

A Landscape-Level Assessment of Composition, Structural Heterogeneity and Distribution Pattern of Trees in Temperate Forest of Kashmir Himalaya, India

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Abstract

Background: A landscape-level quantitative assessment of tree species was conducted across three forest types viz., low-level blue pine (BP), mixed conifer (MC) and subalpine (SA) forests of Kashmir Himalaya, India to ascertain patterns of species composition, and stand structure heterogeneity. We performed analyses of tree composition and structural heterogeneity, and multivariate ordination for the distribution of species across the landscape.

Results: In total, thirteen tree species ranging from five in SA forest to ten species in MC forest were recorded. There was an overall forest compositional dissimilarity among the forest types. *Pinus wallichiana* and *Abies pindrow* were exclusive dominants under BP and SA forests, respectively, whereas, *Abies pindrow* and *Pinus wallichiana* prevailed in sampled plots from mid-elevation MC forest. Pinaceae family contributing more than 98% individual stems was the most speciose and dominant, followed by Sapindaceae (0.52%) and Betulaceae (0.44%). Stand density, basal area, as well as mean DBH differed among the forest types with an overall positive response to elevation. Besides MC forest, the diameter class distribution of BP and SA forests displayed characteristics 'reverse J-shaped' pattern, concluding its degenerated forest structure. *Abies pindrow* and *Pinus wallichiana* across the forests showed bell-shaped tree size distribution, indicated sporadic recruitment and/or due to targeting specific size classes. A single cluster in SA forest and two sub-clusters in BP and MC forests were displayed in abundance and species-based Bray-Curtis cluster analysis. Topographical factors, elevation and slope, were identified as the principal factors of tree species distribution patterns and positively correlated with Canonical Correspondence Analysis 1 (CCA1) and CCA2, respectively.

Conclusions: The quantitative landscape-level inventory of diversity across forest types indicated an overall less heterogenous tree composition with structural heterogeneity. CCA predicted elevation and slope as principal drivers determining species distribution. Information about these forest attributes are expected to provide better ecological insights and prospects for sustainable forest management and utilisation, and improving conservation strategies and ecosystem services.

Background

Topographical complexity across ecosystems contributes significantly to ecological diversity (Badgley et al., 2017). Mountain habitats reported to cover about 12% of the total earth's surface, contribute approximately 25% of the global species diversity and are rich in endemic species (Barthlott et al., 2005; Spehn et al., 2006). In fact, half of the global 36 hotspots and more than 33% of the terrestrial species diversity are in mountain systems (Körner, 2005). Continuous variations in elevation, terrain and related environmental factors are critical attributes of the mountain system. These features directly influence biotic composition, growth habits, diversity and ecosystem functions, contributing to changes in species composition. Similarly, the Himalayas exhibit a wide range of topographical heterogeneity with ecological, economic, social and cultural significances (Geneletti and Dawa, 2009; Charlery et al., 2016; Hoy et al., 2016). It also harbors one of the 36 biodiversity hotspots viz., the Himalaya, with a broad scope of endemic flora and fauna. However, Himalayan ecosystems are listed among the most threatened habitats (Schickhoff, 1995), with 23 % forest cover loss from the last thirty years in Western Himalayas (Anonymous, 2005). Gradient investigations in the mountains, thus pave the way to formulate many primary ecological and evolutionary principles (McCain and Grytnes 2010; Körner 2018).

There is logical agreement on the significance of climatic factors, geology, location, and interactions among organisms besides natural and anthropogenic interferences for forest diversity (Johnson and Miyanishi 2007). Previous studies in the Kashmir Himalayan region have investigated species richness and composition along altitudinal gradient across diverse habitats and taxa (Khuroo et al., 2011; Shaheen et al., 2012). Recent research has suggested that stand structural characteristics increase stand performance, regardless of the obstruction of species richness (Ali and Mattsson, 2017). Shaheen et al. (2012) emphasized the significance of geographical variables for large-scale species distribution trends across the Himalayas. Nonetheless, the relationship among forest structural heterogeneity, topographical variations and species composition has been genuinely under-examined. Stand structural features such as basal area (BA), diameter at breast height, and tree density can push the ecosystem diversity, interactions among organisms, gene flow and consequently forest inhabitants and overall diversity (Jafari et al., 2013). Connecting structural attributes with diversity is of extreme significance in managing forest.

The Himalayas are the tallest and longest mountain ranges with diverse landscapes (Xu, et al., 2009). They also define the climatic regime of the Indian subcontinent, besides promoting the people's livelihood (Resurreccion et al., 2019). It is assessed that 75% of the forest cover in the Himalaya was destroyed in the last century alone. Knowledge of how the nature and structure of temperate ecosystems vary across different places is crucial to set regional conservation targets. Effective conservation and management practices involve an unequivocal investigation of plant diversity patterns and an appreciation of factors regulating such patterns. Unfortunately, temperate ecosystems, particularly Himalayan forests, were underestimated for ecological studies (Peer et al., 2007) until recently and are poorly explored than their European counterparts.

All the ecological processes and functions, particularly the forest stand structure, depend significantly on trees. Moreover, density and diversity were also determined by the number of stems within the forest (Podlaski et al., 2019). Recently, several studies have focussed on trends of tree species composition, structural patterns and diversity in Himalayan temperate ecosystems along various ecological gradients, including elevation (Sharma et al., 2017; Sharma et al., 2018), disturbance (Khera et al., 2001; Gautam et al., 2016), aspect (Baduni and Sharma, 1999; Sharma et al., 2010), etc. and also across different areas of Kashmir valley (Dar et al., 2002; Khuroo et al., 2004; Khuroo et al., 2011; Dar and Sundarapandian 2016). However, the transition zone from low-level blue pine (BP) to subalpine (SA) forests via mixed conifer (MC) forest and also the influence of geographical variables and stand characteristics on species distribution deserves investigation. Moreover, reports documenting species diversity in these mountain ranges cover only particular regions leaving several areas unexplored. Thus, evaluation of forest composition and structure and factors influencing them in unstudied mountain environments is instrumental in understanding species density, and territories of conservational importance.

Hence, the aim of the present study was to report the outcome of intensive study of phytosociology and diameter-class complexity of tree species in low-level blue pine (BP), mixed conifer (MC) and subalpine (SA) forest types between 1800 – 3300 m a.m.s.l in temperate Kashmir Himalaya, India. Accordingly, the objectives of the work were to characterize and compare tree species composition and structure across these forest types and to examine the relationship between the tree species and environmental variables and other community features.

Materials And Methods

Study area

The study area spans over five districts of Kashmir valley (33.51° – 34.66° N and 74.02° – 75.01° E) Jammu and Kashmir Union Territory, India (Fig. 1). Data on tree species abundance were collected from hitherto unstudied areas harbouring low-level blue pine (BP), mixed conifer (MC) and subalpine (SA) (Champion and Seth, 1968) in 2019 after a preliminary field survey in 2018.

Kashmir valley exhibits a warm summer and humid continental climate (Dfa; Peel et al., 2007) with four recognisable seasons. Climatic data from the last 40 years revealed a mean annual minimum and maximum temperature of 7.75° C and 19.98° C with 800 to 1200 mm of annual precipitation range. Due to the recurrent disturbances posed by the Mediterranean Sea in the winter season, Kashmir valley receives frequent rain and snowfall. The period of snowfall spans from as early as October and can extend up to March. Frost is a common phenomenon during this season. Geologically the study area comprises rocks from the Pre-Cambrian era chiefly composed of slates, phyllites, quartzites, etc. (Krishnan, 1982). The soil orders in the study area are deep, overwhelmingly entisols (typis udifluvents) accompanied with inceptisols (typic eutrochrepts and fluventic eutrochrepts), alfisols and mollisols (Sidhu and Surya, 2014; Mahapatra et al., 2000) with loamy texture. The whole region, especially the low altitude area, is prone to over-exploitation of non-timber forest products, land encroachment, illegal logging, over-grazing etc.

