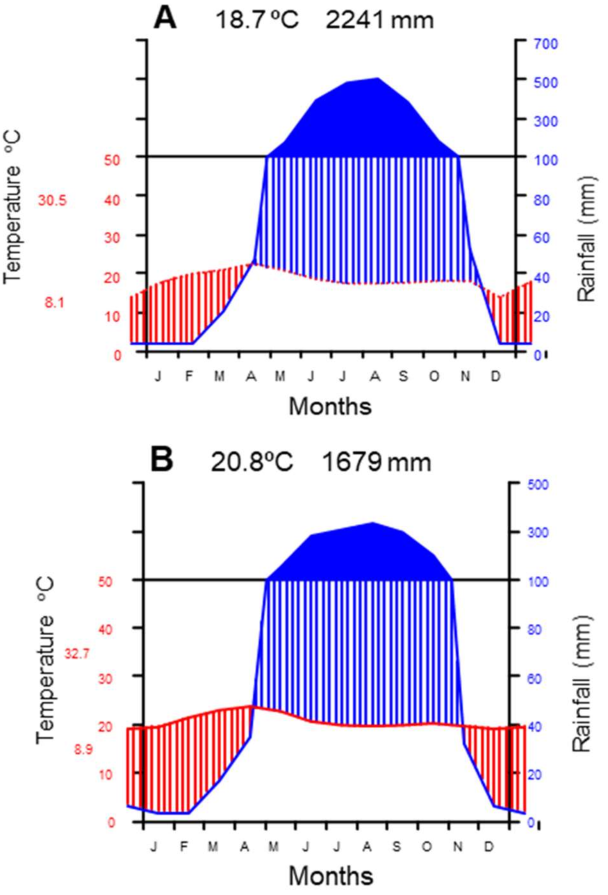

Fig. 2. Mean annual rainfall and temperature at Kidamaja (**A**) and Chagni (**B**) weather stations. Average monthly rainfall (horizontal black line); rainfall in each month (blue line); temperature in each month (red line)

The dbh of the tree species was measured using a diameter tape. A total of 160 subplots (area = 25 m^2 each) were established to determine the diversity and estimate abundance of shrubs and lianas. In this study, the shrub is defined as a woody plant that is multi-stemmed at the base of the plant whereas a liana is any long-stemmed, woody vine that uses trees or other means for vertical support. The herbaceous species richness and their percent cover was estimated visually and recorded in the 400 subplot (1m^2) by employing cover-abundance classes, i.e.: 1 (< 0.5%), 2 (0.5–1.5%), 3 (1.5–3%), 4 (3–5%), 5 (5–12.5%), 6 (12.5–25%), 7(25–50%), 8 (50–75%) and 9 (75–100%)

(van der Maarel and Franklin 2012).

Plants were identified in the field, and for those difficult to identify in the field, specimens were collected, processed and identified through comparing them with already identified specimens and deposited in the National Herbarium (ETH) of Ethiopia. Nomenclature of plants in this article follows those published in the Flora of Ethiopia as well as Flora of Ethiopia and Eritrea (Hedberg and Edwards 1989, 1995; Edwards *et al.* 1995; Hedberg *et al.* 1997; Edwards *et al.* 2000; Hedberg *et al.* 2003; Tadesse 2004).

Data on environmental factors and disturbances

The slope, aspect, elevation and geographical coordinates of the quadrats were measured using Suunto Clinometer and Garmin GPS. Values of slopes were recorded using percent scale and average values of slopes and elevations of quadrats were taken for determination of gradients. All visible individuals of tree species showing signs of damage by harvesting were identified and counted. Grazing intensity was observed and recorded through the presence-absence method by using signs of livestock browsing and feeding of branches or the whole species. Forest canopy openness was recorded using a densiometer that was positioned at the center of the quadrat. Soil samples were collected using an auger at the four corners of the main quadrats with two profile depths, (i.e. 0-15 and 15-30 cm). A total of 160 soil samples were collected, composited separately, labeled and transported to the Water Works Design and Supervision Enterprise (WWDSE) Laboratory in Addis Ababa, Ethiopia. Soil pH and total nitrogen (TN) were analyzed using 1:2.5 pH-H_2O and Micro-Kjeldahl methods (Nelson and Sommers 1996), respectively.

Data analyses

All statistical data were analyzed in R software using vegan packages (R Core Team 2016). The mean cover abundance and Euclidean Distance measures with Ward's method were employed for cluster classification (Kent, 2011). The indicator species in each community type were tested by Monte Carlo simulation ($P < 0.05$) (Dufrêne and Legendre1997). The indicator values were calculated from the product of relative abundance (specificity) and relative frequency of species (fidelity) within a community (Dufrêne and Legendre 1997).

A multivariate analysis was performed using ordination tools (Leps and Smilauer 2001) after preparing species and environmental data matrices. Leps and Smilauer (2001) suggested a simple rule for the decision based on the first axis of Detrended correspondence analysis (DCA) value. When DCA value exceeds four, CCA is preferable for a unimodal method and when DCA value did not exceed three, RDA is preferable. If the first axis of DCA value is found in between three and four, both techniques are used. Since the DCA analysis showed an intermediate standard unit (SD = 2.33), constrained redundancy analysis (RDA) was preferred to verify possible environmental influences on community composition, and its significance was checked with permutations test (Šmilauer and Lepš 2014). The four diversity indices were calculated based on the abundance of woody species (Pielou 1966; Magurran 2004). These were:

Shannon diversity index (H') = $-\sum P_i \ln P_i$ ……………. (1)

where, $P_i = N_i/N$, N_i = number of individuals of species i; ln = natural logarithm, N = total number of individuals of all species.

Evenness index (E) = $H'/\ln S$ ……………………….. (2)

where, E = Pielou's evenness index, H'= Shannon diversity index, S = number of species and ln = natural logarithm. Evenness indicates how even the species are distributed in the forest with values ranging from 0 to 1, where 1 means an equal distribution and values approaching 0 mean unequal distribution.

Simpson index of diversity (SID) = $-\sum[(N_i(N_i-1)]/N(N-1)$ .... (3)

where, Ni = number of individuals of species i and N = total number of individuals of all species.

Hill's (1973) diversity numbers (Effective number of species) were, then, derived from the Shannon diversity index and Simpson's index of diversity (SID), which are unaffected by species richness and tend to be independent of sample size. They were calculated as an exponential of Shannon index ($e^{H'}$) and Simpson reciprocal index, respectively. These give two new indices that measure diversity in units of species richness ……………………………..………………. (4)

Shannon diversity T-test, Pearson correlation, and multivariate analysis were employed to test the variation of species diversity and richness along environmental and disturbance gradients. Harvesting index (Hi) was calculated using the modified method developed by Sagar *et al.* (2003) from the density of stumps/total density (stumps + live individual trees). In this study, stumps are defined as remains of the stems after cutting down of trees measuring dbh of ≥ 5 cm. Richness (the number of species ha^{-1}) was estimated separately for trees, shrubs, and lianas as a total number of species/total area sampled ×10,000. All tests of statistically significant differences were decided at a significant level (α) of 0.05.

RESULTS

Species richness, diversity, and evenness

A total of 153 plant species, representing 63 families, were recorded in the five forests of which six species (3.9%) were endemic (Appendix 1). Of all the plant species, six species were recorded outside of quadrats for the purpose of floristic description and characterization of the forests. Asteraceae (11 Genera and 16 species, 10.45%), Fabaceae (13 Genera and 13 species, 8.49%), Lamiaceae (9 Genera and 9 species, 6.2%) and Acanthaceae (5 Genera and 7 species, 4.57%) were the most species-rich families. Euphorbiaceae and Rubiaceae

Table 2. Diversity indices calculated in dry Afromontane forests. (Mean ± SE = Mean ± standard error)

	Afromontane Forest					
Diversity index	**Tsahare Kan**	**Dabkuli**	**Apini**	**Bari**	**Kahtasa**	**Mean ± SE**
Number of woody species (S)	41	43	42	44	47	43.4 ± 1.03
Number of herbaceous species	30	25	36	22	34	29.4 ± 2.64
Shannon-Weiner diversity (H')	2.63	2.42	2.52	2.39	2.06	2.40 ± 0.09
Effective number of species	13.87	12.43	11.25	10.17	7.85	11.11± 1.02
Simpson reciprocal index (SRI)	8.33	7.69	6.25	6.67	3.13	6.41 ± 0.90
Pielou's evenness (E)	0.71	0.67	0.64	0.63	0.53	0.64 ± 0.03
Tree richness (species ha^{-1})	25.0	31.3	32.8	28.1	35.9	30.6 ± 1.88
Shrub richness (species ha^{-1})	212.5	200.0	150.0	200.0	175.0	187.5 ± 11.18
Lianas richness (species ha^{-1})	100.0	87.5	112.5	125.0	125.0	110.0 ± 7.28
Harvesting index (%)	16.8 ± 0.04	19.8 ± 0.04	18.6 ± 0.03	13.3 ± 0.01	22.5 ± 0.03	18.1 ± 0.01

Table 3. Diversity indices in elevation and slope gradients.

	Diversity index					
Topographic factors	**S**	**A**	**H'**	**ENS**	**SRI**	**E**
Elevation (m)						
Lower (N = 26) (1900 – 2100)	55	1833	2.63^{b}	13.87	7.14	0.65
Middle (N = 31) (2100 – 2300)	53	2169	2.62b	13.74	7.69	0.66
Higher (N= 23) (2300 – 2500)	57	2059	2.23^{a}	9.30	3.70	0.55
Slope (%)						
Flat (N = 29) (5 – 10)	67	2876	2.52^{b}	12.43	5.56	0.60
Intermediate (N = 22) (10 – 20)	62	2331	2.65^{b}	14.45	6.67	0.64
Steep (N = 13) (>20)	46	854	2.45^{a}	11.59	4.76	0.63

N = Number of quadrats, S = Number of species, A= abundance, H'= Shannon-Weiner diversity, ENS= Effective number of species, SRI = Simpson reciprocal index and E= evenness. The different letters in H' values show significant differences at P < 0.05.

were equally represented by six species while Celastraceae, Malvaceae, Rosaceae, and Solanaceae contained each four species. The remaining (53) families were represented by three or less species. Woody species had the highest number (86 species, 56.21%) while the remaining 67 species (43.79%) represented herbaceous plants, including grasses and forbs. The five forests had mean richness values of 30.6 ± 1.88, 187.5 ± 11.18, and 110.0 ± 7.28 for tree, shrub, and liana species ha^{-1} (Table 2).

Diversity and evenness varied among the studied forests (Table 2). Among the five forests, the effective number of species ranged from 7.85 to 13.87, and evenness ranged from 0.53 to 0.71. The lowest and highest number and evenness of species was recorded in Kahtasa and Tsahare Kan forests, respectively. Simpson reciprocal index value in Kahatsa was also lower than Tsahare Kan forest.

