Analyzing environmental determinants of tree species distributions and regeneration pattern in Western Himalaya, India

Arun Kumar Thakur (✉ arun_wii@yahoo.co.in)

Forest Survey of India <https://orcid.org/0000-0002-7280-6447>

Rajesh Kumar

NSSO

Raj Kumar Verma

Himalayan Forest Research Institute

Pankaj Kumar

Kadorie Farm and Botanic Garden Corporation

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Abstract

Proper documentation of tree distribution across the globe has been considered crucial to assess the relationships between species occurrence and changing climate, and accordingly in designing the conservation action plans. Himalaya is one of the regions in the world where the temperature is gradually increasing at a rate higher than the global average. Therefore, it becomes imperative to understand the most influential parameters for major tree species distribution and its regeneration pattern across their habitat in Western Himalaya (WH) via direct gradient analysis. We used National Forest Inventory (NFI) data which has a robust statistical design with data collected in a consistent manner across the timeline in systematic order. This allowed us carrying out detail analysis to reveal the aforesaid relationship and pattern. Three topographical factors (altitude, aspect, slope), four major climatic variables (temperature, temperature seasonality, precipitation and its seasonality) and four edaphic factors (soil depth, soil humus, soil consistency and soil coarse fragments) were considered as defining variables. The results indicated that the altitude and temperature were the most determinant factors followed by precipitation in shaping the distribution of major tree species in WH. The analysis also indicated the upward shift of regenerating individuals of these tree species towards higher altitude. These relevant information about the extent of current tree distribution and their regeneration pattern over the last one and half decade might help in systematic conservation planning and monitoring range dynamics under future climate change conditions.

Background

Under ongoing rapid climate change scenario, understanding the ecological requirements of tree species distribution is a major research agenda in plant ecology (Enquist et al. 2016; Franklin et al. 2016). This would help in better understanding of tree diversity, a key driver of forest functioning (Paquette and Messier 2011; Pichancourt et al. 2014) and forest ecosystem service provisioning (Gamfeldt et al. 2013; Thompson et al. 2014).

The information related to plant species distribution patterns along complex environmental gradients are ecologically important from management perspectives because it can be used (i) for woodland conservation management plans (Roces-Díaz 2014), (ii) for successful ecological restoration plans (Onaindia et al. 2013, Pei 2018), (iii) to identify biodiversity and productivity patterns (Fischer et al. 2014) and biodiversity protection practices such as forest degraded areas (Zhang et al. 2016) and (iv) for identifying the ecological niches of plant species to predict their potential response to climate change (Zonneveld et al. 2009). Since studies based on species range shift indicates that all species have climatic limitations beyond which they cannot survive (Xu et al. 2007), it becomes important to understand and monitor the influencing factors of distribution patterns of plant species (Bai et al. 2004). However, for many regions in the world including Himalayas, historical data on species distribution are lacking (Hamid et al. 2018).

Studies have shown that the distribution of vegetation types and floristic patterns are most associated with environmental factors, including local variables/topographic factors (elevation, slope aspect, slope degree), soil factors (a soil's physical and chemical properties) (Huang 2002; Jabeen and Ahmad 2009; Zhang et al. 2012), and human impact factors (Enright et al. 2005; Hoang et al. 2011). Soil type and topographic variables were the most significant factors affecting species diversity and woody vegetation of a locality (Hejcmanova-Nezerková and Hejcman 2006; Zhang et al. 2012). Climatic factors were central in controlling the distribution and species richness patterns of various tree species (Sharma et al. 2009). The edaphic factors were reported to be more important than climatic one in shaping distribution of twelve temperate tree species in Switzerland (Walthert and Meier 2017). Since the environmental factors such as temperature, precipitation, atmospheric pressure, solar radiation, and wind velocity change systematically with elevation, thus elevational gradients are powerful natural experiments for testing the ecological and evolutionary responses of forests to environmental changes (Cui et al. 2005; Körner 2007). Such rapid change in altitudinal gradient at small distances found in Himalaya makes it noteworthy for ecological studies (Singh and Singh 1992; Chandra 2010).

The Himalaya is recognized as among the 36 global biodiversity hotspots (<http://www.cnservation.org/priorities/biodiversity-hotspots>). Due to diverse ecological, biogeographical and evolutionary factors that favor high endemic biodiversity (Joshi and Pant 2012), the region is highly sensitive to climate change and have been a data-deficient region (IPCC, 2007) and is under-represented in scientific literature on climate change-induced species range shifts in comparison to other mountains of the world (Schickhoff 2005; Dutta et al. 2014; Schickhoff et al. 2015). Since Himalayan ecosystems have been referred to be extremely sensitive under future climate (Chaturvedi et al. 2011) and heavily influenced by climate change (Polanski et al. 2014; Chakraborty et al. 2018), any change in temperature or rainfall pattern will adversely impact the entire ecosystem already under stress due to anthropogenic activities (Ravindranath et al. 2006). Evidences indicate that the Himalayan region is warming at a higher rate than the global average rate (Shrestha et al., 1999; Jianchu et al. 2007; Shrestha & Aryal, 2011; Xu *et al.*, 2009). Dash et al. (2007) reported that in the WH a 0.9 °C average increase was observed during the 102-year period 1901–2003. Shrestha et al. (1999) reported that temperature increments are greater in the uplands than that in the lowlands regions in the Himalaya. However, the precipitation doesn't show definite trend, but a distinct shift from snow to rain has been described in literature (Singh et al. 2011).

The temperature and precipitation-related vegetation studies in Himalaya are limited and concentrated to localized places (Xu & Liu, 2007; Liang et al., 2015). The changes at the regional level are yet to be documented (Singh et al., 2014) and therefore the landscape level primary data on distribution and abundance could be critical in understanding key aspects of macro-ecological patterns (Oommen and Shanker 2005).

The species and environmental relationship have been explored in Himalaya in recent past (Acharya et al. 2011; Gaire et al. 2014). The energy variables (potential evapotranspiration and temperature seasonality) were reported to be major determinants of species richness in WH (Panda et al. 2017). Kharkwal et al.

(2005) found the altitude, temperature and rainfall as major determinants of species richness in Kumaon Himalaya whereas many acclaims that it is the forest structure and composition which are mainly driven by elevation and climate (Vetaas 2000; Sharma et al. 2016b; Sharma et al. 2017, 2018). Climate and soil properties have been reported to strongly constrain the species distribution (Dubuis et al. 2013). The distribution pattern of a plant species indicates its adaptability to various environments (Wang et al. 2004). Under the climate change regime (Tewari et al. 2017; Upgupta et al. 2015) various environmental parameters may respond differently (degree and rate of change). The vegetation distributions are likely to undergo change in near projected climate change (Gao et al. 2017).

