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Population structure and regeneration status of tree species in old growth *Abies pindrow* dominant forest: A case study from western Himalaya, India

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ABSTRACT

To understand regeneration dynamics and population structure of tree species in west Himalayan conifer forests, we investigated phytosociological data from an old growth *Abies pindrow* dominant forest (2200–3000 m amsl) of Sainj valley in Himachal Pradesh, India. A total of 20 quadrats (size 400 m^2) were established following random stratified method to gather tree data. Four sapling quadrats (size 25 m^2) and eight seedling quadrats (size 1 m^2) were nested within each tree quadrat to inspect the regeneration status of tree species. This study resulted in documentation of 18 tree species (belonging to 15 genera and 12 families) from the sampled area (400 $m^2 \times 20$ quadrats). *Abies pindrow* with importance value index (IVI) 39.06% and *Aesculus indica* (IVI 19.90%) revealed as dominant tree species while other associated species showed low IVI (< 9%) comparatively. Out of the total, only for 4 tree species showed 'good' regeneration status, 5 species 'fair' and 5 species 'poor' regeneration status while 4 species recorded at mature stage (without seedlings) only hence showed 'nil' regeneration status. In general, mature tree individuals contribute 3.20%, saplings 2.19% and seedlings 94.61% in the total density (ind. ha^{-1}) which indicates poor seedling survival rate in the studied forest. Consequently, it can be predicted from the results that the existing tree community may change into another community in upcoming future in terms of population structure, dominance and richness. The regeneration failure for greatest forest forming species is a matter of concern for the studied and other west Himalayan forests. Therefore, further study on seedling survival and development of proper management strategies are needed for maintenance and sustainability of the Himalayan forests.

1. Introduction

Community composition and structure are the important ecological attributes of forests which influence by the regional environmental, edaphic and anthropogenic factors (Saxena and Singh, 1984; Singh et al., 1984; Tiwari, 2005; D.S. Rawat et al., 2020). Assessment of the forest community composition and structure is very useful in understanding the tree population dynamics, regeneration pattern and diversity (Mishra et al., 2013; Singh et al., 2016; Dash et al., 2021). In a forest community, trees are the fundamental component as they influence the resources and physical structure of habitats for almost all other forest organisms (Rawat et al., 2018a). The subsistence of a tree species in forest community is mainly depends on its regeneration potential under varied environmental conditions (Gairola et al., 2012; Malik and Bhatt, 2016). Regeneration of any species is confined to particular range of habitat conditions and extent of those conditions is the primary determinant of its geographic distribution (Grubb, 1977). Regeneration study can depict the current status of forest composition as well as provide hints about forest composition in future (Henle et al., 2004). It can be predicted by analyzing the density of seedlings, saplings and mature trees within a particular forest (Austin, 1977). The regeneration status of a forest can also be assessed by studying the distribution of tree individuals of different diameter classes. High density of new recruits (seedling) and low diameter individuals in comparison to the mature indicates good regeneration potentials. In a forest, older trees serve as seed banks which produce young ones and the process continues in time and space (Pokhriyal et al., 2010). For a successful natural regeneration, survival and growth of seedlings/saplings and the pace at which the younger trees are replacing the older ones are the most determining factors (Good and Good, 1972). Poor regeneration due to habitat loss, land degradation, deforestation, forest fires, over-grazing, lopping, *etc.* is the major problem of mountain forests (Krauchii et al., 2000; Ballabha et al., 2013; Parveen et al., 2017; Rawat et al., 2018b; Sharma et al., 2018; Pant and Samant, 2012).

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Fig. 1. (**a**) Maror village near Humkhani forest, Sainj valley, Himachal Pradesh, (**b**) & (**d**) *Abies pindrow* dominant sites and (**c**) *Aesculus indica* dominant site.