Richness and diversity along environmental gradients

The regression analysis showed that species richness, diversity and evenness exhibited statistically significant differences ($P < 0.05$) along elevation gradients (Figure 3). The regression analysis indicated that Simpson diversity ($R^2 = 0.07$, $P < 0.05$) (Figure 3a) and evenness ($R^2 = 0.06$, $P < 0.05$) (Figure 3b) declined significantly along elevation gradients. However, woody species richness increased with increasing in elevation ($R^2 = 0.11$, $P < 0.05$) (Figure 3c) because some woody species encountered at higher elevations (e.g. Kahatsa forest) were not found at lower elevations (Tsahare Kan forest) (see Table 1). In contrast, the richness of herbaceous species declined from lower to middle elevation and peaked towards higher elevation ($R^2 = 0.12$, $P < 0.05$) (Figure 3d) because the middle elevation of forests favored abundance of woody species which in turn might outcompete and reduce herbaceous species richness (Table 3).

Shannon paired T-test analysis revealed that statistically insignificant decline of H' diversity occurred from lower to middle ($t = 1.516$, $P > 0.05$) and middle to higher elevations ($t = 0.647$, $P > 0.05$) (200 m interval each). However, significant differences of H' diversity existed between lower and higher elevations ($t = 2.118$, $P < 0.05$) (> 400 m interval). The effective number of species in lower elevations (14 species) was also higher than in higher elevations (9 species). Similarly, the Shannon paired T-test analysis showed that statistically significant difference ($P < 0.05$) of H' diversity occurred between the steep and intermediate slopes ($t = -4.81$, $P < 0.001$) as well as flat and steep slopes ($t = 4.74$, $P < 0.001$). Shannon paired T-test confirmed that statistically significant differences of H' diversity ($P < 0.05$) were found between south and west aspects ($t = 9.84$, $P < 0.001$). The analysis also showed that H' diversity (Figure 4a) and its effective number of species ranged from 2.51 to 12.01 species in all topographical aspects (Figure 4b).

Richness and diversity along a disturbance gradient

The results showed that richness and diversity varied that though insignificant, the declining of the effective

Table 4. Pearson correlation between species richness and diversity indices and site factors.

Variables	H'	E	SID	RT	RS	HS	Elv	Slp	CaP	Hi	Gri
Shannon -Weiner diversity (H')											
Pielou's evenness (E)	**0.66**										
Simpson reciprocal index (SRI)	**0.92**	**0.76**									
The richness of trees (RT)	**0.25**	-0.08	0.07								
The richness of shrubs (RS)	**0.33**	-0.03	0.09	0.09							
The richness of herbaceous (HS)	-0.14	**-0.25**	**-0.26**	-0.05	**0.31**						
Elevation (Elv, m)	-0.16	**-0.26**	**-0.28**	**0.28**	0.14	-0.02					
Slope (Slp, %)	0.05	**0.22**	0.03	-0.08	0.01	0.00	-0.03				
Canopy openness (Cap, %)	-0.20	**-0.22**	**-0.23**	-0.20	0.13	**0.34**	-0.11	-0.12			
Harvesting index (Hi)	-0.01	-0.04	-0.09	-0.09	0.10	0.12	-0.05	0.10	**0.52**		
Grazing intensity (Gri)	**-0.25**	**-0.30**	**-0.27**	0.15	**-0.22**	-0.02	**0.38**	-0.05	-0.03	-0.07	

Bold fonts indicate statistical significance at P <0.05.

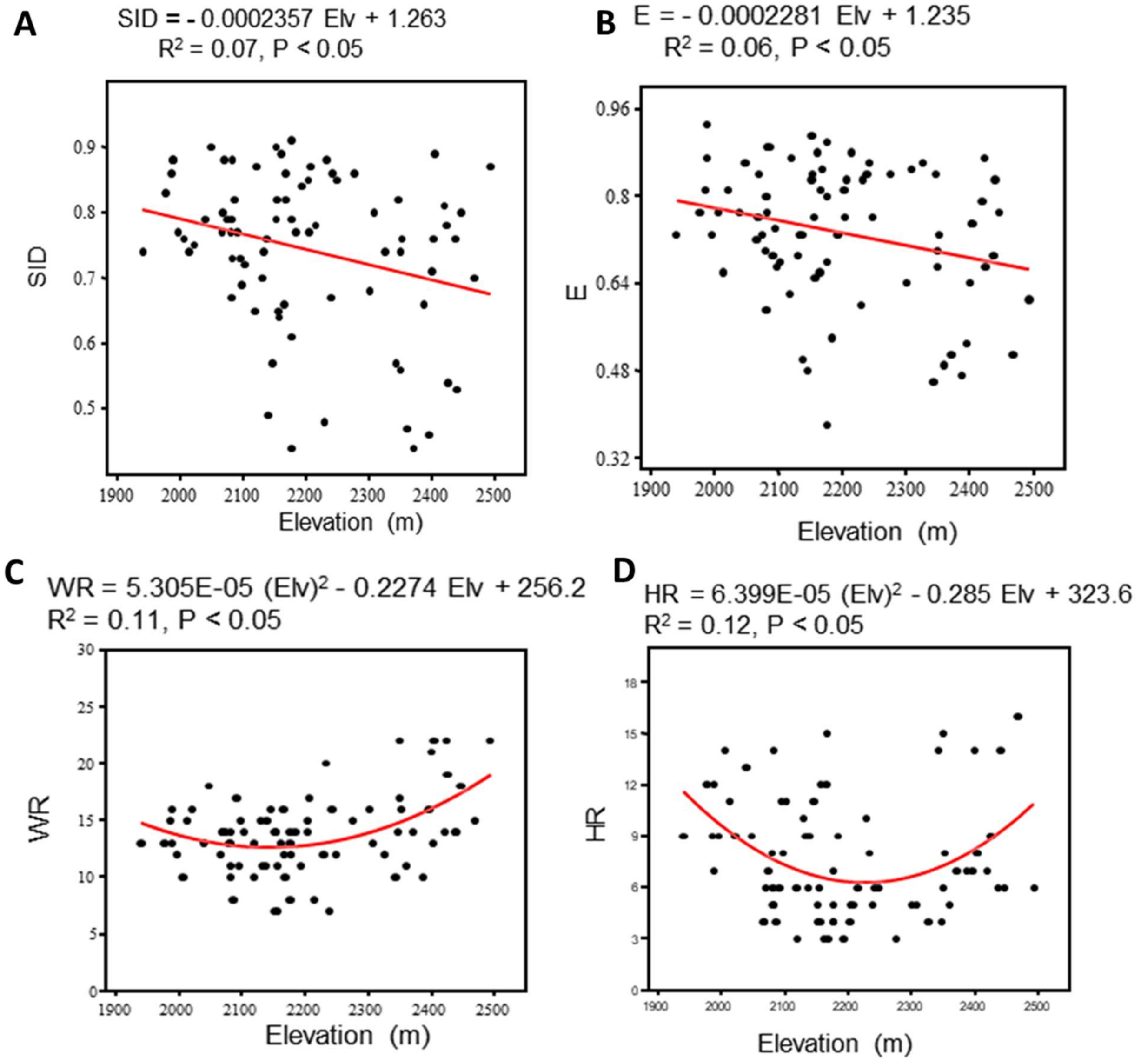

Fig. 3. The regression analysis along elevation gradients**. A**. Simpson index diversity. **B**. Pielou's evenness **C**. Woody species richness. **D**. Herbaceous species richness. SID = Simpson index diversity, E = Pielou's evenness, WR = woody species richness, HR = herbaceous species richness, elevation (Elv), dots and lines represent quadrats and fitted values.

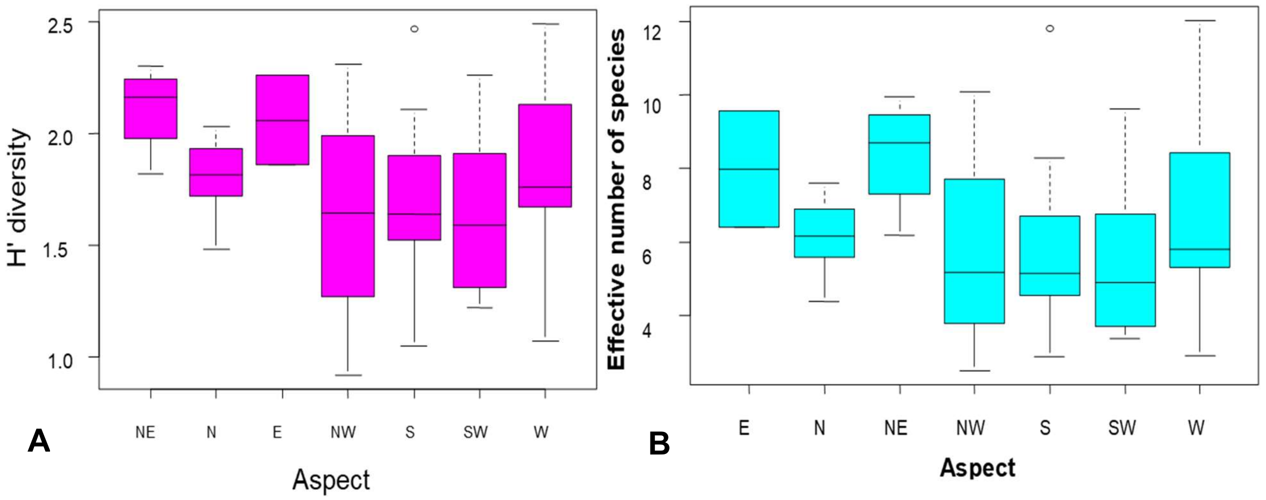

Fig. 4. Hill diversity numbers in topographical aspect. **A**. H' diversity **B**. Hill diversity numbers. (E= east, N = north, NE = northeast, NW = northwest, S = south, SW = southwest, W = west, dots are outliers and lines are medians.)