Regeneration is another critical aspect as it determines future species composition and stocking. If it gets confined to a particular range of habitat conditions, that extent becomes crucial in determining species's geographical distribution (Grubb 1977). It also decides the existence of a community under varied environmental conditions, and therefore becomes more important to study the regeneration pattern, which may be influenced by both natural (Behera et al. 2012; Mishra et al. 2013) and anthropogenic (Chaturvedi et al. 2017) factors. The lack of adequate forest regeneration is an important issue recognized by both foresters and ecologists (Ceccon et al. 2004; Mishra and Singh 2017). It may be due to lack of viable seed production, insect and animal predation, unfavorable microclimatic conditions, overgrazing, habitat changes, and biological invasions. The regeneration patterns may also act as early indicator of the impact of climate change (Bulletin E-3221, 2014). Regeneration in himalayan forests was quoted to be adversely affected by the uncontrolled grazing by domestic livestock by removing young seedlings and saplings, which also causes soil loss due to trampling (Saberwal 1995). Deficit regeneration will affect the entire ecosystem structure and functioning. From the very past, literature reports it to be of utmost importance to have baseline scientific data on regeneration characteristics of dominant tree species on landscape level to understand ecological implications in distribution of trees (Forman and Godron 1986). The regeneration pattern predicts future growth of the forest, and hence important for forest management (Khanna 1996).

There is a serious lack of systematic studies and empirical observations about species-level impacts of climate change in the Himalayas (Gautam et al. 2013). The literature reports that major/widespread species with large population and high fecundity are more likely to persist and adapt but species with small populations, fragmented ranges, or low fecundity, may face population collapse and need facilitated migration (Serra-Diaz et al. 2017). However we believe that if major species distribution is driven by very few environmental parameters with narrow regeneration zone, then they may not be able to persist and adapt without facilitated migration and therefore it becomes important to monitor reproduction and regeneration.

The WH contributes with reportedly 490 tree species inventoried out of which 372 species found in wild (Bhatt et al. 2016). Despite apparent similarity to temperate forests in terms of tree species (oak and pine-dominated systems) and cool average temperatures, these forests possess distinct ecological traits. High nutrient turnover rates and productivity and a phenology adapted to the summer drought, make them more similar to tropical ones (Thadani et al. 2014).

This study targeted 15 major tree species identified in NFI forming representative major forest types of WH. We included major abiotic components of environmental heterogeneity i.e. climatic parameters like temperature and precipitation, soil variables like soil depth, humus, soil consistency, coarse fragments and topographic variables like slope, aspect and altitude. We also used one very significant NFI variable i.e. most commonly found tree species under regeneration observed in an area of 2 ha around the center of the inventory plot. Such sites can be considered promising for the growth and perpetuation of the corresponding tree species. With the huge amount and wide coverage of data availability in NFI, this study explores the physiographic zone level of environmental influence on the distribution of tree species in WH. Our main objective of current analysis is to find whether such a scenario exist for major tree species of WH? We test for the null hypothesis i.e. all the environmental variables play equal role in determining the distribution of selected tree species in WH. As our study focuses on the relative importance of climate variables, soil and topography, we do not include biotic interactions and disturbances. In addition, we sought to see the most determining variable for the 15 tree species. Since mature trees are long lived and may not be good indicators of climate change tree regeneration pattern of these 15 species are analyzed. The range of species regeneration in comparison to their natural course of occurrence would help us to understand their overall status in the recorded forest area.

Materials And Method

Study Area

Study area is WH and comprises 19 districts belonging to three different states of India - Jammu and Kashmir, Himachal Pradesh and Uttarakhand (Fig. 1) These three states possess largest number of forest types (35 in each) as mentioned by Champion & Seth (1968) in India and collectively has more than 28% area under forest (FSI 2019). The WH exhibit semi-arid and cold arid climates, respectively, the far eastern ranges represent some of the wettest places on earth with > 4000mm annual precipitation. The effect of the monsoon becomes less pronounced in the WH. Unlike the central and eastern parts, the WH receives higher precipitation during winter in the form of snow. The WH is structurally complex with elevations ranging from 300 to over 8126 m, and the drainage system is composed of rivers, lakes and glaciers. The WH forest vegetation ranges from tropical dry deciduous forests in the foothills to timberline followed by alpine scrub and alpine meadows. The forest types greatly varies from dry and moist deciduous forest in tropical zone dominated by *Shorea robusta*, Sub-tropical pine forest ruled by *Pinus roxburghii*, moist and dry temperate forest consisting of broad leaved species of evergreen Oak species (*Q. oblongata*, *Q. dilatata* and *Q. semecarpifolia*) and *Rhododendron* spp. and by deciduous species like *Carpinus viminea*, *Juglans regia*, *Aesculus indica*, *Alnus nepalensis* etc., then sub-alpine forest of *A.pindrow*, *A. spectabilis*, *Pinus walliciana*, *Picea smithiana* and *Betula*, followed by alpine scrub comprising of *Juniperus* species (FSI 2011).

The mountains rise abruptly, resulting in a diversity of ecosystems that range from alluvial grasslands, subtropical broadleaved forests to dominance of conifers in the temperate zone to alpine meadows above the tree line. High-altitude cold desert ecosystems encompass a significant area of the region. The

region supports a number of glaciers that are key source of water for sustaining downstream ecosystems and the world's largest human population.

Methodology and Data Collection

Stratified two stage sampling was employed, with districts as the primary sampling units, within which secondary units are selected by stratified systematic sampling (Fig. 2a and 2b). Different sampling approach were used at the second stage for (1) forests, (2) urban Trees outside Forest (TOF) and (3) rural TOF. Over the selected districts, systematic square grids based on Survey of India toposheets were laid out that define the sample locations for the secondary sampling units.

Two $1\frac{1}{4}' \times 1\frac{1}{4}'$ minute sub grid within each grid of $2\frac{1}{2}' \times 2\frac{1}{2}'$ minutes forms the basic sampling units. The intersection of diagonals of such $1\frac{1}{4}' \times 1\frac{1}{4}'$ minute sub grid marked as the center of plot on the map where a plot of 0.1 ha in size (Fig. 2c) was laid out to inventory all the trees with diameter at breast height (dbh) ≥ 10 cm. Tewari and Kleinn (2015) described the developmental history of NFI in India in detail and its biodiversity relevance has been mentioned by Thakur et al. (2018). Since the NFI data covers a significant part of WH and in an in systematic manner, it allows the assessment of the distribution pattern of tree species encountered in NFI. The NFI data collected during the period 2002-2015 was used for the study. The data afterwards was not used since the methodology got changed for the new NFI in the year 2016. There were one thousand eight hundred and thirty two (1832) plots found with at least one of the 15 selected tree species across the large environmental gradients. These selected 15 tree species were found in more than 10 plots.