The evergreen conifer forests are the main forest types found in the high elevation (up to timber line) of the western Himalayan landscape. Conifer tree species tend to grow in extensive pure patch in upper montane belts of this region. However, some broad leaved species (*Acer* spp., *Betula* spp., *Prunus* sp., *Rhododendron* spp., *etc.*) are also found in association with the conifers in these forests. Various changes are appearing in the structure, composition, and regeneration of natural forests of the Indian Himalayan Region (IHR) due to climate change and anthropogenic disturbances. The Himalayan forests are sensitive to pronounced climate change impacts as these are usually governed by low-temperature conditions (Wester et al., 2019). The ongoing changes in any Himalayan forests can be monitored comparing the current vegetation and climate data with the past trends. Hence, the quantitative study of the Himalayan forests is necessary to assess the role of climate change on future species coexistence, provide a baseline data for the long term monitoring processes and species shift (Sharma et al., 2016; Dash et al., 2021). The quantitative assessment of tree communities is also important for sustainable utilization, management and conservation of species in particular forest community (Rawat et al., 2018a).

Thus, the present study aimed to evaluate the community structure and the regeneration status of tree species in a temperate coniferous forest of Sainj Valley of western Himalaya, India.

2. Materials and methods

2.1. Study area

The river Sainj originates from the Raktisar glacier (ca. 4200 m amsl) of the Great Himalayan National Park Conservation Area (GHNPCA) and flow in the east-west direction in criss-cross through deep gorges and joins the main stream (Beas river) at Larji (ca. 970 m amsl). The Sainj river valley is characterized by steep mountain slopes, numerous high ridges, deep gorges, precipitous cliffs and rocky crages. The underlying rock is mainly limestone. Quartzite, schist, phyllite, dolomites, shale, slate, gneiss and granites are also found (Singh and Rawat, 2000). The climate of the area can be divided into three distinct seasons *viz*. summer (April to June), rainy (July to September) and winter (October to March). Besides permanent snow covered peaks at higher elevations, snowfall is common in downhill to 1800 m during winter. Sainj valley is endowed with a great diversity of plants due to its unique topography, wide altitude range and relatively undisturbed terrains. The Chir pine forests, temperate broadleaved forests, temperate conifer forests, sub-alpine forests, alpine scrubs and alpine meadows are the typical plant communities from lower elevation to snow clad mountain peaks (D.S. Das et al., 2020). In present study, a typical western Himalayan temperate conifer forest ecosystem namely Humkhani forest, located at the left flank of Sainj river adjacent to the Shakti and Maror villages of the Sainj Wild Life Sanctuary (SWLS) was selected (**Fig. 1**). It extended from 2200 m (Sainj river bank) to 4000 m (tree line) through the ridge top and continues up to ca. 4400 m (alpine zone).

2.2. Methodology

Field surveys were conducted during the year 2018 to collect the phytosociological data. Twenty sampling plots of 20 m × 20 m (0.04 ha) size were laid in random stratified manner across the Humkhani forest. Tree data was recorded at three life stages *viz*. mature trees (circumference ≥ 31.5 cm, at 1.37 m above ground level), saplings (circumference = 10.5–31.4 cm) and seedlings (circumference < 10.5 cm). Whole plot of 400 m^2 size was considered as tree quadrat. Four quadrats (25 m^2 size) for saplings and eight quadrats (1 m^2 size) for seedlings were nested within each tree quadrat. Number of individuals of each species were counted within respective quadrats and noted on field data sheets (separate sheets for trees, saplings and seedlings). Tree circumference

Table 1
Phytosociological attributes and regeneration status tree species in the Humkhani forest (Sainj Valley, western Himalaya, India).