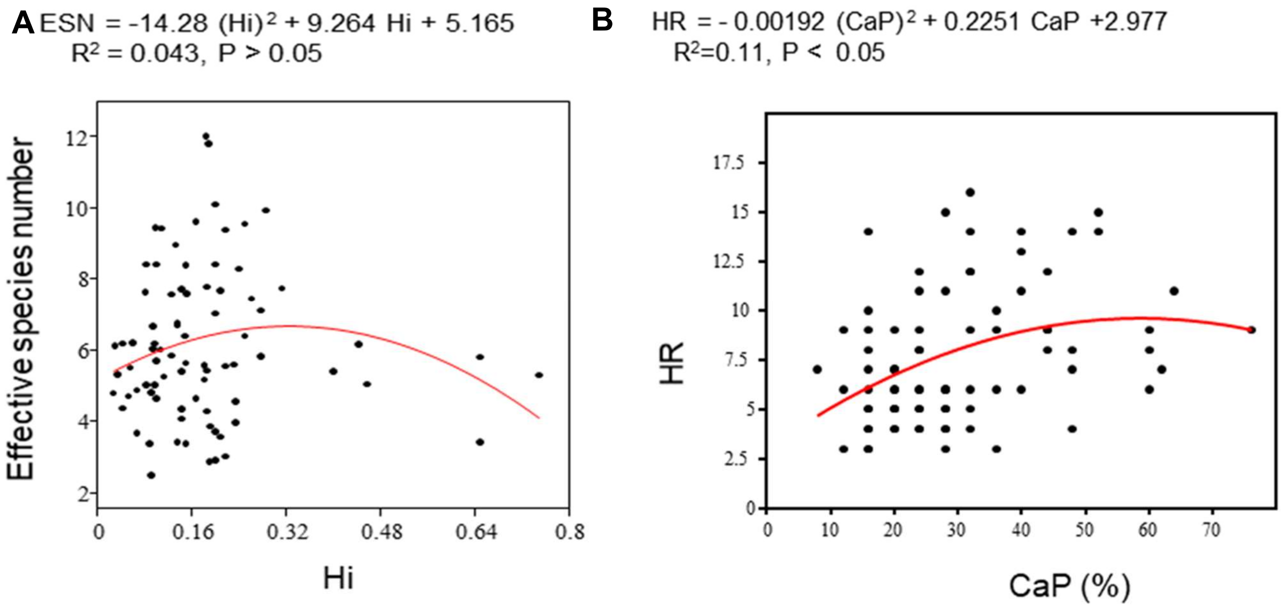

Fig. 5. Species diversity and richness along the harvesting gradient. **A**. Hill diversity numbers. **B**. Herbaceous species richness. ESN = effective species number, HR = herbaceous species richness, Hi = Harvesting index and canopy openness (CaP); dots and lines represent quadrats and fitted values.

number of species ($R^2 = 0.043$, $P > 0.05$) (Figure 5a) was observed along the harvesting index. Herbaceous species richness also showed quadratic pattern along forest canopy openness ($R^2 = 0.11$, $P < 0.05$) (Figure 5B), suggesting that a moderate level of openness of forests might facilitate herbaceous species richness. along the harvesting index (Hi) and forest canopy openness (Figure 5). The regression analysis indicated

Relation between richness and diversity with site factors

Pearson correlation (r) analysis showed that forest canopy openness correlated negatively with richness of trees (r = -0.20), but positively with richness of shrubs (r = 0.13) and herbaceous species (r = 0.34) at $P < 0.05$ (Table 4). Similarly, canopy openness (r = -0.23) and grazing intensity (r = -0.27) exhibited significant negative impact on diversity at $P < 0.05$. However, increased harvesting index (r = -0.09, $P > 0.05$) showed insignificant negative impact on diversity. Simpson diversity (r = -0.28, P = 0.01) and evenness (r = -0.26) correlated negatively with elevation, but slope correlated positively with evenness (r = 0.22) at $P < 0.05$. Furthermore, Simpson diversity exhibited strong positive correlation with Shannon diversity (r = 0.92, $P < 0.001$) and evenness (r = 0.76, $P < 0.001$).

Table 5. Significant indicator distribution of species in the clusters

Species	Cluster	Specificity	Fidelity	Indval	P–value
Lepidotrichilia volkensii	1	0.756	0.632	0.478	0.001
Erythrococea trichogyne	1	0.495	0.842	0.416	0.003
Ehretia cymosa	1	0.847	0.316	0.268	0.002
Achyranthes aspera	1	0.362	1.000	0.362	0.001
Impatines sp	1	0.703	0.684	0.481	0.001
Buddleja polystachya	2	0.167	0.786	0.149	0.043
Achyrospermum schimperi	2	0.385	0.821	0.316	0.007
Hypoestes triflora	2	1.000	0.179	0.179	0.020
Dombeya torrida	2	0.786	0.412	0.324	0.001
Maytenus arbutifolia	3	0.348	1.000	0.348	0.001
Embelia schimperi	3	0.911	0.706	0.643	0.001
Vernonia auriculifera	3	0.711	0.765	0.544	0.001
Nuxia congesta	3	1.000	0.471	0.471	0.001
Rytigynia neglecta	3	0.712	0.529	0.377	0.001
Apodytes dimidiata	3	0.488	0.765	0.373	0.001
Brucea antidysenterica	3	0.746	0.471	0.351	0.001
Olea capensis	3	0.584	0.412	0.241	0.012
Rhus glutinosa	3	1.000	0.235	0.235	0.003
Rosa abyssinica	3	0.769	0.294	0.226	0.008
Cyperus fischeranus	3	0.416	0.647	0.269	0.027
Justicia ladanoides	3	0.868	0.176	0.153	0.030
Rumex nepalensis	3	1.000	0.235	0.235	0.002
Albizia gummifera	4	0.375	0.938	0.351	0.007
Asparagus africanus	4	0.925	0.188	0.173	0.008
Cassipourea malosana	4	0.717	0.500	0.359	0.001
Dracaena steudneri	4	0.781	0.188	0.146	0.037
Justicia schimperiana	4	0.609	0.687	0.419	0.001
Millettia ferruginea	4	0.528	0.375	0.198	0.039
Rhoicissus tridentate	4	0.661	0.313	0.207	0.019
Solanecio gigas	4	0.682	0.375	0.255	0.002
Urera hypselodendron	4	0.511	0.687	0.351	0.006
Vernonia myrianth	4	1.000	0.187	0.187	0.005
Bidens sp.	4	1.000	0.438	0.437	0.001
Cissus petiolata	4	1.000	0.563	0.568	0.001
Girardinia bullosa	4	0.589	1.000	0.179	0.020
Phaulopsis imbricata	4	0.945	0.937	0.886	0.001
Persicaria sp.	4	1.000	0.125	0.125	0.031
Thalictrum rhychocarpum	4	1.000	0.125	0.125	0.042

Specificity = relative abundance, Fidelity = relative frequency, Indicator species in the respective community types at P < 0.05, Indval = Indicator values in class.

Classification of plant communities

The cluster analysis classified the 80 quadrats, including both woody and herbaceous species, into four communities. The cophenetic correlation coefficient (rc) reached a value of 0.76, indicating a considerable amount of similarity in classification (Figure 6). Grouping of quadrats into plant communities was undertaken through the recognition of one or two dominant indicator species in the clusters at P < 0.05 (Table 5). The major characteristic of each plant community (C) is summarized below.

C1: *Lepidotrichilia volkensii-Erythrococea trichogyne* community: was composed of 19 quadrats in which the majority of quadrats were found in Dabkuli (16 quadrats) and Apini (three quadrats) forests. It was found at elevations ranging from 2,082 to 2,250 m. This plant community had five indicator species, namely *Erythrococea trichogyne*, *Lepidotrichilia volkensii, Ehretia cymosa, Achyranthes aspera* and *Impatines sp.* The most dominant herb layer in the community was comprised of *Hypoestes forskaolii*, *Achyrospermum schimperi*, *Justicia ladanoides*, and *Impatiens* sp. The community had 69 species, Shannon-Weiner Index (H') diversity of 3.42 and evenness of 0.81. The soil was characterized by a mean pH value of 5.8 and a total nitrogen concentration of 0.56.

C2: *Bersama abyssinica-Pavetta abyssinica* community: was represented by 28 quadrats distributed at elevations ranging from 2,100 to 2,496 m of which 16 quadrats were from Bari and 12 quadrats in Apini forests. The community had four significant indicator species, namely *Buddleja polystachya*, *Dombeya torrid*, *Hypoestes triflora* and *Abutilon mauritianum*. *Capparis tomentosa*, *Carissa spinarum*, *Acacia abyssinica*, *Galiniera saxifrage* and *Schefflera abyssinica* were found only in this community. The ground layer was covered by dominant herbs, namely *Drymaria cordata*, *Parochaetus communis*, *Girardinia bullosa*, *Hypoestes triflora*, *Carduus schimperi*, *Bidens pilosa,* and *Ageratum conyzoides.* The community was represented by 96 species, H' diversity of 3.16 and evenness of 0.69. The soil is characterized by a mean pH value of 5.4 and a total nitrogen concentration of 0.77.

C3: *Maytenus arbutifolia-Rytigynia neglecta* community. A community comprised of 17 quadrats that occurred at elevations ranging from 2,300 to 2,500 m. It comprised of the majority of quadrats in Kahtasa forest. The community had 13 indicator species with significant values. *Maytenus arbutifolia*, *Apodytes dimidiata*, *Vernonia auriculifera*, *Rytigynia neglecta*, *Brucea antidysenterica*, *Olea capensis*, *Rhus glutinosa, Nuxia congesta* and *Rumex nepalensis* had the highest indicator values. *Hagenia abyssinica*, *Hypericum revolutum*, *Gymnema sylvestre*, *Vernonia amygdalina*, *Pittosporum viridiflorum*, *Juniperus procera*, *Maesa lanceolata*, *Maytenus senegalensi*, and *Tacazzea apiculata* were recorded only in this community. The ground layer was, mainly dominated by the herbaceous species, such as *Acmella caulirhiza, Ageratum conyzoides,* and *Achyranthes aspera.* This community hosted 83 species, H' diversity of 2.73 and evenness of 0.61 that characterized a degraded Afromontane forest. The mean soil pH value and nitrogen concentration were 5.1 and 0.76, respectively.

C4: *Albizia gummifera-Justicia schimperiana* community: was represented by 16 quadrats distributed in Tsahare Kan forest at elevations ranging from 1,988 to 2,176 m. This community had eight woody indicator species where *Albizia gummifera*, *Justicia schimperiana* and *Cassipourea malosana* had the highest values (Table 5). The ground layer was covered, mainly by herbaceous species, namely *Achyranthes aspera*, *Cardamine africana*, *Hypoestes forskaolii*, *Achyrospermum schimperi*, *Cynoglossum coeruleum,* and *Ageratum conyzoides.* The community has 72 species richness, H'