The literature recommends few major environmental variables characterizing macroscale hypotheses for biodiversity patterns (Mouchet et al. 2015) out of which we selected 4 climatic variables (Table 1): monthly climatic variables and bioclimatic variables were obtained from [WorldClim database](http://www.worldclim.org) (<http://www.worldclim.org>). These variables were selected to reflect the averages as well as the climatic boundaries of the species range. These data are a set of global climate layers with a spatial resolution of approximately 1 km^2 . The coordinates of the plots were used to get the value of various climatic data used in the study.

Various soil parameters used in the study have been defined in the NFI manual: "Manual of instructions for field inventory—2002" (http://fsi.nic.in/documents/manualforest_invetyory_2.pdf) specifically designed for field inventory. Humus is the decomposed organic matter (leaves, twigs, branches etc.) forming the upper most soil layer and distinguished from the undecomposed leaf litter. Soil consistency comprises the nature of soil material that is expressed by the degree and kind of cohesion or resistance to deformation or rupture. Texture of soil refers to relative occurrence of clay, silt and sand particles. Coarse fragments like gravel, boulders, loose stones present in the soil mass. Depth of soil will be estimated from the soil sample plots and guessing the remaining depth. Apart from this soil erosion, texture (clay, sand and loamy soil) and color were noted down in NFI, however since slope is considered soil erosion is not considered, soil texture corresponds to different size of soil particles – it might be useful indicator for

unique species but may not collectively indicate biodiversity, soil color that cannot be linked to biodiversity have not been considered in this study.

Table 1. Environmental variables with their source.

Environmental factors	Name	Code used	Range	Description	Reference
Topographic	Elevation	elev	455–2555m	Through Garmin GPS	NFI Manual
	Slope	slope	In percentage	Through Range finder	
	Aspect	Aspect	Northern, North-Eastern, Eastern, South-Eastern, Southern, South-Western, Western, North-Western, No aspect	Through compass	
Climatic (w.r.t selected 15 species)	Annual mean temperature	BIO1	-1.7 to 24.29°C	Annual mean temperature	WorldClim Global Climate Data
	Temperature seasonality	BIO14	4482 to 8154	Temperature seasonality	
	Annual precipitation	BIO12	447 to 2853 mm	Mean annual precipitation	
	Precipitation seasonality	BIO15	38 to 141 mm	Precipitation seasonality	
Edaphic	Soil depth	sdept	No soil, Very shallow, Shallow, Medium, Deep	Through field work	NFI Manual
	Soil consistency	scons	Friable, Slightly, Compact, Cemented, No Soil		
	Soil humus	shumu	Shallow, Medium, Deep, No humus		
	Soil coarse fragments	cfrag	Loose stones, Bouldery, Gravely, No coarse, fragments		
	Rockiness	rockiness	High, Medium, Low, No rock		
	Erosion	Erosion	Heavy, Moderate, Mild, No erosion		

Data Analysis

The relationship between structure and microenvironment was estimated by simple correlation and Canonical Correspondence Analysis (CCA). We used CCA to establish the importance of environmental drivers for species distribution using PCORD software. CCA is an ordination technique, which shows non-linear relations between species and environmental variables and prefers the best weights for environmental variables. Abundance data for trees were used for this. In CCA, environmental variables were standardized to Z score and squared root transformation of species data were carried out. Monte Carlo permutation test by using 999 permutations was carried out by PCORD to test the significance of the eigenvalues of all the canonical axes. In the ordination diagrams, species names was abbreviated using five letters from the scientific name of each plant by combining the single initial letters for the genus and four letters of species.

The six soil variables (Table 1) were analyzed through literature. The soil erosion was most important because it reduces forest productivity by decreasing the soil water availability and removing plant-available nutrients (Elliot et al. 1999). The other variables were subjected to factor analysis to see the most correlated variable so as to reduce the number of variables finally to be subjected to CCA.

Table 2. Correlation matrix

	rockiness	coarse_frag	Hum_reco	scons_reco	sdept_reco
rockiness	1				
coarse_fra	0.443	1			
Hum_reco	0.103	0.011	1		
scons_reco	-0.061	-0.106	0.065	1	
sdept_reco	0.387	0.316	0.172	-0.23	1

Table 3. KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.638
Bartlett's Test of Sphericity	Approx. Chi-Square	18547.712
	df	10
	Sig.	0

The soil depth shows some correlation to rockiness and coarse fragments individually and a correlation was also found between rockiness and coarse fragments while weaker correlation was observed among others (Table 2). The KMO value (Table 3) shows adequacy of the sample. Therefore, out of listed soil variables in Table 1, two variables soil depth and soil erosion was considered to represent the edaphic components in CCA. A main matrix composed of 1832 plots and 11 environmental factors (included climatic/ topographic/ edaphic variables) and second matrix composed of 1832 plots and 15 species (containing tree abundance per species/ per sample unit) was constructed to analyze the relationships between the species distribution and the environmental factors.

Results

The CCA showed that the eigenvalues for the first three axes were 0.805, 0.402, 0.149 and species-environmental correlations for these axes were 92%, 67% and 42.6% respectively (Table 2a). These values along with the results of Monte Carlo test ($p < 0.001$), indicated a highly significant correlation between the environmental variables and tree species distribution. The gradual decrease of eigenvalues of first three axes indicated a well-structured dataset assuring that the CCA analysis performed well in describing relationships between vegetation and environmental variables (Table 2a). The CCA biplot diagram (Fig. 3), clearly shows that the species are distantly dispersed suggesting different environmental variables influences the distribution pattern to varying extent. The first axis was significantly ($p > 0.001$) responsible for the species environment relationship (Table 2c).

Cumulatively the first three axes of CCA ordination clarified 14.4% of the variance in the species data (table 4a). The higher value of species- environmental relation (92.3%) indicated that species data were strongly related to the measured environmental variables (Table 4c). The Monte Carlo test was attempted to test the significance of an observed test statistica (Table 4b).

The Fig. 3 and Table 5 clearly shows that the first CCA axis negatively correlates with altitude while positively correlates with annual mean temperature (i.e. with increasing altitude the annual mean temperature decreases.) and annual precipitation. The second CCA axis correlates with temperature seasonality. Majority of these 15 tree species are strongly influenced by altitude and temperature seasonality. The table 4a, 4b and 4c shows the overall variance in the data, species species correlations and especies – environemnt correlations as obtained in the results.

