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Floristic Composition, Diversity and Plant Community Along Elevational Gradients in the Afro-alpine Vegetation of Abohoy Gara Mountain, northern Ethiopia

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Abstract

This research was conducted in Afro-alpine vegetation of Abohoy Gara Mountain in northern Ethiopia with the aim of analyzing floristic composition along elevational gradients, threats and conservation methods. Data were collected from 53 quadrats (15 m x 15 m) laid at 100 m interval along parallel vertical transects spaced at 500m to each other to record shrubs and trees, whereas 1 m x 1 m plots were used to record herbs. Cover abundance data were used to do community analysis using R version 3.1.2 software. Analysis of variance (ANOVA) was employed to determine significant level of species richness; abundance and Shannon diversity index along elevational gradient, whereas pearson's correlation test was applied to check the relationship between environmental variables with species richness, species abundance and Shannon diversity index (H') using SPSS v20. Ninety-seven plant species composed of 82 genera under 40 families were recorded. The mean number of plant species showed significant difference along elevational gradient ($P < 0.05$). Besides, significant ($P < 0.05$) negative correlation of elevation with the plant richness, abundance as well as Shannon diversity index had been observed. Based on dominant species, a total of five plant communities were identified. The maximum plant diversity occurred in community type III (3.79), whereas the least plant diversity occurred in community type IV and community type V. Vegetation cover and species composition of Abohoy Gara Mountain is being endangered by agricultural expansion, over grazing and logging of wood for construction material. Hence, it needs application of complementary on-site and offsite conservation approaches. This calls for further joint management of the Abohoy Gara Mountain by the local people and administrative bodies in the overall conservation actions that can save and rehabilitate the plant resources and their habitats.

Introduction

In Ethiopia, climatic and topographical patterns produce various biotas that assist the plant and animal ecosystems (Friis et al 2010). For instance, elevational gradient has an influence on plant species diversity by making differences in climatic condition and soil variation (Lomolino 2001). Besides, plants in mountain area respond to little elevational differences (Kharkwal et al 2005). Studying diversity, plant community and distribution of the vegetation is a basis for designing and implementing sound management intervention plan and assembling plant distribution into an environmentally related ecosystem through clear criteria for identifying the categories (Don et al 2007; Han et al 2011). Mountainous ecosystems are vital for conservation of nature, typically in countries with small protected areas, because most of the ecosystems are centralized in such area (Zhang et al 2012).

The Ethiopian mountains offer various ecosystem services such as climate regulation, water purification and flood regulation (Kelbessa and Soromessa 2008; Bussman et al 2011). However, Afro-alpine ecosystem in Ethiopia is highly fragile due to anthropogenic factors such as an increase in human settlements, grazing, agricultural expansion and logging; and natural factors such as low temperature, harmful short wave radiations (Kelbessa et al 1992). Besides, 10,000 years ago, the uplands of the country were broadly covered with Afro-alpine moorlands and grasslands (Messerli et al 1977), but the large regions of this highlands was affected by human factors, and the extent of variation is frightening and risking the former species richness. Because of this, the previous afro-alpine and subafro-alpine ecosystems are currently nearly exclusively limited to scatter, and not easily accessible areas bounded by encroachments (EBI 2018). Therefore, such fragile environments need much more attention to stop further risk and rate of devastation. Besides, there is high gap of information concerning floristic compositions of the high mountains of Afro-alpine in Ethiopia (Hedberg 1964). For instance, many of Afroalpine studies are still concentrated on the Simien and Bale Mountains (Hedberg 1986). Moreover, except for the above mentioned and few some other authors, most of the investigations are limited to the montane ecosystem (EBI 2018).

Abohoy Gara Mountain is community based conservation area where grazing, cultivation and collection of natural resources are excluded. This Mountain is surrounded by natural features and has been designated so as to restore and maintain the biotic diversity. Nonetheless, the lower belt of this mountain is severely affected by human interference such as agricultural expansion, overgrazing and logging towards the ericaceous belt due to population pressure. Moreover, no study has been conducted in this mountain regarding the general vegetation ecology, threats and conservation status so far. Therefore, we lack information on the overall plant diversity and plant community along elevational gradient in the study area.

Thus, it is imperative to investigate species composition, elevational variation of vegetation composition, threats and conservation approaches that can be an input in developing sound management plan for future conservations and sustainable management. This is in turn, needs baseline study on the plant ecology and existing human impacts of the mountain. Hence, this study was conducted with the aim of investigating species diversity, elevational variation of vegetation composition, identifying plant communities, assessing threats and conservation approaches.

