Effects of Landscape Change on Floristic Composition and Structure in the Bale Mountains National Park, Southeastern Ethiopia

Annissa Muhammed (annissamuhammed@gmail.com)
Arsi University https://orcid.org/0000-0003-3004-4728
Eyasu Elias
Addis Ababa University College of Natural Sciences

Research

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Abstract

Background

Bale mountains national park (BMNP) is one of the 34 International Biodiversity Hotspots that comprise a variety of life forms. However, it faces a critical challenge from subsistence farming and overgrazing. This study was made to analyze the effects of landscape change on floristic composition, diversity, and structure in BMNP. The vegetation and environmental data were collected from 96 plots that were laid along 8 line transects. Vegetation hierarchical clustering and landscape structural analysis was made using R software version 3.5.2 and FRAGSTATS version 4.2.1, respectively.

Results

A total of 205 species that belongs to 153 genera and 71 families were identified. The overall Shannon diversity and evenness index was 4.34 and 0.81, respectively. Both the species richness and Shannon diversity index were significantly higher ($p < 0.05$) in the edge habitat (40 ± 0.2 and 2.93 ± 0.2, respectively) than the interior (25 ± 4.5 and 2.43 ± 0.4, respectively). Conversely, the basal area was lower in the interior habitat (173.79 m^2 ha^{-1}) than the edge (64.15 m^2 ha^{-1}). Moreover, as AREA_MN and COA of patches increases, species richness, diversity, evenness, woody species density, basal area, DBH, and height also increases. Whereas, as PN, SHAPE_MN, ED, ENN_MN, and IJI of patches increases, those floristic compositions and structural variables decrease.

Conclusion

This study revealed that BMNP is a biologically diverse and ecologically significant area that provides a variety of ecological and economic benefits to the surrounding communities and the country at large. However, its landscape is changing alarmingly and urgent restoration and conservation action needs to be taken to reverse this condition.

Introduction

Tropical montane ecosystems are one of the hot spot ecosystems on earth (Aliyi, Hundera, and Dalle 2015) that comprises more than 200,000 species of flowering plants (Vergara-Rodríguez et al. 2017). The Ethiopian highland encompasses over 50% of the Afromontane vegetation in African (Ahmedin and Elias 2020). A suitable geographical position, a wide range of altitude, high amount of rainfall and a wide range of temperature variations equips the country with huge ecological diversity and a wealth of biological resources (Yimer 2007). The ecosystems are highly diverse and it ranges from afro-alpine to desert. However, severe deforestation coupled with cultivation of steep marginal lands, overgrazing and socio-political uncertainty, has resulted in rigorous land degradation over large areas of the country (WBISPP 2004). The overdependence of Ethiopian economy on agricultural production and the existence of 80% of the population in the highlands (Hurni 1998) mainly contribute for the degradation of ecological resources and biodiversity loss.

The mountainous topography and the mosaic of natural vegetation in the Bale Mountains have substantial economic, recreational, aesthetic and scientific importance (Yimer 2007). The Bale Mountains National Park (BMNP) is the most important conservation area in Ethiopian that was established in 1969 (Mekonnen et al. 2010; Stephens et al. 2001) to conserve the endemic and indigenous floras and faunas in the area. It is one of the 34 International Biodiversity Hotspots and qualifies for World Heritage Site and Biosphere Reserve Listing (Tesfaye and Bires 2015). However, the park is facing a critical challenge from subsistence farming and over grazing due to human settlement and livestock rearing in and around the park. No research provides detailed information about the landscape structure and its potential impact on vegetation composition and structure in the park. Therefore, this research was made to analyze the potential impact of landscape change on floristic composition, diversity and structure in BMNP. Particularly, comparative analysis was made on the species richness, diversity, and regeneration status as well as the population structure of woody species between edge and interior habitats of the park.

Materials And Methods

Description of the study site

BMNP is located at 6° 30' - 7° 10’ north and 39° 30'- 39° 55’ east and it encompasses 2, 178 km^{-2} (Fig. 1). It belongs to Bale-Arsi massif, which forms the western section of the south-eastern highlands of Ethiopia. It encompasses a broad range of habitats between 1,500m and 4,377m altitude. Based on the agro-climatic classification of Ethiopia (Hurni 1998), the study area falls into three agro-ecological zones namely Weynadega (1500–2300 m), dega (2300–3200 m), and Wurch (above 3200 m). Rainfall is well distributed throughout the wet season, that ranging from 1000 to1400mm annually. The park is a globally important center of endemism, harboring 26% of Ethiopia’s endemic species, including more than half of the global population of the endangered Ethiopian wolf, two thirds of the global population of the endangered Mountain nyala, and the entire global population of the giant mole-rat (Wakjira, d’Udine, and Crawford 2015).

Vegetation sampling design

A reconnaissance survey was carried out from 13 to 20 November 2018 to get insight about the physiognomy of the vegetation and identify sampling sites in the study area. Subsequently, the actual fieldwork was made in the dry season between November 2019 and January 2020. A 20 x 20 m sample plots were systematically laid on transect lines in 8 directions along the altitudinal gradients at 100 m elevational difference as it maximizes the distance between plots and minimizes spatial correlation among observations (Barry 2008). A total of 96 sample plots (8 transect lines x 12 plots at each transect lines) with an area of 3.84 ha were plotted to collect vegetation and environmental data. Equal number of sample plots was laid in the edge and interior habitats to make a comparison among their vegetation data’s.

Species identification

Plant species in the nested plots were identified at the field with the help of local peoples (for vernacular names) and by referring different volumes of Flora of Ethiopia and Eritrea books (Edwards et al. 2000; Hedberg et al. 2006). For the species that were difficult to identify in the field, representative specimens were cut, numbered and pressed at the site. The collections were named using folk taxonomy and identification of formal taxonomy was determined using the voucher specimens at the National Herbarium, Addis Ababa University.

Floristic and landscape data preparation

Initial data collected from the field was arranged in three-column format in Microsoft Excel according to (Woldu 2017). Then percent canopy cover was converted into ordinal scales from 1-9 following Braun-Blanquet as modified by van der Maarel (Berhanu, Woldu, and Demissew 2017; Van der Maarel 1979). The three-column data were imported and matrified using 'labdsv" package to perform the multivariate analyses of species richness, diversity, and evenness using "vegan" package in R version 3.5.2. The raster data set of the land use and land cover change map in tiff format was prepared using Arc GIS 10.3 and exported in to FRAGSTATS software version 4.2.1 (McGarigal 2002) to analyze the landscapes special patterns.

Floristic composition and diversity

The most commonly used diversity indices of species richness, Shannon diversity, and evenness index were computed to analyze the patterns of plant diversity at different scales following (Magurran 2013) and (Økland 1990). The value usually falls between 1.5 and 3.5, it rarely exceeding 4.5. Conversely, the values of evenness lay between 0 to 1, and 1 represents all species are equally abundant (complete evenness) (Magurran 2013). To determine the floristic similarity among the communities, Sørensen's similarity index was employed (Sorensen 1948).

Floristic structure and plant community analysis

The woody species density, frequency, dominance, and their relative values were computed to obtain the important value index and describe the woody species structure following (Martin 2010) and (Ellenberg and Mueller-Dombois 1974). Moreover, diameter at breast height (DBH), tree height, and basal area were analyzed to determine the population structure. The woody species population structure was analyzed by arranging the stems in a defined DBH and height classes following (Van der Maarel 1979) and (Kitessa, Tamrat, and Ensermu 2007). Hierarchical cluster analysis was made for plant communities classify based on the cover abundance data and floristic similarities (McCune, Grace, and Urban 2002) using the Cluster and Vegan packages in R software version 3.5.2. A hierarchical agglomerative clustering technique was applied using Euclidean distance and Ward's method to classify plots that produced a dendrogram and cluster IDs (Ahmedin and Elias 2020).

Measurement of landscape structure

Nine fragmentation indices were determined to analyze the spatial characteristics of patches, classes of patches, and the entire landscape mosaic using FRAGSTATS version 4.2.1 (McGarigal, Umass, and Turner 2004). This metrics were selected from two categories of landscape structure (composition and configuration) following (McGarigal, Cushman, and Ene 2012; Smiraglia et al. 2015). Two-way correlation and linear regression between fragmentation indices, environmental variables, and species composition and structure parameters were made using PAST version 4.02 (Hammer, Harper, and Ryan 2001).

Results And Discussion

Floristic composition and diversity

A total of 205 species that belongs to 153 genera and 71 families were identified in the BMNP. Asteraceae was the richest family with 31 species and the most species-rich genus was Helichrysum with 9 species. Twenty endemic species (about 9.7% of the total) including *Alchemilla haumanii* Rothm, *Erythrina brucei* Schweinf, and *Kniphofia isoetifolia* Hochst. Rich were identified in the study area. According to IUCN (International Union for Conservation of Nature) and GBIF (Global Biodiversity Information Facility), 1 species found near threatened, 4 species least concern and 15 species not evaluated. The number of species recorded in this study was significantly higher (at $p < 0.05$) than similar studies in Kimphe Lafa forest (Aliyi et al. 2015), Kuandisha forest (Berhanu, Demissew, et al. 2017), and Berhane-Kontir forest (Senbeta et al. 2014). Conversely, the species richness among the edge (143) and interior habitat (98) was significantly different (at $p < 0.05$) and the mean (± SE) value was 40 ± 0.2 and 25 ± 4.5, respectively. This was due to the dominance of generalist species in the edge habitat and specialists in the interior habitat. An increase of richness in fragments may occur due to the colonization of generalist species from the matrix and to edge effect (Battisti 2003).

