Research article

Stand structure and regeneration status of tree species in four major forest types along an altitudinal gradient in Kumaun Himalaya, Uttarakhand

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[Accepted: 10 April 2020]

Abstract: The present study was undertaken in four major forests (Teak forest, Sal forest, Pine forest and Oak forest) along an altitudinal gradient between altitude 300 m – 2080 m of Kumaun Himalaya. The total density and basal area of trees ranged between 470 ind. ha⁻¹ and 916.67 ind. ha⁻¹ and from 37.82 m² ha⁻¹ to 67.41 m² ha⁻¹ respectively. Maximum species richness for trees was reported at site KD (17) and minimum at site MG (7). The maximum beta diversity index was recorded for KD forest (5.46) and the minimum was reported for BP forest site (3.12). Regeneration status of forest sites varied from good regeneration to poor or no regeneration. Site MG was found very poor in regeneration. Proportionate distribution of trees, seedlings and saplings showed that site KD contained maximum density of seedlings in comparison with other sites. The minimum density of seedlings was recorded at site MG. This is due to heavy livestock grazing pressure at this site. The results of the study provide baseline data to conserve and recover different forests along the altitudinal gradient and will also help to formulate conservation strategies of forests in Himalaya.

Keywords: Altitudinal gradient - Beta diversity - Equitability indices - Species richness - Regeneration status.

[Cite as: Gahlot T, Joshi P & Rawat YS (2020) Stand structure and regeneration status of tree species in four major forest types along an altitudinal gradient in Kumaun Himalaya, Uttarakhand. *Tropical Plant Research* 7(1): 176–189]

INTRODUCTION

The ecosystems of Himalaya are rich in forest cover and biodiversity. Himalayan forests are crucial not only for the people living in Himalaya but also for many more living in the adjoining plains (Singh *et al.* 2014). Himalayan forests play an important role in tempering the inclemencies of the climate, cooling and purifying the atmosphere, protecting the soil, holding the hill-slopes in position, sequestering carbon, building up huge reserves of soil nutrients and providing numerous ecosystem services to mankind (Gairola *et al.* 2011). A great variety of forest types inhabit the Himalaya, ranging from dry deciduous forests in the subtropical foothills to evergreen coniferous forests in the subalpine zone (Vetaas & Chaudhary 1998). In the foothills of Kumaun Himalaya planted teak *Tectona grandis* L.f. and naturally occurring sal (*Shorea robusta* C.F. Gaertn.) forests are best-surviving forest communities. As we go high in the middle belt of Uttarakhand state in Kumaun western Himalaya, Pine (*Pinus roxburghii* Sarg.) and Oak (*Quercus* spp.) form the dominant forest vegetation and provide a range of ecosystem goods and services to the inhabitants (Joshi & Negi 2011). Understanding of the forest structure is a pre-requisite to describe various ecological processes and also to model the functioning and dynamics of forests (Elouard *et al.* 1997).

The regeneration pattern of any forest gives an idea of its future existence. The potential regeneration status of tree species often depicts the future composition of forests within a stand in space and time (Henle *et al.* 2004). Halle *et al.* (1978) described regeneration as the process of Sylvigenesis (forest building) by which trees and forest survives over time. Natural regeneration of the plant is a fundamental element for tropical forest ecosystem dynamics (Getachew *et al.* 2010, Sharma *et al.* 2014). An understanding of the processes that affect

the regeneration of forest species is of crucial importance to both ecologists and forest managers (Slik *et al.* 2003, Deb & Sundriyal 2008). Sustained regeneration and growth of all species in the presence of older plants is required for better growth of any plant community (Taylur & Zisheng 1988). The successful regeneration of a tree species depends on the ability of its seedlings and saplings to survive and grow (Good & Good 1972). The interactive influence of biotic and abiotic factors of the environment affects the survival and growth of seedlings and sprouts (Muller-dombios *et al.* 1980). Seed germination, emergence, growth, survival and establishment of seedlings affect forest regeneration by influencing plant populations in the forest (Osunkjoya *et al.* 1992). Presence of enough seedlings, saplings and young trees in each population indicated a successful regeneration, while the inadequate number of seedlings and saplings of tree species in a forest indicate poor regeneration (Saxena & Singh 1984). If a species does not occur in seedling and sapling stage it represents no regeneration and if a species occurs only in seedling or sapling stage (no tree) then it represents the presence of new species to the region. Regeneration of tree species and survival and growth of their seedlings depend upon the interactive influence of biotic and abiotic factors of the forest environment (Khan *et al.* 1986). Habitat conditions and the extent of those conditions is a major determinant of regeneration of any species for its geographic distribution (Grubb 1977). Regeneration also provides an idea of disturbance level in the forest community. Less number of seedlings are mostly influenced by intense grazing. An understanding of the processes that affect regeneration of forest species is of crucial importance to both ecologists and forest managers (Slik *et al.* 2003). Hence the present study aims to understand the stand structure and regeneration pattern of the forests communities situated along the altitudinal gradient to understand their future survival.

MATERIALS AND METHODS

Study area

The study area lies in the subtropical and subtemperate regions of Kumaun Himalaya, Uttarakhand. The study sites are distributed among Barhaini central forest division, Ramnagar central forest division and Nainital forest division. The details of the sites have been given in table 1 and the locations are elaborated in figure 1. The studied area covers a range of 55 km of forest area along altitudinal gradient. The sites are named based on adjacent villages. Site I was named BH (for Barhaini forest region), Site II was named KD (for Kaladhungi forest region), Site III was named MG (for Mangoli forest region) and Site IV was named BP (for Barapathar forest region). The altitudinal positions of different forest sites are related to the type of their geographical distribution. BR site is present in Terai belt, KD site is present in Bhabhar belt, MG site is mid altitudinal in position and BP site is situated on hill (high altitude).