Name of species	Tree Density (ind. ha^{-1})	B. Cover (m^2 ha^{-1})	IVI (%)	Saplings Density (ind. ha^{-1})	B. Cover (m^2 ha^{-1})	IVI (%)	Seedlings Density (ind. ha^{-1})	B. Cover (m^2 ha^{-1})	IVI (%)	Regeneration status
Abies pindrow	123.75	66.07	39.06	40	0.046	17.27	4000	0.039	36.18	Fair
Acer acuminatum	22.5	1.42	8.88	70	0.093	36.84	2875	0.038	27.67	Good
Acer caesium	1.25	0.01	0.69	5	0.005	2.42	–	–	–	Poor
Acer cappadocicum	5	1.4	1.47	10	0.011	4.94	250	0.002	2.44	Good
Aesculus indica	51.25	28.62	19.9	10	0.009	4.84	500	0.081	17.06	Poor
Betula alnoides	2.5	0.79	1.03	–	–	–	125	0.002	1.43	Fair
Carpinus viminea	12.5	11.2	6.03	–	–	–	–	–	–	Nil
Cedrus deodara	2.5	1.29	1.17	–	–	–	250	0.008	2.85	Fair
Cornus macrophylla	5	1.25	1.44	5	0.004	2.32	–	–	–	Poor
Corylus jacquemontii	21.25	2.7	4.71	–	–	–	125	0.002	1.43	Fair
Euonymus tingens	1.25	0.06	0.7	–	–	–	–	–	–	Nil
Ilex dipyrena	–	–	–	5	0.004	2.32	–	–	–	Fair
Juglans regia	2.5	1.96	1.9	–	–	–	–	–	–	Nil
Prunus cornuta	5	1.63	2.08	10	0.013	5.29	250	0.003	2.59	Good
Quercus semecarpifolia	13.75	2.57	3.3	35	0.062	16.41	500	0.025	8.36	Good
Salix tetrasperma	3.75	0.11	0.99	10	0.009	4.84	–	–	–	Poor
Salix wallichiana	2.5	0.11	0.85	–	–	–	–	–	–	Nil
Taxus wallichiana	25	3.12	5.79	5	0.006	2.53	–	–	–	Poor
Total	**300.25**	**124.34**	**100**	**205**	**0.264**	**100**	**8875**	**0.2001**	**100**	

measured with help of graduated tape while circumference of saplings and seedlings were measured using calipers.

The species accumulation curve (SAC) was obtained to determine the pattern of species richness with increasing number of samples and to assess sampling efficiency. Cluster analysis was performed to classify the samples into different tree communities with similar species composition and abundances using PC–ORD, version 4.34 (McCune and Mefford, 1999). The collected data were analyzed for density, basal area and importance value index (IVI). The tree individuals were divided into successive diameter classes i.e. 10–30 cm, 31–50 cm, 51–70 cm, 71–90 cm, and so on. The diversity index (Shannon and Wiener, 1963) and concentration of dominance (Simpson, 1949) also calculated. The regeneration status of tree species was determined on the basis of population size of seedlings and saplings following Khan et al. (1987) and Shankar (2001).

$$\text{Importance value index }(\%) = \frac{\text{RF} + \text{RD} + \text{RBA}}{3}$$

where; RF = relative frequency (%), RD = relative density (%), RBA = relative basal area (%).

3. Results and discussion

A total of 18 tree species (under 15 genera and 12 families) were recorded from the sampling area of Humkhani forest (20 plots × 400 m^2), Sainj valley, western Himalaya, India (**Table 1**). The resulted tree species richness was found high in comparison to the previous studies from other *Abies pindrow* forests stands of the western Himalaya (Gairola et al., 2011; Rawat et al., 2014; Parveen et al., 2017; D.S. Rawat et al., 2020; Sharma and Samant, 2013). Variations in the phytosociological attributes of the Himalayan forests are mainly caused by the changed environmental conditions. However, difference in size and number of quadrats in different studies also caused variations in reported phytosociological results from different forests. It is well known that the species richness tends to increase with increasing sampling area (quadrat size and cumulative number of quadrats) due to environmental heterogeneity. In terms of number of species, Aceraceae and Betulaceae (3 species each) revealed as dominant families while *Acer* (3 species) as dominant genus. The study area is part of the Great Himalayan National Park (GHNP). The GHNP is rich in plant diversity (more than 945 taxa) with Asteraceae, Poaceae, Ranunculaceae, Rosaceae, Lamiaceae and Fabaceae as dominant families while *Potentilla, Carex, Saussurea, Saxifraga, Primula, Nepeta, Silene* and *Thalictrum* as dominant genera (Singh and Rawat, 2000; Das et al., 2017, 2018, 2019; D.S. 2020).

