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RESEARCH ARTICLE

Regeneration complexities of *Pinus gerardiana* in dry temperate forests of Indian Himalaya

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Abstract *Pinus gerardiana* is considered an important species in dry temperate forests of North-Western Indian Himalaya because of its influence on ecological processes and economic dependence of local people in the region. But, large numbers of biotic and abiotic factors have affected *P. gerardiana* in these forests; hence, there is a crucial need to understand the regeneration dynamics of this tree species. The present investigation was conducted in *P. gerardiana* forests to understand vegetation pattern and regeneration processes on different sites in the region. Statistical analysis was performed to know variability in growing stock and regeneration on sample plots, while correlation coefficients and regression models were developed to find the relationship between regeneration and site factors. The vegetation study showed dominance of *P. gerardiana*, which is followed by *Cedrus deodara*, *Pinus wallichiana* and *Quercus ilex* in the region. The growing stock of *P. gerardiana* showed steep increasing and then steadily declining trend from lower to higher diameter class. The distribution of seedling, sapling, pole and trees was not uniform at different sites and less number of plots in each site were observed to have effective conditions for continuous regeneration, but mostly showed extremely limited regeneration. Regeneration success ranging from 8.44 to 15.93 % was recorded in different sites of the region, which suggests that in different sites regeneration success is influenced by collection of cone for extracting seed, grazing/browsing and physico-chemical properties of soil. Regeneration success showed significant correlation and relationship with most of abiotic and biotic factors. The regeneration success is lower than the requirement of sustainable forest, but varies widely among sites in dry temperate forests of Himalaya. More forest surveys are required to understand the conditions necessary for greater success of *P. gerardiana* in the region.

Keywords *Pinus gerardiana* · Regeneration · Himalaya · Growing stock · Biotic factor · Abiotic factor

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Introduction

Pinus gerardiana Wall. ex D.Don is an important ecological and economic species of North-West Indian Himalaya. The species yields edible nuts/seeds, a rich source of carbohydrates, proteins, fats, fiber and mineral matter (Thakur et al. 2009). But, this species is subjected to various biotic and abiotic disturbances (Fig. 1) that have reduced or eliminated *P. gerardiana* regeneration (Sharma and Minhas 1993; Wahab et al. 2008; Ahmed et al. 2009; Khan et al. 2015; Akbar et al. 2013; Kumar et al. 2014, 2016). The lack of regeneration had led to pre-dominance of mature and overmatures *P. gerardiana* trees, while young trees were lacking in these forests (Sharma et al. 2010a). The most important factor affecting its regeneration is collection of cone by the local people for extracting seeds/nuts and these fetch high price in local and international market (Peltier and Dauffy 2009; Kumar et al. 2015; Ranot and Shrama 2015). These biotic interferences affect tree regeneration and stand

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development, which leads to forest degradation and change in soil physico-chemical properties and succession patterns in forests (Romme et al. 1998). *P. gerardiana* species has been declared endangered under IUCN red list category (Thakur et al. 2011; Urooj and Jabeen 2015)

Pre-summing all environmental conditions are favourable, *P. gerardiana* will regenerate, where protection was provided and if large or grievous disturbances were uncommon (Lakhanpal and Kumar 1995). Similarly, if area is closed against seed collection and grazing/browsing, it resulted in sufficient seed on forest floor, which promoted seedling emergence and better growth of seedling (Reddy 1963; WWF-P 2014) and consequently increased regeneration (Glover 1937; WWF-P 2014). Site factors, such as climate and physico-chemical properties of soil also affect regeneration of a particular species (Gaur et al. 1995). So, aridity and low nitrogen levels in these soils are also responsible for slow growth and establishment of *P. gerardiana* in the region (Kaushal 1993; Kumar et al. 2016).

The study of *P. gerardiana* regeneration in dry temperate forest of Himalaya is essential for so many reasons. First, our knowledge regarding *P. gerardiana* regeneration is lacking, so it is important to understand regeneration pattern in the species. Several previous researchers have concluded that regional site factors (e.g. cone collection, grazing/browsing, change in land use and development activities) significantly affected *P. gerardiana* regeneration in the region (Singh et al. 1973; Sehgal and Sharma 1989; Anonymous 2000). Second, *P. gerardiana* is a dominant component of dry temperate forests; the reduction of area under species would adversely affect ecology and economy of the region (Urooj and Jabeen 2015). The area under species has declined from 2500 ha (Singh 1992) to 2040 ha (Sharma et al. 2010a; Thakur et al. 2011) in the Kinnaur region. Pine forests play important ecological role in regulating river and streams that originates and flow in a particular region (Harmon et al. 1986; Bilby and Bisson 1998), and *P. gerardiana* helps in watershed protection in the Himalaya (Akbar et al. 2014). Because of the major ecological role played by *P. gerardiana* in dry temperate forests of Himalayas, it is essential to understand the functioning of processes within these forests systems. Third, the construction of hydroelectric projects and other development activities (Yadav 2009) had led to reduction of species distribution that will adversely affect ecology of the region (Sarkar 2008); for future management and monitoring of these forests, it is essential to get basic knowledge of the present conditions of these forests systems. Research in some of the regions has revealed 18–22 % of regeneration success in *P. gerardiana* (Malik et al. 2012) and that too on inaccessible sites and on steep slopes (Tandon 1963). Indeed, to manage *P. gerardiana* forest effectively, there is need to have detailed knowledge of the natural processes and how these processes may vary by location. The overall aim of this research is to get basic data of site-wise regeneration status and general structure of *P. gerardiana* forests at regional level in dry temperate forests of Indian Himalaya.

Materials and methods

Study area

The research was conducted during May–June and September–October (2009–2010) in dry temperate forest of *P. gerardiana* in North-Western Himalaya (31° 55′N to 32° 05′N and 77° 45′E to 79° 35′E) of India, which covers almost the whole distribution zone of the species in the region (Fig. 2). *P. gerardiana* is the most dominant tree species and it occupies more than 70 % area in the region (Sharma et al. 2010a; Kumar et al. 2013). The detailed description of the sites chosen for study purpose has been given in Table 1.