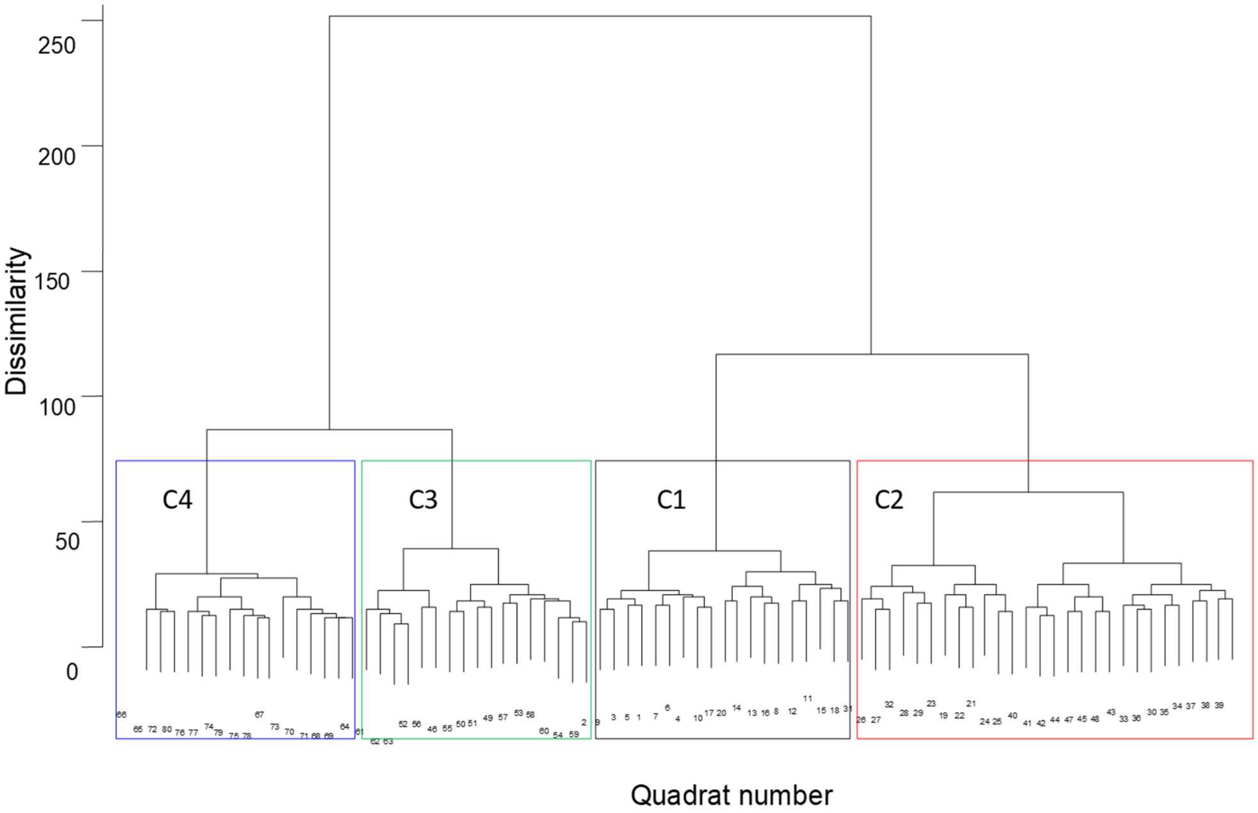

Fig. 6. Agglomerative hierarchical cluster using Euclidean distance. (Order of the quadrats along the x-axis of the dendrogram: **C4** (16 quadrats): 66, 65, 72, 80, 76, 77, 74, 79, 75, 78, 67, 73, 70, 71, 68 , 69 ; **C3** (17 quadrats): 64, 61, 62, 63, 52, 56, 46, 55, 50 , 51, 49, 57, 53, 58 , 60, 54, 59 ; **C1** (19 quadrats): 2, 9 , 3, 5 , 1, 7 , 6 , 4 , 10 , 17, 20 , 14, 13, 16, 8, 12, 11, 15, 18; **C2** (28 quadrats): 31, 26, 27, 32, 28, 29, 23, 19, 22, 21, 24, 25 , 40, 41, 42 , 44 , 47, 45, 48, 43, 33, 36, 30, 35 , 34, 37, 38 , 39)

diversity of 2.36 and evenness of 0.55. The mean soil pH value and the concentration of total nitrogen were 6.01 and 0.37, respectively. The results revealed that indicator species analysis accompanied by Monte Carlo test produced four significantly different community types ($P < 0.05$) (Table 5) and (Appendix 1). Among the 147 species involved in the analysis, 38 species were considered as indicators of four different clusters. For each cluster, the number of valid indicators was highly variable, ranging from 12.5 to 88.3% (Table 5). Among indicators species (Appendix 1), some species like *Rhus glutinosa* and *Nuxia congesta* were associated with a single community type (C3) and referred as perfect indicators. Some indicator species were associated with combinations of two or three community types only (e.g. *Justicia ladanoides and Brucea antidysenterica*) that share ecological characteristics. Some species were also associated to four community types (e.g. *Albizia gummifera*, *Apodytes dimidiata* and *Maytenus arbutifolia*).

Table 6. Eigenvalues and species-environment partitioning variance for the first four axes.

Importance of components	RDA1	RDA2	RDA3	RDA4	Total inertia
Eigenvalues	7.229	2.565	2.348	2.289	19.31
Proportion explained	0.374	0.133	0.122	0.118	
Cumulative explained	0.374	0.507	0.628	0.747	

Constrained ordination

In the constrained redundancy analysis (RDA), the eigenvalues obtained for the first and second axes were 7.229 and 2.565, respectively. The species– environment correlations were 0.84 (elevation), 0.37 (total nitrogen), 0.35 (soil pH) and 0.30 (grazing intensity), suggesting a two–dimensional solution, which was statistically significant ($P < 0.05$). RDA showed that the cumulative percentage of variance explained by the first four axes accounted for 14.43% of the species variation and 74.6% of the species-environment variation (Table 6). The environmental factors that contributed most to explaining species-environment variation included elevation (37.3%), total nitrogen (13.3%), soil pH (12.2%) and grazing intensity (11.8%). The first axis was positively correlated with elevation and total nitrogen ($P< 0.05$), and negatively correlated with soil pH (Figure 7). The second axis was positively associated with soil pH but negatively correlated with elevation, total nitrogen, and grazing intensity. The analysis of variance (ANOVA) in RDA ordination showed that the influences of seven environmental predictors on plant community formation were statistically significant (Variance = 19. 31, F= 1.54, P = 0.001).

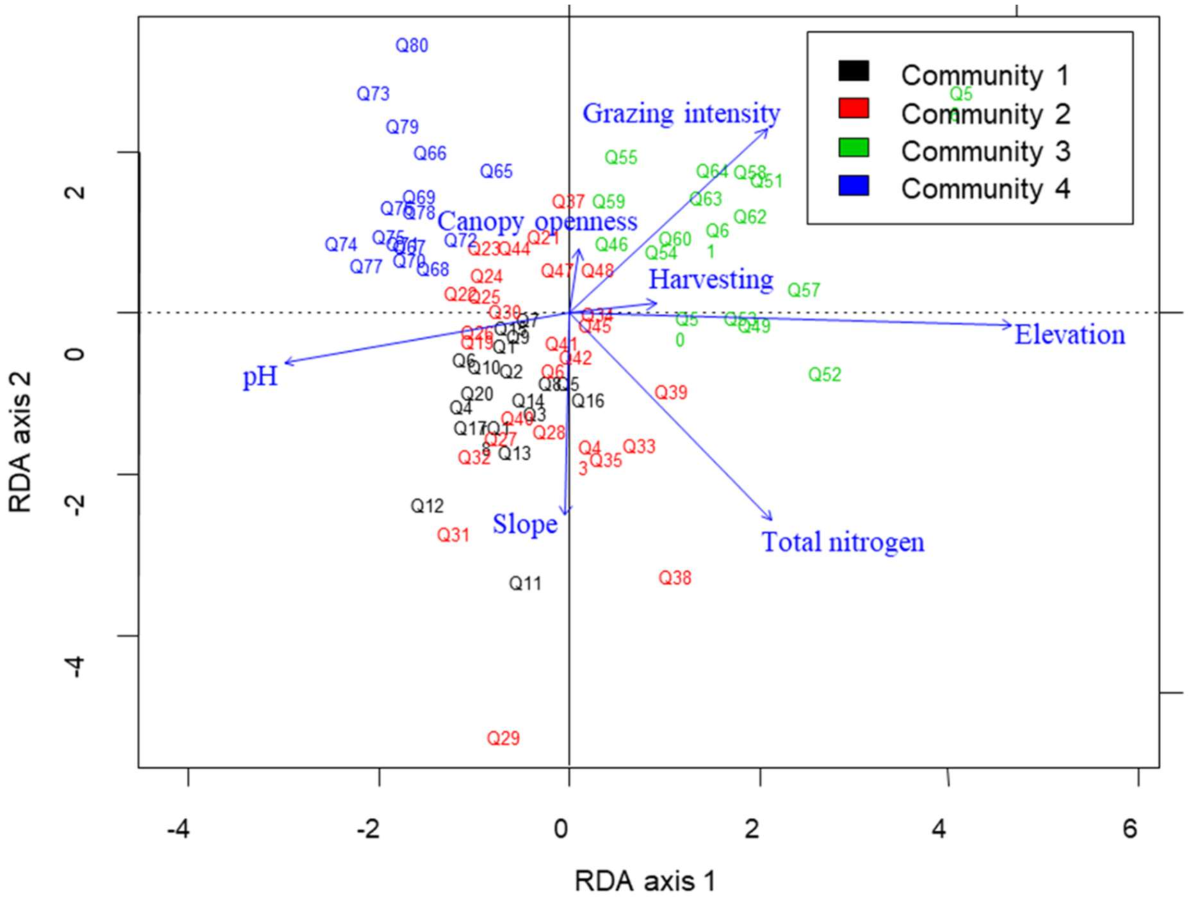

Fig. 7. The plot of constrained redundancy analysis for environmental variables and community types. (Sites denoted by Q1– 80 and its weighted sum of mean cover – abundance score of species)

DISCUSSION

Variation of richness and diversity

The total species richness in the five studied forests was comparable to the species richness (153 spp.) reported from the dry Afromontane forests of Ethiopia (Betemariam 2011). The tree species richness (30 species ha^{-1}) in five forests was lower than species richness (80 species ha^{-1}) in the dry evergreen Afromontane forests (Lemenih and Bongers, 2011). The low value of tree richness and increasing richness of shrubs and lianas was due to selected harvesting (Table 2). The results on species richness and diversity make the study of considerable importance. This was because not only richness and diversity were quantified, but also factors affecting species richness and diversity were highlighted in five the studied forests in Banja and Guangua District.

The results also showed that three plant families (Asteraceae, Fabaceae, Lamiaceae) contributed the most to species richness of the studied forests, which is similar to descriptions in the Flora of Ethiopia (Kelbessa and Demissew 2014). There were more woody species (86 spp.) encountered than herbaceous species (67 spp.), but woody species richness was lower than results from the richness (113 spp.) of Peninsula of Zegie, northwestern Ethiopia (Alelign *et al.* 2007). Woody species might have developed better adaptation from environmental stress than herbs in the forests. The results showing correspondence between species diversity and disturbance is not a new phenomenon. Other study in tropical forests also demonstrated high biodiversity coupled with disturbances (Gibson *et al.* 2011). Thus, diversity became more susceptible to human-induced disturbances in the forests because disturbance might produce multiple influences in woody and herbaceous species richness (e.g. harvesting severity and grazing intensity) within small forest patches. A decrease in forest patch size results in lower species richness according to the well-known species-area relationship (Rosenzweig, 1995) and leads to an increased edge to core ratio, which is often detrimental to habitat specialists (Ries et al., 2004). This might accelerate the rate of change and alter forest conditions.