Material And Methods

Study area

The study was conducted in the Abohoy Gara Mountain located at $12^{o}03'$ - $12^{o}06'$N, and $39^{o}22'$ - $39^{o}24'$E, elevation ranging from 3,000 – 4,000 m a.s.l, in the Amhara region of northern Ethiopia (Figure 1). It is roughly linked by narrow ridges with the other Afro-alpine mountain block of Abune Yosef Massive to the West. Although the high elevation plateau consists of silty soil, which has less water infiltration and low ground water recharge, infiltration is relatively better at the base of the mountain where farmlands occur (ESP 2001). Analysis of meteorological data (1997 -2017) showed that the mean annual temperature in the study area was 19 ^{0}C and the mean minimum and maximum were 11.8^{0}C and 27.5^{0}C respectively (Supplemental material 1) (National Metreology Agency, 2018). The mean annual rainfall is 758 mm which varied greatly from year to year.

Sampling methods

Preliminary survey was done during September, 2017 to get an impression on the overall physiognomy of the vegetation, accessibility to the site and distinguish sampling area. Consequently, with in 3462 m – 3914 m a.s.l mountain range, three sampling sites were selected based on aspect, vegetation cover and accessibility. We selected the sites purposively (based on aspect, cover and accessibility) and laid the plots systematically to get vegetation data (Muller-Dombois and Ellenberg 1974; Tiksa et al 2009). In each site (I–III) replicates of three line transects a total of nine were laid vertically along the elevation with 500m gap in between, starting at the highest elevation up to the lowest elevation point where farm lands are encountered.. Fifty three plots having a size of 15 m x 15 m were laid out (Fetene et al 2006) along the line transects at 100 m elevation intervals to collect data on plant species, while herbaceous species were measured in cover abundance value using 1 m x 1 m subplot inside the main plot at five places, four plots were placed at each corner and one at centre (Wodaj et al 2016). In each plot; herbs, shrubs and trees were documented. Cover abundance values of each species were assessed visually in the field and then changed into 1-9 modified Braun Blanquet following (van der Maarel 1979). Identification was done in the field and herbarium using taxonomic literature, by comparing with authentic specimens, expert assistance, and using various book of flora of Ethiopia and Eritrea while those unknown samples were identified in the National Herbarium, Addis Ababa. Environmental data such as elevation, slope and aspect were determined for every releve selected. GPS was used to measure elevation, clinometer was employed to measure slope, and Silva ranger compass was used to determine aspect.

Sampling technique for threats and conservation methods

Three kebeles; Wondanch, Kemeha and Tuba surrounding Abohoy Gara Mountain were selected following purposive sampling method. The selection of these study kebeles was influenced by the fact that they had better vegetation cover, near to the mountain. Informants were selected systematically with the assistance of local officers and local people from the district that are found within or bordering the Abohoy Gara Mountain (Martin 1995; Balemie et al 2004). A total of 177 informants were chosen following the method described by Cochran’s formula as indicated in Bartlett and Higgins (Bartlett and Higgins 2001) as follows;

$$n = \frac{N}{1+n(e)2} \qquad (1)$$

where *n* is sample size the research uses, *N* is total number of households in the kebeles, *e* refers to maximum variability or margin of error 5% (.05), 1 is the probability of the event occurring. Semi-structured interviews were prepared and used as guide based on the checklist of questions prepared previously in English language and then interpreted into Amharic (Martin 1995; Cotton 1996; Cunningham 2001). Besides, focus group discussions were also employed with the knowledgeable informants in the study area. Threats and major problems, recommendation of local people to conserve the resource of the mountain were points of the interview and group discussion.

Analysis

Agglomerative hierarchical classification using cluster analysis was performed using R packages cluster, mgcv and ggplot2 (R Development Core Team 2014) to categorise the vegetation into community types based on cover-abundance (following 1-9 Modified Braun- Blanquet, as revised by (van der Maarel 1979) of each species. Shannon-Wiener and Shannon's evenness (Krebs 1989; Barnes et al 1998) were computed using R version 3.1.2 software to describe the community diversity.

Shannon diversity index

Diversity index was calculated (Shannon-Wiener and Weater 1949) by using the following formula:

$$H' = -\sum_{i=i}^{x} Pi^{ln}\mathrm{Pi} \qquad (2)$$

Where H'= Shannon diversity index, $\sum$= Summation symbol, Pi = the proportion of individuals or the abundance of the i th species expressed as a proportion of the total cover and ln = log base n(natural logarithm).

Evenness

Evenness index (E) was computed to measure the homogeneous distribution of plant species (Kent and Coker 1992).

$$E = H'/Hmax = \frac{H1}{ln\,S} = \frac{\sum_{i}^{S}=1PilnPi}{ln\,S} \quad \text{With } H_{max} = ln\,S \qquad (3)$$

Where S is species richness, P_i is individuals proportion of the i th species or the proportion of the total species.

ANOVA was computed to determine significant differences of the number of plant species along elevational gradient whereas pearson's correlation test was applied to check the correlation of environmental variables with species richness, species abundance and Shannon diversity index. ANOVA and Pearson's product moment correlation coefficients were determined using the SPSS v20.

