Influence of Environmental Factors on Tree Species Diversity and Composition in the Indian Western Himalaya

Shinny Thakur

Govind Ballabh Pant National Institute of Himalayan Environment and Sustainable Development

Rupesh Dhyani

Institut national de la recherche scientifique

Vikram S Negi (✉ vikramsnegii@gmail.com)

Govind Ballabh Pant National Institute of Himalayan Environment and Development

<https://orcid.org/0000-0002-3380-7930>

I D Bhatt

Govind Ballabh Pant National Institute of Himalayan Environment and Sustainable Development

A K Yadava

Kumaun University

Research

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Abstract

Understanding patterns and forest communities and its driving factors play a critical role in ecological studies. In view of this, present study attempted to understand the role of environmental and anthropogenic factors in relation to species diversity and composition along the altitudinal gradient (700-4000 m asl) in Indian western Himalaya. A total of 51 tree species (28 families) were recorded; pinaceae (5) and fagaceae (5) were the species rich families. α -diversity indices i.e., Margalef's richness index (R), Shannon index (H') and Simpson index showed a humped shaped distribution, whereas Evenness index (E) showed an inverted humped shaped distribution along the altitude range. Based on non-metric dimensional scaling (NMDS), four different community types were identified. Redundancy analysis (RDA) revealed a strong relationship of tree species composition with environmental (41.73% variation) and anthropogenic factors (17.35% variation). RDA further indicated that the bulk density (BD), disturbance index (DI), mean diurnal temperature range (Bio2) and solar radiation (SR) are significantly associated with sub-tropical (below 1200 m) and lower temperate forest (1200-1700 m) types. Likewise, soil organic carbon (SOC), precipitation of the driest quarter (Bio17) and pH were significantly associated with upper temperate (1700-2900 m) and subalpine forest composition (<2900 m). Both NMDS classification and RDA ordination clearly demonstrate spatial variability in composition of tree community and environmental properties.

1. Introduction

The importance of mountains for biodiversity and sustaining ecosystem services, has been recognized for long specifically in the aftermath of Rio Earth Summit (1992) when Chapter 13 Agenda 21 (1992) established mountains as an important habitat that support all forms of living organisms (UN 1992). Mountains are home to 50% of global biodiversity hotspots, and support approximately one-quarter of world's terrestrial biological diversity (Spehn et al., 2010; Price et al., 2011). Among others, the Himalaya has been recognized as one of the globally important biodiversity hotspots that encompasses world's most diverse montane environment, characterized by high diversity of both plant communities and species (Kala et al., 2002; Oommen and Shanker, 2005; Rawal et al. 2013; Boscutti et al., 2018; Negi et al. 2019).

Indian Himalayan Region (IHR) represents a large part of Himalayan Biodiversity Hotspot, where richness, representativeness, and uniqueness of biodiversity components (at gene, species and ecosystem levels) are well recognized (Rawal et al. 2013). Further, IHR is well known for diversity of forest types across its horizontal and vertical extent with 41.47% of total forest cover of the country. The composition of forest community and distribution of plant species in the region is the reflection of environmental gradients (Chawla et al., 2008; Chian et al., 2016; Gómez-Díaz et al., 2017; Ahmad et al., 2020). The spatial variation of biodiversity along altitudinal gradients is one of the basic issue and important aspect in biodiversity research in IHR (Rawal et al. 2018). The higher species diversity in the region is broadly characterized by physiography, climate, soil, and anthropogenic disturbance (Shah et al., 2011). As such, forest in the Himalaya are reported vulnerable to climate change and subjected to severe ecological deterioration due

to anthropogenic pressures (Upgupta et al., 2015; Chakraborty et al., 2016; Sharma et al., 2017; Negi et al. 2018a; Thakur et al., 2020). Studies have demonstrated that anthropogenic activities are responsible to change the species richness, diversity, and distribution patterns, and subsequently influence the edaphic and environmental conditions (Ahmad et al., 2018; Wang et al., 2019).