Sampling design and field data collection

A landscape-level field census was undertaken in 143 plots of 0.25 ha (50m × 50m) area sampled across the three forest types. To overcome the bias of within-plot differences, a random sampling approach was employed within each category of the forest. Attempts were made to replicate plots evenly between the forest types; nonetheless, this was not always possible because of the logistic constraints imposed on the field survey and the availability of sites within each forest type.

Field survey

Three forest types ranging in elevation from 1800 m to 3300 m were considered for the present study after a preliminary field survey in December 2018. Fieldwork was conducted from April to July 2019. In established 50 m × 50 m sampling units, abundance and diameter at breast height (DBH) at 1.37 m above the ground level of each tree (≥ 10 cm DBH) were recorded (Pearson et al., 2005; UNFCC, 2015). At the central point of each sampled plot, Geographical Positioning System (GPS) coordinates, elevation (m) and slope (degree) were recorded during data collection (JUNO 3E; accuracy 2 – 5m; inclinometer). Voucher specimens of all inventoried tree species were prepared and identified with *Flowers of the Himalaya* (Polunin and Stainton, 1984) and cross-verified at Centre for Biodiversity and Taxonomy, Department of Botany, University of Kashmir.

Data analysis

The information theory-based indices analysed includes species richness (Menhinick, 1964, Shannon-Wiener index (H') (Magurran, 2004), and Fisher's Alpha index (S) (Fisher et al. 1943) as they comprehend rare species within the community; whereas, dominance measures examined was Simpson index (D) (Simpson, 1949) of

diversity occasionally referred to as Yule index (Southwood 1978) and is biased by the abundance rather than number of species.

One of the robust and unconstrained tool of ordination in community ecology *viz.*, NMDS (Leps and Smilauer, 2007) was used to display the general contrasts in species structure among the three forest types using tree abundance data (Legendre and Legendre, 1998). To enumerate the dis/similarity matrix, one-way Analysis Of SIMilarity (ANOSIM) statistics (Bray-Curtis distances-Bray and Curtis, 1957; 999 permutations) was executed. To determine the minimum acceptable area ideal for vegetation survey, besides comparing species assemblages, species-area curve was plotted for each forest type. Rarefaction, an interpolation method was used to estimate the expected species richness within the given number of individuals (Gotelli and Colwell, 2011). The important value index (IVI) for each species was enumerated as the entirety of phytosociological attributes; relative density, relative dominance/relative BA and relative frequency (Curtis and McIntosh, 1950). Family importance value (FIV) was calculated following Mori *et al.* (1983).

Vegetation data were used for hierarchical agglomerative Bray-Curtis (Single-linkage) clustering analysis to combine plots of similar species and relatively comparable abundance into groups (Kassambara, 2017), thereby recognising the microclimatic variability across the humid temperate ecosystems (Shaheen et al., 2012). A two-sample Kolmogorov-Smirnov test was used to test the clustered groups.

The stand-structure of three forest types and stem-size distribution patterns of dominant species were assessed using tree size class distribution using DBH classes (m) and their BA (m²). Statistical significance of each size class distribution was tested by Kruskal Wallis test.

To visualise and summarise the inertia (information) within data, which consists of observations defined by several interrelated statistical variables, PCA was performed (Husson et al., 2017; Kassambara and Mundt, 2017). The relationship between environmental variables and tree species abundance besides within environmental variables and species were assessed by Canonical Correspondence Analysis (CCA; Ter Braak, 1987) utilising species abundance and environmental data. Permutation results were checked for model significance.

The R version 3.6.2 (R Core Team, 2019), PAST 3.26 (Hammer et al. 2001) and SPSS 25.0 statistical software also in addition to Microsoft Excel 2016 were adopted to perform the obligatory statistical data analysis.

Results

Compositional attributes

Species composition

From the total 143 plots of 0.25 ha (35.75 ha area) of three temperate forest types of Kashmir Himalaya, India, altogether 7808 trees (≥ 10 cm DBH) were enumerated, which belonged to 13 species, 13 genera and 8 plant families. Tree density was lowest (191.25 ha⁻¹) in BP forest, moderate (228.92ha⁻¹) in MC forest and maximal (232.72ha⁻¹) in SA forest (Table 1).

The species richness in three forest types varied from five species in SA forest and six in BP to a maximum of ten species in the MC forest. Out of 13 species, seven (53.9 %) were hardwood deciduous species, while the remaining six were evergreen coniferous species. One singleton species *Robinia pseudoacacia*, with just a single individual across the landscape, was confined to MC forest. Furthermore, uniques (species restricted to only one sample plot), two in BP forest (*Populus nigra* and *Juglans regia*) and three in MC forest (*Juglans regia*, *Aesculus indica* and *Robinia pseudoacacia*) were present. One duplicate (species present in only two sample plots) occurred in MC forest. However, no uniques or duplicates occurred in SA forest. Besides species richness in BP and SA forests, diversity indices varied across forest types. MC forest being most diverse, has eminent H' (1.1), D (0.6) and S (2.1) indices among the three forest types. The D scores unveiled just 37 % randomly chosen pairs consist of different species indicating overall low diversity across the landscape. Regression analysis displayed an influence of elevation on species count within forest types ($R^2_{BP} = 0.04$, $R^2_{MC} = 0.02$, $R^2_{SA} = 0.05$) and also across the landscape ($R^2 = 0.07$). Moreover, the number of species displayed a significant positive correlation with elevation ($r_s = 0.237$, $p \leq 0.01$) and density ($r_s = 0.18$, $p \leq 0.05$). Abundance scores revealed that BP and SA forests are monospecific dominant forest dominated by *Pinus wallichiana* (60.23%) and *Abies pindrow* (76.44%), respectively, whereas, MC forest dominance was shared by *Abies pindrow* (46.12%; dominant) and *Pinus wallichiana* (38.77%; codominant). Three species *Abies pindrow*, *Pinus wallichiana* and *Picea smithiana* were widespread and occurred in all three forest types (Table 1).

Table 1 Summary of tree inventory in low-level blue pine (BP), mixed conifer (MC) and subalpine (SA) forests of temperate Kashmir Himalaya, India

Variable	BP forest	MC forest	SA forest	Landscape-level
Tree abundance on plots (area sampled in ha)	1529 (8)	4460 (19.5)	1919 (8.25)	7908 (35.75)
Tree density (stems ha ⁻¹)	191.25	228.92	232.72	221.20
Mean DBH (cm)	46.96	52.62	55.06	52.12
Max. DBH (cm)	207.01	226.11	254.78	254.78
Total basal area (m ²)	367.90	1244.23	614.79	2226.92
Basal area (m ² ha ⁻¹)	45.88	63.81	74.52	62.29
Total no. of species	6	10	5	13
Dominant species & % abundance	<i>Pinus wallichiana</i> , 60.23%	<i>Abies pindrow</i> , 46.12% & <i>Pinus wallichiana</i> ; 38.77%	<i>Abies pindrow</i> , 76.45%	<i>Abies pindrow</i> , 46.51% & <i>Pinus wallichiana</i> ; 37.41%
Diversity indices				
Species richness (d=S/N ^{1/2})	0.15	0.15	0.11	0.15
Shannon-Weaver Index (H')	0.8	1.13	0.63	1.2
Simpson diversity Index (D)	0.47	0.62	0.37	0.63
Fisher's α index (S)	0.96	2.14	0.68	3.02
No. of evergreen species, their abundance and %	4, 1521, 99.48	5, 4423, 99.17	3, 1879, 97.86	6, 7822, 98.91
No. of deciduous species, their abundance and %	2, 8, 0.52%	5, 37, 0.83 %	2, 41, 2.13 %	7, 86, 1.08

There were no predictable contrasts in tree community composition due to a strong overlap among the studied forest types (Stress = 0.08; $R^2 = 0.99$). Out of 13 tree species documented, just three species were shared among the three forest types (Fig. 2).