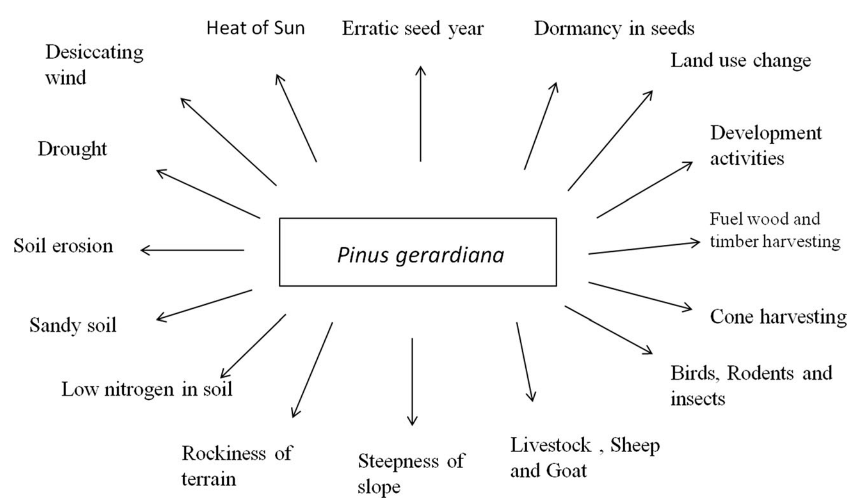


Fig. 1 Factors affecting regeneration of *P. gerardiana*

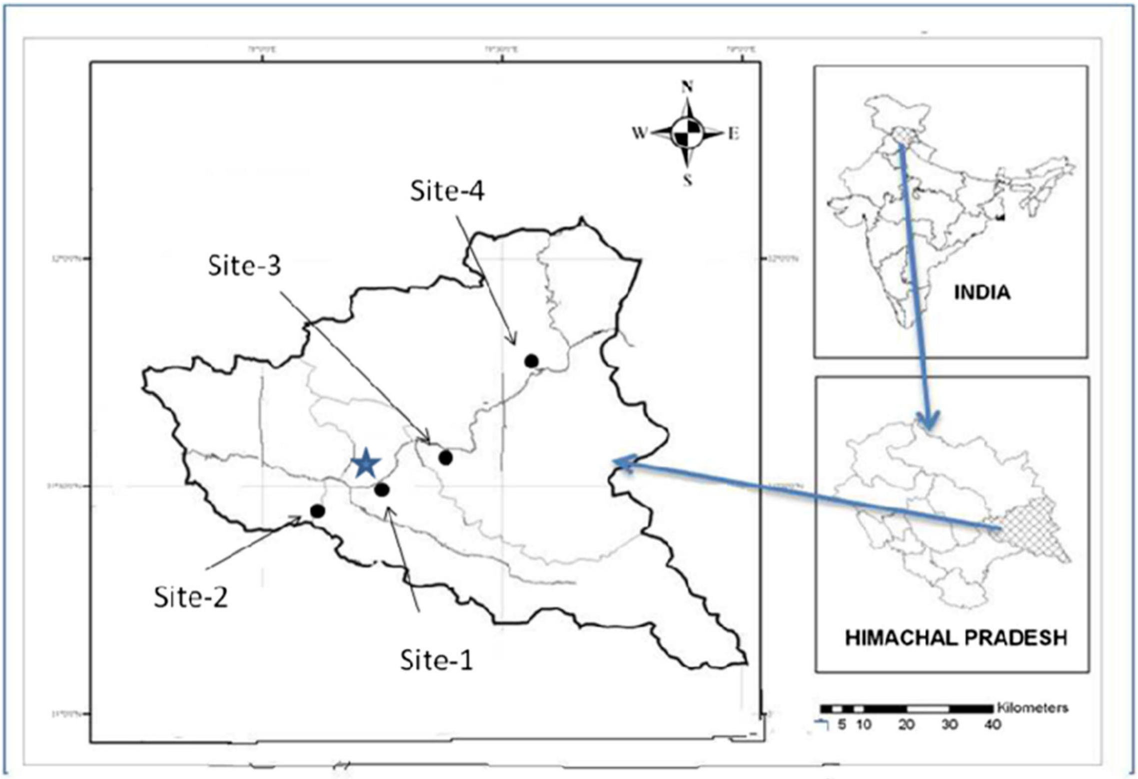


Fig. 2 Map of the study area (*star* indicates location of meteorological station)

The region is characterized by extreme topographic variation, with most of land having slope more than 10 %, with elevation ranging from 1500 to 3500 m. This region is mountainous having rugged topography, deep and narrow valleys and steep slopes, which makes it extremely prone to different types of slope failure. The area is characterized by long winters from October to April, short summers from June to August, absence of summer monsoon and prevalence of winter precipitation (mostly snow), contributing to formation of dry temperate forests dominated by *P. gerardiana*. Meteorological data information was available only at Reckong peo (31° 32′N and 78° 15′E), a place nearest to site-1. It shows that there was periodic change in precipitation, while slight increase in temperature in the last century (Fig. 3). Annual precipitation and average annual temperature was observed maximum in 1936 (1701.00 mm) and 1999 (14.37 °C), while their lowest value was observed in 1918 (581.11 mm) and 1905 (11.59 °C), respectively, in the last century (1901–2000).