Floristic similarities

Floristic comparison was made with in the communities of the study area to get information on floristic similarity between the communities. The floristic similarities between communities were determined using Sorensen's Coefficient Index (Greig-Smith 1983; Kent and Coker 1992).

$$Ss = 2a / (2a + b + c) \qquad (7)$$

Where Ss is Sorensen's similarity, a= number of species common to the two samples, b= the number of species present in sample1 and c= the number of species in sample 2 (Kent and Coker 1992).

Results And Discussion

A total of 97 plant species composed of 82 genera under 40 families were recorded from Abohoy Gara Mountain (Supplemental material 2). The number of plant species documented was higher than similar alpine mountains in Ethiopia, Guassa Community Conservation Area (n=82) (Wodaj et al 2016), Guna Mountain (n=56) (Molla 2004), Sanettie plateau in Bale Mountains (n=65) (Gashaw and Fetene 1996) and Simien Mountain (n=86) (Melese et al 2017). Out of the total species recorded, 85 (87.63%) were herbs, Nine (9.28%) shrubs and three (3.09%) tree. The highest number of plant habit recorded was herbs, this finding is in line with the result of Afro-alpine vegetation of Guassa Community Conservation Area (Wodaj et al 2016). Asteraceae was the dominant plant families represented by 15 (18%) genera and 21 (21.6%) species followed by Poaceae composed of seven (8.53) genera and eight (8.24%) species (Supplemental material 3). The occurrence of greater number of plants species from family Asteraceae might relate to the adaptation potential of the species under this family in a wider range of elevation in the study area. This finding is also in line with the results of (Wodaj et al 2016) in that Asteraceae was the highest family recorded.

Records of endemic plants

We recorded 16 (16.5%) plant species belonging to 14 genera under nine families endemic to Ethiopia (Supplemental material 2). Our record of endemic plants was higher than the endemic plants recorded from Guassa community conservation area (Wodaj et al 2016). Family Asteraceae contributed seven endemic plant species, Poaceae contributed two endemic plant species and six other families contributed just one endemic plant species (Supplemental material 3). It should be stressed that, two near threatened, one vulnerable and one least concern endemic plant species were found in the IUCN Red list categories (Vivero at al 2006). *Becium grandiflorum* and *Inula confertiflora* were near threatened, *Euryops pinifolius* was vulnerable and *Solanecio gigas* was least concern (Vivero at al 2006) (Supplemental material 2). The reason for mountain ecosystems often possessing several endemic plant species is due to alpine ecosystems make island biota and the high mountain plateau protrude as isolated temperate islands above the hot nearby plains (Beniston 2006).

Plant community along elevational gradient

We identified five plant communities for the vegetation of Abohoy Gara Mountain from the output of Agglomerative Hierarchical Classification (Figure 2). The names for each community were given based on two species of a cluster that have the highest synoptic value (Table 1). The number of community identified for Abohoy Gara Mountain was higher than for Choke Mountain range (n=3) (Belachew 2015) and Simien Mountain (n=3) (Melese at al 2017).

I. Festuca abyssinica - Thymus schimperi community

This herbaceous community consisting of 14 plots and 50 species was situated at elevational range of 3529 – 3813 m a.s.l (Table 2). *F. abyssinica* and *T. schimperi* were the dominant plant species of the community. Others, such as *Festuca macrophyla, Alchemilla abyssinica* and *Arabis alpina* were also present in this community. *Achyranthes aspera* , *Plantago lanceolata* and *Plantago palmata* were the species recorded only in this community.

II. *Erica arborea- Hypericum revolutum* community

This community structure consisting of 10 plots and 42 species was distributed at elevations above sea level 3569 – 3697 m (Table 2). *E. arborea* and *H. revolutum* were the dominant plant species of the community. Most frequently, a mass of moss species (*Neckera platyantha*) grew on the ground and under the *Erica* shrub species (Supplemental material 2). This community occurred predominantly in swampy areas. Elevational distribution of *E. arborea* in this community is comparable to that of Choke Mountain (3450 – 3814 m a.s.l) (Belachew 2015).

III. *Alchemilla abyssinica - Koeleria pyramidata* community

This community structure consisting of 13 plots and 73 species was situated at elevational range between 3507 – 3657 m a.s.l (Table 2). It was found to cover the largest area of the Afro-alpine vegetation of the study area with large number of plant species. *A. abyssinica* and *K. pyramidata* were the dominant plant species of this community. Species such as *Crotalaria karagwensis* and *Cyperus reduncus, Primula verticillata*, *Senra incana* and *Spergula arvensis* were character species in that they were found particularly in this community.

IV. *Euryops pinifolius - Cyathula cylindrical* community

This community structure consisting of 10 plots and 27 species was distributed at elevational range between 3462 – 3914 m a.s.l (Table 2). *E. pinifolius* and *C. cylindrical* were the dominant plant species of the community. *C. cylindrica* is most dominantly found in the upper hill of the mountain from 3700 - 3914 m where there is lack of moisture and sloppy ground while *E. pinifolius* were most dominantly distributed at the lower and middle elevation and it becomes sparse at the higher elevation.