Table 4a

Number of canonical axes: 3

Total variance ("inertia") in the species data: 9.4154

Axis 1 Axis 2 Axis 3

Eigenvalue 0.805 0.402 0.149

Variance in species data

% of variance explained 8.6 4.3 1.6

Cumulative % explained 8.6 12.8 14.4

Pearson Correlation, Spp-Env^t* 0.923 0.670 0.426

Kendall (Rank) Corr., Spp-Env^t 0.775 0.449 0.214

* Correlation between sample scores for an axis derived from the species data and the sample scores that are linear combinations of the environmental variables. Set to 0.000 if axis is not canonical.

Table 4b

Monte Carlo Test Results – Eigenvalues

Randomized data

Real data Monte Carlo test, 999 runs

Axis	Eigenvalue	Mean	Minimum	Maximum	p
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1	0.805	0.025	0.013	0.061	0.0010
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2	0.402	0.017	0.010	0.029	
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3	0.149	0.013	0.007	0.021	
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p = proportion of randomized runs with eigenvalue greater than or equal to the observed eigenvalue; i.e.,

$p = (1 + \text{no. permutations} \geq \text{observed}) / (1 + \text{no. permutations})$

p is not reported for axes 2 and 3 because using a simple randomization test for these axes may bias the p values.

Table 4c

MONTE CARLO TEST RESULTS – SPECIES-ENVIRONMENT CORRELATIONS

Randomized data

Real data Monte Carlo test, 999 runs

Axis Spp-Envr Corr. Mean Minimum Maximum p

1 0.923 0.183 0.132 0.287 0.0010

2 0.670 0.155 0.119 0.207

3 0.426 0.134 0.092 0.174

p = proportion of randomized runs with species-environment correlation greater than or equal to the observed species-environment correlation; i.e.,

$$p = (1 + \text{no. permutations} \geq \text{observed}) / (1 + \text{no. permutations})$$

p is not reported for axes 2 and 3 because using a simple randomization test for these axes may bias the p values.

Table 5. Intraset Correlations of 11 Variable

Correlations*

Variable Axis 1 Axis 2 Axis 3

1 slope - 0.388 - 0.235 -0.196

2 aspect 0.045 - 0.005 0.084

3 Alt_dem - 0.987 - 0.030 0.094

4 b1_TdegC 0.893 - 0.065 0.060

5 b4 -0.036 0.923 - 0.129

6 b12 0.506 - 0.246 0.473

7 b15 0.830 - 0.230 0.459

8 Hum_reco - 0.300 0.337 0.174

9 scons_re -0.081 0.139 0.128

10 sdept_re 0.063 0.261 - 0.132

11 cfrag_re 0.011 - 0.020 - 0.075

* Correlations are "intraset correlations" of ter Braak (1986)

As can be seen biplot ordination diagram (Fig. 3), *Shorea robusta* (Srobu), a tropical tree species falls in entirely different zone of environment. *P. roxburghi* is found in sub-tropical zone and shows positively distributed along b12 (annual precipitation) which is supported by literature where the growth of chir pine has been found positively correlated with the precipitation (Sigdel et al., 2018; Chaunhan et al.; 2017, Aryal et al., 2018).

The monsoonal and non-monsoonal regimes are known to influence the tree distribution (Singh et al, 2017). *P. roxburghi*, *S. robusta* and *Q. oblongatum* are seems to be driven by precipitation and its seasonality thus may be influenced strongly by monsoon which forms extensive forest in WH. Rise in temperature and resultant enhanced evapo-transpiration desiccates the seeds of *Q. oblongata* more rapidly in the soil seed banks due to global temperature rise has been hypothesized in literature (Bhatt et al. 2015). *P. gerardiana*, *P. wallichiana*, *P. smithiana* have been reported to be non monsoonal and are falling in the region of low precipitation seasonality. Enough moisture and temperature during favorable growth season are key determinant for growth and development in *S. robusta*. (Kumar and Chopra, 2018)

Four of the fifteen tree species – *Betula utilis* (Butil), *Pinus gerardiana* (Pgera), *Abies spectabilis* (Aspec) and *Abies pindrow* (Apind) falls in the high elevation zone quite separated from other tree species. The literature also reports *B. utilis* and *A. spectabilis* forming associations in around 4000 m in treeline in WH (Singh and Singh, 2002). *A. spectabilis* shows good regeneration between 2268-3000m as evident in literature (Sharma et al. 2017). Phytosociologically, *P. gerardiana* shows high endemism in its natural zone and reported to occur in more than 70% of the area wherever it exist in north-west Himalaya (Kumar et al. 2016).

Picea smithiana and *Cedrus deodara* are distributed above 2000 m whereas *Pinus wallichiana* is found along the entire length of WH (1200-3800m). Literature reports these species at very high altitude usually in dominant form or codominant form (Liang et al, 2014; Gairola and Todaria, 2008). *B.utilis* and *P. gerardiana* shows no association with any other tree spp. *A.pindrow*, *B.utilis* and *Acer caesium* have been found to occur in equal importance value indices (IVI) in Kumaun region of WH (Gairola et al., 2008). The oak forest is distributed along the altitudinal gradient in WH with, *Q. leucotrichophora* (1200–2200 m), *Q. floribunda* (2201–2700 m) and *Q. semecarpifolia* (2701–3300 m) (Singh and Rawat, 2012).

We didn't find *B. alnoides* as most commonly found tree species under regeneration in any of the NFI plots under study. *P. smithiana* showed its presence in 3.82% of total plots wherever it was found while *B. utilis* and *R. arboreum* were found on less than 15% of total plots wherever it occurred. All the rest were present in more than 22% of their total plot of occurrences. We found six tree species reported in less than 33% (of their total occurrence) with reported as most commonly found tree species under regeneration. Their regeneration along the altitude (Fig. 4) clearly shows their presence throughout the altitude. We also analyzed (for all the fifteen tree species) the presence of trees (dbh > = 10 cm) in parallel to their regeneration along the altitude as observed in the inventory plots and found that in except for *A. spectabilis*, *P. wallichiana* and *S. robusta*, the minimum altitude at which regenerating individuals are found are higher than the altitude where parent trees are reported from. The regenerations of *B. utilis*, *A. spectabilis*, *A. pindrow*, and *A. acuminatum* have been reported to be evidently expanding into alpine zone (Sharma et al, 2018).

Conclusion

The study proves that the distribution of major forest forming tree species in WH is governed by the altitude, annual mean temperature and precipitation seasonality. Considering the altitude to be a stable parameter, under the changing climatic regime, the annual mean temperature and precipitation seasonality are likely to be the major driving factors for any alteration in the distribution of forest forming tree species in WH. The species *Betula utilis*, *Pinus gerardiana* and *Abies spectabilis* shows dominant and endemic behavior showing little tendency to mix over with other nearby species.

This is different from what has been reported for 12 tree species in Switzerland where soil properties were more important than climate variables in shaping tree species distribution (Walthert and Meier 2017). The result is also different from what has been reported from Western Ghats where rainfall plays the dominant environmental gradient influencing vegetation pattern followed by elevation (Joseph et al, 2012).