The overall Shannon diversity and evenness index were 4.34 and 0.81, respectively and this was higher relative to other similar areas such as Bonga forest (Senbeta et al. 2014), Agama forest (Dibaba et al. 2020), and Munessa forest (Ahmedin and Elias 2020) (Table 1). The Shannon diversity index of the edge habitat (4.16) was significantly higher compared to the interior (3.69) at $p < 0.05$ and the mean value was 2.93 ± 0.2 and 2.43 ± 0.4, respectively. Whereas, the Shannon evenness index in the interior habitats (0.83) was higher, but not significant, than the edge habitat (0.79). Conversely, the computed Sorensen's similarity index depicted that the number of species in the edge habitats was 45% similar with the species in the interior habitats. This value indicated that the similarity of edge and interior habitat was weak.

Table 1 Shannon (H') and evenness (J) index in BMNP and other vegetation areas in Ethiopia

Vegetated areas	H’	J	Authors
BMNP	4.34	0.81	**Present study**
Bonga	3.17	0.67	(Senbeta et al. 2014)
Agama	3.25	0.78	(Dibaba et al. 2020)
Tara Gedam	2.98	0.65	(Zegeye, Teketay, and Kelbessa 2011)
Menagesha Suba	2.57	0.92	(Beche 2011)
Munessa	2.60	0.39	(Ahmedin and Elias 2020)

Vegetation classification

The vegetation classification in BMNP at 81-dissimilarity level from hierarchical cluster analysis resulted in five plant community types: *Anthemis tigreensis - Alchemilla pedata* (CI), *Alchemilla haumanii - Helichrysum gofense* (CII), *Podocarpus falcatus - Croton macrostachyus* (CIII), *Croton macrostachyus - Syzygium guineense - Olea capensis* (CIV), *Solanum marginatum - Euphorbia dumalis - Rubus steudneri* (CV) (Table 2; Fig. 2). Some of the indicator species in BMNP (*Croton macrostachyus*, *Podocarpus falcatus, and Syzygium guineense*) were also identified as dominant species in similar areas reported by (Ayalew 2018), (Aliyi et al. 2015), and (Ahmedin and Elias 2020) and they were indicated as a species with wide ecological ranges in Ethiopia by (Edwards, Nemomissa, and Hedberg 2003).

Table 2 Synoptic table based on mean cover–abundance value for species reaching ≥ 1 in at least one community (values in bold refer to characteristic species of the community)

	Plant Communities				
Species	**CI**	**CII**	**CIII**	**CIV**	**CV**
Alchemilla abyssinica	0.00	3.43	0.00	0.00	0.00
Alchemilla haumanii	0.00	**5.07**	0.00	0.00	0.00
Alchemilla pedata	**2.72**	1.36	0.00	0.00	0.00
Anthemis tigreensis	**3.03**	0.21	0.00	0.00	0.00
Centella asiatica	0.00	2.61	0.00	0.00	0.00
Coffea arabica	0.00	0.00	3.19	0.00	0.00
Croton macrostachyus	0.00	0.00	**3.78**	**5.38**	0.00
Ehretia cymosa	0.00	0.00	2.44	0.25	0.00
Euphorbia depauperata	2.22	1.14	0.00	0.00	0.00
Euphorbia dumalis	1.00	0.00	0.00	0.00	**4.34**
Helichrysum citrispinum	0.00	2.54	0.00	0.00	0.00
Helichrysum gofense	1.03	**3.68**	0.00	0.00	0.00
Helichrysum splendidum	0.86	2.50	0.00	0.00	0.00
Jasminum abyssinicum	0.00	0.00	2.41	0.00	0.00
Juniperes procera	1.17	0.00	0.00	0.50	3.53
Maytenus arbutifolia	0.00	0.00	0.00	0.94	2.13
Olea capensis	0.00	0.00	0.34	**1.31**	0.00
Podocarpus falcatus	0.00	0.00	**4.16**	0.44	0.00
Rapanea melanophloeos	0.00	0.00	0.00	0.00	3.34
Rubus steudneri	0.67	0.00	0.56	0.00	**4.00**
Solanum marginatum	1.78	0.00	0.00	0.00	**4.69**
Syzygium guineense	0.00	0.00	2.41	**1.31**	0.00
Trifolium semipilosum	2.19	0.00	0.00	0.00	0.00
Triumfetta pentandra	0.00	0.00	2.47	0.94	0.00

Floristic structure

The density of all woody species with DBH > 2 cm in BMNP was 1567 individuals ha^{-1}. This was relatively higher compared to Wof-Washa Forest (Ayalew 2018), Munessa forest (Ahmedin and Elias 2020), and

Agama forest (Dibaba et al. 2020). The ratio of stem density with DBH > 10 cm to those with DBH > 20 cm was 1.19. This ratio was lesser compared with other vegetation areas such as Masha forest (Assefa, Demissew, and Woldu 2014), Belete forest (Gebrehiwot and Hundera 2014), and Agama forest (Dibaba et al. 2020). This value in the edge habitat was 320.31 stems ha^{-1} and it was 451.56 stems ha^{-1} in the interior habitat. This was due to the selective cutting of trees for timber production, house construction, and firewood, which ultimately leads to a reduced density of large trees and greater canopy openness (Laurance 2004).

The frequency of woody species in BMNP ranged from 2 to 81%. Five frequency classes were identified and 76 % of woody species belongs to frequency class A, i.e., they were absent in most of the sample plots laid (Fig. 3). *Croton macrostachyus* was the most frequently appeared woody species in many of the sample plots laid with 81% frequency followed by *Juniperus procera* with 79%, *Podocarpus falcatus* with 63%, *Hagenia abyssinica* with 60%, and *Hypericum revolutum* with 50%.

Compared with other similar sites the highest DBH of the study area was relatively lower than woody species in Wof-Washa forest (Bekele 1993) and Kuandisha forest (Berhanu, Demissew, et al. 2017) (Fig. 4). The distribution of woody species along the height classes tends to decrease towards the highest height class (Fig. 5). The mean DBH and height of woody species in the interior habitat (78.62 ± 4.56 cm and 33.63 ± 2.71 m) was significantly higher than the edge habitat (44.12 ± 6.42 cm and 25.12±3.34 m) at $p < 0.001$ and $p < 0.05$, respectively. The loss of forest structural complexity in the edge causes great differences between the two habitat types in addition to disturbance, forest area reduction and patch shape complexity (Paciencia and Prado 2005).

The total basal area of woody species with DBH > 2 cm was 170.26 m^2 ha^{-1} and it was considerably higher compared with the top seven vegetated areas selected in Ethiopia (Table 3). This was due to the presence of relatively larger DBH trees in the study area. About 75 % of the basal area was contributed by five tree species such as *Juniperus procera* (46.71 m^2 ha^{-1}), *Syzigium guineense* (24.76 m^2 ha^{-1}), and *Cordia africana* (20.95 m^2 ha^{-1}). Conversely, the basal area of woody species in the interior habitat (173.79 m^2 ha^{-1}) was significantly higher than the edge (64.15 m^2 ha^{-1}) at $p < 0.05$. This shows big size trees are more in the interior habitat than the edge. Selective cutting of large size trees in the edge habitat was responsible for it.

Table 3 Basal area of woody species in the BMNP and other vegetation areas in Ethiopia

Vegetated areas	Basal Area (m^2 ha^{-1})	Authors
BMNP	170.26	**Present study**
Wof-Washa	153.26	(Ayalew 2018)
Tara Gedam forest	115.36	(Zegeye et al. 2011)
Menagesha Suba	158.68	(Beche 2011)
Dodola	129	(Kitessa et al. 2007)
Kimphe Lafa	114.4	(Aliyi et al. 2015)
Menna Angetu	94.22	(Lulekal et al. 2008)
Munessa	91.75	(Ahmedin and Elias 2020)

The IVI value was ranged from 0.59 to 26.43. *Juniperus procera* was the dominant woody species with IVI of 26.43, followed by *Croton macrostachyus* with 19.85, and *Syzigium guineense* with 17.4 (Table 4). The species with higher IVI values in the study area are among the characteristic species in the similar vegetation types elsewhere (Sebsebe and Friis 2009; Woldu, Fetene, and Abate 1999).

Table 4 IVI of top 10 woody species with their corresponding Relative Density (R_{de}), Relative Frequency (R_{fr}), and Relative Dominance (R_{do}) in BMNP

Species	R_{de} (%)	R_{fr} (%)	R_{do} (%)	IVI
Juniperus procera	6.48	8.37	11.58	26.43
Croton macrostachyus	7.91	8.59	3.35	19.85
Syzigium guineense	2.19	5.07	10.14	17.40
Podocarpus falcatus	6.83	6.61	2.86	16.30
Hypericum revolutum	8.51	5.29	1.70	15.49
Hagenia abyssinica	2.33	6.39	6.00	14.71
Ehretia cymosa	4.29	3.74	5.86	13.89
Cordia africana	1.40	1.76	8.22	11.38
Olea europaea	3.79	3.96	2.13	9.88
Ocotea kenyensis	3.99	3.08	1.50	8.57

Population structure

The population structure of 17 tree species was examined and six representative patterns were identified following (Teketay 2005) (Fig. 6). This patters are Inverted-J shaped (a), J shaped (b), Broken Inverted-J shaped (c), Unimodal/bell shaped (d), the pattern that consists of abundant individuals at the lower DBH classes and the absence of individuals at the intermediate and higher DBH classes (e), and the pattern that comprises fewer matured individuals in the higher DBH classes and lack of individuals at the lower and intermediate DBH classes (f).

Regeneration status of woody species

The total density of seedling, sapling and mature tree in the BMNP was 8751, 4413, and 1567 individuals ha^{-1} respectively (Fig. 7). This was less than Kuandisha forest (Berhanu, Demissew, et al. 2017) and Wof-Washa forest (Fisaha, Hundera, and Dalle 2013). The ratio of seedling to mature tree, sapling to mature tree, and seedling to sapling was 5.58, 2.82, and 1.98 respectively. These shows the recruitment potential of the forest is relatively higher. The mean density of seedling, sapling, and mature trees in the interior habitat was significantly higher (995.42 ± 19.27, 509.29 ± 9.06, and 187.60 ± 4.70 individuals ha^{-1}, respectively) than the edge habitat (584.61 ± 12.76, 353.92 ± 7.35, and 121.45 ± 2.83 individuals ha^{-1}, respectively).