Figure 1. Map of study area lies in district Nainital and parts of district Udham Singh Nagar.

Table 1. Sites locations of different forest types along an altitude.

Sites	Altitude (m)	Latitude	Longitude	Dominant Tree Species
BR	300	N 29° 14'	E 79° 17'	<i>Tectona grandis</i> L.F.
KD	510	N 29° 28'	E 79° 34'	<i>Shorea robusta</i> C.F.Gaertn.
MG	1120	N 29° 35'	E 79° 40'	<i>Pinus roxburghii</i> Sarg.
BP	2080	N 29° 38'	E 79° 44'	<i>Quercus floribunda</i> Lindl. ex A.Camus

The foothill Himalaya is a 10 km to 50 km wide Miocene to Lower Pleistocene molasse sequence represented by rocks of the Sirmur Group (*i.e.* Subathu and Dagshai + Kasauli or Murree/Dharmshala) Siwalik Group. This belt is a domain of active tectonics having participation in the terminal phase of the Himalayan Orogeny and followed to the north by the Lesser and Higher Himalaya, represented by geological sequences of the Proterozoic age with the Phanerozoic cover of variable thickness in different parts (Geological Survey of India 2016). The soil at altitudinal slope is derived from rocks including slates, phyllites, sandstones and intercalated limestone. The soil at slope altitude is sandy loamy, loose and quite deep at gentle slope. At the higher altitudinal position rocks are complex mixture of mainly sedimentary, low grade metamorphosed and igneous (Valdiya 1980). Soils vary from coarse loamy sand (lower elevation) to clay loam (higher elevation). The pH of the soil varied between 5.6–7.2. High values for pH was recorded for forest sites located at lower altitude regions while higher elevation forest soil was slightly acidic. The soil under higher elevation is rich in nutrient content compared to lower elevations. The Colour of soil varied from light yellowish-brown to dark-brown. Meteorological data shows that the annual rainfall and temperature along the altitude varied considerably. Sites present at lower to mid-altitude are influenced by sub-tropical monsoon pattern of rainfall. The average rainfall received is approximately 2076 mm, mainly between mid-June to mid-September. Mean temperature ranged between 13°C (in winters) and 33°C (in summers). Forest sites located at higher altitudes received more rain throughout the year compared to lower altitude sites. The average mean rainfall recorded for the site of high altitude is 2357.6 mm (maximum rain received in rainy season). Winters are colder than lower altitude sites, here the temperature goes down up to -3°C. In summers temperature doesn't exceed to 25°C.

Sampling and data analysis

Regeneration survey of the different forest sites situated at different altitude was carried out during different seasons from the year 2017–2019. For the sampling of vegetation four major forest types according to altitude and tree species composition were selected. The forest types were named according to the composition of dominating species (Prakash 1986). The analysis of trees, saplings and seedlings was carried out by placing ten quadrats of sized 10 m × 10 m for trees, 10 m × 10 m for saplings and 5 m × 5 m for seedlings (Curtis & McIntosh 1950, Phillips 1956). The size and number of quadrats were determined using the species area curve following Misra (1968) and running mean method (Kershaw 1973). All the trees present in a quadrat were measured for CBH (Circumference at Breast Height, *i.e.* 1.37 m from the ground level). Plants with >31.5 cm CBH were considered trees (Knight 1975) and those that had 10.5 cm to 31.5 cm CBH were considered as saplings and less than 10.5 cm CBH were considered as seedlings (Saxena & Singh 1982). For better results for regeneration each site was further divided into three sub-sites (BHI, BHII, BHIII, KDI, KDII, KDIII, MGI, MGII, MGIII, BPI, BPII and BPIII).

For analysis of vegetational parameters for each species, the values for density, abundance and frequency were calculated (Curtis & McIntosh 1950). The Importance Value Index was calculated by summing up the values of relative frequency, relative density and relative dominance (Phillips 1959). The basal cover of the trees was calculated by dividing the square of CBH with 4π . For estimation of total basal cover the mean basal cover was multiplied with density. The index for diversity was calculated by following Shannon & Weaver (1963) as:

$$H = - \sum_{i=1}^s \left[\frac{N_i}{N} \right] \log_2 \left[\frac{N_i}{N} \right]$$

Where, H indicates Shannon-Wiener Diversity Index; N_i number of individuals of each species; N is the total number of all species.

Beta diversity (β) was calculated by following Whittaker (1972):

$$\beta = \frac{Sc}{S}$$

Where, Sc is the total number of species occurring in a set of samples counting each species only once, S is the average number of species per individual sample.

Simpson's concentration of dominance index (Cd) and diversity index (SDI)

$$Cd = \sum_{i=1}^S Pi^2$$

$$SDI = 1 - Cd$$

Where, $Pi = Ni/N$

Pielou's equitability (Ep)

$$Ep = \frac{H'}{H'_{max}}$$

Where, H' is Shannon- Wiener Diversity Index, H'_{max} is ln of species richness

Menhinick index (MeI) was calculated by Menhinick (1964) formula as:

$$MeI = \frac{S}{\sqrt{N}}$$

Where, S is number of species; N is total number of individuals of all species.