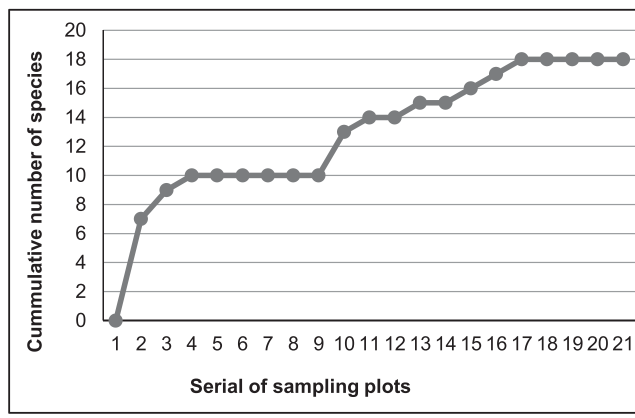

Fig. 2. Species accumulation curve (SAC) of tree species in study area.

The species accumulation curve (SAC) predicts higher species richness than the observed species richness in the study area (**Fig. 2**). The SAC appeared flatten between 5th and 10th plots and from 17th to 20th plots. The first 10 plots were established along the left flank (horizontal trail) of the Sainj river with nearly similar elevation (2200–2500 m) while other plots (plot 11th to 20th) laid from river bank at lower elevation to timber line (uphill) with remarkable difference in elevation (2500–3000 m) of each plot. Hence, the curve appeared flattened after 6–7 plots in forest stands with similar species compositions. It can be inferred from this pattern of species area curve that the some species well flourishes in lower elevation on riverside or deep shady gorge habitats while other in higher elevation towards timber line. Elevation is an important gradient that drives abiotic factors (including water, temperature, soil properties) and known to affect the spatial patterns of species diversity (Körner, 2000). Elevation gradient play a significant role in the distribution woody species in western Himalaya, India (Gairola et al., 2011; Rawal et al., 2018; Bhat et al., 2020; D.S. Das et al., 2020; Rawat et al., 2021; Thakur et al., 2021).

The cluster analysis identified two distinct tree communities (clusters) with similar species composition in the study area denoted as C1 and C2 in **Fig. 3**. C1 represented by the plots with high abundance of *Aesculus indica* whereas C2 by the *Abies pindrow* dominant plots. It is well known that the conifers (e.g. *Abies pindrow*) tend to grow in pure stands at higher elevation while in mixed with many broad leaved species

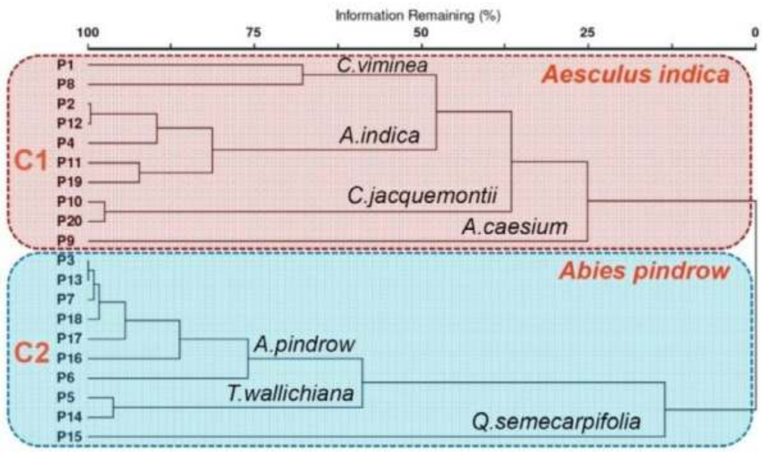

Fig. 3. Cluster analysis based on species matrix (distribution 18 species into 20 plots).