Simpson diversity and evenness exhibited monotonically decreasing trends, but richness exhibited increasing trends with increasing elevation gradients. Woody species richness increased from lower to higher elevations because increasing elevation might change rainfall pattern and shifts species richness. These results are consistent with a previous study that reported increased species richness in parallel with increased elevation (Matteodo *et al.* 2013). In contrast, other studies had showed decreasing species richness along increasing elevation (Davidar *et al.* 2005; Kebede *et al.* 2013). The reason for different species richness pattern might arise from the scale of elevation gradient such as shorter (1000 -1200 m) (Song *et al.* 2016), medium (250 -1550 m) (Davidar *et al.* 2005) and longer elevations (700 -2200 m) (Zhang *et al.* 2013). In some sites, migration of species may not occur in response to environmental changes (Zhu *et al.* 2014). In contrast to woody species richness, the herbaceous species richness exhibited inversely hump-shaped distribution along the elevation gradients. This was because in middle elevations the influence of woody species via shade effects on herbaceous species is more that consequently reduce their richness. A detectable net–change of H' diversity or the effective number of species occurred between lower and higher elevation (> 400 m interval) than between lower and middle elevation (< 200 m interval) (Table 3). Earlier findings showed that diversity could be associated with elevation gradients in different ways, such as hump-shaped (Zhang *et al.* 2013; Betemariam 2011), U-shaped (Dossa *et al.* 2013), linearly decreasing and, even, no relationship (Pellissier *et al.* 2012). On the other hand, diversity would increase or decrease with increasing elevation depending on, largely, specific patterns of interactions among plant communities, species and environmental factors (Körner *et al.* 2007). Therefore, it is also important to consider the level of disturbances and species competition.

The highest diversity and equitable distribution occurred at the intermediate (10–20%) than flat (< 10%) and steep (> 20%) slopes as was found in other study (Méndez-Toribio *et al.* 2016). The west and south aspects also contained the highest diversity than other aspects since these topographical aspects and slopes are, often inaccessible to agricultural expansion, grazing, and wood harvesting. Topographical aspect and slopes may also affect environmental conditions, such as light, soil moisture, temperatures and nutrients besides disturbance regimes that, in turn, affect plant diversity (Dyer 2009). Exposures to west aspect for light might support increased species richness and diversity than the south aspect.

Effect of harvesting and grazing intensity on richness and diversity

Results demonstrated that the effective number of species showed no significant patterns along the harvesting gradient. However, the intermediate harvesting showed favorable environmental conditions for enhancement of diversity in a similar manner as was found in other studies (Zhang *et al.* 2013; Shrestha *et al.* 2013). After harvesting index (HI) surpasses an intermediate level (HI > 0.18), immense changes in forest conditions occur, which are favorable for a few sets of species (Figure 5). Most individual species such as *Junperus procera*, *Hagenia abyssinica* and *Schefflera abyssinica* found rarely (Appendix 1), and might not tolerate harvesting severity, which lower diversity in disturbed forests. The correlation analysis also showed that harvesting of tree species had shown negative effects on diversity and distribution of species in the forests (Table 4). Previous study also showed that tropical Afromontane forests are subjected to various disturbances like harvesting and grazing with different severity and intensities, which change the diversity (Putz *et al.* 2012).

The correlation analysis showed that canopy openness correlated negatively with lower tree richness, but exhibited a positive relationship with shrub and herb species richness. This suggests that removal of tree species might favor increasing abundance of shrub species. Previous studies also found that harvesting of tree species might increase canopy opening, facilitating dominance of shrub species (Asbjornsen *et al.* 2004) and change in species-specific growth forms (Crausbay and Martin 2016). A positive relationship between the richness of herbaceous and canopy openness found in this study agrees with the results of previous study (Mandle and Ticktin 2013).

The correlation between herbaceous species and grazing intensity was a weak negative association in the present study because of the occurrence of shade tolerant herbaceous species like *Hypoestes forskaoliia* and *Achyrospermum schimperi* and incidences of free grazing in the forests (Table 4). In addition, effects of grazing might increase the richness of forbs, but decrease palatable grasses, resulting in a weak negative relationship. Other studies have also explained that herbaceous species react quickly to natural and anthropogenic disturbances (Kikoti and Mligo 2015) and, hence are used as indicators of site conditions and conservation status of forests (Chávez and Macdonald 2012). However, long-term free grazing might degrade understory palatable vegetation (Kikoti and Mligo 2015). The understory communities and forests were occupied, mainly by unpalatable herbaceous species composed of *Achyranthes aspera*, *Hypoestes forskaoliia*, *Impatiens* sp. and *Achyrospermum schimperi.* This reduction in the proportion of palatable plant species is indicative of the long-term effects of uncontrolled grazing which ultimately leads to land degradation.

Effect of environmental factors, harvesting and grazing intensity on community types

Species diversity and community types depended on a combination of factors, including both disturbances and environmental factors. The four different plant community types and indicator species in the present study are comparable with that of other forest vegetation sites in Ethiopia (Alelign *et al.* 2007; Betemariam 2011). In gradient analysis, the cumulative variance explained by the first four axes accounted for 74.6% of the species-environment variation, indicating that topographic and soil factors are the important drivers determining the distribution of the plant species in dry Afromontane forests (Figure 7). It has been suggested that the result of this type of analysis can be useful if the eigenvectors represent over 40% of the total variance (Li *et al.* 2017). Consequently, the first two axes are sufficient to reflect the relationship between plant species and environmental factors. Of all the factors, elevation is most strongly associated with axes relating to differentiated community types because elevation exerts a great influence on temperature and moisture availability (Dyer 2009). For instance, elevation separated mean cover abundance of C3 from C2. In addition to elevation, total nitrogen was important in structuring C2, while pH was the most important factor in structuring C1. This reflects that the distribution of soil nitrogen and pH strongly regulated the abundance of species in these clusters. For instance, availability of high soil nitrogen concentration (0.77) and moderate soil pH (5.4) might facilitate abundance of *Bersama abyssinica* and *Pavetta abyssinica* that formed separate community (C2) with high H' diversity (3.16). In contrast, low soil nitrogen concentration (0.37) and high soil pH value (6.01) might favor abundance of *Albizia gummifera* and *Justicia schimperiana* that in turn formed separate community (C4) with lower H' diversity (2.36).

The grazing intensity was also important factor responsible for the separation of C3 and C4 and apparently affected diversity and evenness in these community types than others. C3 consisted of samples of vegetation data from grazed areas and harvesting, which were commonly represented by woody species such as *Maytenus arbutifolia*, *Vernonia auriculifera*, *Rytigynia neglecta* and *Brucea antidysenterica*, and the herbaceous species such as *Achyrospermum schimperi*, *Ageratum conyzoides* and *Achyranthes aspera.* The abundance of these shrubs and unpalatable herbs than tree species in C3 indicated increasing of harvesting and grazing effect. These community associations in response to disturbances indicate the dynamics of forests.

Plant community types provide important information on the underlying environmental factors. For instance, the C4 found in the lower elevations (1,988 to 2,176 m) has low soil nitrogen concentration (0.37) and should be prioritized for soil rehabilitation before other community types. In contrast, C3 inhabited some indicator species like *Rhus glutinosa* and *Nuxia congesta*; and others like *Hagenia abyssinica* and *Juniperus procera* that occurred rarely in the higher elevation (2,300 to 2,500 m) with better soil nitrogen concentration (0.76). This community type should be given priority in enrichment planting of those rare species.

CONCLUSIONS

The results confirmed that dry Afromontane forests contain considerable plant diversity, six endemic species, and four community types. Species richness, diversity and evenness varied among forests, suggesting the influence of environmental, harvesting and grazing factors. Diversity and evenness declined along with an increase in elevation. Diversity and evenness attained maximum values at intermediate slope, but diversity and evenness decreased in flat and steep slopes. The maximum plant diversity values achieved on moderately harvested forests, but neither deceasing nor increasing of harvesting favored diversity along the gradient. Variation of elevation, soil nitrogen concentration, and pH played significant role to differentiate community assemblages. Grazing intensity altered understory palatable species, leading to abundance of non-palatable herbaceous species such as *Hypoestes forskaolii*, *Achyrospermum schimperi*, *Achyranthes aspera* and *Ageratum conyzoides* in the community types. Harvesting resulted in rare occurrence of *Juniperus procera, Hagenia abyssinica* and *Schefflera abyssinica* in plant community types. Therefore, an effective management plan is needed for sustainable harvesting of species, the establishment of area exclosures, designing enrichment planting of rare plants and in gaps of the disturbed forests.

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LITERATURE CITED

Abiyu, A., M. Lemenih, G. Gratzer, R. Aerts, D. Teketay, G. Glatzel 2011. Status of native woody species diversity and soil characteristics in an enclosure and in plantations of Eucalyptus globulus and Cupressus lusitanica in Northern Ethiopia. Mt. Res. Dev. **31(2):** 144-152.

Aerts, R., K. van Overtveld, M. Haile, M. Hermy, J. Deckers, B. Muys 2006. Species composition and diversity of small Afromontane forest fragments in northern Ethiopia. Plant Ecol. **187(1):** 127-142.

Alelign, E., D. Teketay, Y. Yemshaw, S. Edwards 2007. Diversity and status of regeneration of woody plants on the peninsula of Zegie, northwestern Ethiopia. Trop. Ecol. **48:** 37-50.

Asbjornsen, H., K.A. Vogt, M.S. Ashton 2004. Synergistic responses of oak, pine and shrub seedlings to edge environments and drought in a fragmented tropical highland oak forest, Oaxaca, Mexico. For. Ecol. Manag. **192(2-3):** 313-334.

Betemariam, E.A. 2011. Forest diversity in fragmented landscapes of northern Ethiopia and implications for conservation.Ph.D. Dissertation. Addis Ababa.

Chávez, V. and S.E. Macdonald 2012. Partitioning vascular understory diversity in mixedwood boreal forests: the importance of mixed canopies for diversity conservation. For. Ecol. Manag. **271:** 19-26.

Crausbay, S.D. and P.H. Martin 2016. Natural disturbance, vegetation patterns and ecological dynamics in tropical montane forests. J. Trop. Ecol. **32(5):** 384-403.

Dattaraja, H. S., S. Pulla, H.S. Suresh, M.S. Nagaraja, C. A. Srinivasa Murthy, R. Sukumar 2018. Woody plant diversity in relation to environmental factors in a seasonally dry tropical forest landscape. J. Veg. Sci. **29(4):** 704-714.

Davidar, P., J.P. Puyravaud, E.G. Leigh 2005. Changes in rain forest tree diversity, dominance, and rarity across a seasonality gradient in the Western Ghats, India. J. Biogeogr. **32(3):** 493-501.

Deichert, G., F. Krämer, A. Schöning 2014. Turning degraded land into productive landscapes, Ethiopian highlands. ETFRN News **56:** 82-87.

Dossa, G.G., E. Paudel, J. Fujinuma, H. Yu, W. Chutipong, Y. Zhang, S. Paz, R.D. Harrison 2013. Factors determining forest diversity and biomass on a tropical volcano, Mt. Rinjani, Lombok, Indonesia. PLoS One **8(7):** e67720.

Dufrêne, M. and P. Legendre 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol. Monogr. **67(3):** 345-366.

Dyer, J.M. 2009. Assessing topographic patterns in moisture use and stress using a water balance approach. Landsc. Ecol. **24(3):** 391-403.