Margalef Index (MI) was calculated by Margalef (1958) formula as:

$$MI = \frac{S-1}{\ln(N)}$$

Where, S is species richness; N is total number of individuals.

Berger- Parker Index (BP)

$$BP = N_{max}/N$$

Where, N_{max} stands for number of individuals of most abundant species and N is total number of individuals

The index of similarity (in percentage) between forest sites was calculated following Sorenson (1948) as:

$$I_s = \frac{2C}{A+B} \times 100$$

Where, I_s is Sorenson index of similarity; C is the common species to both comparable sites; A is total number of species present at site A; B is the total number of species present at site B.

For regeneration status field survey was carried out seasonally. The quadrat method given by Khan *et al.* (1987) was followed for investigating the regeneration status of the trees on different selected sites during July 2017 – July 2019. The density of trees, saplings and seedlings were recorded in each quadrat. The method given by Khan *et al.* (1987) was used for generating the regeneration status of trees in each selected forest sites as:

- If seedlings > saplings > adults = Good regeneration;
- If seedlings > or = saplings ≤ adults = Fair regeneration;
- If the species survives only in sapling stage, but no seedling (saplings may be <, > or = adults) = Poor regeneration;
- If a species is present only in adult form = No regeneration;
- If a species has no adults but occur in seedlings and saplings = New regeneration.

RESULTS AND DISCUSSION

Phytosociological analysis of forest sites

The overall phytosociological analysis of all the forest sites generalizes the pattern of community structure and composition of every forest (Table 2). The generated data indicated that a maximum number of species were present at KD forest site (17) followed by site BH. A noticeable decline in the number of species was observed with the increase in altitude (Brown 1988 and Stevens 1992). Site MG and BP were poor in species richness as they were situated at the increasing altitude. The total density of stems at different forest sites ranged between 470 ind. ha⁻¹ and 916.67 ind. ha⁻¹ and the total basal cover ranged between 37.82 m² ha⁻¹ and 67.41 m² ha⁻¹. Bohra (2010) reported stem density ranged from 600 ind. ha⁻¹ to 820 ind. ha⁻¹ in forest of Kumaun Himalaya along with the altitude. The Importance Value Index of all the four forest sites generalizes the dominance of single tree species with more than 50% IVI value. The dominant tree species was *Tectona grandis* (IVI 167.35) at site BH, *Shorea robusta* (IVI 160.98) at KD site, *Pinus roxburghii* (IVI 178.30) at MG site and *Quercus floribunda* Lindl. ex A.Camus (IVI 165.23) at BP site. The highest dominance index (Cd) value was reported for site BH (0.52) followed by site BP (0.46) and least value for dominance index was reported for site

KD (0.40). Mishra *et al.* (2000) and Tiwari & Singh (1985) reported almost similar range of values for dominance index in their study (0.31 to 0.42 and 0.11 to 0.93, respectively) for different forest types of Uttarakhand. Shannon-Wiener diversity index values were highest at site KD (2.05). Moderate Shannon-Wiener diversity index values were reported at BP (1.76) and MG (1.71) sites, whereas the least value was recorded at site BH (1.52). Bohra (2010) reported higher values for species diversity at middle elevation while at lower elevation he reported almost similar values. Shannon-Wiener diversity index values between 0.83 to 4.10 was reported for Central Himalayan forests of India (Singh *et al.* 1984). The values of Simpson diversity index recorded was maximum for site KD (0.60) and minimum for planted forest site (0.48). Values of equitability index in the present study ranged between 0.61 and 0.88. Similar values were recorded for the tree layer of different forest in Kumaun Himalaya (Kumar & Ram 2005). However, values less than those reported in present study for tree layer were recorded for forests of Trikuta hills of Jammu (Sharma *et al.* 1998) and also for forests of Garhwal Himalaya (Ghilidiyal 1998). Species richness indices *i.e.*, Margalef's index (MI) and Menhinick's index (MeI) revealed similar results. Higher values of species richness indices were recorded for site KD and lower values were recorded for site MG. Berger- Parker Index (BP) indicates the importance of the dominant species in the community. In the present study the values for BP were highest at BH site (0.71) and lowest at KD and MG (0.59 for both forests) sites. Beta diversity was defined by Whittaker (1972) as the extent of species replacement or species turnover along an environmental gradient. For the present study beta diversity values were recorded between 3.12 and 5.46. These values of beta diversity indicates that species composition with increasing altitude varied considerably. Beta diversity values reported by Tripathi *et al.* (2004) ranged from 1.54 to 5.1. Sharma *et al.* (1999) recorded 1.11 to 2.4 values of beta diversity for Trikuta Hills (Jammu). Malik & Bhatt (2016) reported similar values in western Himalayan forests.

Table 2. Sorenson Similarity Index (%) of tree layer at different forest sites.

	BH	KD	MG	BP
BH	100	41.38	21.05	0
KD		100	16.67	0
MG			100	11.76
BP				100

Similarity among the forest was recorded poor. For calculating similarity index all the forests were compared and the values for similarity index (Sorenson similarity index) was found highest among KD and BH forest sites of lower altitude (Table 3).

Table 3. The comparative phytosociological attributes of tree layer at different forest sites.