One-way non-parametric ANOSIM revealed an overall compositional dissimilarity among forest types ($R = 0.12$; $p = 0.001$). Pairwise examination of forest types indicated that structural composition of BP forest varied considerably from MC ($p \ll 0.001$) and SA ($p \ll 0.001$) forests, although there were no noteworthy distinctions between MC and SA forest ($p = 0.8$) combinations. (Fig. S1).

Species accumulation and rarefaction curves

Species accumulation curve of BP, MC and SA forests for sampled plots 32, 78 and 33 respectively exhibited a monotonic increase and reached more or less an asymptote indicating that sufficient area was sampled (Fig. S2). In contrast to BP and MC forests, species-area curve of SA forest levelled off quickly after 4.25 ha (17 plots) of sampling. The number of species ranged from five to ten across the three forest types with six, ten and five species in BP, MC and SA forests, respectively. In BP and MC forests, 50 % of species were trapped within 12.5 % (1 ha) and 12.8 % (2.5 ha) sampled area, whereas it looks only slightly greater than 6.06 % (0.5 ha) area to capture 60 % of species count in SA forest. Plot-based rarefaction curves of BP, MC and SA forests attained an asymptote and the number of individuals to attain maximal within plot diversity ranged from just one to \approx 50 individuals. Bi-plot species richness in MC forest was maximum for plot MC-54 with five species, while in SA and BP forests with a maximum of four and three species in 4th/8th/17th and 7th/28th plots, respectively (Fig. 3).

Important value index (IVI), and family composition

Across the landscape, three abundant and frequent species; *Abies pindrow* (46.4 %), *Pinus wallichiana* (36.2 %) and *Picea smithiana* (11.0 %) shared > 90 % of IVI. *Pinus wallichiana* (206.1) among the species inventoried in BP forest exhibited maximum IVI followed by *Cedrus deodara* (45.2) and *Abies pindrow* (25.7). However, in MC and SA forests *Abies pindrow* (135.7; 216.7) followed by *Pinus wallichiana* (108.4; 46.8) were the most important species.

The tree species enumerated across landscape belonged to a total of eight families with three evergreen and five deciduous species. Taxonomically, Pinaceae was the most diverse and abundant family with four (30 %) species accounting for more than 98 % of total tree abundance, followed by Betulaceae and Sapindaceae with two species each. A significant variation in family richness was observed among the three forest types ($F = 7.77$, $p = 0.0004$). Among the forest types, MC was most diverse and speciose forest comprising of 10 species of seven families and 4460 tree individuals as compared to BP and SA forests with six and five species, respectively. At landscape level, five families harboured single species. Apart from being the only family common to all the three forest types, the Pinaceae was dominant ($FIV_{BP} = 293.59$; $FIV_{MC} = 278.75$ and $FIV_{SA} = 284.57$), followed by Salicaceae ($FIV = 3.33$), Sapindaceae ($FIV = 6.90$) and Betulaceae ($FIV = 14.40$) in BP, MC and SA forest respectively (Table S1).

Cluster analysis

In BP forest, the optimal number of clusters with maximal average Silhouette width represented two major clusters excluding an outlier (BP-1), which appeared as a distinct cluster (Fig 4a). Two-sample Kolmogorov-Smirnov test for the distribution of individuals among the clusters proved to be insignificant ($D = 0.67$, $p = 0.14$).

In MC forest, irrespective of a couple of outliers (MC-41 and MC-47), two principal clusters with an agglomerative coefficient of 0.8 seemed to be more informative as per the average Silhouette method (Fig. 4b). Nevertheless, in relation to BP forest, statistical analysis unveiled an insignificant distribution of individuals between the clusters ($D = 0.3$, $p = 0.75$) in MC forest. SA forest, in contrast to BP and SA forests, formed a single large cluster with a relatively low agglomerative coefficient of 0.7 (Fig 4c).

Structural heterogeneity

Stand density and basal area (BA)

The cumulative tree density and BA of the study plots from the three temperate forests were 7908 individuals and 2226.9 m² in 35.6 ha area (Table 2). Tree density and BA ranged from a low of 72 stems ha⁻¹ in SA forest to as high as 924 stems ha⁻¹ in BP forest and 13.0 m² ha⁻¹ and 125.7 m² ha⁻¹ BA in MC forest respectively.

Tree density did not vary significantly among the three forest types ($F = 1.159, p = 0.317$). In BP forest, mean stand density (191.1 ± 29.2 stems ha⁻¹) was lower than overall mean stand density (221.2 ± 10.6 stems ha⁻¹) in contrast to MC forest (228.7 ± 12.8 stems ha⁻¹) and SA forest (232.6 ± 20.6 stems ha⁻¹). Furthermore, stand density in sampled plots of MC and SA forests, ranged from 72 – 632 stems ha⁻¹ and 72 – 628 stems ha⁻¹ respectively whereas, it was markedly greater 72 – 924 stems ha⁻¹ in BP forest.

A considerably significant variation in BA was obtained across the three forest types ($F = 9.824, p \ll 0.001$) principally contributed by BP-SA and MC-BP forest pairs (Fig. S3a). Tree BA was maximum 74.5 ± 4.5 m² ha⁻¹ in SA forest followed by 63.8 ± 2.9 m² ha⁻¹ and 46.0 ± 3.6 m² ha⁻¹ in MC and BP forests respectively. Further, mean BA in MC and SA forest stands was more remarkable than landscape-level mean stand BA (62.3 ± 2.2 m² ha⁻¹). Although BA displayed different elevation patterns within three forest types, BA across the landscape showed a hump-shaped pattern, which decreased rapidly towards the end with elevation.

Density and diversity-diameter class distribution pattern

Tree density, species count and H' followed an inverse trend with larger diameter classes from 10 – 270 cm leading to nearly a hierarchical pattern. Nonetheless, species occurrence rate defined as the ratio of species count to density increased proportionally with increasing diameter class. Notably, the contribution of the lowest diameter class was 26.3 % to all individuals inventoried and 92.3 % to all total species count encountered (Table S2). Moreover, an insignificant dissimilarity is evident in the share of trees segregated into 12 diameter classes to density ($F = 0.07294, p = 0.9298$) and number of species ($F = 1.018, p = 0.3725$).

The density-diameter distribution followed the above-generalised pattern, besides 30 – 50 cm and 10 – 30 cm classes in BP and MC forests, respectively, in which density of former class was less than the subsequent diameter class. Relative distribution of density to various diameter classes revealed that threshold diameter class (10 – 30 cm) in BP forest shared 38 % of all individuals whereas, it was only 24.57 % and 22.76 % in SA and MC forests. Notably, in MC forest, 60 – 90 cm class scored 3.36 % greater density than lowest diameter class.

Species diameter-dominance does not show much variation in three forests. Although species diameter-dominance does not vary in SA forest (10 – 190 cm), BP and MC forests displayed a shift from *Pinus wallichiana* (10 – 110 cm) to *Abies pindrow* (110 – 150 cm) and again to *Pinus wallichiana* (190 – 210 cm), and *Abies pindrow* (10 – 170 cm) to *Picea smithiana* (170 – 230 cm), respectively (Table S2).