Table 1 Detailed description of selected sites for study in the region

Site	Altitude	Latitude	Longitude	Slope	Soil texture
Site-1	2457 m	31° 51′	78° 28′	25.0–40.0°	Loam, loamy sand
Site-2	2384 m	31° 30′	78° 06′	>45.0°	Loamy sand
Site-3	2570 m	31° 35′	78° 23′	33.0–60.0°	Loamy sand
Site-4	2865 m	31° 46′	78° 26′	>50.0°	Loamy sand

Vegetation analysis

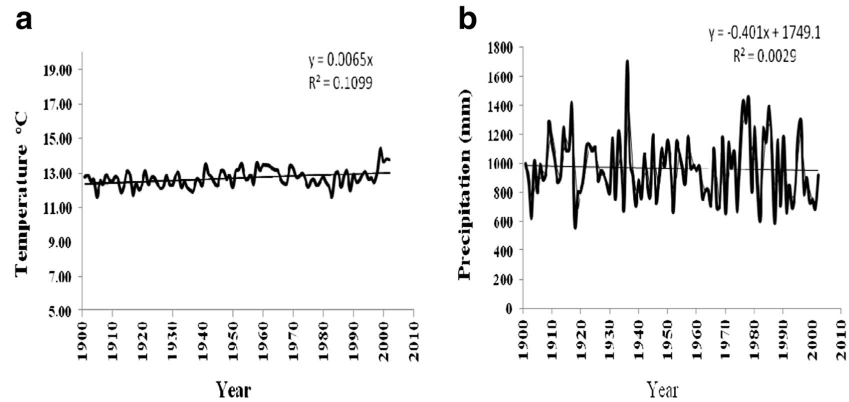
The growing stock of *P. gerardiana* was studied and presented at regional level, while regeneration was studied at site specific to know site-wise variability in regeneration. At general, plots selected in the region had similar floristic composition and structure to know regeneration status for devising site-wise forest management and conservation strategy. To record growing stock and regeneration observations, 25 m × 20 m size plots for trees and of 2 m × 2 m size sub-plots for regeneration were laid randomly at each site. A total of 10 plots for trees and 40 sub-plots within main plots for regeneration per site were established to reduce vegetation-site factor variability. The characteristics of tree viz., height, diameter at breast height (dbh) and volume were measured and calculated as per the methodologies given by West (2009). The Importance Value Index (Eq. 1) was calculated for all species of trees and shrubs of the region as per procedure given by Mueller-Dombois and Ellenberg (1974) and using the following formula:

$$IVI = \left(\frac{ni}{Ni} \times 100\right) + \left(\frac{Gi}{Gj} \times 100\right) + \left(\frac{ri}{R} \times 100\right) \qquad (1)$$

Where;

IVI Importance Value Index
ni number of individuals of species *i*

Fig. 3 Average annual variations in temperature (**a**) and precipitation (**b**) in the study area during last century



Ni total number of individuals of all the species
Gi total basal area of species *i*
Gj total basal area of all the species
ri number of surveys with species *i*
R total number of surveys

Within each sub-plot, plants of *P. gerardiana* were inventoried and divided into three size classes: seedlings (diameter <5 cm), saplings (diameter 5–9.9 cm), poles (dbh, 10–19.9 cm) and trees (dbh >20 cm) (Omeja et al. 2004). Sampling regeneration by size-class provides more accurate information on regeneration complexities rather than age-class because plant mortality is more size dependent (Rooney and Waller 1998; Rooney et al. 2000). The height of seedling, sapling and pole were also measured and categorized into two classes, i.e. unestablished plants (<2 m) and established plants (>2 m) to calculate regeneration success (Eq. 2) as per procedure given by Chacko (1965) by using the following formula:

$$RS = \left(\frac{1}{2500} \times \frac{UE}{4} + EP\right) \times 100 \qquad (2)$$

Where;

RS is regeneration success (%)
UE is unestablished plants (ha^{-1})
EP is established plants (ha^{-1})

Site factors study

Geographic and land surface parameters such as altitude, longitude, latitude, aspect, slope steepness and slope characteristics were recorded in each plot of the study sites. The global positioning system was used to record geographic features of the study sites. Solar radiation was estimated both under and outside the tree canopy with the help of luxmeter. Litter depth was calculated in the all the plots to know organic matter contents. Organic matter thickness was measured as depth of the column from top of leaf litter layer to the point under humus where soil exists. A soil sample at 0–30 cm depth in each plot was taken for physical and chemical analyses. Soil texture and bulk density was determined by rapid feel method and hydrometer method, respectively. Soil pH and organic carbon was determined by 1:2.5 water suspensions (Jackson 1973) and wet digestion (Walkley and Black 1954) methods, respectively. Available N, P and K was determined by alkaline permanganate (Subbiah and Asija 1956), SnCl2 reduced phosphomolybdate (Jackson 1973) and flame photometer methods, respectively. Effect of cone harvesting and lopping on regeneration was determined by recording the difference in number of cones and branches found on tree before and after cone/seed harvesting, respectively, and comparing it with number of *P. gerardiana* plants in the sample plots. Similarly, grazing damage was recorded by finding out the difference in number of *P. gerardiana* plants between closed and open areas in the sample plots of the studied sites.

Statistical analysis

Summary statistics of density of seedling, sapling, pole and tree, while basal area of trees was calculated to know statistical variability in the sampling plots. Ordinary least-squares (OLS) regression was performed to relate regeneration success with the site factors. Multiple comparison test viz. Tukeys HSD (honest significant difference) was performed in conjunction with one-way ANOVA to know growing stock variability in the region, while site-wise variability in regeneration of *P. gerardiana*. Linear regression equation of annual variation in temperature and precipitation was developed for assessing their association with time period. All the statistical analysis was done using SAS 9.2 software.