Edwards, S., M. Tadese, I. Hedberg 1995. Flora of Ethiopia and Eritrea Vol. 2, Part 2: Canellaceae to Euphorbiaceae, AAU.

Edwards, S., M. Tadesse, I. Hedberg eds. 2000. Flora of Ethiopia and Eritrea. Vol. **2**, part 1. Addis Ababa University, Addis Ababa, 532 pp.

Flynn, D. F., M. Gogol-Prokurat, T. Nogeire, N. Molinari, B.T. Richers, B.B. Lin, N. Simpson, M.M. Mayfield, F. Declerck 2009. Loss of functional diversity under land use intensification across multiple taxa. Ecol. Lett. **12(1):** 22-33.

Gibson, L., T.M. Lee, L.P. Koh, B.W. Brook, T.A. Gardner, J. Barlow, C.A. Peres, C.J. Bradshaw, W.F. Laurance, T.E. Lovejoy 2011. Primary forests are irreplaceable for sustaining tropical biodiversity. Nature **478(7369):** 378.

Hedberg, I., O. Hedberg, S. Edwards, S. Demissew 1997. Flora of Ethiopia and Eritrea. Vol. 6, Hydrocharitaceae to Arecaceae, National Herbarium, Addis Ababa University.

Hedberg, I., S. Edwards and N. Sileshi eds. 2003. Flora of Ethiopia and Eritrea. Vol. 4:1. Apiaceae to Dipsacaceae. Addis Ababa and Uppsala.

Hedberg, I. and S. Edwards eds. 1989. Flora of Ethiopia. Vol. 3. Addis Ababa University, Addis Ababa, 659 pp.

Hedberg, I., S. Edwards eds. 1995. Flora of Ethiopia. Vol. 7. Addis Ababa University, Addis Ababa, 420 pp.

Hill, M. O. 1973. Diversity and evenness: a unifying notation and its consequences. Ecology **54(2)**: 427-432.

Kebede, M., E. Yirdaw, O. Luukkanen, M. Lemenih 2013. Plant community analysis and effect of environmental factors on the diversity of woody species in the moist Afromontane forest of Wondo Genet, South Central Ethiopia. Biodiv. Res. Conserv. **29(1)**:63-80.

Kelbessa, E., S. Demissew 2014. The diversity of vascular plant taxa of the flora of Ethiopia and Eritrea. Ethiop. J. Biol. Sci. **13:** 37-45.

Kent, M. 2011. Vegetation description and data analysis: a practical approach John Wiley & Sons.

Kikoti, I. A. and C. Mligo 2015. Impacts of livestock grazing on plant species composition in montane forests on the northern slope of Mount Kilimanjaro, Tanzania. International Journal of Biodiversity Science, Ecosystem Services and Management **11(2):** 114-127.

Körner, C., M. Donoghue, T. Fabbro, C. Häuse, D. Nogués-Bravo, M.T.K. Arroyo, J. Soberon, L. Speers, E.M. Spehn, H.S un 2007. Creative use of mountain biodiversity databases: the Kazbegi research agenda of GMBA-DIVERSITAS. Mt. Res. Dev. **27(3):** 276-281.

Kumar, A. and J. Ram 2005. Anthropogenic disturbances and plant biodiversity in forests of Uttaranchal, central Himalaya. Biodivers. Conserv. **14(2)**: 309-331.

Lee, C.B. and J.H. Chun 2016. Environmental drivers of patterns of plant diversity along a wide environmental gradient in Korean temperate forests. Forests **7(12):** 19.

Lemenih, M. and F. Bongers 2011. Dry forests of Ethiopia and their silviculture. Silviculture in the Tropics (Tropical Forestry) **8**: 261-272.

Li, W., L. Cui, B. Sun, X. Zhao, C. Gao, Y. Zhang, M. Zhang, X. Pan, Y. Lei, W. Ma 2017. Distribution patterns of plant communities and their associations with environmental soil factors on the eastern shore of Lake Taihu, China. Ecosystem Health and Sustainability **3(9):** 1385004.

Liu, Y., Y. Zhang, D. He, M. Cao, H. Zhu 2007. Climatic control of plant species richness along elevation gradients in the Longitudinal Range-Gorge Region. Sci. Bull. **52(s2):** 50-58.

Magurran, A.E. 2004. An Index of Diversity. Measuring Biological Diversity. Blackwell publishing company.

Mandle, L. and T. Ticktin 2013. Moderate land use shifts plant diversity from overstory to understory and contributes to biotic homogenization in a seasonally dry tropical ecosystem. Biol. Conserv. **158:** 326-333.

Matteodo, M., S. Wipf, V. Stöckli, C. Rixen, P. Vittoz 2013. Elevation gradient of successful plant traits for colonizing alpine summits under climate change. Environ. Res. Lett. **8(2):** 024043.

Mekonnen, M., T. Sewunet, M. Gebeyehu, B. Azene, A.M. Melesse 2016. GIS and remote sensing-based forest resource assessment, quantification, and mapping in Amhara Region, Ethiopia. Landscape Dynamics, Soils and Hydrological Processes in Varied Climates. Springer.

Méndez-Toribio, M., J.A. Meave, I. Zermeño-Hernández, G. Ibarra-Manríquez 2016. Effects of slope aspect and topographic position on environmental variables, disturbance regime and tree community attributes in a seasonal tropical dry forest. J. Veg. Sci. **27(6):** 1094-1103.

Miles, L., A.C. Newton, R.S. Defries, C. Ravilious, I. May, S. Blyth, V. Kapos, J.E. Gordon 2006. A global overview of the conservation status of tropical dry forests. J. Biogeogr. **33(3):** 491-505.

Moeslund, J.E., L. Arge, P.K. Bøcher, T. Dalgaard, J.C.S venning 2013. Topography as a driver of local terrestrial vascular plant diversity patterns. Nord. J. Bot. **31(2):** 129-144.

Nelson, D. W. and L.E. Sommers 1996. Total carbon, organic carbon, and organic matter. *Methods of soil analysis part 3—chemical methods*, 961-1010.

Pandey, S. and R. Shukla 2003. Plant diversity in managed sal (Shorea robusta Gaertn.) forests of Gorakhpur, India: species composition, regeneration and conservation. Biodivers. Conserv. **12(11):** 2295-2319.

Pellissier, L., K. Fiedler, C. Ndribe, A. Dubuis, J.N. Pradervand, A. Guisan, S. Rasmann 2012. Shifts in species richness, herbivore specialization, and plant resistance along elevation gradients. Ecol. Evol. **2(8):**1818-1825.

Pielou, E.C.1966. Species-diversity and pattern-diversity in the study of ecological succession. J. Theor. Biol. **10(2):** 370-383.

Putz, F., P. Zuidema, T. Synnott, M. Peña-Claros, M. Pinard, D. Sheil, J. Vanclay, P. Sist, S. Gourlet-Fleury, B. Griscom 2012. Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. Conserv. Lett. **5(4)**: 296-303.

R Core Team 2016. R: A Language and Environment for Statistical Computing. Vienna, Austria.

Ries, L., R. J. Fletcher JR, J. Battin and T.D. Sisk, 2004. Ecological Responses to Habitat Edges: Mechanisms, Models, And Variability Explained. Annu. Rev. Ecol. Evol. Syst. **35(1)**:491-522.

Rosenzweig, M. L. 1995. Species Diversity in Space and Time. Cambridge University Press.

Sagar, R., A. Raghubanshi, J. Singh 2003. Tree species composition, dispersion, and diversity along a disturbance gradient in a dry tropical forest region of India. For. Ecol. Manag. **186(1-3):** 61-71.

Shrestha, K.B, I.E. Måren, E. Arneberg, J.P. Sah, O.R. Vetaas 2013. Effect of anthropogenic disturbance on plant species diversity in oak forests in Nepal, Central Himalaya. International Journal of Biodiversity Science, Ecosystem Services and Management **9(1):** 21-29.

Šmilauer, P. and J. Lepš 2014. Multivariate analysis of ecological data using CANOCO 5, Cambridge university press.

Song, X., A. Nakamura, Z. Sun, Y. Tang, M. Cao 2016. Elevational distribution of adult trees and seedlings in a tropical montane transect, Southwest China. Mt. Res. Dev. **36(3):** 342-354.

Soromessa, T., D. Teketay, S. Demissew 2004. An ecological study of the vegetation in the Gamo Gofa zone, southern Ethiopia. Trop. Eco. **45:** 209-222.

Teketay, D. 2005. Seed and regeneration ecology in dry Afromontane forests of Ethiopia: II. Forest disturbances and succession. Trop. Eco. **46:** 45-64.

van der Maarel, E. and J. Franklin eds. 2012. Vegetation ecology, John Wiley & Sons. Chichester, United Kingdom.

Zhang, J.T., B. Xu and M. Li 2013. Vegetation patterns and species diversity along elevational and disturbance gradients in the Baihua Mountain Reserve, Beijing, China. Mt. Res. Dev. **33(2):** 170-178.

Zhang, J.T., M. Zhang and R. Mian 2016. Effects of elevation and disturbance gradients on forest diversity in the Wulingshan Nature Reserve, North China. Environ. Earth Sci. **75(10):** 904.

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Appendix 1 List of plant species and community types of five forests (Key: C1, 2,3,4 = Community 1, 2, 3 and 4, GH=growth habit: T=trees, S=shrubs, C=climbers, H=herbs, Gr=grass, Indval cls= indicator values in the class and GGK= Getaneh Gebeyehu‘s samples collected in Kahtasa and associated forests and bolds indicated significant (P <0.05) at respective communities.