The relative distribution of species and H' to lower diameter class among three forests ranged from a low of four (in BP forest) and 0.64 (in SA forest) to 10 (in MC forest) and 1.20 (in BP forest). In contrast to MC and SA forests, species count was maximum in diameter class subsequent to threshold diameter class in BP forest. Similarly, besides MC forest, H' scores in BP and SA forests were maximum in diameter classes (90 – 110 cm & 50 – 70 cm) rather than threshold diameter class. Maximum species count reduction with diameter class was displayed in MC forest (ten-fold), followed by SA forest (five-fold) and least in BP forest (four-fold). Species

occurrence rate scores among three forests were maximum in MC forest in 170 – 190 cm class followed by SA forest in 250 – 270 cm and BP forest in 190 – 210 cm class. 3.2.1. The forest stand-structural heterogeneity

Abundance-based stand structure of BP, MC and SA forests exhibited a reverse J-shaped pattern with abundance frequency distribution declining with respect to increasing diameter class (Fig. 5). The difference in the distribution of individuals to various size classes was significant (Kruskal-Wallis $\chi^2 = 32.06$; $df = 11$; $p = 0.0007$) among the three forest types (Fig. S3b). More than 50 % of individuals fell within the first three diameter classes. The lowest diameter class (10-30 cm) share to abundance in MC forest accounted for 22.8 %, lower than two successive diameter classes, i.e., 30 – 50 cm (26.1 %) and 50 – 70 cm (26.1 %); nonetheless, the trend is quite reverse in BP and MC forests. Although the diameter class distribution pattern in SA and BP forests were more or less similar, there was a sharp decline in MC forest due to very dense first three diameter classes than other two forests. Among the forest types, mean DBH was maximum in SA forest (55.1 cm) followed by MC forest (52.6 cm) and least in BP forest (47.0 cm), thus indicating greater frequency of large-diameter class trees as compared to small-sized trees in SA forest. Moreover, trees with maximum DBH across sampled plots were found in SA forest. Except for one or more diameter class gaps in

all three forest types, none of them harboured even a single tree in 230 – 250 cm class, although 250 – 270 cm size class featured in SA forest.

Nevertheless, with regard to BA, stand structure unveiled an asymmetric Gaussian or bell-shaped curve with a smaller BA in highly dense lower diameter class, reaching a maximal between 70 – 110 cm class across the forest types, and lowered towards the end. Distribution of BA to various diameter classes among the three forest types varied significantly (Kruskal-Wallis $\chi^2 = 31.26$; $df = 11$; $p = 0.001$, Fig. S3c). The R^2 values for abundance and BA varied between 0.64 to 0.80 and 0.37 to 0.39, respectively, for BP and SA forests and were found statistically significant in all three forest types (Fig. 5).

Stem size heterogeneity of dominant species

Structural heterogeneity of top three dominant species drawn by analysing diameter class frequency distribution and BA varied within species in three forest types (Fig. S4). By forest type, dominant species with maximum abundance also varied: *Pinus wallichiana* in BP forest and *Abies pindrow* in both MC and SA forests. Generally, the abundance of each dominant species in three forest types declined with size class increase. However, structural pattern ranged from perfect 'L' or reverse J-shaped distribution in *Abies pindrow* and *Picea smithiana* within MC and SA forests to asymmetric inverse J-shaped curve holding at a minimum one missing or less dense size class other than lower size class as in *Cedrus deodara*. Moreover, an inverse J-shaped pattern with lesser number of individuals in threshold diameter-class than subsequent classes, as depicted in *Pinus wallichiana* and *Abies pindrow* in BP forest and asymmetric normal or bell-shape resulted from the preponderance of individuals in middle size class as displayed in *Pinus wallichiana* within SA forest. The regression coefficient (R^2) with level of significance (p) value for abundance varied from species to species. The R^2 with p -value ranged from 0.505 to 0.933 with $p \leq 0.001$ to ≤ 0.05 . Notably, the highest R^2 with p -values was 0.933 with $p \leq 0.001$ for *Picea smithiana* in MC forest indicating a highly significant correlation between the size class and abundance.

The BA distribution followed a trend of asymmetric Gaussian or normal curves for all dominant species except *Picea smithiana* from MC forest (Fig. S4b). Tree species with the maximal BA were the same with maximum abundance, thus alluded to a considerable number of individuals in higher diameter classes. The BA R^2 with p -value ranged from 0.123 for *Cedrus deodara* in BP forest with $p \leq 0.001$ and *Pinus wallichiana* in SA forest with $p \leq 0.05$, to 0.244 with $p = 0.08$ for *Abies pindrow* in BP forest.

Distribution patterns

Variables on the PCA plot diagram are scattered based on their correlations. A longer distance between origin and projected variable as in mean BA, H_{max} , and smaller angles among the variables respectively indicated a greater quality of the variable and relevance among one another (Fig. 6). The mean DBH, mean BA, H_{max} and also species count, and S (although less than the former three) exhibited high \cos^2 values, thus well represented and were positioned adjacent to the perimeter. However, more than two components were required to thoroughly interpret the variables closer to the point of commencement.

Eigenvalues, an estimate of the magnitude of total inertia retained by each dimension, were examined to determine the estimated number of dimensions. As *eigenvalues* consistently decrease with the number of dimensions, the top five principal components with eigenvalues above one accounted for more than 80% of total inertia, hereafter the residual scores were comparatively insignificant and were analogous to one another (Fig. 7). For axis-1, the most significantly associated variables were H_{max} , species count, S, elevation and density with $p \leq 0.0001$, thus interpreted as diversity axis, as diversity indices explained > 80% of inertia of the given axis. The below expected average contribution variables followed the order: UTM-E (Universal Transverse Mercator easting) \times slope \times UTM-N (Universal Transverse Mercator northing) \times aspect \times mean BA \times density \times mean DBH \times elevation. Nonetheless, variables such as mean BA, mean DBH, density, etc., were significantly associated with axis 2 ($p \leq 0.0001$). However, lower scores of the order of magnitude were UTME-E \times slope \times UTM-N \times aspect \times mean BA \times density \times elevation \times mean DBH. Although significant variables contribute >85% of total inertia to axis 2, altogether 23.6% of total inertia or variance was interpreted by dimension-2. Subsequent dimensions lacked considerable interpretation power.

Individual plots and variables positioned on the same side indicated a high value of the latter for the former and *vice versa*. In Fig. 7, most of the BP forest plots were concentrated opposite to diversity indices (species count, H_{max} , and S indices) and elevation and in positive direction with well-represented dominance and poorly interpreted aspect and UTM-E; in contrast, most of the plots of MC forest were scattered almost all over the factor map. Further, projection points of some SA and MC forests plots scattered in the direction of mean DBH, mean BA, and also towards density, UTM-N and slope projection, thus indicated an association between stand characteristics and location features.

Among all documented variables, elevation and slope formed the principal environmental factors restricting the tree abundance and species distribution as indicated by the length of projections in the CCA plot (Fig. 7).

Eigenvalues for the first two axes were 0.21 (CCA1) and 0.09 (CCA2) with a total of 93.59 % of explained inertia of tree species variability ($p = 0.001$; Table 2). The first axis (CCA1) explained 63.81 % of data inertia and was mainly related to elevation, thus separating low elevation tree species (*Cedrus deodara*, *Robinia pseudoacacia*,

Aesculus indica, etc.) from higher ones ($p = 0.001$), mainly *Betula utilis* (Table 2). Similarly, the second axis (CCA2) was related to the rest of the variables, particularly slope ($p = 0.008$) and interpreted 29.78 % of the explained variance. However, the second axis mainly bifurcated tree species of steep (*Taxus baccata* and *Acer caesium*) and gentle slopes (*Juniperus macropoda*, *Cedrus deodara*, etc.; Fig. 7).