Site	D	TBC	IVI (max)	Cd	SDI	H	Eq	BP	BD	SR	MI	MeI
BH	540.00	37.82	167.35	0.52	0.48	1.52	0.61	0.71	4.86	12	2.16	0.94
KD	643.33	67.41	160.98	0.40	0.60	2.05	0.72	0.59	5.46	17	3.04	1.22
MG	470.00	43.41	178.30	0.45	0.55	1.71	0.88	0.59	4.95	7	1.21	0.59
BP	916.67	62.89	165.23	0.46	0.54	1.76	0.77	0.65	3.12	10	1.60	0.60

Note: D= Density (ind. ha⁻¹); TBC= Total Basal Cover (m² ha⁻¹); IVI= Importance Value Index; Cd= Concentration of Dominance; SDI= Simpson Diversity Index; H= Shannon- Wiener Diversity Index; Eq= Equitability Index; BP= Berger- Parker Index; BD= Beta Diversity; Mat.I= Maturity index; MI= Margalef Index of Species Richness; Me I= Menhinick Index of Species Richness; SR= Species Richness.

Regeneration Status of tree species of forest sites

According to Odum (1971) the reproductive status of the population and its future course can be determined by the ratio of various age groups in a population. Singh *et al.* (1987) concluded that representation of population structure as percent of individuals by size classes was the only workable method to analyze the regeneration status in forest communities as the population dynamics of all tree species in diverse forests at the extensive level is quite impossible.

In the present study regeneration status of dominant tree species, *Tectona grandis* at BH site for all sub-sites (BHI, BHII and BHIII) was found moderate. It was noticed that at two sub-sites (BHI and BHII) saplings to trees (Sa/T) ratio was very low. While at BHIII there was lesser seedlings to trees (Se/T) ratio present compared to other two sub-sites. Forest sites present at KD reported moderate ratios for Se/T and Sa/T for dominant tree species (*Shorea robusta*) at all sub-sites. These sites also showed inverse J-shaped curve of population structure. This means the regeneration potential of dominant tree species is fine and future vulnerability chances are very less for many decades if the community doesn't face any new trend of disturbance. Trees at site MG were found to be regressive as the Se/T and Sa/T ratios indicated for dominant tree species (*Pinus roxburghii*) are moderate for two subsites (MGI and MGII) but very poor for sub-site MGIII. Similar results are indicated in figure 2 for

Figure 2. Population structure and regeneration types (inverse-J, sporadic-S, and uni-modal-U) based on size class distribution of the dominant tree species at different forest sites. Size classes. [Size class A= 0–10 cm, B= 11–30 cm, C= 31–50 cm, D= 51–70 cm, E= 71–90 cm, F= 91–110 cm, G= 111–130 cm, H= 131–150 cm, I= 151–170 cm and J= 171–190 cm, K= 191–210 cm, L=> 211 cm) (BHI, BHII and BHIII represents sub-sites of Barhaini forest region; KDI, KDII and KDIII represents sub-sites of Kaladhungi forest region; MGI, MGII and MGIII represents sub-sites of Mangoli forest region and BPI, BPII and BPIII represents sub-sites of Barapathar forest region]

population structure. Inverse J-shaped curves were obtained for MGI and MGII sites, while for MGIII site a sporadic type of curve was obtained. This indicated that the adjacent classes were not represented normally; there must be a type of disturbance at this site. The values for Se/T and Sa/T for dominant species (*Quercus floribunda*) represented moderate ratios for all subsites at BP forest site. The population curves obtained by size-classes represented inverse J-shaped curves for the dominant tree species at this region. Se/T and Sa/T ratios for all the tree species present at all forest sites have been given in table 4.

Table 4. Regeneration behavior of tree species indicated as the ratio of seedlings (Se) and saplings (Sa) to tree (T) densities at different forest sites.