Results

Forest composition and *P. gerardiana* dominance in the region

The density and basal area of tree species was recorded highest for *P. gerardiana*, which is followed by *Cedrus* *deodara*, *Pinus wallichiana* and *Quercus ilex* in the region (Table 2). Out of the four tree species, density (118.25 stem ha^{-1}) and basal area (20.67 m^2 ha^{-1}) of *P. gerardiana* was recorded greatest, while the rest of the species contributed 87.50 stem ha^{-1} (tree density) and 15.45 m^2 ha^{-1} (tree basal area) in the region (Table 2). The *P. gerardiana* showed maximum variability in both density and basal area, which is followed by *C. deodara*, *P. wallichiana* and *Q. ilex* in the sample plots. The frequency of *P. gerardiana* was higher (100 %) followed by *C. deodara* (53.13 %), *P. wallichiana* (31.25 %) and *Q. ilex* (25.00 %). The importance value index value showed that *P. gerardiana* (162.50) was the dominant species in the region and it mostly grew as pure crop, but sometime mixed with *C. deodara* (80.02), *P. wallichiana* (31.74) and *Q. ilex* (25.74). In shrubs, *Lonicera quinquelocularis* (64.84) was the dominant species followed by *Abelia triflora* (41.68) and *Daphne oleoides* (34.82) (Table 2).

Growing stock of *P. gerardiana* varies with diameter class

The maximum diameter class of 90–100 cm was observed for trees of *P. gerardiana* in the region (Fig. 4). Density of trees (d.b.h > 20 cm) was significantly higher and lower in 30–40 cm and 90–100 cm diameter class, respectively. The highest population of *P. gerardiana* trees was observed between 20–30 cm and 40–50 cm diameter class. The basal area of trees significantly increased from 20–30 cm to 40–50 cm diameter class, and afterward it declined till last diameter class (90–100 cm). The volume showed steep increasing and then steadily declining trend from lower to higher diameter class.

Slope direction and altitude affected growing stock of *P. gerardiana*

The growing stock of *P. gerardiana* was significantly affected by slope direction, while non-significant difference was found between North and East aspect as well as between West and South-West aspect, respectively (Fig. 5). Tree density, basal area and volume of *P. gerardiana* were significantly greater on North aspect and least on South-West aspect, respectively. Similarly, altitude-wise (1900–3500 m) significant variation in growing stock of *P. gerardiana* was recorded in the region (Fig. 6). Tree density, basal area and volume of *P. gerardiana* were recorded significantly greater at 2300 m altitude, while their least value was observed at 3500 m altitude, respectively.

Presence of *P. gerardiana* plants varies on regeneration plots

The distribution of seedling, sapling, pole and trees was not uniform in sample plots of studied sites in the region. Average value of sample sub-plot showed seedling, sapling, pole and trees were present on 38.68, 17.53, 11.61 and 70.32 % of the total sub-plots, respectively (Fig. 7). Among sites, presence of seedling and sapling was observed higher on site-2, while pole and tree on site-1, respectively.

Site-wise variation observed in *P. gerardiana* regeneration

One-way ANOVA revealed a significant *F* value for all regeneration parameters viz. seedling, sapling and pole. Tukeys multiple comparison tests revealed significant difference

Table 2 Forest composition, density, basal area, frequency and importance value index of *P. gerardiana*-dominated forests in the region

Species	Density (number/hectare)	Basal area (m^2/ha)	Frequency (%)	Importance Value Index
Trees				
Pinus gerardiana	118.50 ± 12.14*	20.67 ± 2.10*	100.00	162.50
Cedrus deodara	57.50 ± 2.47*	9.65 ± 1.15*	53.13	80.02
Pinus wallichiana	17.50 ± 2.10*	3.05 ± 1.45*	31.25	31.74
Quercus ilex	12.50 ± 1.15*	2.79 ± 1.56*	25.00	25.74
Shrubs				
Lonicera quinquelocularis	61.00 ± 5.4*	7.06 ± 0.25*	58.75	64.84
Abelia triflora	34.50 ± 6.8*	4.65 ± 0.21*	40.00	41.68
Daphne oleoides	49.00 ± 7.2*	2.44 ± 0.14*	51.25	34.32
Berberis aristata	68.00 ± 5.6*	5.25 ± 0.05*	68.75	30.86
Rubus purpureus	47.00 ± 3.4*	1.58 ± 0.85*	41.25	27.15
Berberis lycium	49.50 ± 6.5*	0.58 ± 0.45*	62.50	26.15
Plectranthus rugosus	51.00 ± 4.8*	0.30 ± 0.25*	45.00	21.21
Rosa webbaiana	40.50 ± 3.9*	0.13 ± .0.15*	48.75	18.90
Rhus semialata	47.00 ± 3.5*	0.10. ± 0.12*	41.25	18.61
Desmodium tiliaefolium	20.50 ± 2.8*	0.10 ± 0.15*	58.75	16.28