No	**Coll. no.**	**Scientific names**	**Family**	**GH**	**Mean cover-abundance of species**				**Indval cls**	**P-value**
					C1	**C2**	**C3**	**C4**		
1	GGK 128	*Acacia abyssinica* Hochst.ex Benth.	Fabaceae	T	0.000	0.178	0.000	0.000	0.036	1.00
2	GGK 122	*Acanthus polystachius* Del.	Acanthaceae	S	0.000	0.464	0.588	0.187	0.056	0.650
3	GGK 105	*Albizia gummifera* (J.F. Gmel.) C.A. Sm.	Fabaceae	T	4.526	3.750	1.941	**6.125**	**0.351**	**0.005**
4	GGK 36	*Allophyllus abyssinicus* (Hochst.) Radlkofer	Sapindaceae	T	3.052	2.000	1.824	1.313	0.176	0.352
5	GGK 109	*Apodytes dimidiata* E. Mey. ex Am.	Icacinaceae	T	2.105	1.714	**4.117**	0.500	**0.373**	**0.001**
6	GGK 32	*Asparagus africanus* Lam.	Asparagaceae	S	0.000	0.036	0.000	**0.438**	0.173	**0.008**
7	GGK 21	*Bersama abyssinica* Fresen.	Melianthaceae	T/S	1.105	2.892	2.765	0.500	0.171	0.236
8	GGK 103	*Bridelia micrantha* (Hocmt.) Baill.	Euphorbiaceae	T/S	0.158	0.000	0.000	0.000	0.053	0.638
9	GGK 120	*Brucea antidysenterica* Swiss Char	Simaroubaceae	S	0.053	0.107	**0.471**	0.000	**0.351**	**0.001**
10	GGK 23	*Buddleja polystachya* Fresen.	Loganiaceae	S	0.158	**0.786**	0.000	0.000	0.148	**0.036**
11	GGK 116	*Calpurnia aurea* (Ait.) Benth	Fabaceae	S	0.789	0.678	0.000	0.000	0.099	0.259
12	GGK 101	*Capparis tomentosa* Lam.	Capparidaceae	C	0.000	0.036	0.000	0.000	0.036	1.000
13	GGK 125	*Carissa spinarum* L.	Apocynaceae	C	0.000	0.428	0.000	0.000	0.107	0.077
14	GGK 14	*Cassipourea malosana* (Baker) Alston	Rhizophoraceae	S	0.158	0.286	0.000	**1.125**	**0.359**	**0.001**
15	GGK 18	*Celtis africana* Burm.f.	Ulmaceae	T	1.158	1.250	0.000	0.000	0.129	0.154
16	GGK 121	*Clausena anisata* (Willd.) Benth.	Rutaceae	S	0.632	1.500	1.941	0.687	0.191	0.106
17	GGK 53	Clematis hirsuta Perro &Guill	Ranunculaceae	C	0.105	0.036	0.647	0.000	0.145	0.051
18	GGK 39	**Clematis longicauda* Steud. ex A. Rich.	Ranunculaceae	C	0.000	0.071	0.411	0.000	0.150	0.054
	GGK 73	*Clerodendrum myricoides* (Hochst.) Vatke	Lamiaceae	S	0.263	0.036	0.000	0.000	0.046	0.640
20	GGK 117	*Clutia lanceolata subsp. lanceolata* Forssk	Euphorbiaceae	S	0.000	0.000	0.058	0.000	0.059	0.415
21	GGK 40	*Crotalaria senegalensis* (Pers.) Bacle ex DC	Fabaceae	S	0.000	0.071	0.000	0.125	0.079	0.137
22	GGK 107	*Croton macrostachus* Del.	Euphorbiaceae	T	3.526	3.250	0.588	1.812	0.243	0.093
23	GGK 42	*Discopodium penninervum* Hochst.	Solanaceae	T	0.157	0.071	0.118	0.062	0.041	0.897
24	GGK 71	*Dombeya torrida* (F. Gmel.) P. Bamps	Sterculiaceae	T	**0.607**	2.235	0.000	0.000	0.324	**0.001**
25	GGK 74	*Dovyalis abyssinica* (A. Rick) Warb.	Flacourtiaceae	T	0.000	0.000	0.176	0.000	0.059	0.403
26	GGK 112	*Dracaena steudneri* Engler	Dracaenaceae	T	0.052	0.000	0.000	**0.187**	0.146	**0.037**
27	GGK 05	*Ehretia cymosa* Thonn.	Boraginaceae	T	**1.736**	0.000	0.000	0.312	0.268	**0.002**
28	GGK 113	*Ekebergia capensis* Spamn.	Meliaceae	T	0.684	0.250	0.529	0.00	0.049	0.673
29	GGK 133	*Embelia schimperi* Vatke	Myrsinaceae	C	0.000	0.035	**1.000**	0.062	0.643	**0.001**
30	GGK 115	*Erythrococea trichogyne* (Muell. Arg.) Prain	Euphorbiaceae	S	**4.789**	2.750	0.058	2.062	0.417	**0.002**
31	GGK 72	*Ficus sur* Forssk.	Moraceae	T	0.263	0.429	0.353	0.437	0.021	0.980
32	GGK 78	*Galiniera saxifraga* (Hochst.) Bridson	Rubiaceae	T	0.000	0.107	0.000	0.000	0.035	1.000
33	GGK 111	*Gounia longspicata* Engl.	Fabaceae	C	0.000	0.035	0.000	0.063	0.039	0.406
34	GGK 111	*Grewia ferruginea* Hochst. ex A. Rich.	Tiliaceae	T	0.263	0.107	0.000	0.000	0.037	0.637
35	GGK 52	*Gymnema sylvestre* (Retz.) R. Br. ex Schult.	Asclepiadaceae	C	0.000	0.000	0.117	0.000	0.117	0.078
36	GGK 135	*Hagenia abyssinica* (Bruce) J.F. Gmel.	Rosaceae	T	0.000	0.000	0.294	0.000	0.059	0.390
37	GGK 07	*Hippocratea goetzei* Loes	Celastraceae	C	0.368	0.928	0.000	0.000	0.217	0.106
38	GGK 55	*Hypericum revolutum* Vahl	Guttiferae	S	0.000	0.000	0.235	0.000	0.059	0.413
39	GGK 30	*Jasminum grandiflorum* L.	Oleaceae	C	0.157	0.178	0.235	0.250	0.076	0.856
40	GGK 136	*Junperus procera* Endl.	Cupressaceae	T	0.000	0.000	0.470	0.000	0.059	0.422
41	GGK 104	*Justicia schimperiana* (Hochst. ex Nees) T.Anders	Acanthaceae	S	1.526	1.964	0.000	**5.437**	0.418	**0.001**
42	GGK 59	*Leonotis ocymifolia* (Bunn. f.) Iwarsson,	Lamiaceae	S	0.000	0.000	0.058	0.000	0.059	0.390
43	GGK 80	*Lepidotrichilia volkensii* (Gilrke) Leroy	Meliaceae	T	**4.105**	0.321	0.000	1.000	0.478	**0.001**
44	GGK 127	*Maesa lanceolata* Forssk.	Myrsinaceae	S	0.000	0.000	0.470	0.000	0.118	0.086
45	GGK 102	*Maytenus senegalensis* (Lam.) &ell	Celastraceae	T	0.000	0.000	0.294	0.000	0.118	0.083
46	GGK 110	*Maytenus arbutifolia* (A. Rich.) Wilczek	Celastraceae	S	4.052	5.107	**7.764**	5.375	**0.348**	**0.001**
47	GGK 110	**Millettia ferruginea* (Hochst.) Bak.	Fabaceae	T	0.421	0.750	0.000	**1.312**	0.198	**0.039**
48	GGK 132	*Mimusops kummel* A. DC.	Sapotaceae	T	0.000	0.607	0.058	0.000	0.130	0.071
49	GGK 27	*Nuxia congesta* R.Br. ex Fresen	Loganiaceae	T	0.000	0.000	**1.705**	0.000	0.471	**0.001**
50	GGK 108	*Ocimium lamiifolium*	Lamiaceae	S	0.000	0.000	0.000	0.062	0.063	0.203
51	GGK 108	*Olea capensis* L.	Oleaceae	T	0.684	0.571	**2.117**	0.250	0.241	**0.014**
52	GGK 11	*Pavetta abyssinica* Fresen.	Rubiaceae	S	4.842	5.764	4.464	3.187	0.278	0.229
53	GGK 58	*Pavetta oliveriana* Hiern	Rubiaceae	T	0.000	0.178	0.000	0.000	0.056	1.000
54	GGK 58	*Periploca linearifolia* Quart.-Dill. & A. Rich	Asclepiadaceae	C	0.000	0.000	0.176	0.000	0.059	0.412
55	GGK 93	*Phytolaca dodecandra* L 'Herit.	Phytolaccaceae	S	0.211	0.035	0.000	0.187	0.102	0.227
56	GGK 48	*Pittosporum viridiflorum* Sims	Pittosporaceae	T	0.000	0.000	0.294	0.000	0.059	0.412
57	GGK 106	*Prunus africana* (Hook. f.) Kalkm.	Rosaceae	T	1.578	2.678	1.294	0.250	0.198	0.091
58	GGK 90	*Pterolobium stellatum* (Forssk.) Brenan	Fabaceae	C	0.000	0.107	0.000	0.000	0.036	1.000
59	GGK 22	**Pycnostachys abyssinica* Fresen.	Lamiaceae	S	0.000	0.464	0.000	0.000	0.071	0.248
60	GGK 29	*Rhoicissus tridentate* (L. f.) Wild & Drummond	Vitaceae	C	0.052	0.000	0.235	**0.562**	**0.207**	**0.019**
61	GGK 26	**Rhus glutinosa* A. Rich.	Anacardiaceae	T	0.000	0.000	**1.000**	0.000	0.235	**0.002**
62	GGK 54	*Rytigynia neglecta* (Hiem) Robyns	Rubiaceae	T/S	0.000	1.107	**3.823**	0.437	0.377	**0.001**
63	GGK 126	*Rosa abyssinica* Lindley	Rosaceae	S	0.052	0.035	**0.294**	0.000	0.226	**0.014**