Effects of landscape change on floristic composition and structure

From the regression analysis made in this study PN established strong and negative effect on species richness (with r = -0.90, $p < 0.05$) and diversity (with r = -0.96, $p < 0.05$). While the number of fragmented habitats increases species richness and diversity, particularly interior dependent species, decreases. However, edge dependent species comfortably flourish. One of the consequences of habitat fragmentation is an increase in the proportional abundance of edge influenced habitat and its adverse impacts on interior sensitive species (Robbins, Dawson, and Dowell 1989). Undoubtedly, while some species (e.g. habitat specialists) may suffer from fragmentation, others may benefit from it (e.g. generalists and edge species) (Henle et al. 2004).

Conversely, PN were strong and negatively correlated with AREA_MN (r = -0.71, $p < 0.001$). Moreover, species richness was strong and positively correlated with AREA_MN (r = 0.95, p < 0.05). This implies that as the PN increases the area of fragments decreases as a result small fragments contain smaller species richness and lowers species density than large fragments (Laurance and Vasconcelos 2009). Large areas of habitat tend to support more individuals, and hence, more species (Rosenzweig 1995). Increasing fragmentation may be detrimental if little habitat is available, but intermediate degrees of fragmentation may be beneficial for competitive communities when the amount of habitat is fairly high (Rybicki, Abrego, and Ovaskainen 2020). Besides modifying the spatial pattern of the landscape, habitat size reduction and increase of isolation cause an alteration of the dispersal rate, affecting survival, and mortality of individuals (Fahrig and Merriam 1994; Hanski 1994). Poor disperser species and those with low density may react negatively to the fragmentation process (Kareiva and Wennergren 1995).

Many population and community changes in habitat fragments were commonly attributed to edge effects (Laurance and Vasconcelos 2009). Interior species may be affected by the size decrease of their habitat, by edge effect and by competition with generalists, which consider the fragmented landscape as a mosaic of suitable polyfunctional habitats (Bolger, Scott, and Rotenberry 2001; Schonewald-Cox and Buechner 1992). The most threatened endemic woody species due to edge effect in the BMNP were *Helichrysum harennense* Mesfin, *Kniphofia insignis* Rendle, *Rubus erlangeri* Engl., and *Vepris dainellii* Pichi. Serm. Kokwaro. Conversely, the most common weed species in the study area favored by edge effect was *Achyranthes aspera* L., which is also common in the disturbed forests and forest edges of the dry Afromontane forests and moist Afromontane forests in Ethiopia (Friis, Demissew, and Van Breugel 2010). The gradual decline of the more sensitive species, caused by changes in the extinction/colonization rates and the proportional increase of edge/generalist species, may induce a species turnover in fragments and cascade effects (Lomolino and Weiser 2001; Pimm et al. 2014).

Among the landscape indices computed only PN and AREA_MN significantly affected some of the floristic structural properties assessed. Thus, PN was strong and negatively affected woody species density (r = -0.84, $p < 0.05$) and basal area (r = -0.96, $p < 0.01$) as well as AREA_MN was strong and positively affected woody species density (r = 0.71, $p < 0.05$) and basal area (r = 0.82, $p < 0.05$). However, the DBH and height of woody species were insignificant but negatively affected by PN, SHAPE_MN, ED, ENN_MN, and IJI and it was insignificant but positively affected by AREA_MN and COA. Habitat destruction, isolation, and transformation affects the structure and dynamics of populations, communities, and ecosystems, as well as ecological processes (Soulé and Orians 2001). Generally, as AREA_MN and COA of patches increases, species richness, diversity, evenness, woody species density, basal area, DBH, and height also increases. Whereas, as PN, SHAPE_MN, ED, ENN_MN, and IJI of patches increases, those floristic composition and structural variables decreases. This implies that the landscape composition and configuration change may potentially affected the vegetation composition and structure of a particular area.

Conclusion

This study revealed that BMNP is one of the richest ecological area that comprises of endemic and indigenous plant species in Ethiopia. However, the expansion of settlements and livestock rearing was the most challenging activities performed in the park even in the higher altitudes up to 3900 m asl. Human induced fire was also the main concern in the ericaceous belt and Afro-alpine region for the expansion of farm and grazing land. These activities are responsible for the occurrence of habitat loss and fragmentation in the park. As a result, the species richness and Shannon diversity index were significantly higher in the edge habitat compared to the interior habitat. This was due to the dominance of generalist species in the edge habitat, which can flourish in the limited resources, and specialist species in the interior habitat, which are sensitive to the limited resources. Moreover, the species in the edge habitat was unevenly distributed and the basal areas of woody species was relatively lower than the interior habitat. This was due to the presence of larger size trees in the interior habitat than the edge. Therefore, illegal

human activities in the park should be band and the settlements need to be relocated to other areas to avoid their potential impacts on floras and faunas that depends on the park.

Abbreviations

AREA_MN: Mean patch size; BMNP: Bale Mountains National Park; COA: Core area; DBH: Diameter at breast height; ED: Edge density, ENN_MN: Mean Euclidean nearest neighbor distance; GBIF: Global Biodiversity Information Facility; IJI: Interspersion and juxtaposition index; IUCN: International Union for Conservation of Nature; PN: Patch number; SHAPE_MN: Mean shape index.

Declarations

Authors' contributions

AM conceived, designed, collected the data, analyzed and wrote the manuscript. EE supervised the inception, design and edited the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The data used in this paper can be provided upon request.

Consent for publication

Not applicable.

Ethics approval and consent to participate

Not applicable.

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Figures

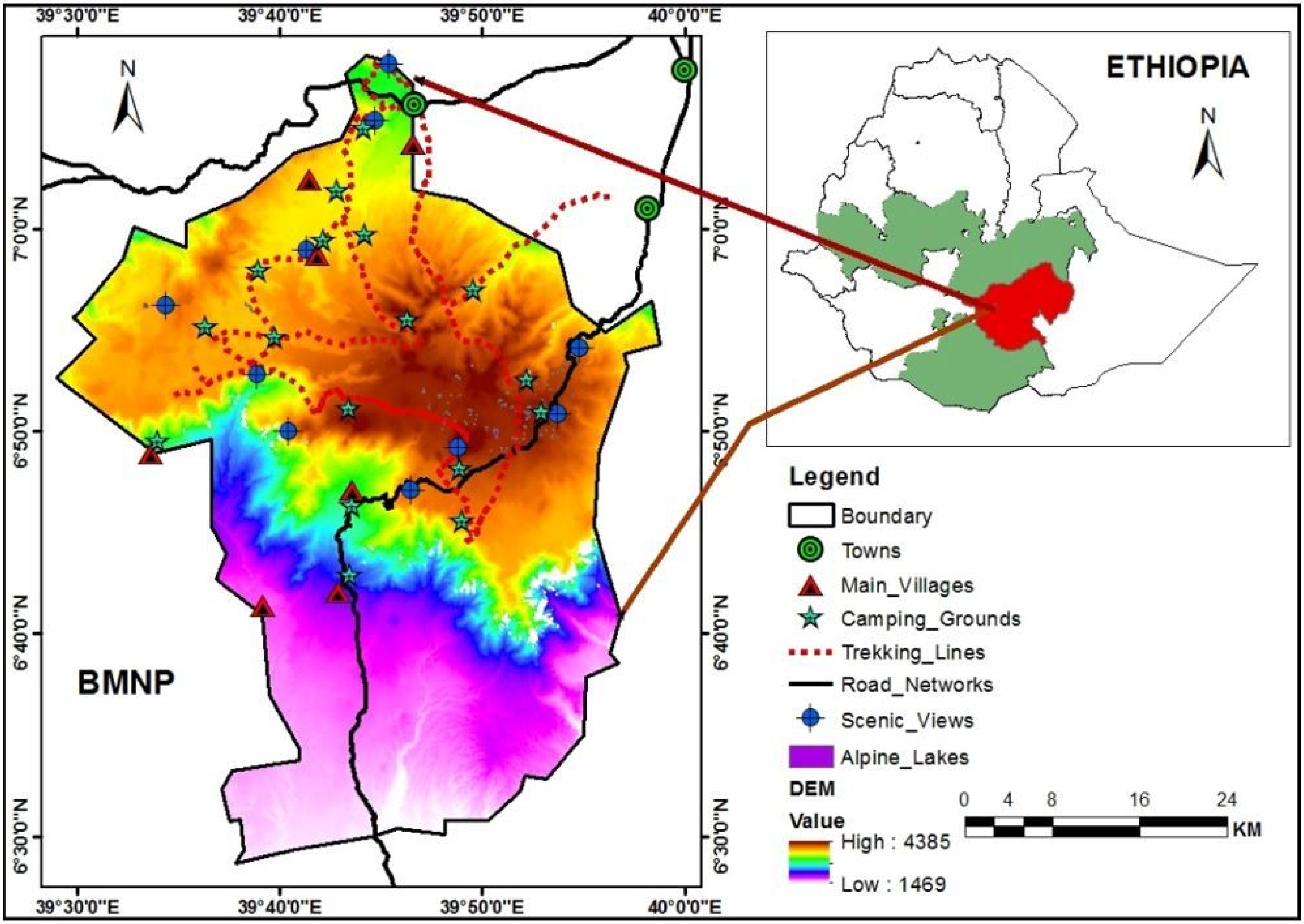
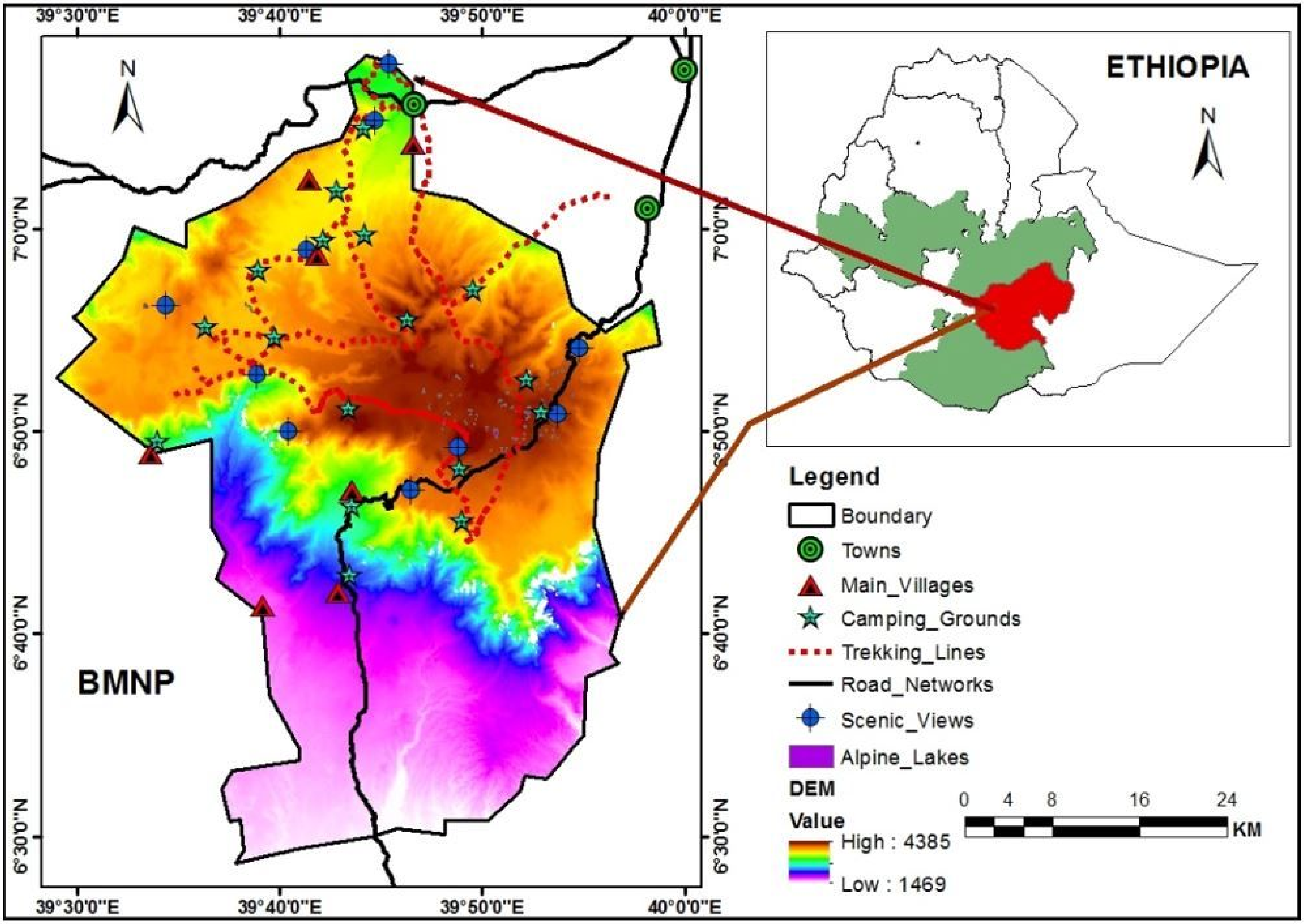