*Value (±) indicates standard deviation of mean

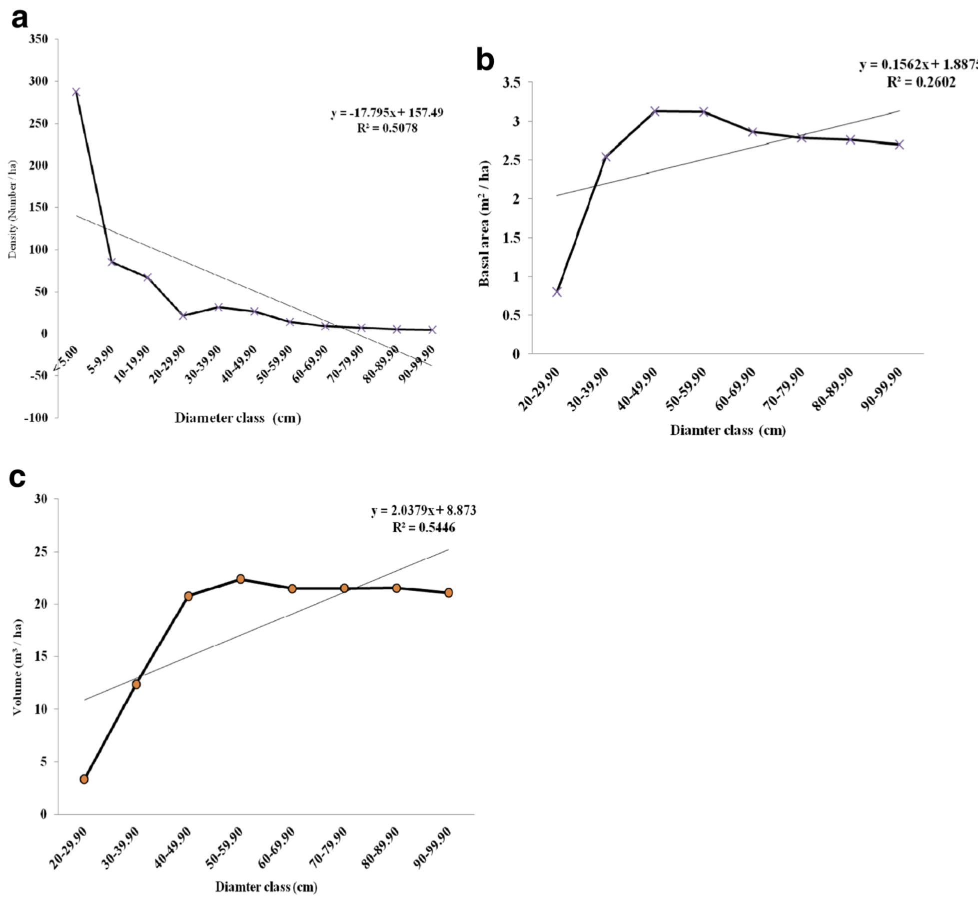


Fig. 4 Diameter class wise variation in density (**a**), basal area (**b**) and volume (**c**) of *P. gerardiana* in the region

among sites, whereas site-1 and site-2 were at par for sapling and pole density (Table 3). The seedling density was recorded greater on site-2, while sapling and pole density was recorded greater in site-1. On the other hand, lesser density of seedling, sapling and pole was recorded in site-4. Regeneration success was ranged from 8.44 to 15.93 % in different sites (Fig. 8). It was observed higher in site-2, closely followed by site-1, while its lowest value was observed in site-4. The pooled comparison of four sites for seedling, sapling, pole and tree showed that the plant density significantly declined as the size of seedling increased to sapling and then to pole, but density of trees was observed significantly greater than sapling and pole (Fig. 9).

Site factors influenced regeneration success

The soil physico-chemical properties, aspect, slope and litter depth varied significantly among sites. Regeneration had shown positive and significant correlation with solar influx ($r=0.72$, $p<0.01$), organic matter layer ($r=0.98$, $p<0.01$), organic carbon ($r=0.80$, $p<0.01$), available nitrogen ($r=0.91$, $p<0.01$), available phosphorus ($r=0.97$, $p<0.01$) and available potassium ($r=0.98$, $p<0.01$), whereas soil bulk density showed a significant negative correlation ($r=-0.77$, $p<0.01$). Slope steepness has also shown significant and positive correlation ($r=0.83$, $p<0.05$) with regeneration success. As soil pH and soil moisture were not significantly different among four sites, so these factors have no impact on regeneration success. Among biotic factors, cone harvest per tree ($r=-0.95$, $p<0.05$), lopping per tree ($r=-0.96$, $p<0.05$) and grazing/browsing of seedling ($r=-0.98$, $p<0.01$) have shown significant impact on regeneration of *P. gerardiana*. Linear regression model with standard error and R-square value has been obtained for regeneration succession on the entire site factors (Table 4). Except soil pH and soil moisture, for all the environmental factors, the slope coefficients are significant ($p<0.05$); hence, regeneration success can be determined using these regression equations for different environmental factors.

Discussion

Previous study examined Himalayan dry temperate forest with focus on diversity (Verma and Kapoor 2011; Chawla et al. 2012), regeneration (Peltier and Dauffy 2009; Malik et al. 2012) and in some cases structure (Sharma 2004; Sharma et al. 2010a; Kumar et al. 2013), but over limited geographic