V. *Lobelia rhynchopetalum - Kniphofia foliosa* community

This community structure consisting of 6 plots and 38 species was distributed at elevational range between 3570 - 3657 m a.s.l (Table 2). *L. rhynchopetalum* and *K. foliosa* were the dominant plant species. This community has a small number of plots and species compared to the other communities. *Helichrysum formosissimum* and *I. confertiflora* were character species recorded only in this community type. In this community type there is very low temperature where during morning water stream is changed into ice.

Diversity measures

The alpha diversity indices across elevations showed that species richness and evenness were maximum in the mid elevation (community III) and tend to decrease gradually toward the high and lower elevations (Table 2). However, they failed to show an obvious U-shaped curve typical of the 'mid- elevation bulge theory' predicting a higher species diversity at mid-elevations. However, the variations in species diversity (H) were not strongly obvious; this could be due to related environmental factor such as elevation, slope and aspect.

Similarities between community types

Sorenson's similarity between community showed that community type I and III showed the highest plant species similarity (0.72) whereas community type III and IV showed the least plant species similarity (The highest dissimilarity) (0.524) (Table 3). The maximum similarity between community I and III could be due their related elevational range of the two communities (Table 2).

Influence of elevation, slope and aspect on species richness

Species richness was negatively correlated with elevation, and their correlation was significant (r = -0.471, P < 0.05) (Figure 3a). Besides, significant difference (P < 0.05) was occurred in the mean number of species richness along elevational gradient. The mean value of species richness for upper elevation (3703-3900m) was 13.88, for the middle elevation (3620-3697m) was 17.47, and for the lowest elevation (3462-3605m) was (21.79), indicating that as elevation increases, species richness gets lower in the study area. Similar result was reported from Abune Yosef Mountain (Gebrehiwot et al 2019) and Arsi Mountain (Girma et al 2018). Number of species was negatively correlated with slope however their correlation was insignificant (r = -0.156, P > 0.05) (Figure 3b). This finding is in line with the report of Wondo Genet Forest (Kebede et al 2013). Slope affects the run-off and drainage through that way also influences the nutrient, depth and water content of the soil (Albaba 2004; Soromessa et al 2004). The species distribution in some sample plots of community II of the Abohoy Gara Mountain was high. Such finding can be attached to the effect of aspect and slope. By affecting the day-to-day cycle of lunar radiation, aspect influences humidity, soil moisture and air temperature of the environment (Rosenberg et al 1983). These factors might relate with distribution of the species in some sample plots of community II of study area. There was weak insignificant positive correlation between aspect and number of species (r = 0.137, P > 0.05) (Figure 4). This finding is in line with result reported from Yunmeng Mountain, China (Zhang and Shao 2015).

Shannon diversity index was negatively correlated with elevation, and their correlation was significant (r = -0.322, P < 0.05) (Figure 5A). Similarly, negative correlation between elevation and Shannon diversity index were reported in the Afro-alpine vegetation of Sanettie plateau of the Bale Mountain (Gashaw and Fetene 1996) and Abune yosef Mountain (Gebrehiwot et al 2019). Likewise, significant negative correlation (r = -0.272, P < 0.05) was occurred between elevation and species cover abundance (Figure 5B). This finding is in agreement with the report of Wondo Genet forest (Kebede et al 2013). Overall, species richness, species abundance and Shannon's diversity get lower as elevation increases in the study area. This could be due to total atmospheric pressure, temperature and air density decrease with increasing elevation while wind velocity, radiation and precipitation increase with increasing elevation (Barry 2008).

Threats to plant resources in Abohoy Gara Mountain

According to the respondents, the highest reported threat for the plant resource in Abohoy Gara Mountain was over grazing (52), logging for construction materials (33) and agricultural expansion (22) (Table 4). Similar findings were reported elsewhere in the country (Kelbessa et al 1992; Chanie and Tesfaye, 2015; Tadesse and Teketay, 2017) in that factors such as over grazing, agricultural expansion, collection of wood for construction pose a great impact on the countries' plant resource.

Recommended methods to conserve plant resources

The highest cited conservation approach mentioned by informants was protecting plants from livestock damage which accounted for 73 (32.6%) followed by protecting in homegarden 46 (20.54%). Furthermore, fencing 43 (19.2%) was cited to be used as a means of conserving plant resource (Supplemental material 4). Sustainable landscape use, including good rangeland management (removing livestock from stressed areas), and forest management should be maintained in Abohoy Gara Mountain so as to reduce poverty and improve ecosystem services. Species listed under IUCN Red list categories such as *B. grandiflorum, I. confertiflora*, *E. pinifolius*, *S. gigas* and endemic species should be prioritized for conservation. Hence, both on-site and off-site conservation is needed, particularly on-site conservation is necessary for endemic species.