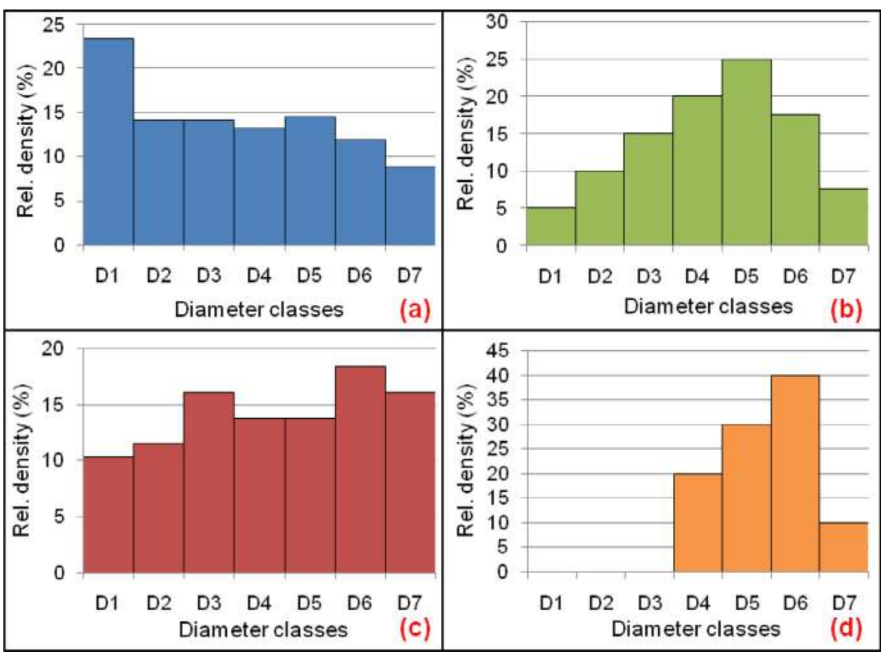

Fig. 4. Population structure of tree species in Humkhani forest (Sainj Valley, western Himalaya, India) (**a**) all species together, (**b**) *Aesculus indica*, (**c**) *Abies pindrow*, and (**d**) *Juglans regia* (D1 = 10–30 cm, D2 = 31–50 cm, D3 = 51–70 cm, D4 = 71–90 cm, D5 = 91–110 cm, D6 = 111–130 cm, D7 > 110 cm).

downhill in western Himalaya (D.S. Das et al., 2020; D.S. Rawat et al., 2020). *Quercus semecarpifolia* and *Acer caesium* also revealed as distinct but smaller clusters in the area.

The density of trees, saplings and seedlings were 301.25 ind. ha^{-1}, 205 ind. ha^{-1} and 8875 ind. ha^{-1} respectively. The basal area (BA) were 124.34 m^2 ha^{-1}, 0.26 m^2 ha^{-1} and 0.20 m^2 ha^{-1} for tree, sapling and seedling layers respectively (**Table 1**). The lower tree density and higher tree basal area in studied forest indicated the tree community with large sized (girth) tree individuals (**Fig. 3**). The stem basal area shows significant negative correlation with tree species density (Carpenter, 2005; Rawat et al., 2018a). The resulted tree density was low and basal area was high in comparison to the reported values from other western Himalayan *Abies pindrow* dominant forest stands (Gairola et al., 2011; Rawat et al., 2014; Parveen et al., 2017; D.S. Rawat et al., 2020; Sharma and Samant, 2013).