Among various ecological parameters, plant species diversity has attracted particular attention because of its applicability in assessing current species performance and predicting future community composition (Wang et al., 2008). Especially, assessment of forest community structure and composition in mountain ecosystem is very helpful in conservation and management planning (Körner, 2007; Chawla et al., 2008; Chian et al., 2016; Gómez-Díaz et al., 2017; Lopez-Angulo et al., 2018; Negi et al. 2018b; Ahmad et al., 2020). Majority of the earlier studies focuses on species composition and vegetation distribution in the different locations i.e., Dhauldhara mountain in Himachal Pradesh (Ahmad et al., 2020), Bhabha valley (Chawla et al., 2008), Uttarakhand Kumaon Himalaya (Rawal & Pangtey 1994); Garhwal region (Hussain et al., 2008; Sharma et al., 2018; Negi et al. 2018a,b; Rawal et al. 2018), Khangchendzonga landscape in Sikkim (Sinha et al., 2018), east Nepal (Bhattarai and Vetaas, 2003), and central Nepal (Bhatta et al., 2018) of the Himalayan regions. However, the patterns of plant diversity across altitudinal gradient in relation to environmental and anthropogenic factors are less known in the Himalayan region. Therefore, present study aim to address the following research questions: (i) how the composition and structure of tree communities vary along altitudinal gradient? and (ii) what environmental and anthropogenic factors influence the pattern of community composition and diversity along the altitude?

2. Material And Methods

2.1. Study area

The district Pithoragarh in Uttarakhand (western Himalaya), India covers 7,090 sq km area and ranges from 436 to 7117 m asl in altitude, forms the broad study area (Fig. 1a). The study area comprises with 505 sq km under Very Dense Forest (VDF), 965 sq km under Moderately Dense Forest (MDF) and 609 sq km under Open Forest (OF) according to FSI (2019). The study area shares international boundaries with Tibet (Autonomous Region of China) and Nepal. This region is an important ecological landscape with varied topography ranging from outer Siwalik to inner high Himalaya represented with diversity of vegetation and forest types covering subtropical to alpine vegetation (Champion and Seth, 1968). As for most of west Himalaya, the study area is altitudinally divisible into subtropical (300 to 1500 m), temperate (1500 to 3500 m) and alpine (>3500 m) zones according to Saxena et al. (1984). During the winters (December-January), the sub-tropical and temperate mountain ridges receive snowfall and having average temperature range between 5.5–8.0 °C (Fig. 1b).

2.2. Vegetation survey and measurement of anthropogenic factors

Along the altitude range between 700-4000 m asl, a total of 37 forest sites were investigated based on previous studies from the region (Negi et al. 2018a, 2019; Rawal et al. 2018; Thakur et al. 2020).

Vegetation assessment in each targeted forest sites were conducted using three randomly placed (50 x 50m) stands. In each stand, 5 quadrats (10m X 10 m) were laid randomly for enumerating tree species. Vegetation data was generated to assess frequency, density and abundance following the standard phyto-sociological approaches (Misra, 1968, Muller Dombois and Ellenberg, 1974; Negi et al. 2018a; Rawal et al. 2018). Quadrat data of each stand was pooled to estimate tree species richness. The α -diversity indices; Margalef's richness index (R), Shannon index (H'), Simpson index (I), and Evenness index (E) was calculated in 'vegan' package using R following Oksanen et al. (2019) and their detail description is given in Table 1. Lopping intensity (LI) and cut stump intensity (CSI) was used as a indication of anthropogenic disturbance. Cut stump intensity was determined following Murali et al. (1996), and lopping intensity was calculated following Rawal et al. (2012). Both the disturbance indicators were calculated for each stand and then averaged to make it representative for a particular forest. After calculation of CSI and LI, disturbance index was calculated following Rawat (2013). The intensities of cut-stump and lopping were given weightage values, so that index can be developed. The average of the weightage value of CSI and LI formed disturbance index (DI) for a particular forest.