Since eleven tree species reportedly showing dominant regeneration at the altitude above the one where parent trees are growing, this pose a question whether forest forming tree species are migrating upwards in general.

The manner in which increasing established sapling at higher elevation of *Pinus wallichiana* (added by growth ring study) indicated upward shift in WH (Dubey et al, 2003), can this phenomenon of finding

regenerating tree individuals in visibly dominant form in large area of 2 ha at higher elevation be considered as sign of upward shift in WH. If so, at least this study is giving a signal towards this trend. With increasing altitude availability of space will decrease and consequently only few of many species will be able to survive and perpetuate.

Since the data belongs to 2002-15, finding *B. alnoides* to be totally absent from important species under regeneration in NFI plots could be an alarming sign since there may be a regenerating individuals but may not be found in visibly dominant condition.

Thus it becomes very important that any change or unusual finding in the distribution pattern/ range of these tree species must be reported to understand the influence of environmental determinants on tree species constituting a particular forest ecosystem and further on ecosystem services provided by that ecosystem. Especially the species like *Rhododendron arboreum*, *Betula utilis*, *Pinus gerardiana* and *Quercus semecarpifolia* seemingly shows dominant regeneration at an altitude where parent trees are found indicating healthy ecosystem. An intensive regeneration based study of forest forming tree species through permanent observation plot studies may provide insight into micro climatically operating drivers. Such studies based on huge datasets from the ground and their linking with the global data helps to understand the observed trend and strengthen the consensus on scientific findings.

Abbreviations

NFI: National Forest inventory

FSI: Forest Survey of India

CCA: Canonical Correspondence Analysis

TOF: Trees outside Forest

Declarations

Ethical approval and consent to participate: NA

Consent for publication: NA

Availability of data and materials: Data will not be shared as it belongs to NFI of India and government policy does not allow putting the raw data on any sort of public domain.

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Author's contribution:

Arun Kumar Thakur carried out the study and drafted the manuscript.

Rajesh Kumar conceived and designed the study.

Raj Kumar Verma coordinated and helped to draft the manuscript.

Pankaj Kumar helped in the statistical analysis and helped in framing the draft.

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Authors' information

Mr. Arun Kumar Thakur is Science post graduate pursuing PhD in NFI of India. He has more than 15 years of experience in Ecology, Forestry and Remote Sensing and GIS.

Mr. Rajesh Kumar is renowned expert in Forest Biometry having more than 30 years' experience who actually designed the NFI of India that began in 2002. He is Science post graduate in Statistics.

Dr. Raj Kumar Verma is a scientist in Himalayan Forest Research Institute in India and holds PhD degree in Forestry. He has over 25 year of experience in studying biodiversity of Western Himalaya.

Dr. Pankaj Kumar is renowned Taxonomist and ecologist having more than 20 years of experience in Asia and South east Asia region.

References

Enquist BJ, Condit R, Peet RK, Schildhauer M, Thiers BM (2016) Cyberinfrastructure for an integrated botanical information network to investigate the ecological impacts of global climate change on plant biodiversity. PeerJ Preprints 4:e2615v2 <https://doi.org/10.7287/peerj.preprints.2615v2>. Accessed 17 June 2017.

Franklin J, Serra-Diaz JM, Syphard AD, Regan HM (2016) Global change and terrestrial plant community dynamics. Proc Natl Acad Sci 113:3725–3734. <https://doi.org/10.1073/pnas.1519911113>.

Paquette A, Messier C (2011) The effect of biodiversity on tree productivity: from temperate to boreal forests: the effect of biodiversity on the productivity. Glob Ecol Biogeogr 20:170–180. <https://doi.org/10.1111/j.1466-8238.2010.00592.x>.

- Pichancourt J-B, Firn J, Chadès I, Martin TG (2014) Growing biodiverse carbon-rich forests. *Glob Change Biol* 20:382–393. <https://doi.org/10.1111/gcb.12345>.
- Gamfeldt L, Snäll T, Bagchi R, Jonsson M, Gustafsson L, Kjellander P, Ruiz-Jaen MC, Froberg M, Stendahl J, Philipson CD, Mikusinski G, Andersson E, Westerlund B, Andren H, Moberg F, Moen J, Bengtsson J (2013) Higher levels of multiple ecosystem services are found in forests with more tree species. *Nat Commun* 4:1340. <https://doi.org/10.1038/ncomms2328>.
- Thompson ID, Okabe K, Parrotta JA, Brockerhoff E, Jactel H, Forrester DI, Taki H (2014) Biodiversity and ecosystem services: lessons from nature to improve management of planted forests for REDD-plus. *Biodivers Conserv* 23:2613–2635. <https://doi.org/10.1007/s10531-014-0736-0>.
- Bai Y, Broersma K, Thompson D, Ross TJ (2004) Landscape-level dynamics of grassland-forest transitions in British Columbia. *Rangeland Ecology & Management* 57:66–75.
- Onaindia M, Ametzaga I, San Sebastián M, Mitxelena A, Rodríguez-Loinaz G, Peña L, Alday JG (2013) Can understorey native woodland plant species regenerate under exotic pine plantations using natural succession? *Forest Ecology and Management*. 308:136-144.
- Fischer H, Micler B, Ewald J (2014) Environmental, spatial and structural components in the composition of mountain forest in the Bavarian Alps. *Folia Geobotanica* 49:361-384.
- Zonneveld M, Koskela J, Vinceti B, Jarvis A (2009) Impact of climate change on the distribution of tropical pines in Southeast Asia. *Unasylva* 231/232:24-29.
- Chaturvedi RK, Ranjith G, Jayaraman M (2011) Impact of climate change on Indian forests: a dynamic vegetation modeling approach. *Mitig. Adapt. Strat. Gl.* 16 (2), 119–142.
- Ravindranath NH, Joshi, NV, Sukumar R (2006) Impact of climate change on forests in India. *Curr. Sci.* 90 (3), 354–361.
- Cui HT, Liu HY, Dai JU (2005) *Research on Mountain Ecology and Alpine Treeline*. Beijing, China: Science Press.
- Körner C (2007) The use of altitude in ecological research. *Trends of Ecology & Evolution* 22:569–574.
- Singh JS, Singh SP (1992) *Forests of Himalaya; Structure, Functioning and Impact of Man*. Gyanodaya Prakashan, Nainital, India.
- Chandra J, Rawat VS, Rawat YS, Ram J (2010) Vegetational diversity along an altitudinal range in Garhwal Himalaya. *Internat J Biodivers Conservat* 2(1): 014-018.
- Sharma CM, Mishra AK, Tiwari OP, Krishan R, Rana YS (2017) Effect of altitudinal gradients on forest structure and composition on ridge tops in Garhwal Himalaya. *Energy Ecology and Environment*