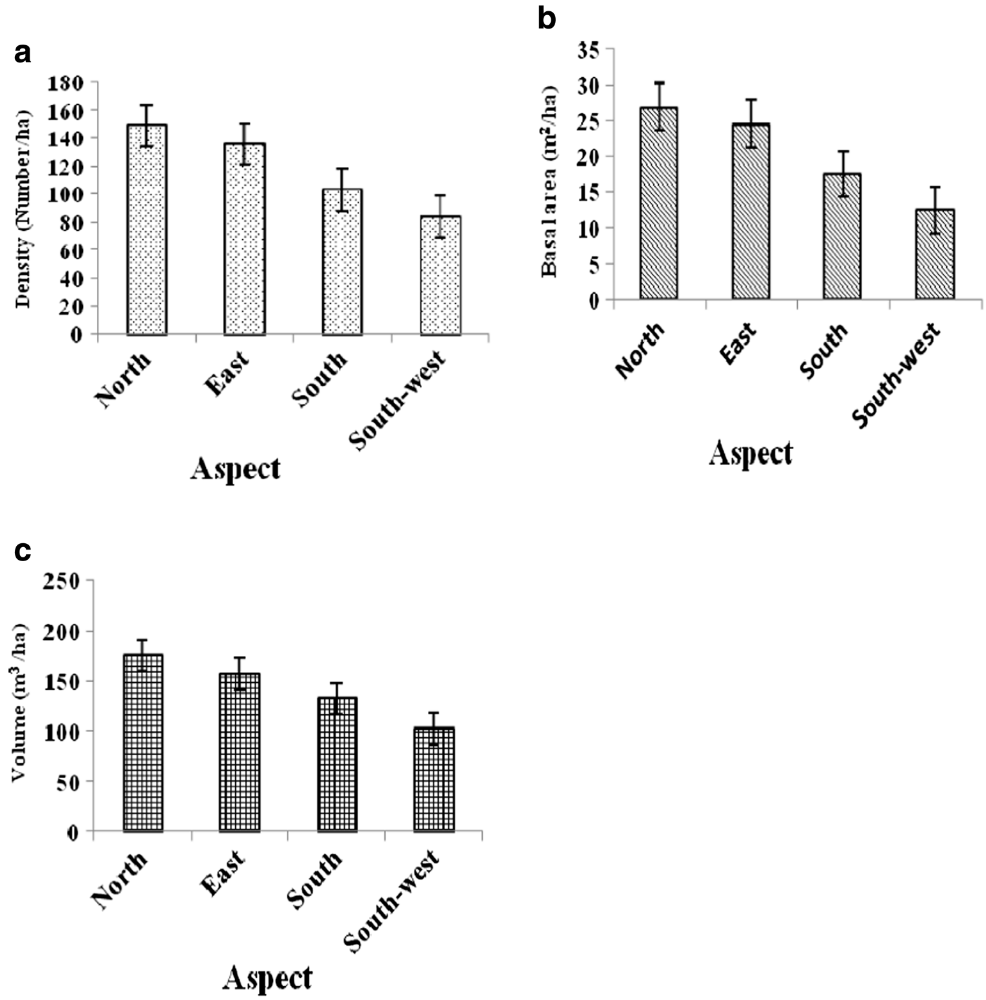


Fig. 5 Effect of aspect on density (**a**), basal area (**b**) and volume (**c**) of *P. gerardiana* in the region

extents and without a focus on the species (Kaushal 1993). The *P. gerardiana* habitats examined in the study were diverse, extending over a wide range of climatic, edhapic, topographic and biotic conditions. Because, variation in site conditions are responsible for growing special kind of plants community in the Himalaya (Gaur et al. 1995).

Throughout its range, *P. gerardiana* mostly occurred in pure stands and sometime in mixture with *C. deodara* and with *P. wallichiana* and *Q. ilex* in the region. Similar kind of association had been reported in *P. gerardiana*-dominated forest in Pakistan (Ahmed and Latif 2007) and in India (Peltier and Dauffy 2009), respectively. This region of Himalaya does not receive rainfall during monsoon (June–September) and precipitation occurs only in the form of snow during winter (November–March). So, *P. gerardiana* tends to replace *P. wallichiana* and continues as dominant vegetation all along the Sutlej catchment (Singh and Singh 1995), which resulted in formation of *P. gerardiana*-dominated forests in the region (Kumar et al. 2014). Some previous findings also revealed mono-dominance of *P. gerardiana*, which occupies more than 70 % area in these forests (Karwaskara 1981; Peltier and Dauffy 2009; Sharma et al. 2010a). The aridity and loamy sandy texture of soil had favoured establishment and development of *P. gerardiana*-dominated forests in the whole region. This region has less and different vegetation diversity than rest of the Himalayan regions (Chawla et al. 2012). The lesser number of species in the region suggests the inability of each species to regenerate, grow and develop in the prevailing environment conditions. However, establishment of a species is finally decided by its tolerance and adaptation to existing climatic conditions (Bhandari et al. 1999).

In mixed forest of *P. gerardiana*, the share of other species to IVI was less than 50 %, but continuous increased coexistence of *P. gerardiana* with other species appears to be result of large-scale disturbances, similar to findings of Mori and Takeda (2004) in subalpine forests of central Japan. The lesser number of individuals and lower basal area of *P. gerardiana* might have developed as a result of large-scale disturbances that had occurred previously in these forests, which resulted in continuously declining dominance and area under *P. gerardiana* (Singh et al. 1973; Sehgal and Sharma 1989; Malik et al. 2012). Similar observation were

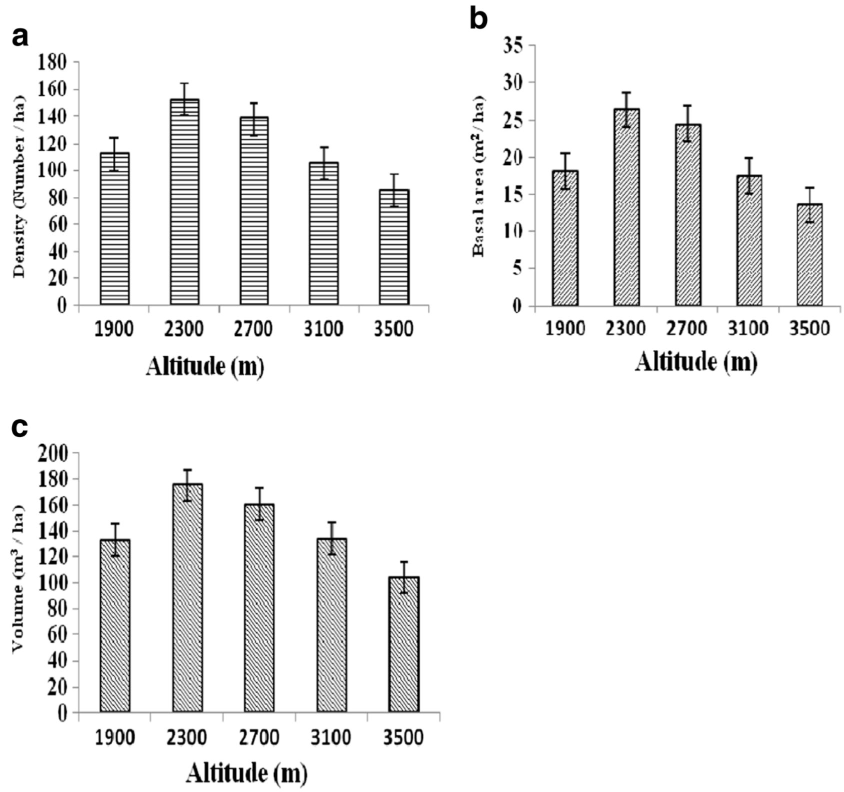


Fig. 6 Effect of altitude on density (**a**), basal area (**b**) and volume (**c**) of *P. gerardiana* in the region

also made by Catovsky and Bazzaz (2002), Peterson and Pickett (2000) and Grime (2001) for other early successional forest species. Thus in the future, pure *P. gerardiana* forests may be replaced by its associates because the latter are less subjected to influence of anthropogenic factors than *P. gerardiana* (Sharma 2004; Kumar et al. 2013).