Table 2 Summary of CCA analysis. (VIF; variance inflation factor, UTM-E; universal transverse Mercator-easting, UTM-N; universal transverse Mercator-northing)

VIF					Eigenvalue (% explained inertia)				
UTM-E	UTM-N	Elevation	Slope	Aspect	CCA1	CCA2	CCA3	CCA4	CCA5
1.15	1.53	1.04	1.47	1.01	0.21 (63.81)	0.098 (29.78)	0.013 (3.95)	0.006 (1.82)	0.002 (0.60)
Permutation test for testing significance of CCA model					Permutation test the significance of first CCA-axis				
χ^2		F-value	p -value		χ^2		F-value	p -value	
0.331		2.31	0.001		0.21		7.327	0.001	
Permutation test for testing significance of environmental variables									
			χ^2	F-value	p -value				
			Elevation	0.174	6.13	0.001			
			Slope	0.079	2.8	0.01			

Discussion

The number of tree species in the three forest types of Kashmir Himalaya ranged from five to ten, and this is congruent with various phytosociological studies from Himalayan forest ecosystems (Khera et al., 2001; Khera et al., 2001; Khera et al., 2001; Pandey et al., 2018), and also from the Alps in vicinity of Austrian border (Karrenberg et al., 2003) and Ontake forest reserve, Honshu Island, Japan (Miyadokoro et al., 2003). The number of tree species is, however, lower than those of the western part of Central Himalaya, Uttarakhand (India) with 16 tree species (Semwal et al., 2010), South Island of Tsushima (Japan) with 45 woody species (Manabe et al., 2000), and Dolpa district in rain shadow of north-western Nepal with 16 tree species (Kunwar et al., 2004). Although a decrease in the number of species with elevation is considered as a general pattern (Francis and Currie, 1998), consistent with the present study, the number of species was greater in the mid-elevation zone similar to the results reported by Lomolino (2001), Alexander et al. (2011) and Fosaa (2004) that was occupied by MC forest in our study area. This can be explained by Gleason's individualistic concept of plant assemblages, which stipulates that the dissemination of every species is driven by its own ability to endure, contend and

reproduce effectively in prevailing environmental conditions (Gleason, 1926). In the Himalayan region, a slight variation in the number of species within the elevation range of 1500 m – 2500 m subsequently decreases with rising elevation (Grytnes and Vetaas, 2002). Nonetheless, microclimate with variability in edaphic properties and differences in aspect and direction of the studied sites could have possibly resulted in such trends (Ferrer-Castán and Vetaas, 2003).

The H' of diversity scores for the present study is within the published estimate of 0.28 to 1.75 (Sharma et al., 2010) and 0.4 to 2.8 (Singh et al., 1994) for the Himalayan range. However, D values were lower than the Western Himalayan forests of Kashmir, Pakistan, as reported by Shaheen et al. (2012). A negative association between evenness and elevation was found in the studied forests, decreasing linearly with elevation, in contrast to studies from other parts of Himalaya (Dar and Sundarapandian, 2016; Shaheen et al., 2012). Furthermore, low evenness scores in SA forests among the three forest types may be due to competing out the other species for resources by dominant ones (Murcia 1995).

The recorded stand density in the studied three forest types was within the range reported for other Himalayan temperate forests, 120 – 374 stems ha^{-1} in Khangchendzonga National park, Sikkim, India (Pandey et al., 2018), 90 – 277 stems ha^{-1} in Western Himalaya, Pakistan (Shaheen et al., 2012), 170 – 283 stems ha^{-1} in Central Himalaya, India (Chaturvedi and Singh, 1986), 103 – 1201 stems ha^{-1} in North-western Himalaya, India (Dar and Sundarapandian 2016) and elsewhere, 216 – 874 stems ha^{-1} in Northern New Zealand (Ahmed and Ogden, 1987) and 24 – 930 stems ha^{-1} in Suleiman Range, Zhob city, Pakistan (Ahmed et al., 1991). However, it was lower when compared to the reported density of 540 – 708 stems ha^{-1} in ridge forests, Garhwal Himalaya, India within the elevational range of 1300 m - > 3400 m (Sharma et al., 2018), 1434 stems ha^{-1} in Huoditang forest region, North-western China (Kang et al., 2017), 295 – 850 stems ha^{-1} in Central Himalaya (Sharma et al., 2010) and 754 stems ha^{-1} in Ontake forest reserve, Honshu Island, Japan (Miyadokoro, et al., 2003). The lower density in the BP forest among the three forest types might be due to various anthropogenic disturbances such as the illegal felling of *Pinus wallichiana* and *Cedrus deodara*. Furthermore, uncontrolled grazing and extraction of non-timber forest products (NTFPs) in these forest stands could have affected the regeneration process. Overall, Kashmir Himalaya recorded a low tree density than the rest of the Himalayan regions, probably attributable to prolonged cold winter spanning about five months.

The BA has been considered as one of the robust components to study the vegetation structure within forest stands (Pragasam and Parthasarathy, 2010). In our study, the BA ranged from 45.88 – 74.52 $m^2 ha^{-1}$, indicating an overall good forest stand structure. The BA reported by Kunwar et al. (2004) (90.1 – 151.9 $m^2 ha^{-1}$) in Nepal, Pande (2001) (86 – 129 $m^2 ha^{-1}$) in Garhwal, India exceeds our documented range. However, Shaheen et al. (2012) reported closer BA values from the Western Himalayan temperate forests of Kashmir, Pakistan. Due to the extremely limited stocking of large-sized trees, BP forest displayed a low BA among the three forest types. The absence of such large size class trees points to anthropogenic disturbances as the fundamental cause mostly during the 1990s. The unconditional felling of middle and large size class of *Pinus wallichiana* and *Cedrus deodara* trees during the 1990s forestalled recovery and resilience, and in our inventory, trees that have attained larger size class were those older trees which existed before 1990s.

Cluster analysis results based on tree abundance and inventoried tree species in three different forest types indicated two different associations in BP and MC forest besides outliers in contrast to SA forest where there

were no such associations (Fig. 4).

Distribution of tree individuals across various diameter classes implies onsite resource utilisation by the tree crop (Pragasan and Parthasarathy, 2010) and also affects multifunctionality and species diversity through multiple ecological processes within forest ecosystems (Yuan et al., 2018). A smaller tree number in the lower and medium-size classes indicates a lesser utilisation of land resources by the trees (Hitimana et al., 2004). An inverse 'J' or perfect 'L' shaped pattern of diameter class distribution is characteristic for forests with a good regeneration process (Khamyong et al., 2004) and also for undisturbed forests. The patterns were in agreement with the Western part of the Himalayas (Dar and Sundarapandian, 2016). Nevertheless, when examined by forest type and dominant species within forest types, the differences in the pole sizes, particularly in 30 – 50 cm and 10 – 30 cm dbh classes, were apparent in the BP and MC forests respectively, correspondingly as in *Pinus wallichiana* among all three forest types (Fig. S4). This disparity is less apparent in SA forest. Multimodal distributions of the size classes are generally demonstrative of disturbance influence in the area (Spies, 1998). Typically, old-growth forests entering an equilibrium state show a lopsided size structure (Leak, 1996); however anthropogenic interventions, for example, selective logging, expels trees and opens the canopy permitting new regeneration and establish uni-, bi-, and multimodal distributions.

The most abundant species are regularly used to characterise the forest structure (Valencia et al., 2004) and in the present study, the most abundant species include *Abies pindrow*, *Pinus wallichiana*, *Picea smithiana*, and *Cedrus deodara* contributed more than 98 % (7761 stems in 35.75 ha) of total tree abundance. Similarly, *Abies pindrow* and *Pinus wallichiana* were recorded as abundant tree species in Indian temperate Himalaya and elsewhere (Kunwar et al., 2004; Gairola et al., 2010; Shaheen et al., 2012). The occurrence of common dominant species across all three forest types may be attributed to wind dispersal syndrome, characteristic in these habitats. This dispersal mechanism represents a significant method for translocation of species to isolated environments of similar climatic patterns (Jacobi and Carmo, 2011).

Pinaceae (represented by four species), Betulaceae and Sapindaceae (two species each) in the inventoried 35.75 ha area of the present study constituted the most speciose families, while Gairola et al. (2010) also found Pinaceae with five tree species as the dominant one in 0.2 ha in community forests of Dolpa district, Nepal.