- Sharma CM, Tiwari OP, Rana YS, Krishan R, Mishra AK (2018) Elevational behaviour on dominance–diversity, regeneration, biomass and carbon storage in ridge forests of Garhwal Himalaya, India. *Forest Ecology and Management* 424:105–120.
- Kharkwal G, Mehrotra P, Rawat YS, Pangtey YPS (2005) Phytodiversity and growth form in relation to altitudinal gradient in the Central Himalayan (Kumaun) region of India. *Current Science* 89(5):873-878.
- Vetaas OR (2000) The effect of environmental factors on the regeneration of *Quercus semecarpifolia* Sm. in Central Himalaya, Nepal. *Plant Ecology* 146:137–144.
- Gao J, Jiao K, Wu S, Ma D, Zhao D, Yin Y, Dai E (2017) Past and future effects of climate change on spatially heterogeneous vegetation activity in China. *Earth's Future* 5(7):679–692.
- Acharya BK, Chettri B, Vijayan L (2011) Distribution pattern of trees along an elevation gradient of Eastern Himalaya, India. *Acta Oecologica* 37:329-336.
- Gaire NP, Koirala M, Bhuju DR, Borgaonkar HP (2014) Treeline dynamics with climate change at the central Nepal Himalaya. *Climate of the Past* 10:1277-1290
- Dubuis A, Rossier L, Pottier J, Pellissier L, Vittoz P, Guisan A (2013) Predicting current and future spatial community patterns of plant functional traits. *Ecography* 36, 1158–1168.doi:10.1111/j.1600-0587.2013.00237.x.
- Tewari VP, Verma RK, Klaus von Gadow (2017) Climate change effects in the Western Himalayan ecosystems of India: evidence and strategies. *Forest Ecosystems* 4:13 DOI 10.1186/s40663-017-0100-4.
- Uppgupta S, Sharma J, Jayaraman M, Kumar V, Ravindranath NH (2015) Climate change impact and vulnerability assessment of forests in the Indian Western Himalayan region: A case study of Himachal Pradesh, India. *Climate Risk Management* 10: 63–76.
- Singh S, Bassignana-Khadka I, Karky B, Sharma E (2011) Climate change in the Hindu Kush-Himalayas: The state of current knowledge, Kathmandu: ICIMOD.
- Dash SK, Jenamani RK, Kalsi SR, Panda SK (2007) Some evidence of climate change in twentieth-century India. *Climate Change* 85:299–321.
- Shrestha AB, Wake CP, Mayewski PA, Dibb JE (1999) Maximum temperature trends in the Himalaya and its vicinity: an analysis based on temperature records from Nepal for the period 1971–94. *J. Clim.*
- IPCC (2007) Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC.

- Polanski S, Fallah B, Befort DJ, Prasad S, Cubasch U. (2014) Regional moisture change over India during the past millennium: A comparison of multiproxy reconstructions and climate model simulations. *Global Planetary Change* 122:176–185.
- Chakraborty A, Saha S, Sachdeva K, Joshi PK (2018) Vulnerability of forests in the Himalayan region to climate change impacts and anthropogenic disturbances: A systematic review. *Regional Environmental Change* 18(6):1783–1799. <http://dx.doi.org/10.1007/s10113-018-1309-7>.
- Roces-Díaz JV, Jiménez-Alfaro B, Álvarez-Álvarez P, Álvarez-García MA (2014) Environmental niche and distribution of six deciduous tree species in the Spanish Atlantic region. *iForest* (early view): e1-e8 [online 2014-08-28] URL: <http://www.sisef.it/iforest/contents/?id=ifor1183-008>.
- Tewari VP, Kleinn C (2015) Considerations on capacity building for national forest assessments in developing countries—with a case study of India. *Int For Rev* 17(2):244–254.
- Thakur, AK, Kumar, R. and Verma, RK. (2018) Analysing India's current national forest inventory for biodiversity information. *Biodivers Conserv* (2018) 27 (12):3049-3069. DOI 10.1007/s10531-018-1587-x.
- Mouchet M, Levers C, Zupan L, Kuemmerle T, Plutzer C, Erb K, et al. (2015) Testing the Effectiveness of Environmental Variables to Explain European Terrestrial Vertebrate Species Richness across Biogeographical Scales. *PLoS ONE* 10(7): e0131924. doi:10.1371/journal.pone.0131924.
- Chaturvedi RK., Gopalakrishnan R, Jayaraman M, et al. (2011) Mitig Adapt Strateg Glob Change. 16: 119. <https://doi.org/10.1007/s11027-010-9257-7>.
- Walthert L, Meier ES. (2017) Tree species distribution in temperate forests is more influenced by soil than by climate. *Ecol Evol*. 7:9473–9484. <https://doi.org/10.1002/ece3.3436>.
- Sharma CM, Suyal S, Gairola S, Ghildiyal SK. (2009) Species richness and diversity along an altitudinal gradient in moist temperate forest of Himalaya. *Journal of American Science* 5:119-128.
- Bhatt D, Sekar CK, Rawal RS, Nandi SK, Dhyani PP. (2016) *Tree Diversity of Western Himalaya*. G.B. Pant Institute of Himalayan Environment & Development, Almora, Uttarakhand, INDIA.
- Kumar and Chopra, (2018) *American Journal of Environmental Sciences*. 14 (4): 185.194 DOI: 10.3844/ajessp.2018.185.194.
- Sigdel SR, Dawadi B, Camarero J, Liang E, Leavitt SW (2018) Moisture-Limited Tree Growth for a Subtropical Himalayan Conifer Forest in Western Nepal. *Forests* **2018**, 9, 340; doi:10.3390/f9060340
- Aryal S, Bhujju DR, Kharal DK, Gaire NP, Dyola N (2018) Climatic upshot using growth pattern of pinus roxburghii From western nepal. *Pak. J. Bot.*, 50(2): 579-588, 2018.

Schickhoff U (2005) The upper timberline in the Himalaya, Hindu Kush and Karakorum: a review of geographical and ecological aspects. In: Broll, G., Keplin, B. (Eds.), Mountain Ecosystems. Studies in Treeline Ecology. Springer, Berlin - Heidelberg, pp. 275-354.

Telwala Y, Brook BW, Manish K, Pandit MK. (2013) Climate-induced elevational range shifts and increase in plant species richness in a Himalayan biodiversity epicentre. PLoS One 2, e57103.

Dutta PK., Dutta BK, Das AK, Sundriyal RC (2014) Alpine treeline research gap in Himalaya: a literature review. Indian For. 4, 419-427.