Figure 1

Location map of the study area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



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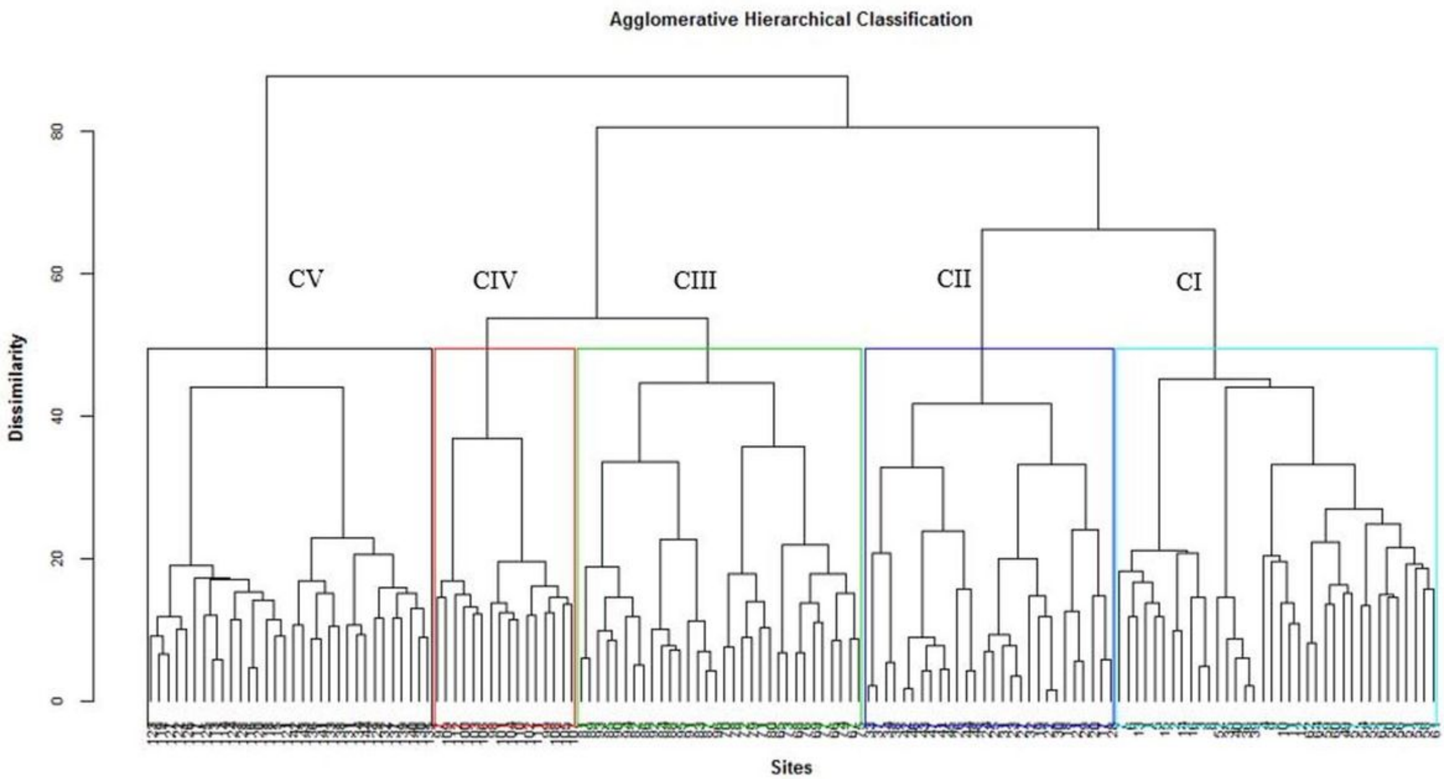
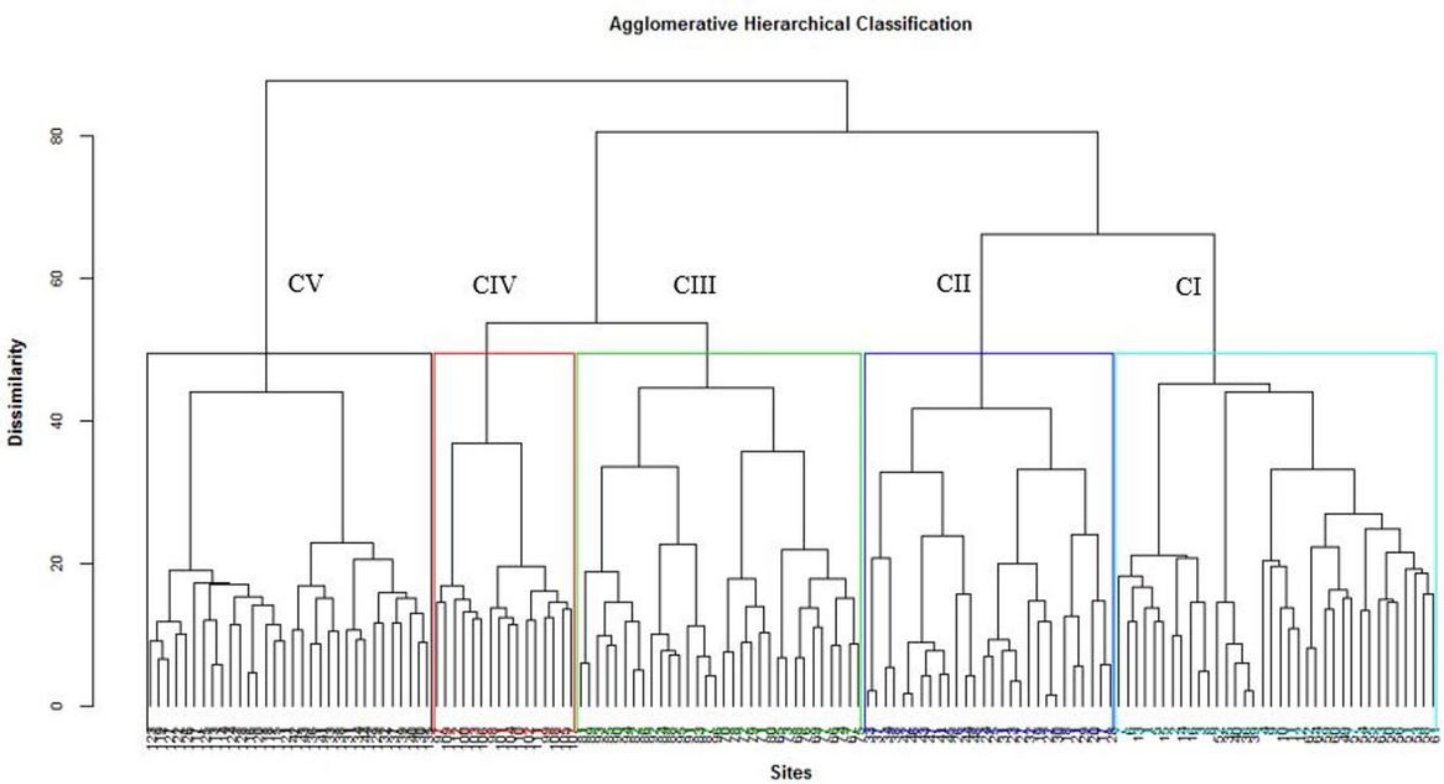