Conclusions

The remnant Afro-alpine vegetation of Abohoy Gara Mountain is uniquely positioned and contains a substantial amount of Afro-alpine plant species and diversity. Conserving the plant resource of this mountain is important to protect the shelter for many species. Overall, 97 plant species were identified in the study area. Of these, 16.5% were endemic to Ethiopia. The Afro-alpine vegetation of Abohoy Gara Mountain was classified into five vegetation community types. Although Abohoy Gara Mountain consists of such vital endemic plant species, it is now under pressure due to human encroachment, overgrazing, agricultural expansion and logging for construction material. Hence, community-based conservation programs, awareness creation, sustainable uses of the remnant natural vegetation, biological and physical management are crucial. The high plant diversity together with the presence of endemic plant species calls for rapid conservation plans with the involvement of local communities and government so as to restore and rehabilitate the ecosystem.

Declarations

The authors declare that they have no competing interests.

Ethics approval and consent to participate

Prior to data collection, agreements indicating consent were taken from Mekelle University and Zonal and District Administration Offices.

Consent for publication

Not applicable.

Availability of data and materials

All data collected for this study were analysed, interpreted, and included in this manuscript, and its supplementary materials were attached as supplementary material 1, 2 and 3.

Competing interests

The authors declare that they have no competing interests.

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Tables

Table 1 Synoptic cover abundance value for species having a value of ≥ 1 in at least one community type.

Species name/community type	C-1	C-2	C-3	C-4	C-5
Number of plots	14	10	13	10	6
Festuca abyssinica	6.0	0.9	5.51	1.1	1.2
Thymus schimperi	5.4	0.8	4.23	2.5	1.8
Festuca macrophyla	3.7	0.5	0.24	0.1	0.2
Avena abyssinica	1.3	0.3	0.41	0.2	0.0
Achyranthes aspera	1.2	0.0	0.0	0.0	0.0
Arabis alpine	1.0	0.4	0.4	0.0	0.0
Eulophia albobrunnea	1.0	0.0	0.6	0.2	0.0
Erica arborea	3.1	8.6	1.7	0.0	0.0
Hypericum revolutum	0.4	5.7	0.7	0.0	0.2
Usnea sp.	0.1	3.2	0.0	0.0	0.0
Senecio fresenii	0.0	2.1	0.12	0.0	0.0
Haplocarpha schimperi	0.22	1.0	0.4	0.0	0.0
Koeleria pyramidata	3.1	4.3	6.3	0.3	1.22
Alchemilla abyssinica	3.0	6	7.85	1	7.1
Hydrocotyle sibthorpioides	2.0	1.4	6.23	1	1.4
Cynoglossum coeruleum	2.0	0.2	4.3	0.3	0.4
Thymus serrulatus	1.0	0.6	3.7	0.0	0.0
Rumex nepalensis	0.1	0.1	3.31	0.1	0.1
Commelina latifolia	0.3	0.6	2.8	2	0.4
Euryops pinifolius	7.0	4.7	7.5	7.6	2.4
Cyathula cylindrica	4.3	0.7	0.3	4.4	0.78
Pentaschistis pictigluma	0.36	0.1	0.23	2.5	0
Dicrocephala chrysanthemifolia	2.0	0.9	0.1	2.4	0.3
Lobelia rhynchopetalum	0.8	0.5	0.44	0.31	8.30
Kniphofia foliosa	0.6	4	5.6	5.7	7.8
Leonotis neptitolia	0.0	0.0	0.23	0.0	1.8
Urtica simensis	0.1	0.0	4	0.4	1.8
Malva parviflora	0.07	0.0	0.5	0.0	1.3
Peucedanum winkleri	0.0	0.0	0.0	0.0	1.3
Inula confertiflora	0.0	0.0	0.0	0.0	1
Maesa lanceolata	0.0	0.0	0.06	0.0	1
Neckera platyantha	0.04	0.1	0.7	0.21	1.0

Table 2 Species diversity indices estimates for Afro-alpine vegetation of Abohoy Gara Mountain.

Community	Altitudinal range (m a.s.l)	Species richness (S)	Shannon's diversity index (H)	Species Evenness (E)	No. of plots
I: *F. abyssinica - T. schimperi*	3529-3813	50	3.75	0.7019	14
II: *E. arborea - H. revolutum*	3569-3697	42	3.6	0.7573	10
III: *A. abyssinica - K. pyramidata*	3507-3657	73	3.79	0.8534	13
IV: *E. pinifolius - C. cylindrica*	3462-3914	27	3.62	0.8155	10
V: *L. rhynchopetalum - K. foliosa*	3570-3657	38	3.5	0.706	6

Table 3 Sorenson’s similarity and dissimilarity among communities in the study area.