2.3. Environmental data

A total of 36 environmental variables were used to determine linkage with species composition and diversity as an explanatory variable, which represent physiographic, climate, anthropogenic and soil (supplementary Table S1). The data of physiography variables, which describe geographic complexity and regulate species diversity at local and regional scales were downloaded from <https://lta.cr.usgs.gov/> and extracted for each sampling site following Moeslund et al., (2013). The bioclimatic variables were extracted for each sample location from global high resolution ($\sim 1\text{km}^2$) database www.worldclim.org. The high resolution ($\sim 250\text{m}$) soil variables were extracted from www.soilgrids.org. Correlation analysis was performed among all environmental variables (Fig. 2). To avoid collinearity among the environmental variables multi-collinearity test were performed. To identify collinear environmental variables **variance inflation factor** (VIF), which defied proportion of variance in one predictor explained by all the other predictors in the model was calculated for each variables (Zurr et al., 2010). A VIF = 1 indicates no collinearity, whereas increasingly higher values suggest increasing multicollinearity.

Statistical analysis

2.1. Non-metric Dimensional Scaling (NMDS)

NMDS is an unconstrained ordination approach, which produces an ordination based on a distance or dissimilarity matrix. NMDS attempts to represent, as closely as possible, the pair wise dissimilarity between plant communities in a low-dimensional space (Minchin, 1987). The aim of NMDS is to represent the position of plant communities in the multidimensional space as accurately as possible using a reduced number of dimensions that can be easily visualized. The main aim is to recognize and interpret patterns and find gradients for underlying geographical, ecological conditions. Bray–Curtis dissimilarity values, calculated on untransformed species abundance data by the 'vegdist' function from

the vegan package, were used in the NMDS. Permutational Multivariate Analysis of Variance (PERMANOVA) post hoc tests using Bray–Curtis dissimilarity were performed with the vegan ‘adonis’ function to quantify the significant difference among the four forest types produced by NMDS. Pairwise comparisons on the dissimilarity between each forest types also used the ‘adonis’ function, with adjustments for multiple comparisons using the ‘p. adjust’ function with the ‘holm’ method (Holm 1979). Significant testing of the sites was done with the vegan ‘permutest’ function, using 999 permutations.

2.2. Canonical Redundancy Analysis (RDA)

The study investigated community ecology quantitative classification; ordination are widely used to understand the relationship between communities and their environment. Redundancy Analysis (RDA) is a method to extract and summarise the variation in a set of response variables (e.g. species abundance data) that can be explained by a set of explanatory variables (e.g. environmental data). This can also be done by NMDS but relating environmental variables to the distances in an NMDS ordination can mislead the interpretation. Typically, this technique represents an approximate of a distance matrix. Therefore, constrained ordination was done for understanding species composition and environmental variables using RDA (Borcard, Gillet & Legendre 2011) and implemented by the ‘decostand’ and ‘rda’ functions from the vegan package. The RDA used forest type and abundance data (both Hellinger-transformed) was considered response variable (Legendre & Gallagher 2001), and a minimal set of environmental and anthropogenic variables as explanatory variables. To obtain the minimal explanatory set of these variables, a forward selection procedure was used and implemented by the ‘forward.sel’ function from the ‘packfor’ package (Dray, Legendre & Blanchet 2013). The selected variables were additionally validated by a second forward selection procedure, using the vegan ‘ordistep’ function.

Variance inflation factors (Borcard, Gillet & Legendre 2011) were calculated on the variables from the RDA using the vegan ‘vif.cca’ function to identify whether any of the selected variables were redundant. Permutation testing of the RDA model was done using the vegan ‘permutest’ function with 99999 permutations.

3. Results

3.1. Species diversity pattern and characteristics

Tree species diversity along altitudinal gradient showed differences in species diversity indices. In general, the Shannon diversity index (H') showed humped shaped pattern along the altitude with maximum diversity at mid-altitude zone (Fig. 3a); species richness also followed the similar pattern (Fig. 3b). Species diversity, increased with an increase in species richness i.e., the level of species diversity depended on the richness of species composition. The trend in the dominance index contrasted with that of the diversity index and played close relationship with the number of dominant species. Dominance and evenness varied from 0.17 to 1 and 0.39 to 1, respectively (Fig. 3c & 3d), and showed inverted humped shaped pattern. The highest species diversity and richness was recorded at mid altitude ranges, whereas evenness and dominance first decreased and then increased with increasing altitude (Fig. 3a–d). Among