64	GGK 44	*Rothmannia urcelliformis* (Hiern) Robyns	Rubiaceae	S	0.789	0.464	0.000	0.000	0.099	0.189
65	GGK 123	*Rubus apetalus* Poir.	Rosaceae	C	0.157	0.607	0.117	0.187	0.162	0.184
66	GGK 67	*Ritchiea albersii* Gilg	Capparidaceae	S	0.000	0.143	0.705	0.062	0.136	0.052
67	GGK 37	*Saba comorensis* (Boj.)	Apocynaceae	C	0.263	0.000	0.000	0.375	0.108	0.191
68	GGK 134	*Schefflera abyssinica* (Hochst. ex A. Rich.) Harms	Araliaceae	T	0.000	0.250	0.000	0.000	0.036	1.000
69	GGK 100	**Solanecio gigas* Boulos ex Humbert	Asteraceae	S	0.000	0.143	**0.411**	1.187	0.255	**0.002**
70	GGK 41	*Solanum incanum* L.	Solanaceae	S	0.368	0.107	0.000	0.250	0.027	0.891
71	GGK 20	*Solanum anguivi* Lam.	Solanaceae	S	0.631	0.678	0.529	1.312	0.104	0.456
72	GGK 129	*Syzygium guineense* (Willd.) DC.	Myrtaceae	T	0.000	0.893	0.000	0.437	0.096	0.226
73	GGK 69	*Tacazzea apiculata* Oliv.	Asclepiadaceae	C	0.000	0.000	0.058	0.125	0.0423	0.480
74	GGK 68	*Teclea nobilis* Del.	Rutaceae	S	2.631	1.393	1.117	2.437	0.165	0.178
75	GGK 131	*Urera hypselodendron* (A. Rich) Wedd.	Urticaceae	C	0.474	0.785	0.176	**1.500**	0.351	**0.003**
76	GGK 65	*Vernonia myrianth*	Asteraceae	S	0.000	0.000	0.000	**0.375**	0.187	**0.005**
77	GGK 97	*Vernonia amygdalina* Del.	Asteraceae	S	0.000	0.000	0.470	0.000	0.117	0.088
78	GGK 118	*Vernonia auriculifera* Hiem	Asteraceae	S/T	0.368	0.500	2.294	0.063	0.544	**0.001**
79	GGK 88	*Vernonia hoshstetteri* Sch. Bip. ex Wa	Asteraceae	S	0.000	0.071	0.058	0.375	0.046	0.558
80	GGK 149	*Vernonia rueppellii* Sch. Bip. ex Walp.	Asteraceae	S/T	0.059	0.063	0.000	0.000	0.032	0.748
81	GGK 38	*Abutilin mauritianum* (Jacq.) Medic	Malvaceae	H	0.000	**0.143**	0.000	0.000	**0.143**	**0.056**
82	GGK 01	*Achyranthes aspera* L.	Amaranthaceae	H	**4.947**	4.214	3.941	0.562	**0.362**	**0.001**
83	GGK 04	*Achyrospermum schimperi* (Hochst. ex Briq.) Perkins	Lamiaceae	H	1.368	**3.428**	3.294	0.812	**0.348**	**0.007**
84	GGK 15	*Acmella caulirhiza* Del.	Asteraceae	H	0.421	0.107	0.470	0.187	0.140	0.168
85	GGK 03	*Ageratum conyzoides* L.	Asteraceae	H	0.157	0.392	0.058	0.062	0.084	0.422
86	GGK 66	*Arisaema schimperianum* Schott	Araceae	H	0.211	0.000	0.000	0.063	0.081	0.260
87	GGK 98	*Bidens pilosa* L.	Asteraceae	H	0.000	0.000	0.035	0.000	0.035	1.00
88	GGK 151	*Bidens sp.* L.	Asteraceae	H	0.000	0.000	0.000	**0.750**	**0.437**	**0.001**
89	GGK 50	**Bothriocline schimperi* Olivo & Hiern ex Benth.	Asteraceae	H	0.000	0.035	0.000	0.000	0.036	1.00
90	GGK 57	*Cardamine africana* L.	Brassicaceae	H	0.263	0.750	0.471	0.250	0.154	0.307
91	GGK 49	*Carduus schimperi* Sch. Bip	Asteraceae	H	0.368	0.178	0.235	0.563	0.209	0.050
92	GGK 17	*Centella asiatica* (L.) Urban	Apiaceae	H	0.000	0.071	0.176	0.000	0.083	0.218
93	GGK153	*Cissus petiolata* Hook. f.	Vitaceae	H	0.000	0.000	0.000	**0.875**	**0.563**	**0.001**
94	GGK 24	*Commelina benghalensis* L.	Commelinaceae	H	0.000	0.107	0.059	0.000	0.046	0.507
95	GGK 46	*Conium maculatum* L.	Apiaceae	H	0.105	0.000	0.110	0.000	0.062	0.343
96	GGK 61	*Crassula alsinoides* (Hook.f) Engl.	Crassulaceae	H	0.000	0.000	0.117	0.000	0.059	0.406
97	GGK 43	*Cuscusta campestris* Yuncker	Cuscustaceae	H	0.526	0.357	0.000	0.625	0.129	0.232
98	GGK 91	*Cyathula uncinulata* (Schrad.) Schinz	Amaranthaceae	H	0.000	0.071	0.117	0.000	0.036	0.567
99	GGK 56	*Cynoglossum coeruleum* (Hochst. A. Rich.) DC.	Boraginaceae	H	0.211	0.393	0.235	0.125	0.087	0.721
100	GGK 141	*Cyperus fischeranus* A. Rich.	Cyperaceae	H	0.368	0.785	**1.176**	0.500	**0.269**	**0.027**
101	GGK 89	*Dalbergia lactea* Vatke	Fabaceae	H	0.000	0.000	0.117	0.000	0.059	0.423
102	GGK 92	*Desmodium repandum* (Vahl) DC	Fabaceae	H	0.000	0.000	0.000	0.063	0.063	0.209
103	GGK 82	*Drymaria cordata* (L.) Schultes	Caryophyllaceae	H	0.789	0.750	1.117	0.188	0.185	0.218
104	GGK 139	*Euphorbia platyphyllos* L.	Euphorbiaceae	H	0.000	0.107	0.000	0.125	0.049	0.619
105	GGK 147	*Galium spurium* L.	Rubiaceae	H	0.000	0.000	0.000	0.063	0.062	0.208
106	GGK 60	*Geranium arabicum* Forssk.	Geraniaceae	H	0.000	0.000	0.058	0.000	0.059	0.403
107	GGK 79	*Girardinia bullosa* (Steud.) Wedd.	Urticaceae	H	1.842	0.714	0.235	**4.000**	**0.589**	**0.001**
108	GGK 75	*Glycine wightii* (Wight & Am) Verde.	Fabaceae	H	0.000	0.107	0.000	0.000	0.036	1.000
109	GGK 86	*Guizotia vilosa* Sch. Bip.	Asteraceae	H	0.053	0.071	0.000	0.000	0.041	0.455
110	GGK 02	*Hypoestes forskaolii* (Vahl) R. Br.	Acanthaceae	H	5.895	5.178	3.705	5.125	0.281	0.257
111	GGK 06	*Hypoestes triflora* (Forssk.) Roem & Schult.	Acanthaceae	H	0.000	**0.500**	0.000	0.000	**0.179**	**0.020**
112	GGK 84	*Impatines sp.* L	Balsaminaceae	H	**2.316**	0.678	0.176	0.125	**0.481**	**0.001**
113	GGK 19	*Ipomea tenuirostris* Choisy	Convolvulaceae	H	0.000	0.035	0.000	0.000	0.036	1.000
114	GGK 12	*Justicia ladanoides* L.	Acanthaceae	H	0.000	0.036	**0.235**	0.000	**0.153**	**0.030**
115	GGK 45	*Kalanchoe petitiana* A. Rieh.	Crassulaceae	H	0.000	0.250	0.294	0.063	0.143	0.114
116	GGK 33	*Lagenaria abyssinica* (Hookf.) C. Jeffrey	Cucurbitaceae	H	0.000	0.000	0.118	0.000	0.118	0.080
117	GGK 99	*Laggera crispata* (Vahl) Hepper &Wood	Asteraceae	H	0.000	0.035	0.000	0.000	0.036	1.000
118	GGK 124	*Leucas deflexa* L.	Lamiaceae	H	0.000	0.178	0.000	0.000	0.036	1.000
119	GGK 76	*Malva verticillata* L.	Malvaceae	H	0.105	0.071	0.235	0.000	0.067	0.353
120	GGK 140	*Momordica foetida* Schumach.	Cucurbitaceae	H	0.053	0.035	0.000	0.063	0.026	0.729
121	GGK 149	*Oplismenus hirtellus* (L.) P. Beauv.	Poaceae	Gr	0.000	0.000	0.000	0.187	0.063	0.218
122	GGK 83	*Parochaetus communis* D. Don	Fabaceae	H	0.105	0.107	0.294	0.000	0.102	0.175
123	GGK 28	*Peristrophe panculeta* (Forssk.) Brummitt	Acanthaceae	H	0.000	0.428	0.235	0.313	0.060	0.742
124	GGK 152	*Persicaria sp.* L.	Polygonaceae	H	0.000	0.000	0.000	0.438	0.125	**0.031**
125	GGK 81	*Phaulopsis imbricata* (Forssk.) Sweet	Acanthaceae	H	0.211	0.000	0.000	**3.625**	0.886	**0.001**
126	GGK 34	*Plantago palmata* Hook.f.	Plantaginaceae	H	0.000	0.117	0.000	0.000	0.117	0.076
127	GGK 70	*Plectranthus garckeanus* (Vatke)J.K.Morton	Lamiaceae	H	0.105	0.000	0.000	0.000	0.105	0.146
128	GGK 09	*Poa simensis* Hochst. ex A. Rich.	Poaceae	Gr	1.053	0.857	1.294	1.313	0.202	0.340
129	GGK 63	*Rumex nepalensis* Spreng.	Polygonaceae	H	0.000	0.000	**0.294**	0.000	0.235	**0.002**
130	GGK 62	*Salvia merjamie* Forssk	Lamiaceae	H	0.000	0.000	0.058	0.000	0.059	0.433
131	GGK 94	*Sanicula elata* Such.-Ham. ex D. Don	Apiaceae	H	0.000	0.000	0.058	0.000	0.059	0.413
132	GGK 77	*Scadoxus multiflorus* (Martyn) Raf	Amaryllidaceae	H	0.053	0.000	0.000	0.000	0.052	0.663
133	GGK 87	*Sida rhombifolia* L.	Malvaceae	H	0.000	0.107	0.000	0.000	0.107	0.055

134	GGK 08	*Sida ternate* L.	Malvaceae	H	0.053	0.000	0.000	0.000	0.053	0.640
135	GGK 95	*Sigesbeckia orientalis* L.	Asteraceae	H	0.000	0.000	0.059	0.000	0.059	0.414
136	GGK 31	*Solanum nigrum* L.	Solanaceae	H	0.053	0.035	0.058	0.000	0.023	0.927
137	GGK 138	*Stephania abyssinica* (Dillon et A. Rick)Walp	Menispermaceae	H	0.000	0.000	0.000	0.063	0.062	0.206
138	GGK 85	*Tacca leontopetaloides* (L.) Ktze.	Taccaceae	H	0.000	0.000	0.117	0.000	0.059	0.436
139	GGK 16	*Tagetes minuta* L.	Asteraceae	H	0.000	0.107	0.000	0.000	0.107	0.070
140	GGK 64	*Thymus schimperi* Ronniger	Lamiaceae	H	0.000	0.000	0.235	0.000	0.118	0.080
141	GGK 25	*Trifolium acaule* Steud. ex A.Rich.	Fabaceae	H	0.316	0.000	0.000	0.187	0.033	0.779
142	GGK 51	*Triumfetta pilosa* Roth	Tiliaceae	H	0.000	0.000	0.058	0.000	0.059	0.407
143	GGK 96	*Triumfetta rhomboidea* Jacq	Tiliaceae	H	0.000	0.035	0.000	0.000	0.036	1.000
144	GGK 146	*Thalictrum rhychocarpum* Dill. &A. Rich.	Ranunculaceae	H	0.000	0.000	0.000	**0.187**	**0.125**	**0.042**
145	GGK 47	*Verbascum stelurum* Murbeck	Scrophulariaceae	H	0.000	0.000	0.058	0.000	0.059	0.441
146	GGK 35	*Viola abyssinica* Oliv.	Violaceae	H	0.053	0.000	0.000	0.000	0.053	0.646
147	GGK 10	*Zehneria scabra* (Linn. f) Sond.	Cucurbitaceae	H	0.000	0.178	0.000	0.063	0.106	0.176
		Plants recorded out of quadrats								
148	GGK 142	*Acacia pilispina* Pic.-Serm.	Fabaceae	S						
149	GGK 150	*Maytenus undata* (Thunb.) Blakelock	Celastraceae	S						
150	GGK 144	*Rumex nervosus* Vahl	Polygonaceae	S						
151	GGK 130	*Schrebera alata* (Hochst.) Welw.	Oleaceae	T						
152	GGK 143	*Euphorbia abyssinica* Gmel.	Euphorbiaceae	S						

*Endemic to Flora of Ethiopia and Eritrea