Similarity	Community	Dissimilarity					Dissimilarity
		I	II	III	IV	V	
	I	1	0.327	0.28	0.429	0.416	
	II	0.673	1	0.402	0.36	0.472	
	III	0.72*	0.598	1	0.476	0.358	
	IV	0.571	0.64	0.524*	1	0.35	
	V	0.584	0.525	0.642	0.65	1	
			Similarity				

Table 4 Threats to vegetation resource in the study area.

Threats	No of informants response
Overgrazing	52
Drought	51
Agricultural expansion	33
Construction materials	22

Figures

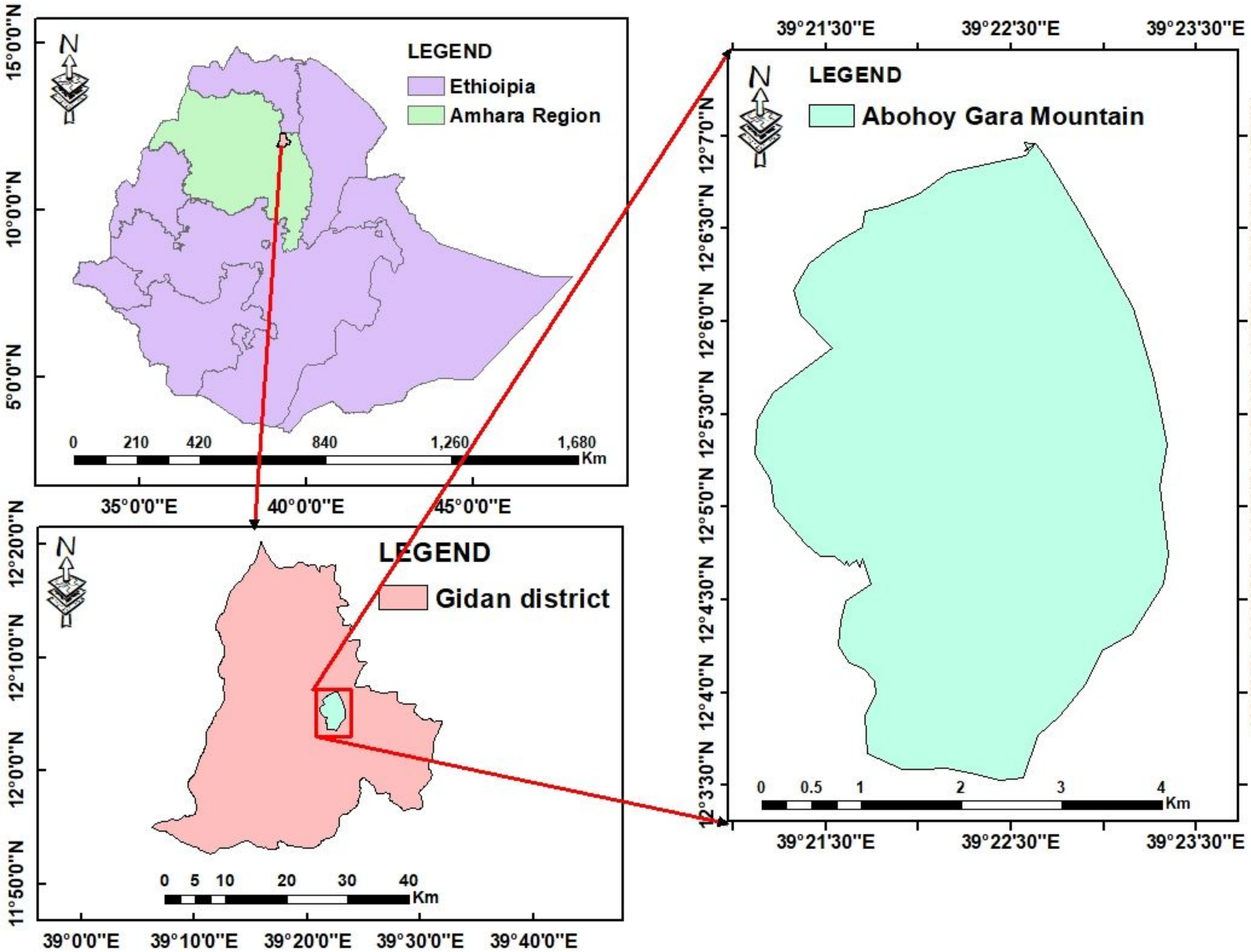

Figure 1

Map of the study area.