Among the mature tree individuals, the highest density was observed for *Abies pindrow* (123.75 ind. ha^{-1}) followed by *Aesculus indica* (51.25 ind. ha^{-1}) and *Taxus wallichiana* (25.01 ind. ha^{-1}) while lowest density was recorded for *Acer caesium* (1.25 ind. ha^{-1}). The density ranged between 5 ind. ha^{-1} and 70 ind. ha^{-1} among the sapling species whereas it varied from 125 to 392 ind. ha^{-1} among seedling species (**Table 1**). Basal area varied from 0.01 m^2 ha^{-1} (*Acer caesium*) to 66.07 m^2 ha^{-1} (*Abies pindrow*) among the tree species. *Abies pindrow* with IVI 39.06% revealed as the dominant tree species in the study area followed by *Aesculus indica* (IVI 19.90%) and *Acer acuminatum* (IVI 8.88%).

Distribution of tree individuals into diameter classes (DBH classes) is shown in **Fig. 4**. Higher densities of the trees in medium to lower girth classes suggests the forests are still in evolving stage (Campbell et al., 1992). Majority of the studies from other Himalayan forests reported reverse J shaped pattern for tree density-diameter distributions (Rawat et al., 2018a; D.S. 2020; Dash et al., 2021). The first two DBH classes *viz*. 10–30 cm and 31–50 cm, represented only 37% of total tree density while 21% individuals by DBH classes ≥ 110 cm, such pattern is rarely seen in other Himalayan forests. From this observation, it can be inferred that this forest is very old and facing regeneration failure. According to Kennedy and Swaine (1992), if a species represented by more individuals in higher DBH classes than the lower in any forest may be considered on the threshold of extinction from that particular forest. Among the dominant tree species, *Aesculus indica* and *Abies pindrow* showed more relative density in higher DBH classes. Individuals of *Juglans regia* is represent by above 70 cm DBH classes in the area.

If the population structure is characterized by the presence number of seedlings > saplings > mature trees depicts 'good' regeneration status; seedlings > saplings < mature trees indicates 'fair' regeneration status;

seedlings < saplings < mature trees indicates 'poor' regeneration; while complete absence of seedlings and saplings indicates 'nil' regeneration (Saxena and Singh, 1984; Rawat et al., 2018b; Dash et al., 2021). Out of the total (18 species), the 'good' regeneration status was observed only for 4 species, 'fair' for 5 species, 'poor' 5 for species while none of the seedlings recorded for 4 species (**Table 1**). *Abies pindrow* and *Aesculus indica* revealed as the dominant species within the study area. The regeneration status of dominant species *viz. Abies pindrow* (fair), *Aesculus indica* (poor), *Carpinus viminea* (not), *Taxus wallichiana* (poor) in the study area indicating the regeneration failure of the forest. None of the seedlings were recorded for 8 species in present study is a matter of serious concern (**Table 1**). The overall regeneration status of the forest is 'fair' as the density of seedlings > saplings < trees. The failure of regeneration of *Abies pindrow* and *Aesculus indica*, in the western Himalayan landscape is a matter of deep concern. Besides natural causes, the anthropogenic disturbances also affect the regeneration of tree species. In the study area and other parts of the IHR, the young straight trunks of tree species such as *Abies pindrow, Alnus nepalensis* and *Pinus* spp. are extracted for timber purpose (to construct houses and agricultural tools). On other hand, local inhabitants collect seed of *Aesculus indica* from nearby forests and sell it to local vendors. Other factors like forest fire, grazing and lopping also impede natural regeneration of tree species in the west Himalayan forests (Ballabha et al., 2013; Malik and Bhatt, 2016; Parveen et al., 2017).

4. Conclusion

For a successful natural regeneration, survival and growth of seedlings/saplings and the pace at which the younger trees are replacing the older ones are the most determining factors (Good and Good, 1972). The current trend of regeneration is an indicative of changes in the structure and composition of species in such forests in future. Further work, on the seedling survival through long term monitoring is suggest to know the causes and consequences of such regeneration failure of greatest forest forming species in western Himalaya. Also, a systematic management plan and conservation strategies are needed to be developed for maintenance and sustainability of such Himalayan forest.

Declaration of Competing Interest

The authors declare no competing interests.

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