Species name		BHI	BHII	BHIII	KDI	KDII	KDIII	MGI	MGII	MGIII	BPI	BPII	BPIII
<i>Acacia catechu</i> (L.f.) Willd.	Se/T	0/30	0/10	0/10	-	-	-	-	-	-	-	-	-
	Sa/T	0.67	0/10	0/10	-	-	-	-	-	-	-	-	-
<i>Acer oblongum</i> Wall. ex DC.	Se/T	-	-	-	-	-	-	-	-	-	0/10	0/20	-
	Sa/T	-	-	-	-	-	-	-	-	-	0/10	0/20	-
<i>Adina cardifolia</i> (Roxb.) Brandis.	Se/T	0/20	-	0	-	-	5.33	-	-	-	-	-	-
	Sa/T	0/20	-	-	-	-	2.0	-	-	-	-	-	-
<i>Aegle marmelos</i> (L.) Correa.	Se/T	0/10	-	0	-	-	-	-	-	-	-	-	-
	Sa/T	1	-	-	-	-	-	-	-	-	-	-	-
<i>Albizia lebbbeck</i> (L.) Benth	Se/T	0	0	0	-	-	-	2.67	0/10	0/10	-	-	-
	Sa/T	-	-	0/20	-	-	-	0.33	0/10	0/10	-	-	-
<i>Albizia odoratissima</i> (L.f.) Benth	Se/T	-	-	-	-	-	0/10	-	-	-	-	-	-
	Sa/T	-	-	-	-	-	0/10	-	-	-	-	-	-
<i>Anogeissus latifolia</i> (Roxb. ex DC.) Wall. ex Guill. & Perr.	Se/T	-	-	-	-	-	6.0	-	-	-	-	-	-
	Sa/T	-	-	-	-	-	2.5	-	-	-	-	-	-
<i>Cassia fistula</i> L.	Se/T	32	14	4	18	14	2.67	-	-	-	-	-	-
	Sa/T	0/20	0.25	10	2.5	1	0/30	-	-	-	-	-	-
<i>Dalbergia sisoo</i> Roxb. ex DC.	Se/T	0/20	0/10	0/40	-	-	-	-	-	-	-	-	-
	Sa/T	0/20	0/10	0/40	-	-	-	-	-	-	-	-	-
<i>Euonymus pendulus</i> Wall.	Se/T	-	-	-	-	-	-	-	-	-	0/30	-	0/40
	Sa/T	-	-	-	-	-	-	-	-	-	0/30	-	0/40
<i>Euonymus tingens</i> Wall.	Se/T	-	-	-	-	-	-	-	-	-	-	-	-
	Sa/T	-	-	-	-	-	-	-	-	-	-	-	-
<i>Holarrhena pubescens</i> Wall. ex G. Don	Se/T	-	-	-	-	-	-	-	-	-	-	-	-
	Sa/T	-	-	-	-	-	-	-	-	-	-	-	-
<i>Holoptelea integrifolia</i> (Roxb.) Planch.	Se/T	-	0/60	-	-	-	-	-	-	-	-	-	-
	Sa/T	-	0/60	-	-	-	-	-	-	-	-	-	-
<i>Ilex dipyrrena</i> Wall.	Se/T	-	-	-	-	-	-	-	-	-	0/50	0/70	0/50
	Sa/T	-	-	-	-	-	-	-	-	-	2.8	0.86	1.2
<i>Juglans regia</i> L.	Se/T	-	-	-	-	-	-	-	-	-	-	2.67	-
	Sa/T	-	-	-	-	-	-	-	-	-	-	0/30	-
<i>Lagerstroemia parviflora</i> Roxb.	Se/T	-	-	-	18.67	8.0	0/10	-	-	-	-	-	-
	Sa/T	-	-	-	4.0	0.75	0/10	-	-	-	-	-	-
<i>Lannea coromandelica</i> (Houtt.) Merr.	Se/T	-	-	-	-	-	-	-	-	-	-	-	-
	Sa/T	-	-	-	-	-	-	-	-	-	-	-	-
<i>Litsea umbrosa</i> Nees.	Se/T	-	-	-	-	-	-	-	-	-	2.29	3.64	5.6
	Sa/T	-	-	-	-	-	-	-	-	-	1.29	0.91	1.2
<i>Mallotus phillipensis</i> (Lam.) Müll. Arg.	Se/T	12	0	-	2.29	6.67	3.6	-	-	-	-	-	-
	Sa/T	0.17	0	-	1.14	1.33	0.8	-	-	-	-	-	-
<i>Myrica esculanta</i> Buch.-Ham. ex D. Don	Se/T	-	-	-	-	-	-	0/20	0/20	-	-	-	-
	Sa/T	-	-	-	-	-	-	0/20	0/20	-	-	-	-
<i>Phyllanthus emblica</i> L.	Se/T	-	-	-	-	0/20	-	-	-	-	-	-	-
	Sa/T	-	-	-	-	0/20	-	-	-	-	-	-	-
<i>Pinus roxburghii</i> Sarg.	Se/T	-	-	-	-	-	-	3.38	0.51	0/310	-	-	-
	Sa/T	-	-	-	-	-	-	0.69	0.59	0.23	-	-	-
<i>Pyrus pashia</i> Buch.-Ham. ex D. Don	Se/T	-	-	-	-	-	-	2.0	1.71	0/10	-	-	-
	Sa/T	-	-	-	-	-	-	0.83	0.43	0/10	-	-	-
<i>Quercus floribunda</i> Lindl. ex A. Camus	Se/T	-	-	-	-	-	-	-	-	-	0.69	1.08	0.71
	Sa/T	-	-	-	-	-	-	-	-	-	0.51	0.95	0.67
<i>Quercus leucotrichophora</i> A. Camus	Se/T	-	-	-	-	-	-	4.0	16	0/20	0/90	1.78	0/70
	Sa/T	-	-	-	-	-	-	0.67	6.0	0/20	0/90	1.11	1.14

<i>Rhododendron arboreum</i> Sm.	Se/T	-	-	-	-	-	-	-	-	-	0/10	4.0	0/10
	Sa/T	-	-	-	-	-	-	-	-	-	0/10	1.0	0/10
<i>Schleichera oleosa</i> (Lour.) Oken	Se/T	24	40	-	-	-	0/30	-	-	-	-	-	-
	Sa/T	0/10	0/10	-	-	-	0/30	-	-	-	-	-	-
<i>Semecarpus anacardium</i> L.f.	Se/T	-	-	-	-	0/20	-	-	-	-	-	-	-
	Sa/T	-	-	-	-	0/20	-	-	-	-	-	-	-
<i>Shorea robusta</i> C.F.Gaertn.	Se/T	-	-	-	1.95	1.67	2.07	3.2	1.5	0/20	-	-	-
	Sa/T	-	-	-	1.02	0.72	1.10	0.2	0.5	0/20	-	-	-
<i>Symplocos chinensis</i> f. pilosa (Nakai) Ohwi.	Se/T	-	-	-	-	-	-	-	-	-	0/30	0/40	0
	Sa/T	-	-	-	-	-	-	-	-	-	0/30	1.5	0
<i>Syzygium cumini</i> (L.) Skeels	Se/T	40	-	2	0	9.33	10.67	0/60	0/30	-	-	-	-
	Sa/T	0/10	-	10.67	0	0.67	0	0/60	0/30	-	-	-	-
<i>Tectona grandis</i> L.f.	Se/T	1.30	1.41	0.10	6.0	0	4.0	-	-	-	-	-	-
	Sa/T	0.12	0.24	1.44	1.5	0	0/20	-	-	-	-	-	-
<i>Terminalia alata</i> Roth.	Se/T	-	-	-	-	-	0/10	-	-	-	-	-	-
	Sa/T	-	-	-	-	-	0/10	-	-	-	-	-	-
<i>Terminalia bellirica</i> (Gaertn.) Roxb.	Se/T	-	-	-	-	8.0	6.67	-	-	-	-	-	-
	Sa/T	-	-	-	-	4.0	0/30	-	-	-	-	-	-
<i>Terminalia tomentosa</i> Wight & Arn.	Se/T	-	-	-	0/10	-	8.0	-	-	-	-	-	-
	Sa/T	-	-	-	0/10	-	0/10	-	-	-	-	-	-
<i>Toona ciliata</i> M.Roem.	Se/T	-	-	-	0/20	-	-	-	0/80	-	-	-	-
	Sa/T	-	-	-	0/20	-	-	-	0/80	-	-	-	-