Figure 2

Dendrogram of sample plots in the plant communities in BMNP



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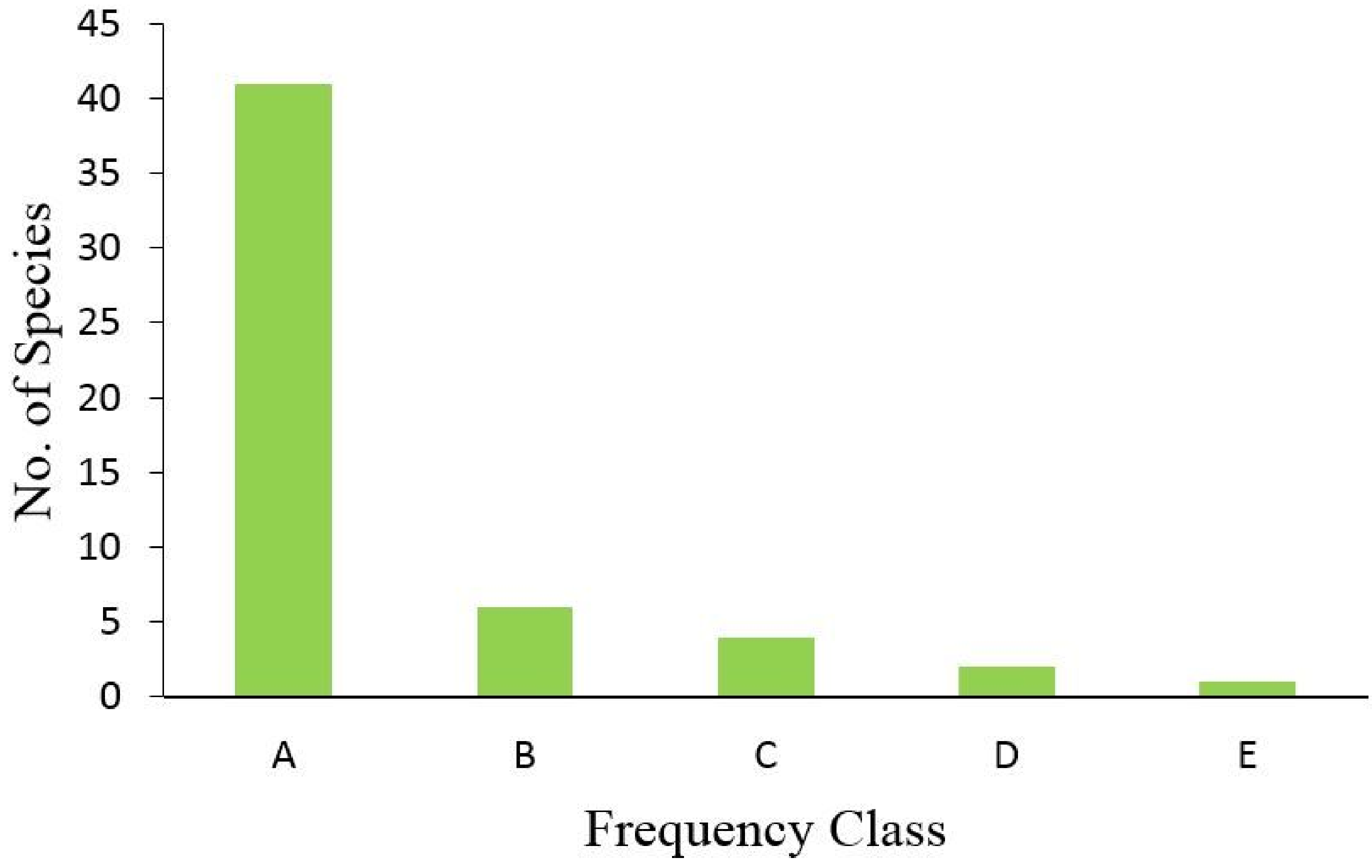
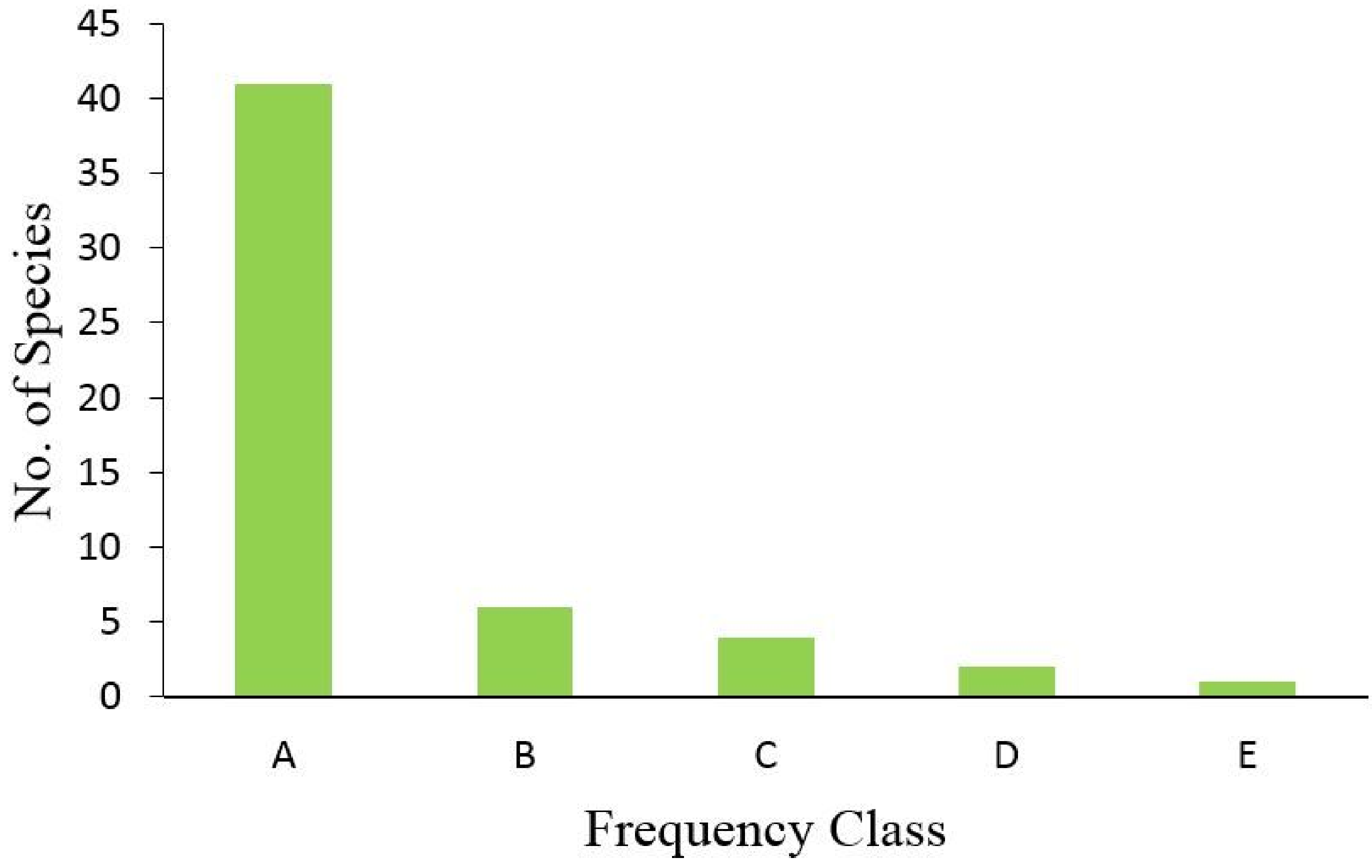


Figure 3

Number of species in each frequency class (A: 1–20 %, B: 21–40 %, C: 41–60 %, D: 61–80 %, E: 81–100 %)