the different forest types, the maximum average Shannon diversity index (H') was observed in upper temperate forest (1.25 ± 0.10), and minimum (0.25 ± 0.15) in subalpine forests (Fig. 4a). Similarly, species richness was higher (5.8 ± 0.58) in upper temperate forest, whereas minimum (1.75 ± 0.25) in subalpine forest (Fig. 4b). Species dominance index was recorded higher (0.83 ± 0.11) in subtropical forest and lowest (5.8 ± 0.58) in upper temperate forest type (Fig. 4c). Tree species evenness was higher (0.79 ± 0.11) in subalpine forest and lower (0.64 ± 0.04) in upper temperate forest (Fig. 4d).

3.2. Community composition and classification

Across 37 studied forest sites, a total of 51 tree species falling in 28 families were recorded; highest number of species was recorded in family Pinaceae (5). *Pinus roxburghii* with dominance in 14 (37.8%) forest sites exhibits clear dominance in the region. *Quercus leucotrichophora* (5; 13.5%), *Betula utilis* (4; 10.8%) and *Pinus wallichiana* (3; 8%) are other dominants species. The details of sites with species composition are provided as supplementary Table S2. Non-metric multidimensional scaling (NMDS) of the sites produced group and separated all the sites into four different forest communities across the altitude (Fig. 2). These include (i) lower zone with subtropical climate (altitude below 1200 m), (ii) middle zone with lower temperate climate (1200–1700 m), (iii) upper zone with cool temperate climate (1700–2900 m) and (iv) subalpine (above 2900 m; Fig. 2). PERMANOVA tests supported that the difference in the different group is significant (PseudoF = 10.16, $R^2 = 0.48$, $p < 0.001$).

3.3. Environmental and anthropogenic attributes of species composition

Constrained ordination using canonical redundancy analysis (RDA) also grouped all the sites in similar fashion as in NMDS. The RDA diagram formed a set of linkages of different forest types along with the environmental factors. Selection of variables for canonical redundancy analysis (RDA) was done by two different forward selection procedures. The variance inflation factors (VIF), which give a measure of the collinearity of each variable with other variables, were low for variable having $VIF < 5$ (Supplementary Fig.1). The RDA1 and RDA2 accounted 41.73 % and 17.35% variance explained by environmental factors and tested significant using permutation test. Also, the amount of variance of the species is explained by the explanatory variables ($R^2 = 0.59$; adjusted $R^2 = 0.31$; $p < 0.001$). The grouping of sites was explained together by combination of soil, climate and anthropogenic variables (Fig. 5). The association of species was tested by ANOVA function in RDA. The results revealed, subtropical and lower temperate forests were significantly ($p < 0.001$) associated with variables: BD, DI, Bio2 and SD, whereas similar association of upper temperate and subalpine forests was apparent with SOC, Bio17 and pH (Fig. 5).

4. Discussions

4.1. Forest structure and tree species diversity pattern

Species richness and diversity are well established parameters of community structure and any changes in these parameters can be used as an indicator of change in community dynamics (Korner 2007; Brinkmann et al., 2009; Zhang and Dong 2010). Spatial variations in species diversity showed significant

characteristics of vegetation patterns in the studied area. The results exhibited that patterns of tree species diversity are related to both large-scale (climate) and small-scale variables (anthropogenic and soil). These variables together determined assemblages of local communities and distribution of species in given space. The humped shaped responses of tree species richness along altitudinal gradient is in line with previous studies from the Himalayan region (Grytnes and Vetaas, 2002; Bhattarai and Vetaas, 2003; Chawla et al., 2008; Dar and Sundarapandian, 2016; Saikia et al., 2017; Bhatta et al. 2018; Sharma et al., 2019; Ahmad et al., 2020). The variation in species diversity and richness might be due to spatial heterogeneity of habitats within different study plots. Low species diversity at lower altitudes might be attributed to higher anthropogenic disturbances and localization of non-native species (Zhang et al., 2016; Ahmad et al., 2018; Rawal et al. 2018). Significant influence of anthropogenic disturbance on species diversity is well established (Newbold et al., 2015, Ahmad et al., 2020).