Population structure of the forests is mostly represented by size class distribution of trees (Saxena & Singh 1984, Khan *et al.* 1987). The inverse J-shaped curves obtained in the present study for most of the sites are similar to those reported for different forests of India (Kadavul & Parathasarathy 1999, Upadhaya *et al.* 2004, Mishra *et al.* 2005, Tynsong & Tiwari 2011, Sahu *et al.* 2012). An inverse J-shaped curve for trees suggested an expanding and growing population. Climax or stable type of population in forest ecosystem, shows that the forest harbours a growing and healthy population (Parthasarathy & Karthikeyan 1997, Mishra *et al.* 2005, Sahu *et al.* 2012). The highest density of tree population was recorded for 0–30 cm girth class and it gradually decreased with increasing girth class almost for all dominant trees present at different forest sites except for site MGIII.

Site BH

The dominant tree species at site BH was *Tectona grandis*. This site is a planted teak forest for many years. The presence of associated species at this site was reported very less. A total of 12 species was recorded at site BH, out of which 9 tree species were present at site BHI, 7 at BHII and 7 at BHIII. Regeneration status at BHI indicated 22% of good regeneration, 56% no regeneration and 22% poor regeneration for different tree species. At site BHII out of 7 species, 14% showed good regeneration, 43% showed no regeneration, 14% showed poor and 14% showed fair regeneration. For site BHIII, regeneration rate was good for 43% of tree species and no regeneration was found for 57% of tree species. The poor regenerating tree species among all sub-sites were *Acacia catechu* (L.f.) Willd., *Aegle marmelos* (L.) Correa., *Schleichera oleosa* (Lour.) Oken. Tree species which exhibited no regeneration were *Adina cordifolia* (Roxb.) Brandis, *Albizia lebbek* (L.) Benth., *Dalbergia sissoo* Roxb. ex DC., *Holoptelea integrifolia* (Roxb.) Planch. and *Lannea coromandelica* (Houtt.) Merr. Good regeneration status was reported for *Cassia fistula* L., *Mallotus philippensis* (Lam.) Müll.Arg., *Syzygium cumini* (L.) Skeels and *Tectona grandis* L.f. (Table 5).

Table 5. Regeneration status (RS) of trees at different sub-sites of Barhaini (BH) Forest. (T= tree density, Sp= sapling density and Sd= seedling density)

Species	BHI				BHII				BHIII			
	T	Sp	Sd	RS	T	Sp	Sd	RS	T	Sp	Sd	RS
<i>Acacia catechu</i> (L.f.) Willd.	30	20	0	Poor	10	0	0	No	10	0	0	No
<i>Adina cordifolia</i> (Roxb.) Brandis.	20	0	0	No	-	-	-	-	-	-	-	-
<i>Aegle marmelos</i> (L.) Correa.	10	10	0	Poor	-	-	-	-	-	-	-	-

<i>Albizia lebbeck</i> (L.) Benth	-	-	-	-	-	-	-	-	20	0	0	No
<i>Cassia fistula</i> L.	20	0	640	No	40	10	560	Good	40	10	400	Good
<i>Dalbergia sisoo</i> Roxb. ex DC.	20	0	0	No	10	0	0	No	-	-	-	-
<i>Holoptelea integrifolia</i> (Roxb.) Planch.	-	-	-	-	60	0	0	-	40	0	0	No
<i>Lannea coromandelica</i> (Houtt.) Merr.	-	-	-	-	-	-	-	-	10	0	0	No
<i>Mallotus philippensis</i> (Lam.) Müll.Arg	60	10	720	Good	0	30	640	New	-	-	-	-
<i>Schleichera oleosa</i> (Lour.) Oken	10	0	240	No	10	0	400	Poor	-	-	-	-
<i>Syzygium cumini</i> (L.) Skeels	10	0	400	No	-	-	-	-	30	60	320	Good
<i>Tectona grandis</i> L.f.	430	50	560	Good	340	80	480	Fair	390	40	560	Good
Total	610	90	2560		470	120	2080		540	110	1280	