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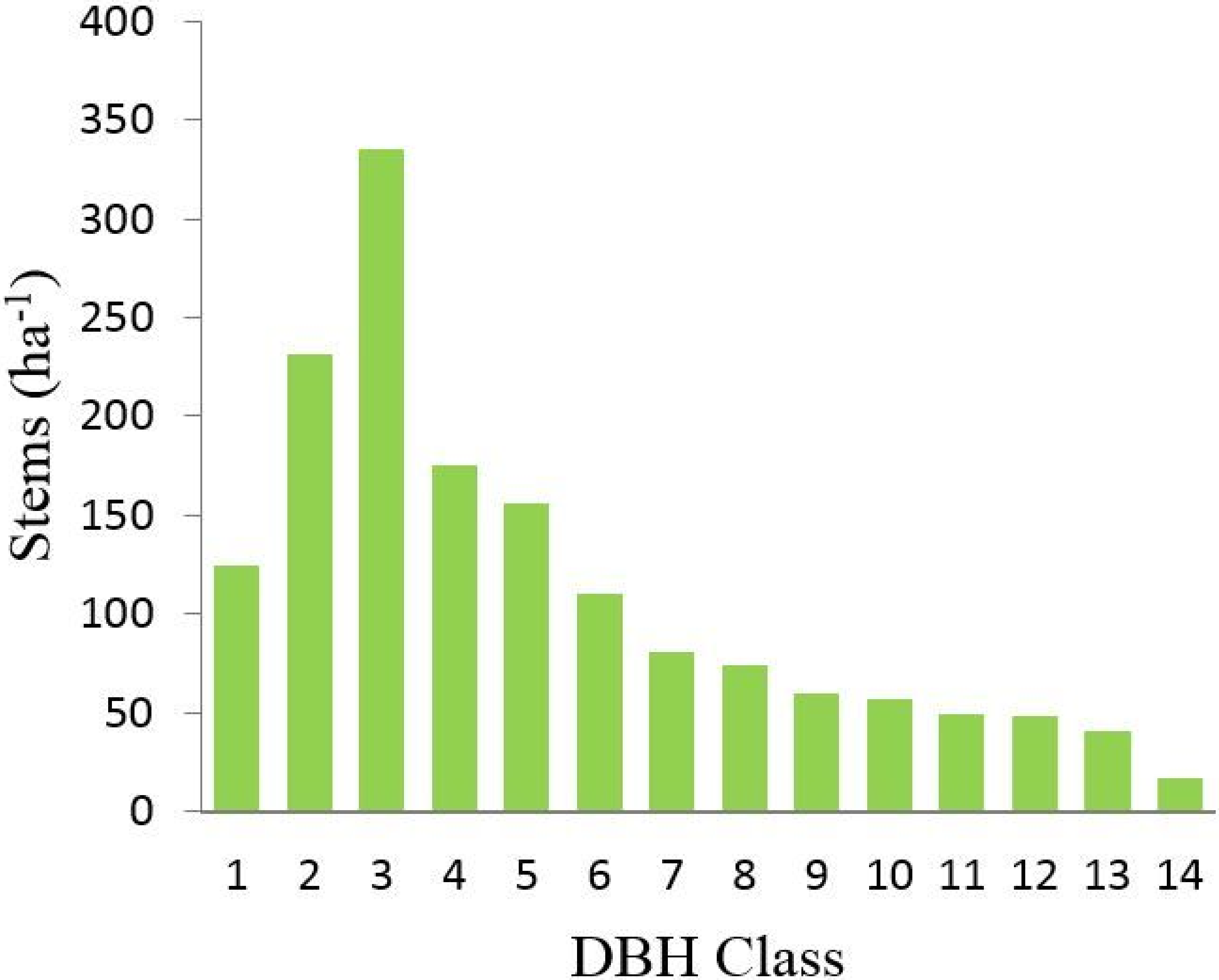
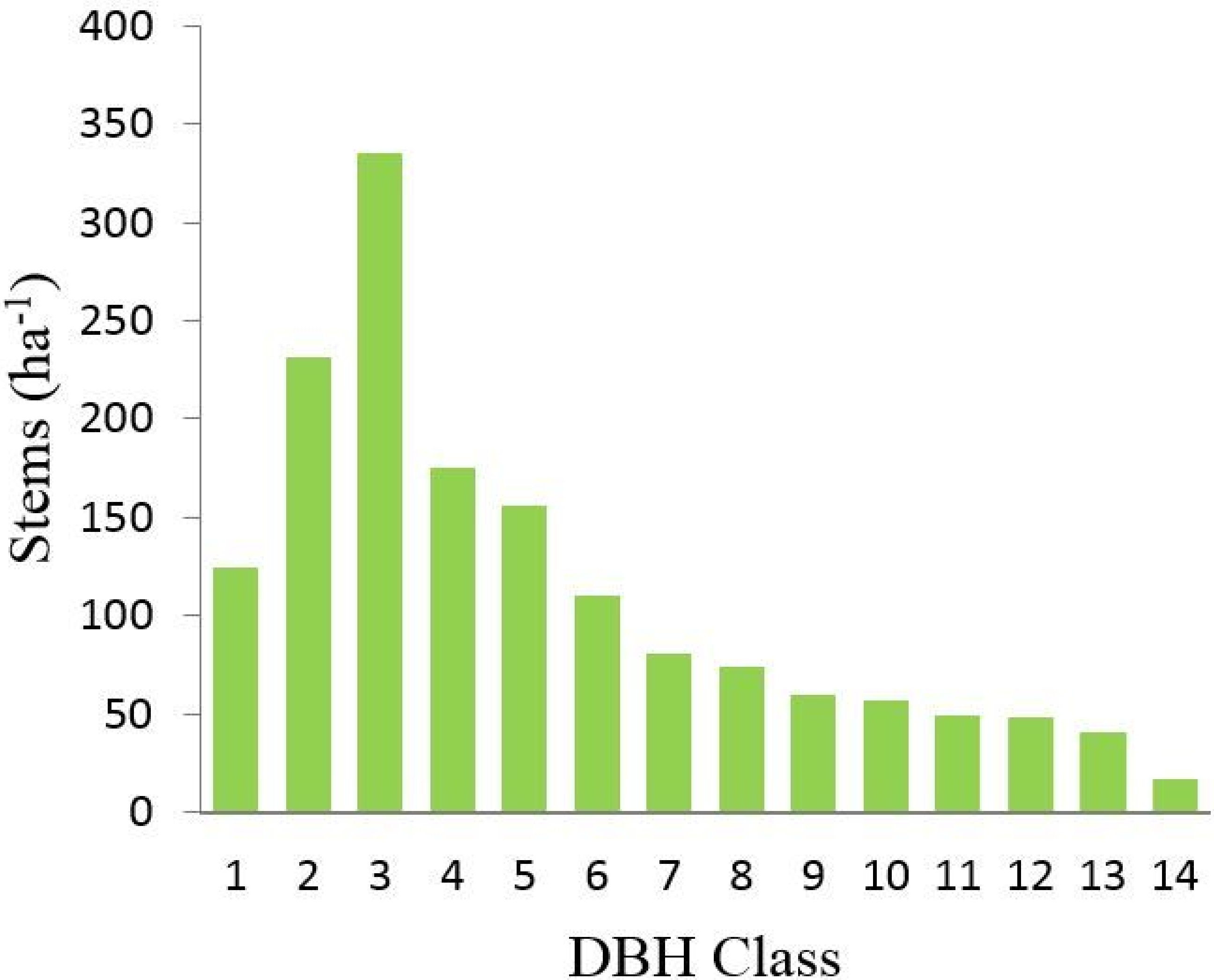