The association among the tree species concludes their almost equivalent response to prevailing environmental conditions (Fig. 2). The CCA plot demonstrated that environmental variables *viz.*, elevation and slope were the major operational factors in influencing the species distribution within the studied area (Fig. 7). In CCA analysis, CCA1 is considered to be the most influencing axis (Gebrehiwot et al., 2018), thus indicating that elevation governs the distribution of species in the present study as also reported by Gebrehiwot et al. (2018) from Abune Yosef mountain, Ethiopia; Sharma et al. (2018) from Bhagirathi catchment area of Garhwal Himalaya, India; Irl et al. (2015) from La Palma of Canary Islands, Spain; Shaheen et al. (2012) from Western Himalaya, Pakistan, were also reported the influence of elevation on species distribution pattern. As the elevation difference between the minimum and maximum elevation is 1500m, this trend certainly represents environmental variations between locations such as climate and soil changes.

In contrast to elevation, topographical factors such as slope and aspect were strongly correlated to CCA2 and also play a significant role in growth, diversity, and dispersal of tree species in the present context. This could be because topographical factors are known to influence both edaphic (physical and chemical properties of the

soil) notably soil moisture (Parker 1991), water retention (Sariyildiz et al., 2005) and transport and retention of nutrients (Zuo et al., 2012) and biotic parameters of the area, such as forest productivity (Hutchins et al. 1976), thus indirectly affecting the distribution of tree species (Dessalegn et al., 2014; Wang et al., 2016; Gebrehiwot et al., 2018).

Conclusions

The quantitative landscape-level inventory of diversity in low-level blue alpine (BA), mixed conifer (MC) and sub-alpine (SA) forests of temperate Kashmir Himalayas, India revealed an overall low diversity with more or less heterogeneous tree composition. The species diversity across the three forest types was maximum in MC forest (mid-elevation zone) followed by BP and SA forests. Three coniferous tree species *Abies pindrow*, *Pinus wallichiana* and *Picea smithiana* were shared by all three forest types. The ordinations revealed elevation and slope as principal drivers that affect species distribution across the forest types. The research data generated on forest tree diversity and stand structure from this study will be valuable and can potentially be utilised for conservation and management of forest of the three studied temperate coniferous forests and similar temperate forests.

Abbreviations

ANOSIM: Analysis of similarity; BA: Basal area; BP: Low-level blue pine; CCA: Canonical correspondence analysis; D: Simpson diversity Index; DBH: Diameter at breast height; FIV: Family importance value; GBH: Girth at breast height; GPS: Geographical Positioning System; H_{max}: Shannon-Weaver Index; IVI: Important value index; MC: Mixed conifer; NMDS: Non-metric multidimensional scaling; NTFPs: Non-timber forest product; PCA: Principal component analysis; S: Fisher's α index; SA: Sub-alpine; SPSS: Statistical Package for the Social Sciences; UTM-E: Universal transverse mercator easting; UTM-N: Universal transverse mercator northing; VIF: Variance inflation factor.

Declarations

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Authors' contributions

AAD and NP added to the study plan; AAD collected the data, did the analysis and wrote the manuscript under the supervision of NP.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

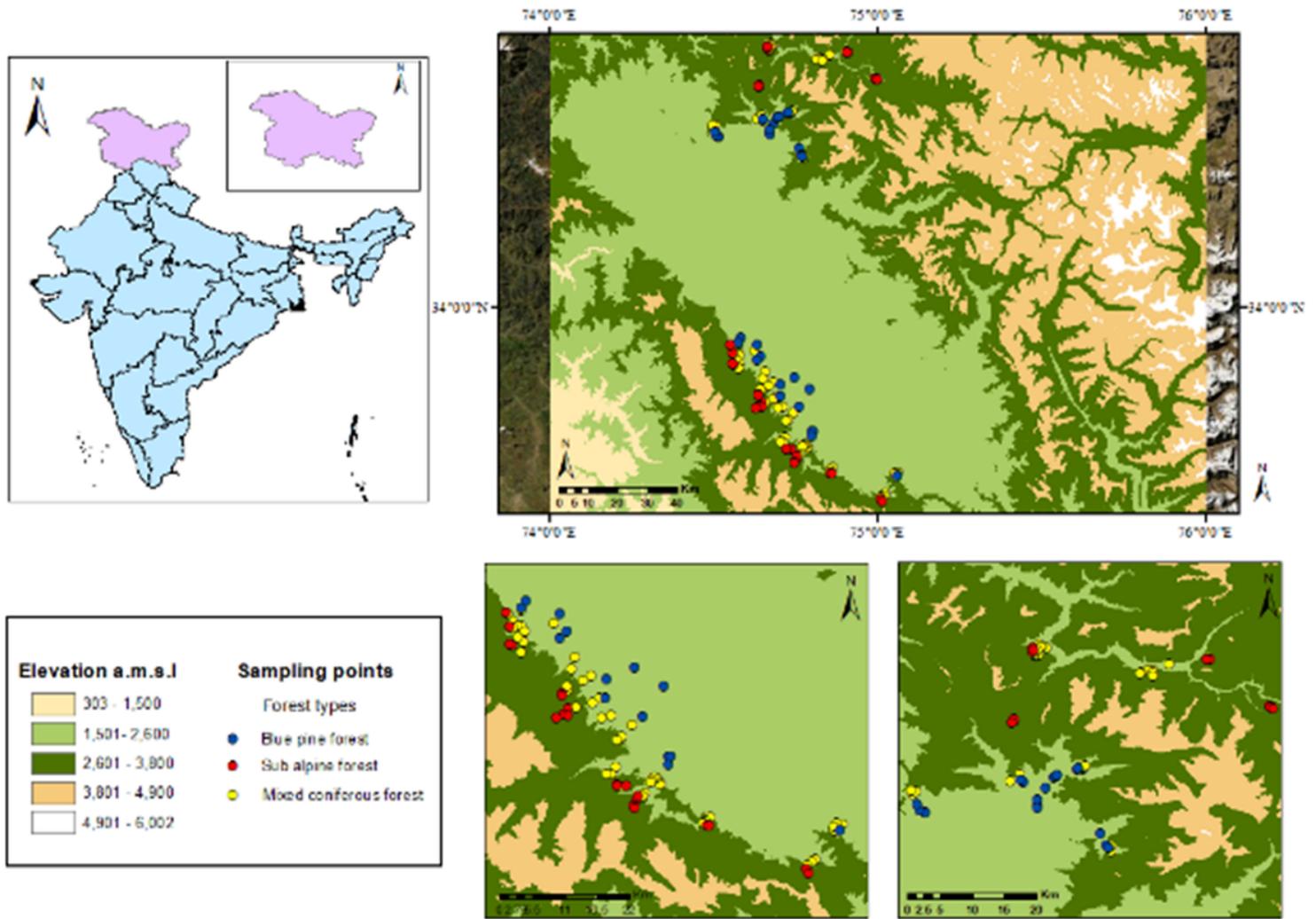


Figure 1

Geographical location of sampled plots in three forest types of temperate Kashmir Himalaya, India. 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.