Low species diversity towards higher altitudes is attributed to harsh environmental conditions that cause physiological stress to the plants (i.e., low temperature, low rainfall), limiting plant growth and their regeneration (McCain, 2007; Körner et al., 2011; Lee et al., 2013; Gómez-Díaz et al., 2017). Further, plants at higher altitudes are reported to have short growing season, and low ecosystem productivity as compared to the plants at lower altitude (Körner, 2003; Körner, 2007). Occurrence of maximum species at mid-altitudes is significantly correlated with availability of water, optimum temperature, rainfall, etc., which is required for better survival and growth performance (Grytnes and Vetaas, 2002; Bhattarai and Vetaas, 2003; Zhang et al., 2016).

4.2. Classification of community composition

The knowledge of plant functional types is very important for differentiating forest communities. This study quantitatively classified and grouped forest community along altitudinal gradients. The community were divided into four groups includes subtropical, lower temperate, upper temperate and subalpine. NMDS analysis showed marked significant differences in tree composition along altitudinal gradients. A clear succession shift in community composition from subtropical to subalpine zone was observed. These four forest communities corresponded to the altitudinal gradient, hence, reiterated the importance of altitude as a covariate to determine the composition of tree species in the region (Fig. 2). This suggests that tree species composition changes with altitude, and demonstrate the role of various environmental factors in dispersion of these forest communities. Similar results have been reported from eastern Himalaya (Sharma et al., 2018). The changes in forest composition might be due to the fact that 'the time needed to recover species composition is longer than to recover species richness' (Lebrija-Trejos et al. 2011; Rozendaal et al. 2019).

4.3. Influence of environmental variables on communities composition

As reflected by RDA analysis, variables such as climate, soil and anthropogenic disturbance together played a significant role in determining species composition along altitudinal gradient. Subtropical and temperate forests gets negatively impacted by environmental variables such as bulk density, disturbance index, mean Diurnal Temperature Range (Bio2) and Solar Radiation (SR), whereas upper temperate and

subalpine forest types get positively influenced by soil organic carbon, precipitation of the Driest Quarter (Bio17) and pH. For example, the RDA analysis showed that subtropical and temperate forests preferred low bulk density (Zheng et al., 2017), which might be due to the variation in bulk density, that indicates low soil porosity and soil compaction. This has been reported to cause restrictions to root growth, and poor movement of air and water there by affecting tree species in tropical forests (Sarvade et al., 2016).

These forests in the region experienced high level of human pressure. Lopping of tree for leaf fodder and fuelwood collection were the main anthropogenic pressure which cause large-scale disturbance in these forests; however, other practices such as logging, cutting and grazing also exist. Earlier studies have reported implications of fuelwood collection and fodder harvesting on species richness of the sub-tropical and temperate forests in western Himalaya (Rawal et al. 2012; Negi and Maikhuri 2017, 2018a) and across the globe (Ramírez-Marcial et al. 2001; Williams-Linera & Lorea 2009; Gibson et al. 2011). Anthropogenic disturbance is likely to regulate the community distribution pattern and certainly modifies natural ecosystem process by changing the land use pattern (Newbold et al. 2015; Panda et al. 2019). The vulnerability of a particular species or forest is primarily dependent on the intensity of disturbance (Thakur et al. 2020). Composition of tree species in subtropical and temperate forest gets affected by disturbance index and Bio2.

The range of diurnal temperature is an important indicator of climate change (Karl et al., 1991; Braganza et al., 2004; Qu et al., 2014; [Yang et al., 2016](#)) as it influence physiological attributes such as photosynthesis, respiration, reproduction, etc. Mean diurnal temperature range in the present study was found significantly associated with species composition in subtropical to temperate forests. The altitude, precipitation and temperature variables were found highly collinear. Diurnal temperature variation associated with solar radiation and photoperiod, has been reported to regulate plant functions, including central carbon metabolism, stomatal opening, and photoperiodism ([Michael et al., 2003](#); Hu et al., 2019).