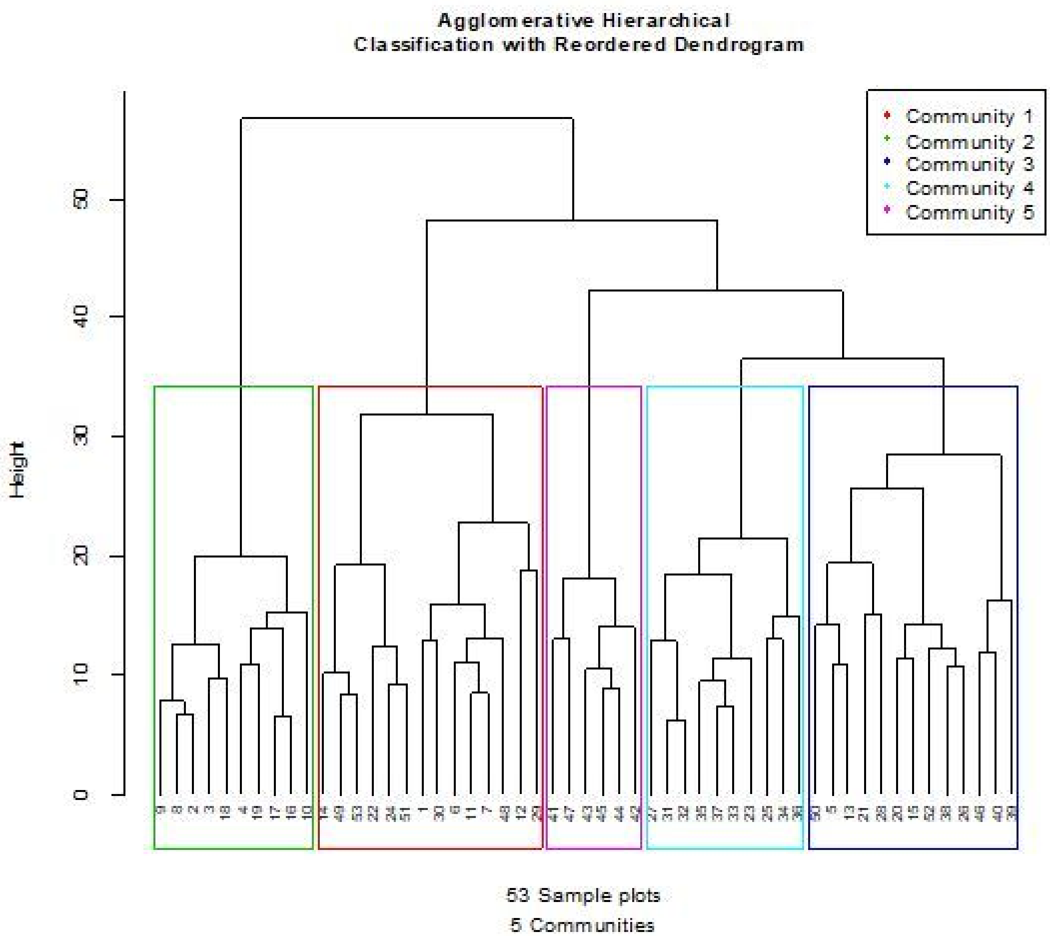

Figure 2

Dendrogram showing plant community types of Abohoy Gara Mountain.

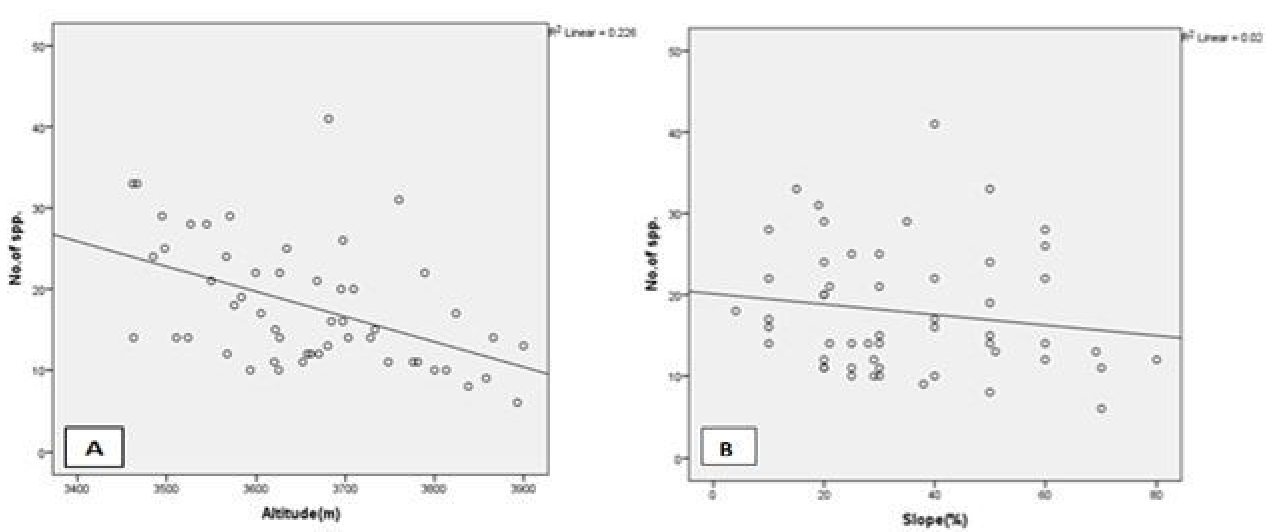

Figure 3

Correlation of number of species with altitudinal gradients (A); number of species with slope (B).