Schickhoff U, Bobrowski M, Böehner JJ, Bürzle B, Chaudari RP, Gerlitz L, Heyken H, Lange J, Müller M, Scholten T, Schwab N, Wedegärtner R (2015) Do Himalayan treelines respond to Tree Species Along an Elevational Gradient in the Garhwal Himalaya. Mountain Research and Development Vol 38 No 3 Aug 2018: 211–21.

Pei J, Yang W, Cai Y, Yi Y, Li X (2018) Relationship between Vegetation and Environment in an Arid-Hot Valley in Southwestern China. Sustainability 2018, 10, 4774; doi:10.3390/su10124774.

Zhang C, Li X, Chen L, Xie G, Liu C and Sha Pei S (2016) Effects of Topographical and Edaphic Factors on Tree Community Structure and Diversity of Subtropical Mountain Forests in the Lower Lancang River Basin. Forests 2016, 7, 222; doi:10.3390/f7100222.

Sharma CM, Mishra AK, Krishan R, Tiwari OP, Rana YS. (2016a.) Impact of climate on structure and composition of ridgetop forests in Garhwal Himalaya. Taiwanania 61(2):61–69.

Sharma CM, Mishra AK, Krishan R, Tiwari OP, Rana YS. (2016b) Variation in vegetation composition, biomass production and carbon storage in ridgetop forests of high mountains of Garhwal Himalaya. Journal of Sustainable Forestry 35(2):119–132.

Mishra AK, Behera SK, Singh K, Chaudhary LB, Mishra RM, Singh B (2013) Influence of abiotic factors on community structure of understory vegetation in moist deciduous forests of north India. Forest Science and Practice 15(4):261–273.

Joshi B, Pant SC (2012) Ethnobotanical study of some common plants used among the tribal communities of Kashipur, Uttarakhand. Indian J Nat Prod Resour 3:262–266

Xu J et al (2007) The melting Himalayas: regional challenges and local impacts of climate change on mountain ecosystems and livelihoods. ICIMOD, Kathmandu

Hamid M, Charles B, Ahmad R, Singh CP, Aravind NA (2018) Impact of climate change on the distribution range and niche dynamics of Himalayan birch, a typical treeline species in Himalayas. Biodiversity and Conservation. <https://doi.org/10.1007/s10531-018-1641-8>

- Huang KY. (2002) Evaluation of the topographic sheltering effects on the spatial pattern of Taiwan fir using aerial photography and GIS. *International Journal of Remote Sensing* 23: 2051-2069.
- Jones MM, Tuomisto H, Clark DB, Olivas P (2006) Effects of mesoscale environmental heterogeneity and dispersal limitation on floristic variation in rain forest ferns. *Journal of Ecology* 94: 181-195.
- Jabeen T, Ahmad SS (2009) Multivariate analysis of environmental and vegetation data of Ayub National Park Rawalpindi. *Soil & Environment* 28: 106-112.
- Zhang H, Qian Y, Wu Z, Wang Z. 2012. Vegetation-environment relationships between northern slope of Karlik Mountain and Naomahu Basin, East Tianshan Mountains. *Chinese Geographical Science* 22: 288-301.
- Enright NJ, Miller BP, Akhter R. 2005. Desert vegetation and vegetation-environment relationships in Kirthar National Park, Sindh, Pakistan. *Journal of Arid Environments* 61: 397-418.
- Hoang VS, Baas P, Keßler PJA, Slik JWF, Steege HT, Raes N. 2011. Human and environmental influences on plant diversity and composition in Ben En National Park, Vietnam. *Journal of Tropical Forest Science* 23: 328-337.
- Hejcmanova-Nezerková P, Hejcman M. 2006. A canonical correspondence analysis (CCA) of the vegetation and environment relationships in Sudanese savannah, Senegal. *South African Journal of Botany* 72: 256-262.
- Sharma CM, Suyal S, Gairola S, Ghildiyal SK. 2009. Species richness and diversity along an altitudinal gradient in moist temperate forest of Himalya. *Journal of American Science* 5: 119-128.
- Shrestha AB, Wake CP, Mayewski PA, D. B. J. E., *J. Climate*, 1999, 12, 2775–2787.
- Jianchu X, Shrestha A, Vaidya R, Eriksson M, Hewitt K (2007) ICIMOD Technical Paper, ICIMOD, Nepal.
- Panda RM, Behera MD, Roy PS, Biradar C (2017) Energy determines broad pattern of plant distribution in Western Himalaya. *Ecology and Evolution*. 2017;7:10850–10860.
- Thadani R, Singh V, Shahabuddin G (2014) Forests of the Western Himalaya. *Current science*, vol. 107, no. 1226 8, 25 October 2014
- Oommen MA, Shanker K (2005) Elevational species richness patterns emerge from multiple Local mechanisms in himalayan woody plants. *Ecology*, 86(11), 2005, pp. 3039–3047
- Bulletin E-3221. Forest Management in a **Changing** Climate: **How the Climate Affects Forests**, July 2014.
- FSI (2011) Atlas forest types of India. Forest survey of India (MoEF).

FSI (2019) Forest Survey of India: India state of Forest Report 2019. FSI, Ministry of Environment and Forests, Government of India, Dehradun.

FSI (2011) Forest Survey of India: India state of Forest Report 2011. FSI, Ministry of Environment and Forests, Government of India, Dehradun.

Serra-Diaz JM, Enquist BJ, Maitner B, Merow C, Svenning JC (2017) Big data of tree species distributions how big and how good. *Forest Ecosystems* (2017) 4:30 DOI 10.1186/s40663-017-0120-0.

Xu, WX and Liu, XD (2007) Response of vegetation in the Qinghai-Tibet Plateau to global warming. *Chinese Geogr. Sci.* 17 (2): 151 – 159. DOI: 10.1007/s11769-007-0151-5.

Mainali, J.; All, J, Jha, PK, Bhujju DR (2015) Responses of Montane Forest to Climate Variability in the Central Himalayas of Nepal. *Mt. Res. Dev.* 35 (1): 66 – 77. DOI: 10.1659/MRD-JOURNAL-D-13-00101.1.

Liang, EY, Liu, WW, Ren, P, Dawadi B, Eckstein, D (2015) The alpine dwarf shrub *Cassiope fastigiata* in the Himalayas: does it reflect site-specific climatic signals in its annual growth rings? *Trees Struct. Funct.* 29 (1): 79 – 86. DOI: 10.1007/s00468-014-1128-5.

Wang, X, Sun, ZY & Zhou, AG (2014) Alpine Cold Vegetation Response to Climate Change in the Western Nyainqentanglha Range in 1972 – 2009. 2014. *Scientific World Journal*. DOI: 10.1155/2014/514736.