The soil organic carbon was important factor that impacted plant species composition of temperate and subalpine forest in the study area. As such, plant functional traits are highly related to soil organic carbon stock and [carbon sequestration](#) that influences plant diversity and composition ([Jobbágy and Jackson, 2000](#); [De Deyn et al., 2008](#); [Stein et al., 2014](#); [Stark et al., 2017](#)). The intensity and durability of rainfall is reported to have impenetrable effect on local plant diversity and vegetation composition. Bio17 (Precipitation of the Driest Quarter) showed a negative relationship with tree species composition towards high altitude. The water stress during dry season also played a critical role in tree species composition. Earlier studies from the region have indicated that precipitation is important for determining plant species richness and composition in west Himalaya (Panda et al., 2017, 2019). Annual rainfall and its seasonal variation is reported to regulate temporal conditions of plant functional traits i.e., leaf flushing and flowering (Eamus 1999). Higher impact of mean annual precipitation on species richness pattern in the tropics is well reported (O'Brien 1993; Leigh et al. 2004; Davidar et al. 2005). Close association of soil pH with Upper temperate and subalpine forest types can be explained with the reported implications of soil pH in leaching of micronutrients, which changes the nutrient balance among plant tissues (Drenovsky et al., 2004; Partel et al., 2004 ; Fontaine and Barot, 2005; Clark et al., 2007).

Cation exchange capacity under the influence of soil pH affects plant diversity through changing N availability (Partel et al., 2000, 2004; Stein et al., 2014).

5 Conclusions

The study provides a comprehensive and quantitative understanding of species richness, diversity and composition of forests focusing on tree species along altitudinal gradient (700 m to 4000 m) in western Himalayan particular and Himalayan region in general. The diversity patterns showed a humped shaped response, which is largely explained by the mid-domain effect. Composition of tree species in four distinct community types has been explained together by environmental factors i.e., climate, soil and anthropogenic variables. The environmental variables i.e., bulk density, disturbance index, mean Diurnal Temperature Range (Bio2) and Solar Radiation (SR) negatively influenced composition of other two Subtropical and lower temperate forests, while upper temperate and subalpine forests significantly get associated with soil organic carbon, Bio17 and pH. Anthropogenic pressure in low altitude has facilitated invasion by alien species and consequently result in lesser richness and regeneration of tree species. Overall, this study suggests that tree species diversity and forest composition in the mountainous region is dependent on combined effect of anthropogenic disturbance, soil and climate.

Declarations

Ethics approval and consent to participate: Not applied

Availability of data and material: All the data presented in the manuscript and other as supplementary material

Consent for publication: Not applied

Competing interests: The authors declare that they have no competing interests.

Author contributions:

IDB: Conceptualization of the study, **ST & RD:** Methodology, Software, Validation, **ST:** Writing- Original draft preparation, Supervision: **AKY,** Writing- Reviewing and Editing: **VSN;** All authors read, provided inputs and approved the final manuscript.

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Tables

Due to technical limitations, table 1 is only available as a download in the Supplemental Files section.

Figures

Figure 1

(a): Location of sampling sites, and (b): temperature zones of Pithoragarh District 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.

Figure 2

Correlation plot among the environmental factors

Figure 3

Non-metric multidimensional scaling biplot (NMDS). Bray–Curtis dissimilarity using all species was used in the NMDS; plot stress: 0.12.

Figure 4

a-d: Variation of α -diversity across the altitudinal gradient a) Shannon index b) Species richness index, c) Evenness index. d) and Simpson diversity index, Nonlinear regressions and 95% confidence interval are depicted as lines and shaded areas, respectively

Figure 5

a-d: Boxplot showing descriptive statistics of α -diversity indices across different forest types a) Shannon index b) Species richness index, c) Evenness index. d) and Simpson diversity index,

Figure 6

Ordination diagram showing the results of RDA of the species composition and environment variables of study sites. The direction of the arrow indicating a positive or negative correlation among the environmental factors with the ordination axes. The length of the arrow reflects the strength of correlation

between the environmental factors and the distribution pattern of diversity indices, with long lines indicating strong correlations.

Supplementary Files

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