Site KD

Site KD was dominated with *Shorea robusta* C.F. Gaertn. The tree species richness at this site was recorded 17, out of which 8 tree species were reported at site KDI, 10 tree species were reported at KDII and 13 tree species were reported at KDIII. The regeneration results showed that 63% of tree species exhibited good regeneration, 25% no regeneration and 13% showed the presence of new tree species at site KDI. At site KDII 40% of tree species showed good, 20% fair and 30% no regeneration. While 10% species were new to the site. Site KDIII exhibited 23% good, 23% fair, 23% poor and 31% no regeneration. The poor regenerating tree species recorded for site KDIII were *Lagerstroemia parviflora* Roxb., *Schleichera oleosa* (Lour.) Oken and *Terminalia alata* Roth. No regeneration occurred for two species at KDI (*Terminalia tomentosa* Wight & Arn. and *Toona ciliata* M.Roem.), at KDII for three tree species (*Holarrhena pubescens* Wall. ex G.Don, *Phyllanthus emblica* L. and *Semecarpus anacardium* L.f.), at KDIII four tree species were not regenerating at all (*Albizia odoratissima* (L.f.) Benth., *Cassia fistula* L., *Terminalia bellirica* (Gaertn.) Roxb. and *T. tomentosa* Wight & Arn.). Fair regeneration was showed by *Syzygium cumini* (L.) Skeels and *Terminalia bellirica* (Gaertn.) Roxb. at site KDII, *Adina cordifolia* (Roxb.) Brandis, *Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill. & Perr. and *Tectona grandis* L.f. at KDIII. Good regeneration exhibited by *Shorea robusta* C.F.Gaertn at all sub-sites followed by *Cassia fistula*, *Lagerstroemia parviflora* Roxb., *Mallotus philippensis* (Lam.) Müll.Arg., *Syzygium cumini* (L.) Skeels and *Tectona grandis* L.f. The occurrence of *Tectona grandis* was new at site KDII (Table 6).

Table 6. Regeneration status (RS) of trees at different sub-sites of Kaladhungi (KD) Forest. (T= tree density, Sp= sapling density and Sd= seedling density)

Species	KDI				KDII				KDIII			
	T	Sp	Sd	RS	T	Sp	Sd	RS	T	Sp	Sd	RS
<i>Adina cordifolia</i> (Roxb.) Brandis.	-	-	-	-	-	-	-	-	30	60	160	Fair
<i>Albizia odoratissima</i> (L.f.) Benth	-	-	-	-	-	-	-	-	10	0	0	No
<i>Anogeissus latifolia</i> (Roxb. ex DC.) Wall. ex Guill. & Perr.	-	-	-	-	-	-	-	-	20	50	120	Fair
<i>Cassia fistula</i> L.	20	50	360	Good	20	20	280	Good	30	0	80	No
<i>Holarrhena pubescens</i> Wall. ex G.Don	0	0	0	-	10	0	0	No	-	-	-	-
<i>Lagerstroemia parviflora</i> Roxb.	30	120	560	Good	40	30	320	Good	10	30	0	Poor
<i>Mallotus philippensis</i> (Lam.) Müll.Arg	140	160	320	Good	60	80	400	Good	100	80	360	Good
<i>Phyllanthus emblica</i> L.	0	0	0	-	20	0	0	No	-	-	-	-
<i>Schleichera oleosa</i> (Lour.) Oken	-	-	-	-	-	-	-	-	30	40	0	Poor
<i>Semecarpus anacardium</i> L.f.	0	0	0	-	20	0	0	No	-	-	-	-
<i>Shorea robusta</i> C.F.Gaertn.	430	440	840	Good	430	310	720	Good	290	320	600	Good

<i>Syzygium cumini</i> (L.) Skeels	0	0	360	New	30	20	280	Fair	30	60	320	Good
<i>Tectona grandis</i> L.f.	20	30	120	Good	0	0	200	New	20	40	80	Fair
<i>Terminalia alata</i> Roth.	-	-	-	-	-	-	-	-	10	30	0	Poor
<i>Terminalia bellirica</i> (Gaertn.) Roxb.	0	0	0	-	10	40	80	Fair	30	0	200	No
<i>Terminalia tomentosa</i> Wight & Arn.	10	0	0	No	-	-	-	-	10	0	80	No
<i>Toona ciliata</i> M.Roem.	20	0	0	No	-	-	-	-	-	-	-	-
Total	670	800	2560						620	680	2000	

Site MG

Site MG was dominated by tree species *Pinus roxburghii* Sarg. Regeneration status results indicated that 29% of tree species showed no regeneration, 57% showed fair and 14% showed good regeneration at site MGI. Site MGII showed 38% no regeneration, 50% fair regeneration and 13% tree species were new to this site. Regeneration status for site MGIII was seen poor for 20% tree species and 80% tree species at this site showed no regeneration. Overall scenario indicated that two sites (MGI and MGII) showed fair to good regeneration for *Pinus roxburghii* Sarg. but at site MGIII *Pinus roxburghii* was represented only by trees and saplings. Other tree species showed a fair regeneration pattern at two sites MGI and MGII (*Albizia lebbeck*, *Pyrus pashia* Buch.-Ham. ex D.Don, *Quercus oblongata* D.Don and *Shorea robusta*). *Myrica esculenta* Buch.-Ham. ex D.Don and *Syzygium cumini* (L.) Skeels didn't show regeneration at any site. *Toona ciliata* M.Roem. was represented only by seedlings at MGII site, this indicated new regeneration of this species at this site (Table 7).