The lesser number of young trees and greater number mature trees of *P. gerardiana* owes to influence of biotic and abiotic factors. The density and basal area of *P. gerardiana* was recorded 118.25 ha^{-1} and 20.87 m^2 ha^{-1}, respectively, in the region. Some previous researchers have also reported similar growing stock of *P. gerardiana* forests in the Himalaya (Ahmed et al. 1991; Akbar et al. 2014). High biotic pressure has been the main cause for the reduction in *P. gerardiana* growing stock in these forests (Kumar 2015), which showed urgent requirement of sustainable management of *P. gerardiana* in the Himalaya (Urooj and Jabeen 2015).

P. gerardiana growing stock was recorded significantly greater on North aspect. Similarly, Sharma et al. (2010b) recorded higher basal area of *Quercus semecarpifolia* and dominance of *Pinus roxburghii* on north aspect. Nevo (1997) also confirmed that species inhabit on different aspect display genetic, morphologic, physiological and behavioural adaptive complexes in relation to each of the aspect. Altitude-wise growing stock of *P. gerardiana* was recorded significantly greater at 2300 m. The better growth at this altitude was the

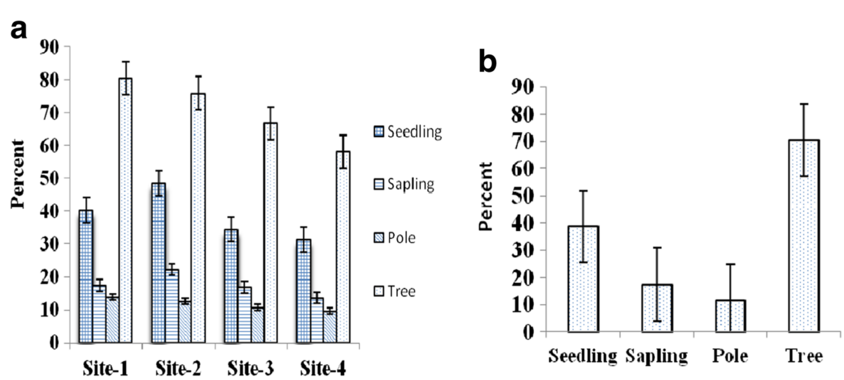


Fig. 7 Presence (%) of *P. gerardiana* plants in different sites (**a**) and in the region (**b**)

Table 3 Regeneration variability of *P. gerardiana* in different sites of the region

Site	Seedling (number/hectare)	Sapling (number/hectare)	Pole (number/hectare)
Site-1	306.25b ± 15.47*	107.50b ± 11.89*	91.31a ± 12.84*
Site-2	368.75a ± 22.14*	93.75b ± 9.76*	79.74a ± 8.47*
Site-3	293.75b ± 20.78*	76.16a ± 8.18*	54.64b ± 8.87*
Site-4	181.25c ± 12.47*	62.54c ± 5.59*	42.74c ± 7.47*

Means with the same letter are not significantly different

*Value (±) indicates standard deviation of mean

result of favourable climatic conditions because the climate of a place varies with altitude, which resulted in varied growth pattern in the species (Sharma et al. 2009; Kharkwal et al. 2005).

The presence of seedling, sapling, pole and trees of *P. gerardiana* were not observed in all the sample plots of sites in the region. Less number of plots in each site observed to have effective conditions for regeneration, many plots exhibited occasional, while mostly showed extremely limited regeneration. The regeneration success recorded was ranged from 8.44 to 15.93 % in studied sites. Similarly, Malik et al. (2012) had observed 18 to 22 % regeneration success of *P. gerardiana* in the region. The regeneration success of this pine was extremely low in all the sampling plots owing to influence of site factors. One of the important site factor is the collection of cone/seed by local villagers from most of the trees (Ahmed et al. 2009; Wahab et al. 2008; Kumar et al. 2016), while few trees those grows in remote areas and steep slopes, which cannot be harvested, only provide seeds for the regeneration (Singh et al. 1973; Tandon 1963). In our present study, better regeneration in site-1 and site-2 was due to better site condition or lesser influence of biotic factors. To reduce impact of biotic factors, fencing of the area for some period to augment *P. gerardiana* regeneration has also been suggested (Reddy 1963; Lakhanpal and Kumar 1995).

The results have also shown less density of sapling and pole than trees. This situation has occurred because, previously *P. gerardiana* trees were not completely harvested and forests were able to regenerate. On the other hand, significantly lesser density of sapling and pole than seedling density occurred as a result of effect of grazing, climate and soil physico-chemical properties on seedling growth and development (Luna 2008). This resulted in poor regeneration in this pine and our observation are in agreement with the findings of previous researcher, whom observed dependence of villagers on chilgoza and giving nut contracts to private contractors (Peltier and Dauffy 2009) for lopping branches to extract cones (Singh and Yadav 2007; Thakur et al. 2011), which became one of the major reasons for poor natural regeneration in the species (Glover 1937; Reddy 1963; Ahmed and Latif 2007; Sharma et al. 2010a; Kumar et al. 2014). Poor regeneration in other conifer species such as *Taxus* (Ali et al. 2009), *Abies pindrow* (Agarwal and Patil 1956) and *Picea morinda* (Jha et al. 1984) has been also reported due to influence of site factors in the Himalaya.