Singh N, Patel NR, Bhattacharya BK, Soni P, Parida BR, Parihar JS (2014) Analyzing the dynamics and inter-linkages of carbon and water fluxes in subtropical pine (*Pinus roxburghii*) ecosystem. *Agri. For. Meteor.* 197: 206 – 218. DOI: 10.1016/j.agrformet.2014.07.004.

Wang T, Liang YH, Ren B, Yu D, Ni J, Ma KP. 2004. Age structure of *Picea schrenkiana* forest along an altitudinal gradient in the central Tianshan Mountains, northwestern China. *Forest Ecol Manage*, 196: 267–274.

Dubey B, Yadav RR, Singh J, Chaturvedi R (2003) Upward shift of Himalayan pine in Western Himalaya, India. *Current Science*, Vol. 85, NO. 8, 25 October 2003.

Shrestha AB, Aryal R (2011) Climate change in Nepal and its impact on Himalayan glaciers. *Regional Environmental Change*, 11(1): 65-77.

Xu J, Grumbine RE, Shrestha A, Eriksson M, Yang X, Wang Y, Wilkes A (2009) The melting himalayas: cascading effects of climate change on water, biodiversity, and livelihoods. *Conservation Biology*, 23: 520-530.

Singh N, Patel NR, Bhattacharya BK, Soni P, Parida, BR, Parihar, JS (2014) Analyzing the dynamics and inter-linkages of carbon and water fluxes in subtropical pine (*Pinus roxburghii*) ecosystem. *Agri. For. Meteor.* 197: 206 – 218. DOI: 10.1016/j.agrformet.2014.07.004

- Behera SK, Mishra AK, Sahu N, Kumar A, Singh N, Kumar A, Bajpai O, Chaudhary LB, Khare PB, Tuli R (2012) The study of microclimate in response to different plant community association in tropical moist deciduous forest from northern India. *Biodiversity and Conservation* 21:1159–1176.
- Mishra AK, Behera SK, Singh K, Chaudhary LB, Mishra RM, Singh B. 2013. Influence of abiotic factors on community structure of understory vegetation in moist deciduous forests of north India. *Forest Science and Practice* 15(4):261–273.
- Chaturvedi RK, Raghubanshi AS, Tomlinson KW, Singh JS (2017) Impacts of human disturbance in tropical dry forests increase with soil moisture stress. *Journal of Vegetation Science* 28:997–1007.
- Grubb PJ (1977) The maintenance of species-richness in plant communities: The importance of the regeneration niche. *Biological Review* 52:107–145.
- Ceccon E, Sanchez S, Campo-Alves J (2004) Tree seedling dynamics in two abandoned tropical dry forests of different successional status in Yucatán, Mexico: A field experiment with N and P fertilization. *Plant Ecology* 170:12–26.
- Mishra AK, Singh RP (2017) Shift in plant species distribution and regeneration potential due to global warming and climate change in Himalayan region. *EnviroNews* 23(4). <http://isebindia.com/17-20/17-10-2.html>; accessed on 10 September 2018.
- Gautam MR, Timilsina GR, Acharya K (2013) Climate change in the Himalayas current state of knowledge. The World Bank Development Research Group Environment and Energy Team, Policy research working paper WP-6516, p 47
- Elliot WJ, Page-Dumroese D, Robichaud PR. 1999. The Effects of Forest Management on Erosion and Soil Productivity. https://forest.moscowfs.wsu.edu/smp/docs/docs/Elliot_1-57444-100-0.html.
- Singh MP, Singh, BS, Dey S. 2002. Plant Biodiversity and taxonomy. Daya Publishing House. Delhi. pp43.
- Gairola, S., Rawal, R.S. and Todaria, N.P. 2008. Forest vegetation patterns along an altitudinal gradient in sub-alpine zone of west Himalaya, India. *African Journal of Plant Science* 2(6): 42-48.
- Singh G and Rawat GS. 2012. Depletion of Oak (*Quercus* spp.) Forests in the Western Himalaya: Grazing, Fuelwood and Fodder Collection. www.intechopen.com. Global perspectives on sustainable forest management. Edi. Clement AO. eBook ISBN: 978:953-51-5283-5.
- Champion H.G. and Seth S.K. (1968). A revised survey of: The Forest Types of India. Forest Research Institute, Dehradun

- Bhatt J, Tewari A and Mittal A. 2015. Regeneration Problem in *Quercus leucotrichophora* A. Camus in Nainital Forest Division of Kumaun Himalaya. Int. J. Pure App. Biosci. 3 (3): 284-290. ISSN: 2320 – 7051.
- Singh G and Rawat GS (2012) Depletion of oak (*Quercus* spp.) forests in the Western Himalaya: grazing, fuelwood and fodder collection. In: Okia CK (ed) Global perspectives on sustainable forest management. Intech publishers, Croatia, pp 39–42
- Forman TTR, Godron M (1986) Landscape ecology. Wiley, New York
- Khanna LS (1996) Principles and practice of silviculture. Khanna Bandhu, Dehradun
- Saberwal VK. 1995. Pastoral politics: Gaddi grazing, degradation and biodiversity conservation in Himachal Pradesh, India. Conservation Biology 10:741-749.
- IPCC (2007) Contribution of Working Group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge
- Kumar R, Shamet GS, Pandey A, Kakade V, Dinesh D, Sharma N and Gupta D (2016) Impact of Anthropogenic Disturbances on Ecology of *Pinus gerardiana* Wall in Indian Himalaya: A Review. Agri Res & Tech: Open Access J 1(3): ARTOAJ.MS.ID.55561 (2016)
- Singh SP, Singh RD, Gumber S and Bhatt S (2017) Two principal precipitation regimes in Himalayas and their influence on tree distribution. Tropical Ecology 58(4): 679-691, 2017.
- ISSN 0564-3295.

Figures

Figure 1

WH in India (a) comprising Inventoried districts (b) and NFI sample plots within RFA (c).

Figure 2

sampling

Figure 3

CCA biplot diagram showing the distribution of 15 tree species in relation to various environmental variables. Aspec = *Abies spectabilis*, Apind = *Abies pindrow*, Aacum = *Acer aesculus*, Balno = *Betula alnoides*, Cdeod = *Cedrus deodara*, Psmit = *Picea smithiana*, Pwall = *Pinus wallichiana*, Pgera = *Pinus gerardiana*, Proxb = *P. roxburghii*, Qflor = *Quercus floribunda*, Qoblo = *Q. oblongatum*, Qseme = *Q. semecarpifolia*, Rarbo = *Rhododendron arborheum*, Srobu = *Shorea robusta*.

Figure 4

Regeneration of six tree species (found in less than 33% of their occurrence as major species under regeneration) along altitude

Figure 5

Distribution of major regenerating tree species (among most commonly found tree species under regeneration) versus their occurrence with dbh=> 10cm as found in WH over a decade (2002-2015).