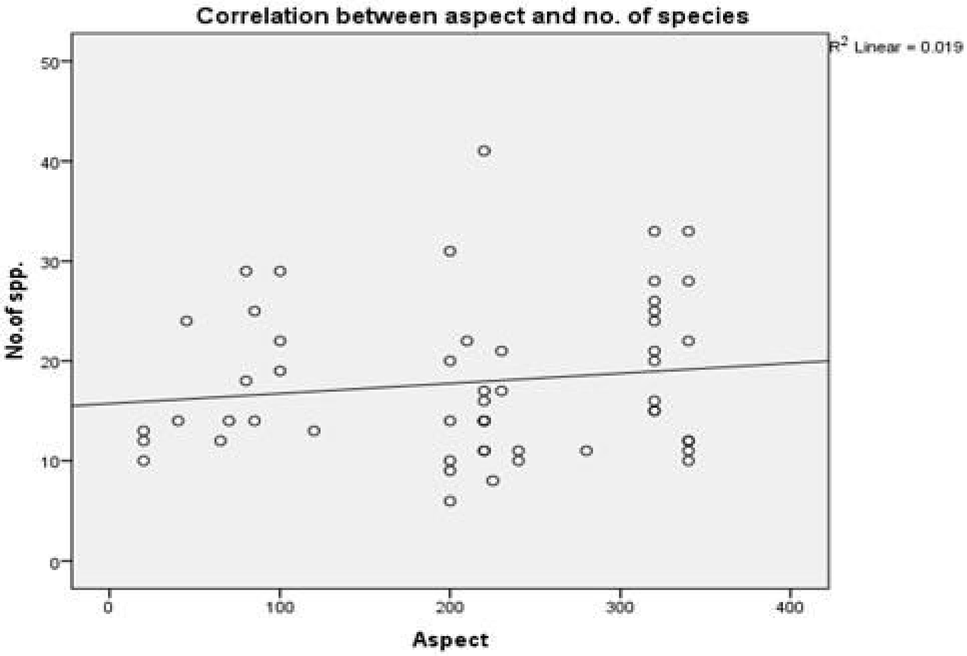

Figure 4

Correlation between aspects and number of species.

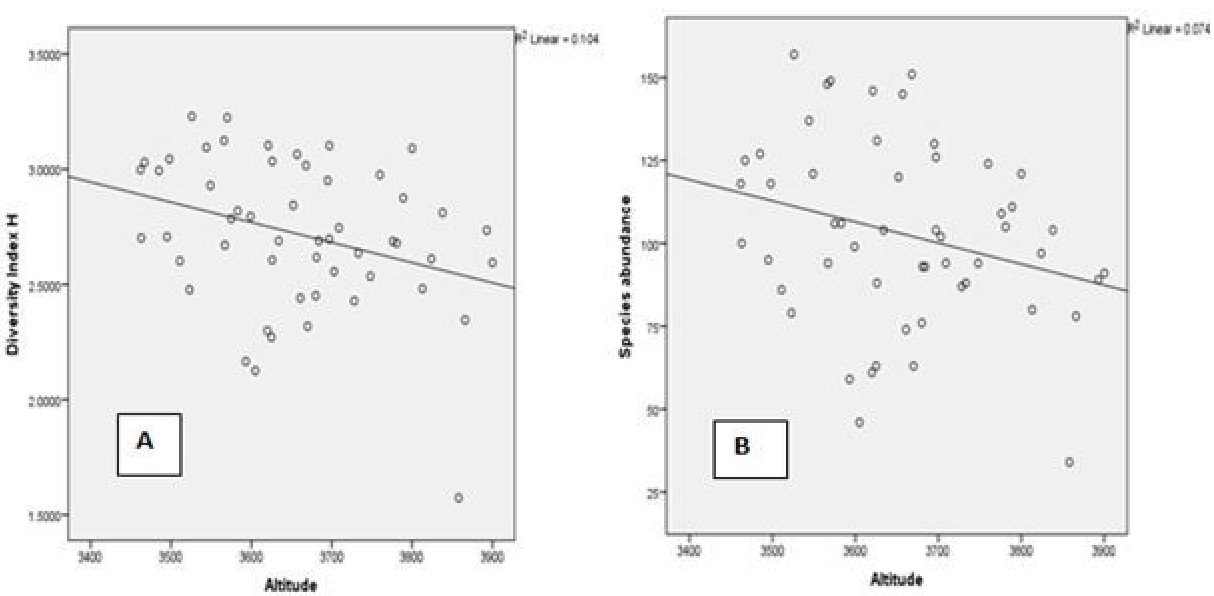

Figure 5

Relationship between elevation and Shannon’s diversity index (A): Altitude and species cover abundance (B).

Supplementary Files

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- SupplementalMaterial1.pdf
- SupplementalMaterial2.docx
- SupplementalMaterial3.docx
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