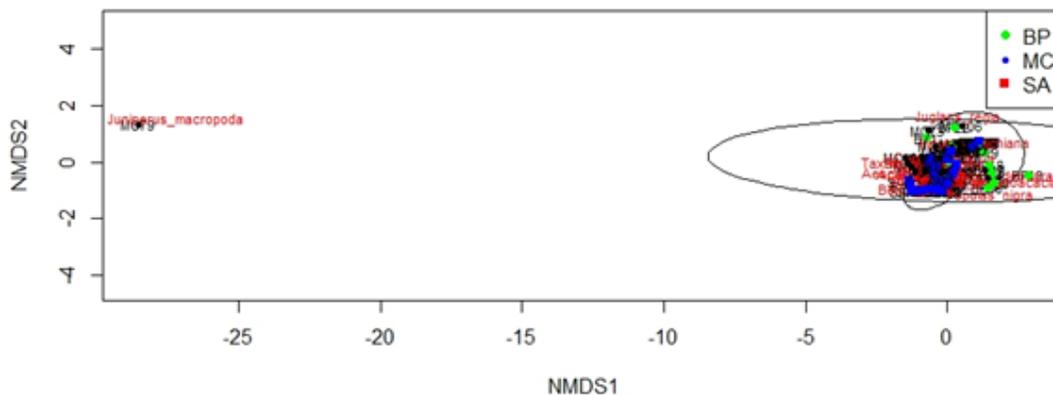


Figure 2

Non-metric multidimensional scaling (NMDS) analysis for three temperate forest types of Kashmir Himalaya, India. Small circles indicate the site and forest type. Plus symbols represent species scores. Names of the tree species are shown in red.

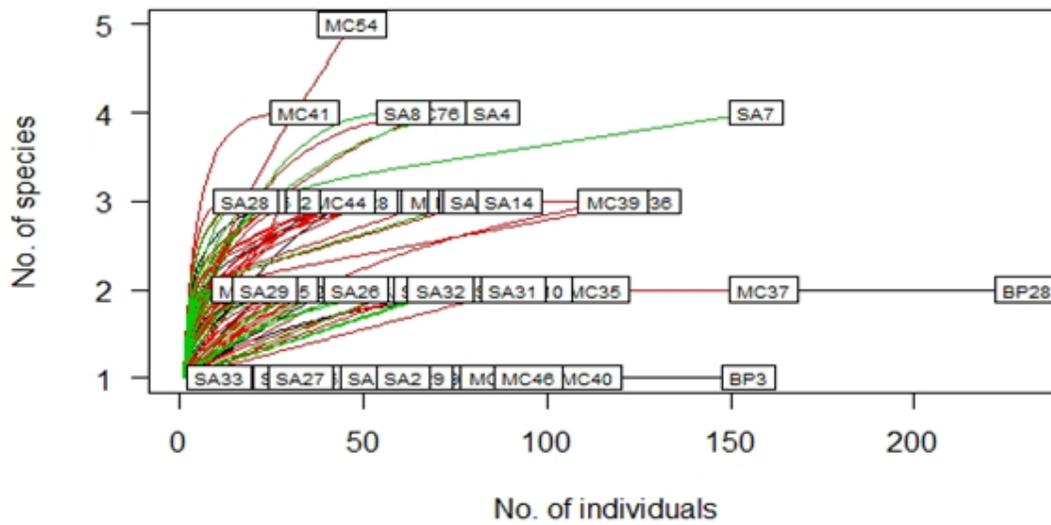


Figure 3

Rarefaction curve for 143 plots of (a) low-level blue pine (BP), (b) mixed conifer (MC) and (c) SA forests of temperate Kashmir Himalaya, India. Numeric numbers indicate the plots number within the respective forest type.

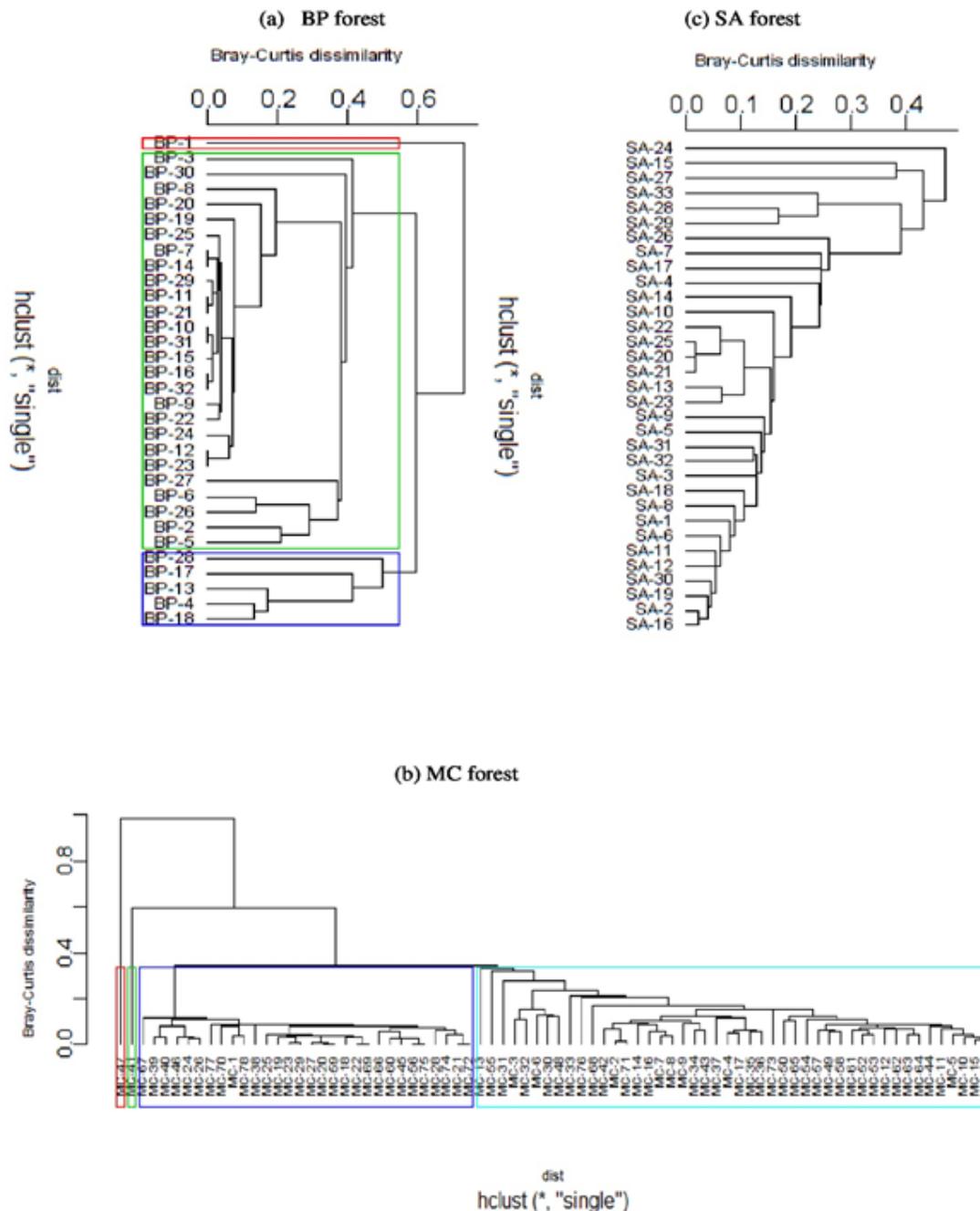


Figure 4

Dendrograms of Bray-Curtis (Single-linkage) cluster analysis based on species count and abundance in (a) low-level blue pine (BP), (b) mixed conifer (MC) and (c) SA forests of temperate Kashmir Himalaya, India