Figure 4

Stems density along DBH class



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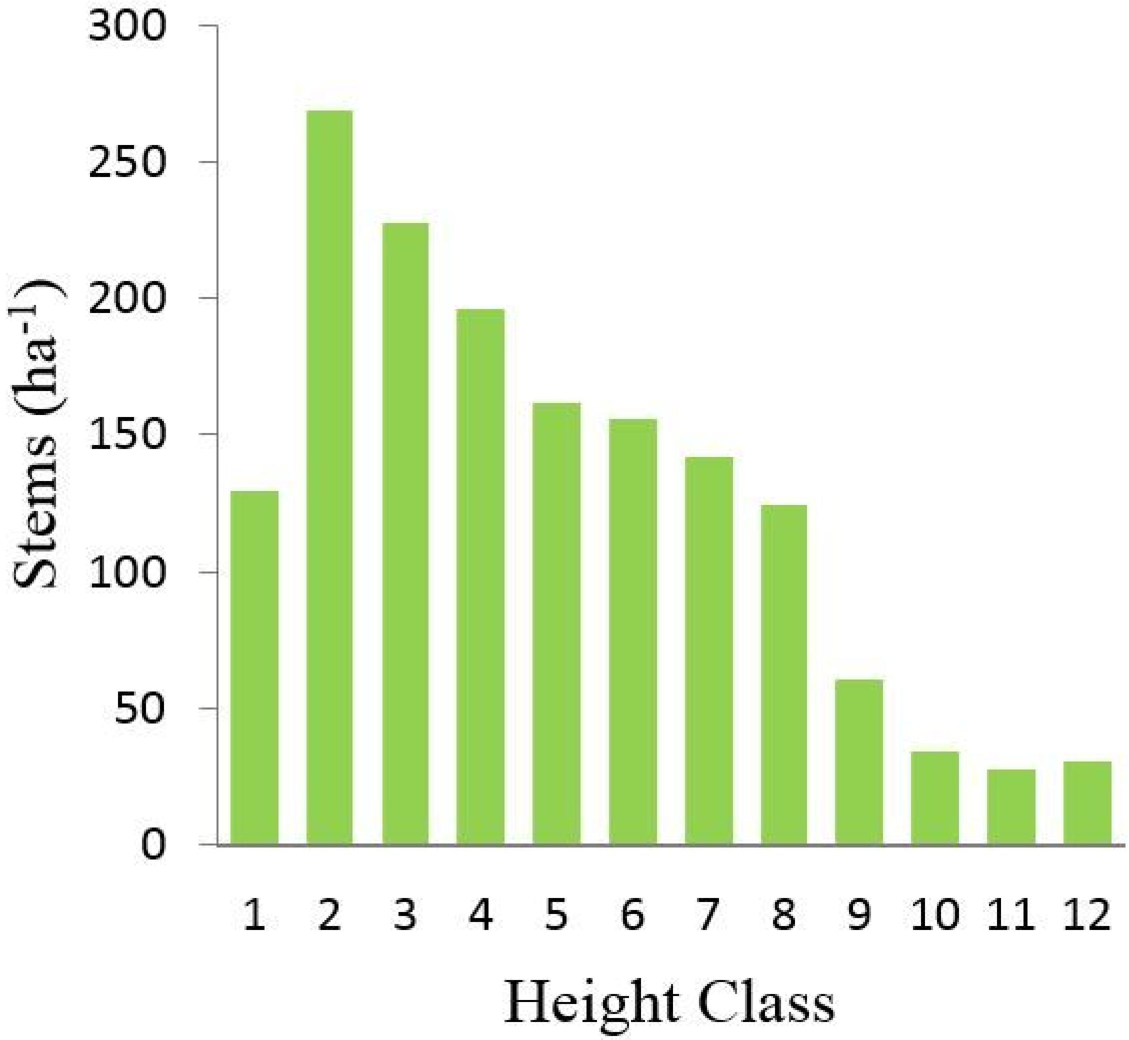
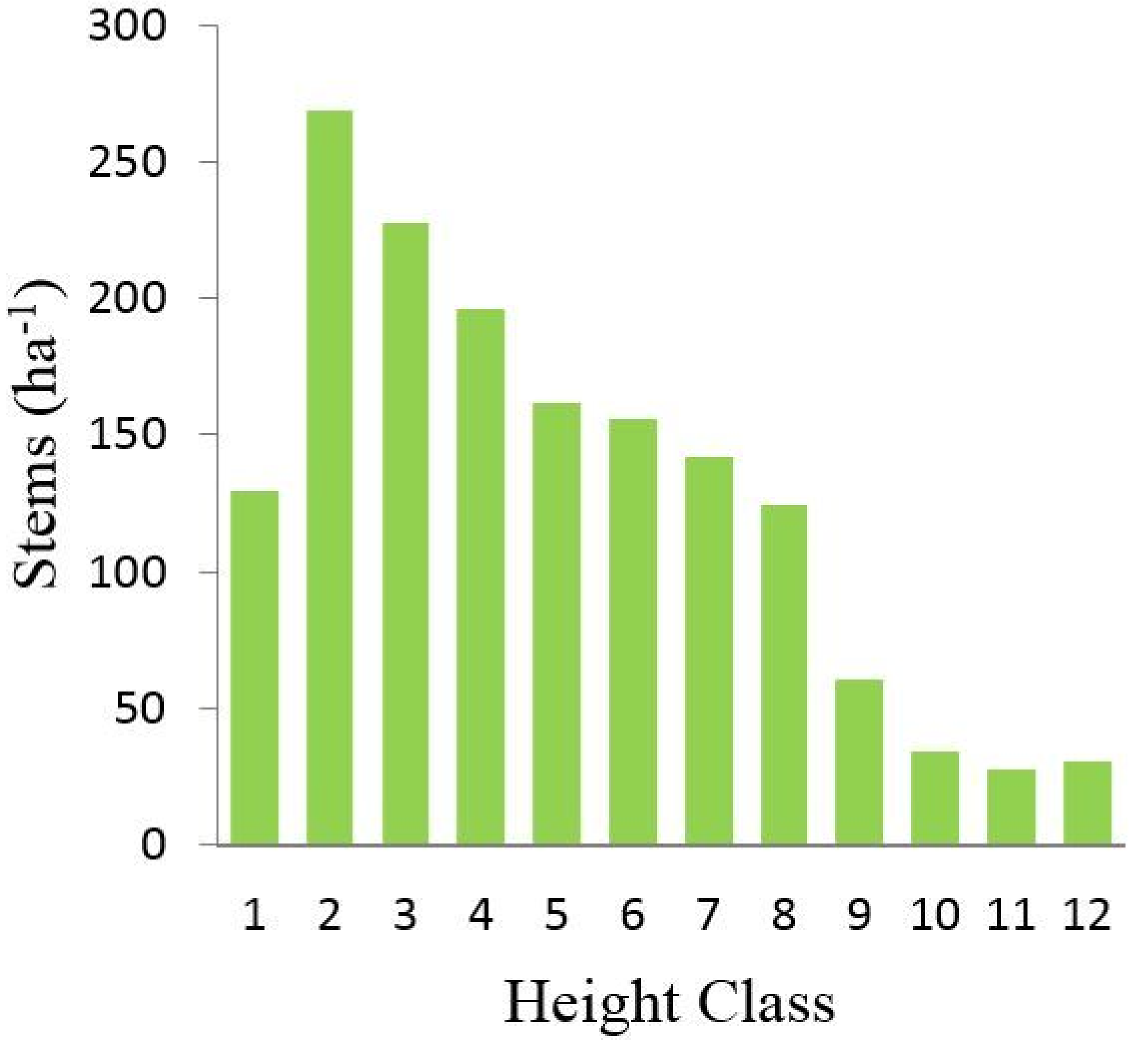


Figure 5

Stems density along height class



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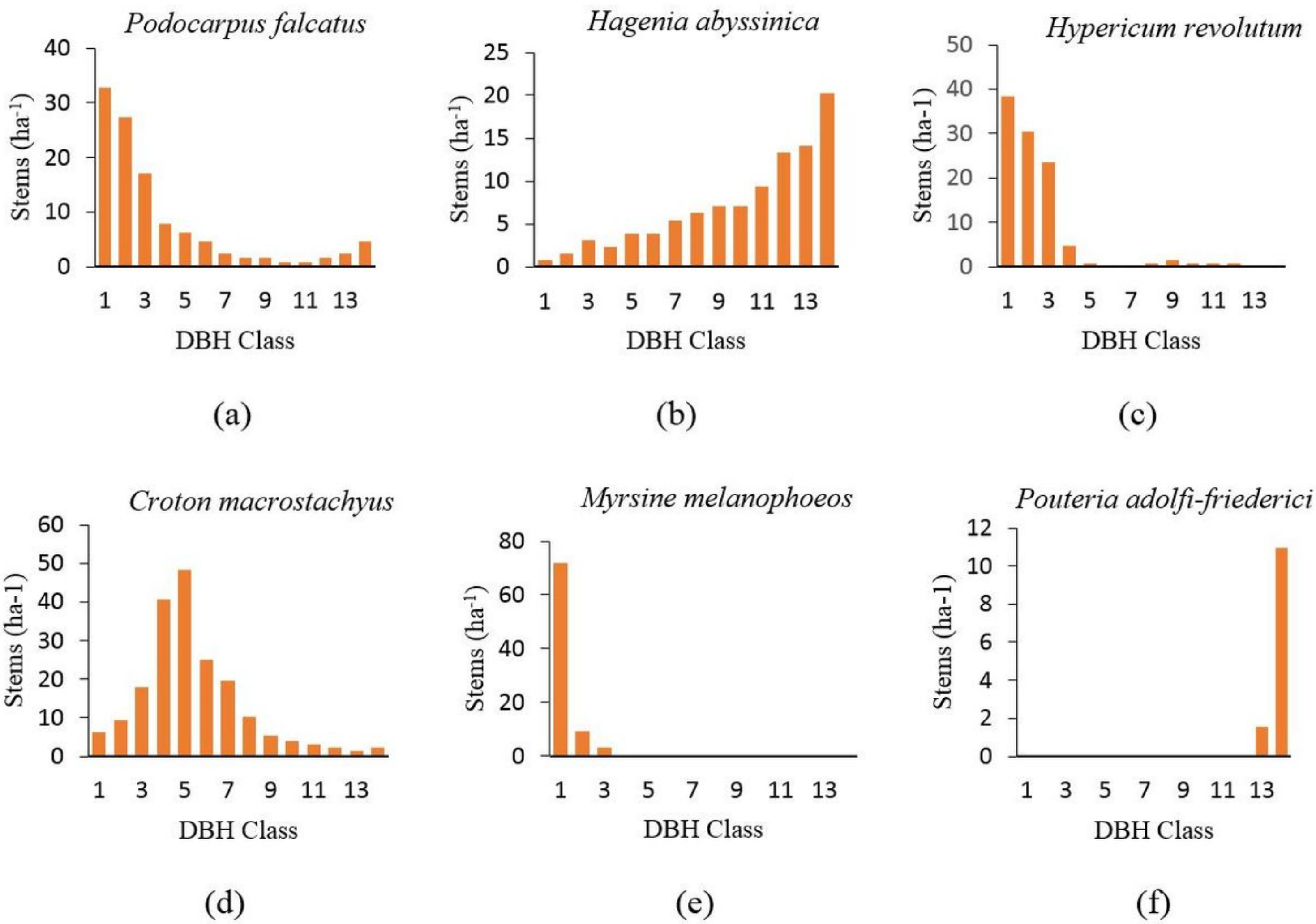
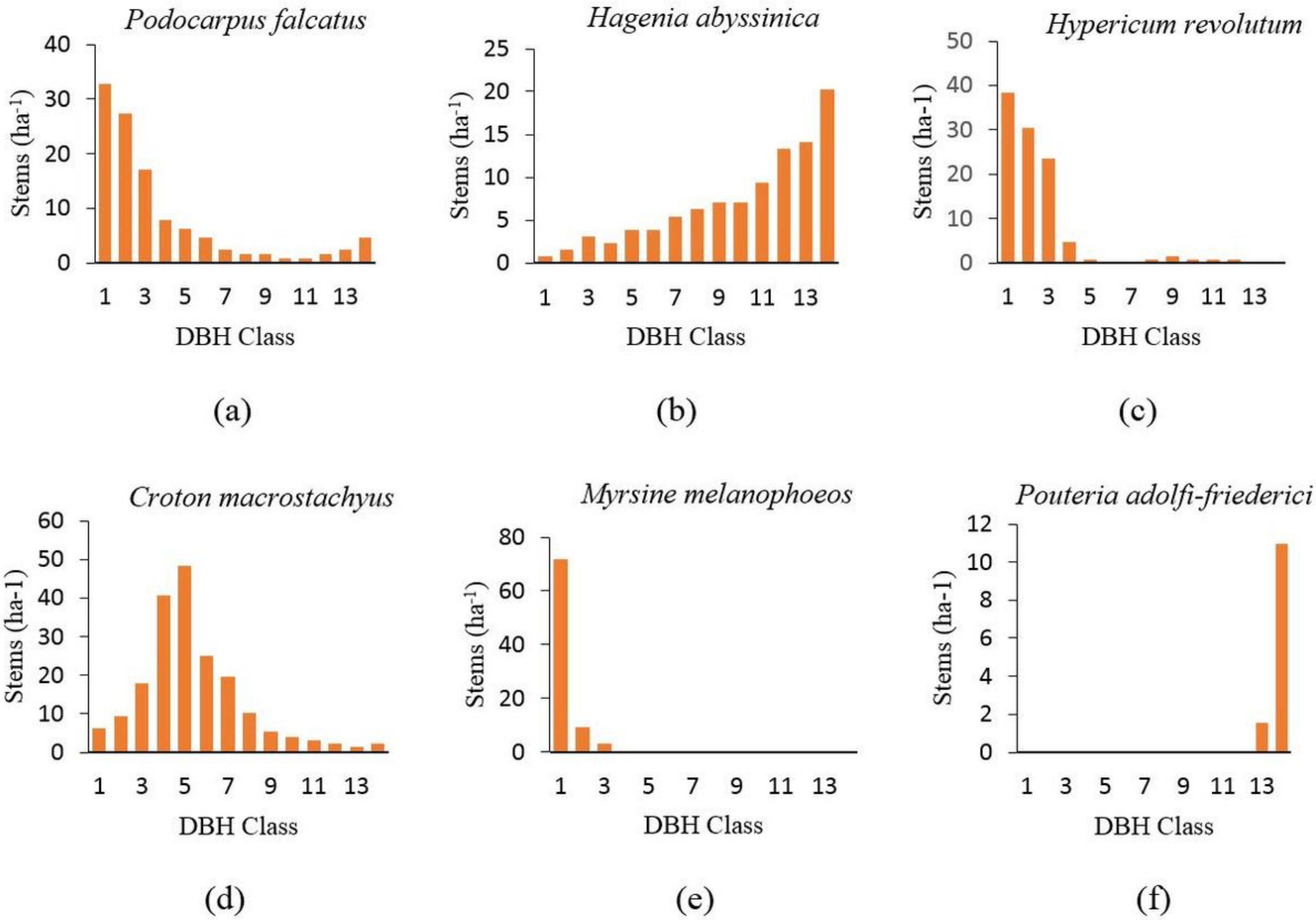