The plants of *P. gerardiana* are subjected to influence of various climatic-edhapic factors under natural conditions. The seedling growth and establishment is significantly influenced by soil physico-chemical properties (Singh et al. 1973). As explained in our study, significant correlations of regeneration with most of site factors were found except for bulk density and soil moisture. The lesser variability in bulk density and soil moisture among sites resulted in their non-significant effect on regeneration. Other researchers have also shown that

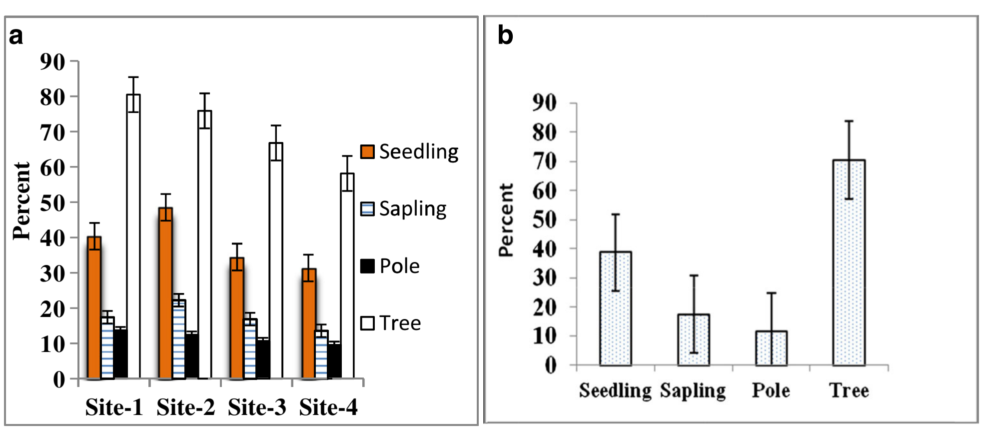


Fig. 8 Site-wise variation in regeneration success (%) of *P. gerardiana* in the region

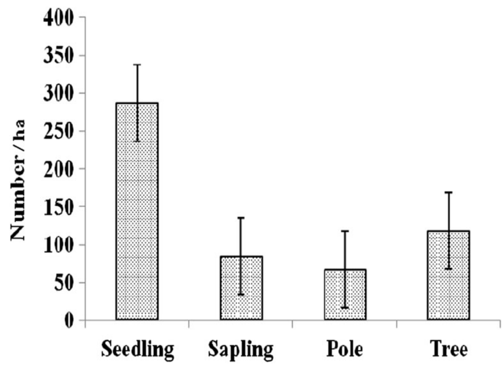


Fig. 9 Comparison of density (number/ha) of *P. gerardiana* in the region

sandy soil and soil nutrients affected seedling density in different plots (Kaushal 1993; Luna 2008). Other abiotic factors, such as temperature, drought and desiccating winds, have affected the growth of seedling. Therefore, adaptability of *P. gerardiana* to these conditions is urgently required to cope with changing climate conditions (Baba et al. 2005; Kumar et al. 2013). Similarly, significant correlation was found between regeneration and biotic factors, such as cone harvesting, lopping of branches and grazing by animals. Because, it has been observed that regeneration was affected by heavy incidence of grazing, trampling by sheep and goats, and eating by birds and rodents (Singh et al. 1973; Luna 2008; Malik and Shamet 2008). But the most important factor responsible for absence of natural regeneration in *P. gerardiana* was,

Table 4 Linear regression between regeneration success of *P. gerardiana* (*Y*) and site factors (*x*) in the region

Site factors	Linear regression	R-square value
Solar influx	$Y = 1.449x - 18.93$ (0.97) (21.93)	0.528
Organic matter layer	$Y = 18.81x + 1.636$ (2.08) (1.32)	0.976
Organic carbon	Y = 26.94 × −17.30 (14.36) (16.29)	0.638
Bulk density	$Y = -58.82x + 93.72$ (34.15) (46.76)	0.597
Available nitrogen	$Y = 0.126x - 9.833$ (0.03) (7.02)	0.854
Available phosphorus	$Y = 2.136x - 35.17$ (0.33) (7.45)	0.954
Available potassium	$Y = 0.051x - 9.897$ (0.01) (3.32)	0.961
Slope	$Y = 0.30x + 26.85$ (0.13) (6.99)	0.664
Cone harvesting	$Y = -0.80x + 101$ (0.18) (2.56)	0.897
Lopping of branches	$Y = -1.57x + 51.57$ (0.33) (4.60)	0.912
Grazing/browsing of seedling	$Y = -1.23x + 50.54$ (0.14) (1.93)	0.973

Value in the parenthesis are standard error of the parameters

however, the practice of collection of cones by local people for extracting seeds (Ahmed and Latif 2007; Peltier and Dauffy 2009; Sharma et al. 2010a; Ranot and Shrama 2015).

It has been observed that pine regeneration is controlled by a complete interaction between seed availability and existing micro sites for germination, early growth and establishment (Bonnet et al. 2005; Galipeau et al. 1997). Similarly, *P. gerardiana* regeneration is also affected by climatic, edhapic, topographic and biotic factors in dry temperate forests of the Himalaya. Similar result has been documented previously by Glover (1937), Reddy (1963), Ahmed and Latif (2007), Sharma et al. (2010a) and Kumar et al. (2016) for the *P. gerardiana* in Himalaya.

Conclusion

P. gerardiana is an important ecological and economic species of Himalaya, but a large number of biotic and abiotic factors have eliminated its regeneration in the natural forests. Forest's regeneration after collection, harvest or deforestation was thus neglected. Consequently, the *P. gerardiana* forest was faced with possible extinction, environmental deterioration and loss of value to state and national economy. Regular monitoring of the habitats and populations of *P. gerardiana* that is native and endemic species facing high anthropogenic pressure is essentially required, so that adequate planning for their conservation management can be done in time. Enlightenment campaigns to educate the populace for protection of *P. gerardiana* forest and very serious commitment on the part of government to ensure adequate funds for regeneration, abrogation of dereservation, increase reservation and sustainable management of *P. gerardiana* forests are needed.

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