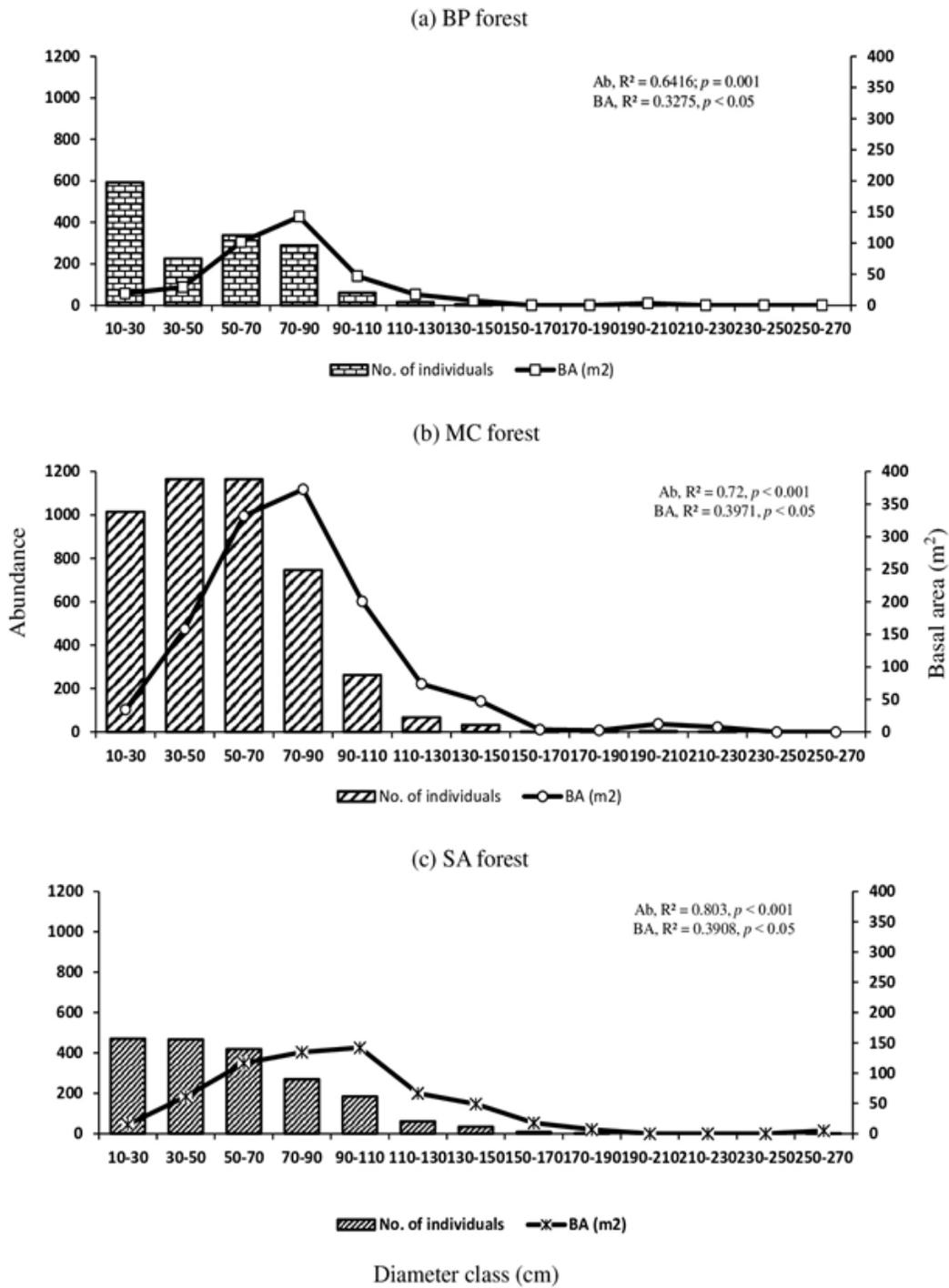


Figure 5

Abundance and BA by diameter class of tree species in (a) low-level blue pine (BP), (b) mixed conifer (MC), and (c) subalpine (SA) forests of temperate Kashmir Himalaya, India.

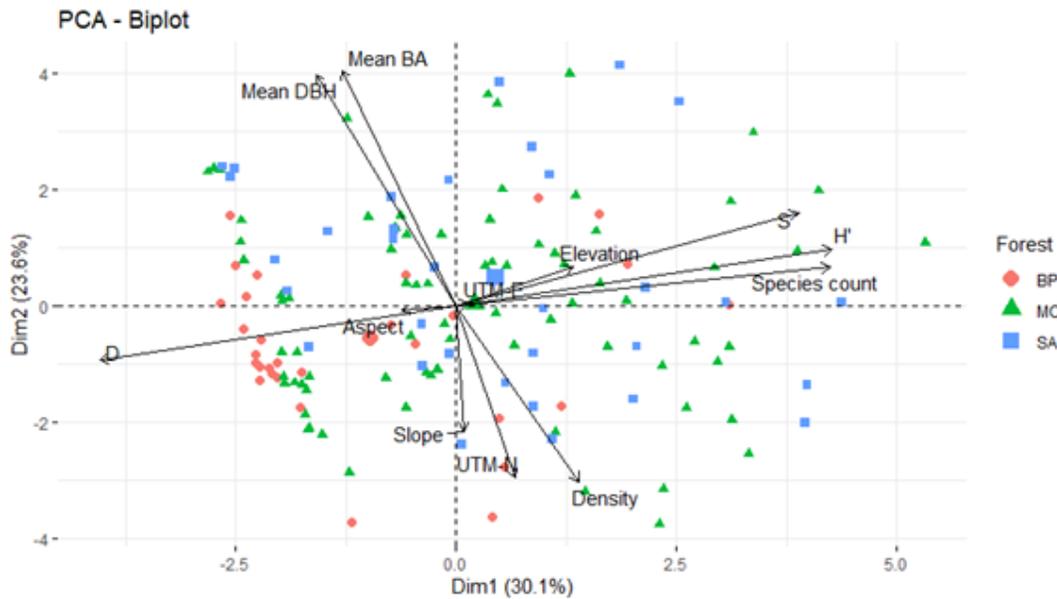


Figure 6

PCA ordination biplot diagram of 143 plots from BP, MC and SA temperate forests of Kashmir Himalaya for environmental factors, tree diversity, stand characteristics and geographical location. S, Fishers- α index; H' , Shannon-Wiener index; UTM-N, universal transverse mercator northing; D, Simpson index; UTM-E, universal transverse mercator easting.

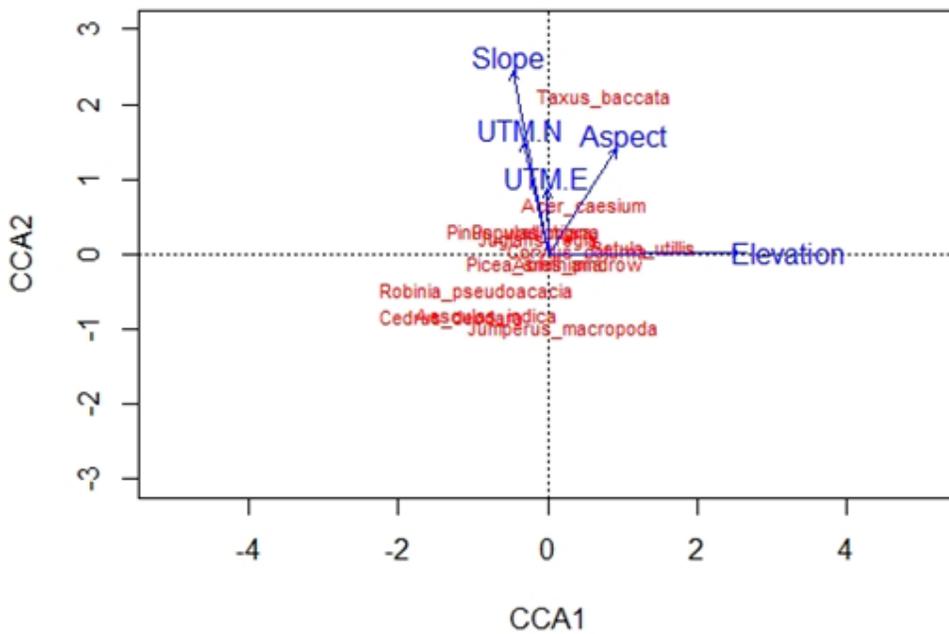


Figure 7

The plot of tree species and environmental variables (lines with arrows) from Canonical Correspondence Analysis.

Supplementary Files

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