Figure 6

Representative patterns of woody species population structure along DBH classes



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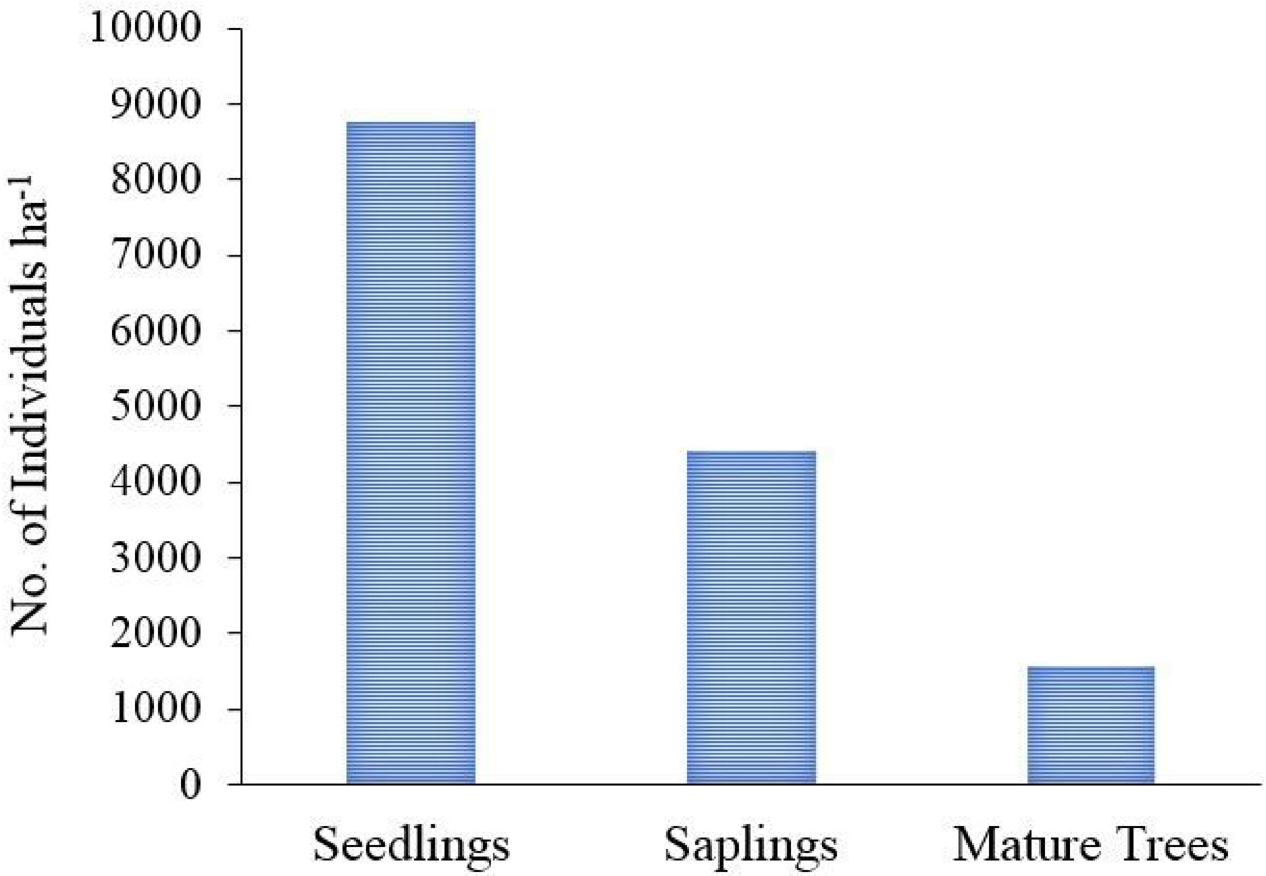
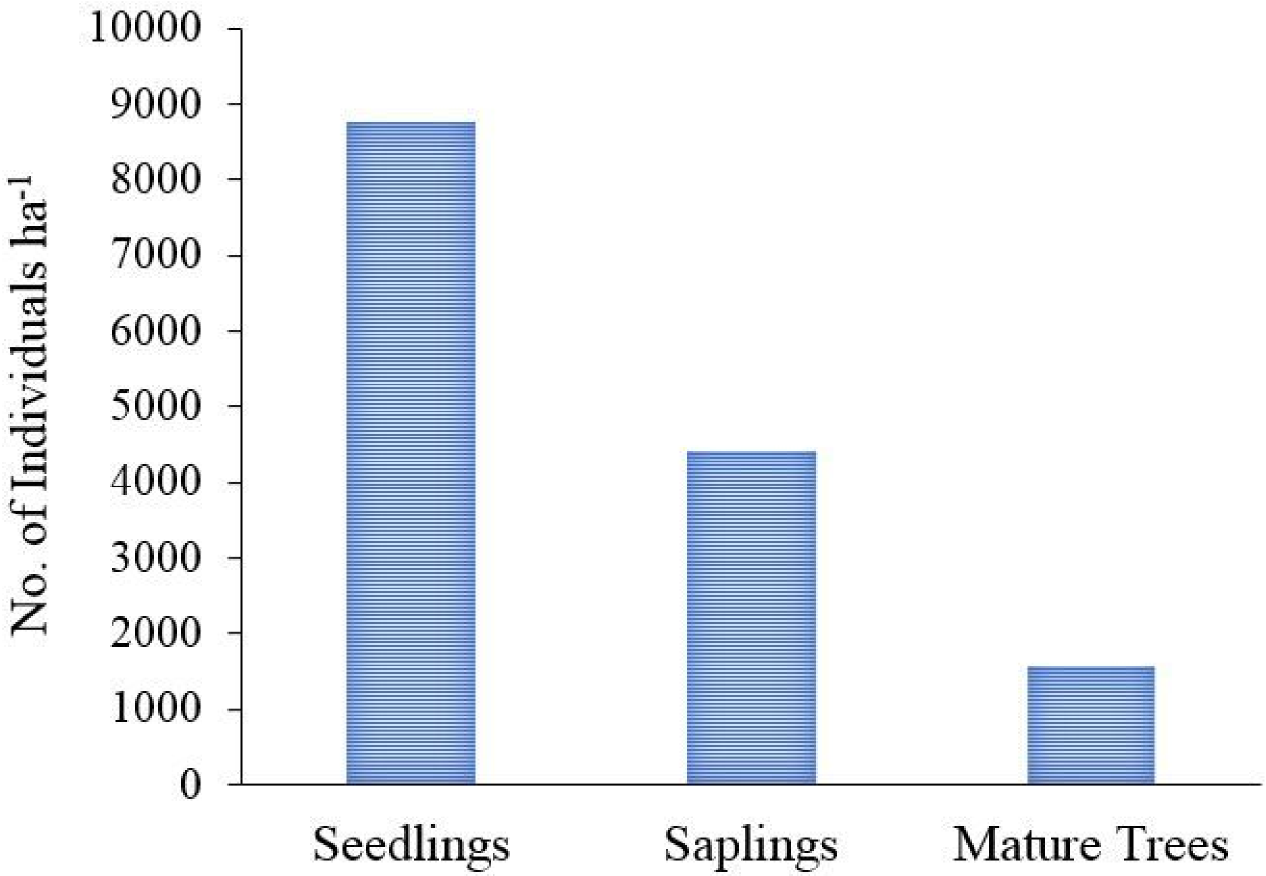


Figure 7

Density of seedlings, saplings and mature trees in BMNP



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