Table 7. Regeneration status (RS) of trees at different sub-sites of Mangoli (MG) Forest. (T= tree density, Sp= sapling density and Sd= seedling density)

Species	MGI				MGII				MGIII			
	T	Sp	Sd	RS	T	Sp	Sd	RS	T	Sp	Sd	RS
<i>Albizia lebbeck</i> (L.) Benth	30	10	80	Fair	10	0	0	No	10	0	0	No
<i>Myrica esculenta</i> Buch.-Ham. ex D.Don	20	0	0	No	20	0	0	No	-	-	-	-
<i>Pinus roxburghii</i> Sarg.	130	90	440	Good	390	230	200	Fair	310	70	0	Poor
<i>Pyrus pashia</i> Buch.-Ham. ex D.Don	60	50	120	Fair	70	30	120	Fair	10	0	0	No
<i>Quercus leucotrichophora</i> A. Camus	30	20	120	Fair	10	60	160	Fair	-	-	-	-
<i>Shorea robusta</i> C.F.Gaertn.	100	20	320	Fair	80	40	120	Fair	20	0	0	No
<i>Syzygium cumini</i> (L.) Skeels	60	0	0	No	30	0	0	No	20	0	0	No
<i>Toona ciliata</i> M.Roem.	-	-	-	-	0	0	80	New	-	-	-	-
Total	430	190	1080		610	360	680		370	70	0	

Site BP

Quercus floribunda Lindl. ex A.Camus was the dominant tree species at site BP. A total of 10 tree species were present at the site. Regeneration status showed that 63% of tree species showed no regeneration, 13% showed poor and 25% showed fair regeneration at site BPI. At site BP II 13% tree species showed no regeneration, 38% showed poor, 38% showed fair and 13% showed good regeneration. Site BP III results indicated that 43% of tree species showed no regeneration, 43% showed fair and 14% tree species were new to the site. Overall results indicated that no regeneration was noticed for *Acer oblongum* Wall. ex DC., *Euonymus pendulus* Wall. and *E. tingens* Wall. at any site. *Quercus leucotrichophora* A.Camus ex Bahadur and *Rhododendron arboreum* Sm. showed no regeneration at site BPI but at site BP II both species showed fair results for regeneration. Fair to good results for regeneration were showed by two species *Quercus floribunda* Lindl. ex A.Camus and *Litsea umbrosa* (Nees) Nees at all of sub-sites this forest. Species like *Juglans regia* L. and *Ilex dipyrrena* Wall. showed poor to no regeneration at site BPI and BP III. On the other side *Symplocos chinensis* f. pilosa (Nakai) Ohwi. showed no regeneration at site BPI, poor regeneration at site BP II and at BP III site this tree species was found only in seedling stage (Table 8).

Regeneration of a species is affected by various factors (Khan & Tripathi 1989, Sukumar *et al.* 1994, Barik *et al.* 1996, Iqbal *et al.* 2012) including anthropogenic and natural phenomenon (Welden *et al.* 1991). Regeneration process of forests is adversely affected by the uncontrolled grazing by domestic livestock by removing young seedlings and saplings, which also cause soil loss due to trampling (Saberwal 1995). In the present study, most of the forest sites showed good to fair regeneration for dominant tree species but poor to no

regeneration for other associated species. Site MGIII was found poor in regeneration for *Pinus roxburghii* Sarg. and other tree species at this site were represented by individuals only in the adult stage. In general, more than 40% of tree species showed no regeneration at their respective sites. These tree species were present only in the adult stage. Those forest areas that are characterized by the presence of only adults and the absence or low frequency of seedlings and saplings are expected in time to face local extinction (Dalling *et al.* 1998). The presence of new species was also reported at many sites. These new arrivals are struggling to get established and in time they may form a sub-canopy in the respective forests (Malik & Bhatt 2016). Proportionate distribution graph (Fig. 3) showed that the maximum density of seedlings was reported at all sub-sites of KD forest and the minimum was present at MG forest sites. The occurrence of less density for seedlings is possibly the cause of human interference at the respective forest sites. The fruitful regeneration of a tree species depends on its ability to produce large number of seedlings and saplings to survive and grow (Good & Good 1972). The presence of fewer seedlings and saplings in any forest is a matter of concern for its future survival. The findings of the present study will be helpful to understand future existence of forests and also for formulating strategies for recovery of disturbed forests.

Table 8. Regeneration status (RS) of trees at different sub-sites of Barapathar (BP) Forest. (T= tree density, Sp= sapling density and Sd= seedling density)

Species	BPI				BP II				BP III			
	T	Sp	Sd	RS	T	Sp	Sd	RS	T	Sp	Sd	RS
<i>Acer oblongum</i> Wall. ex DC.	10	0	0	No	20	0	0	No	-	-	-	-
<i>Euonymus pendulus</i> Wall.	30	0	0	No	-	-	-	-	40	0	0	No
<i>Euonymus tingens</i> Wall.	-	-	-	-	-	-	-	-	20	0	0	No
<i>Ilex dipyrrena</i> Wall.	50	140	0	Poor	70	60	0	Poor	50	60	0	No
<i>Juglans regia</i> L.	-	-	-	-	30	0	80	Poor	-	-	-	-
<i>Litsea umbrosa</i> Nees.	70	90	160	Fair	110	100	400	Fair	50	60	280	Fair
<i>Quercus floribunda</i> Lindl. ex A. Camus	350	180	240	Fair	590	560	640	Good	900	600	640	Fair
<i>Quercus leucotrichophora</i> A. Camus	90	0	0	No	90	100	160	Fair	70	80	0	Fair
<i>Rhododendron arboreum</i> Sm.	10	0	0	No	30	30	120	Fair	-	-	-	-
<i>Symplocos chinensis</i> f. pilosa (Nakai) Ohwi.	30	0	0	No	40	60	0	Poor	0	30	120	New
Total	640	410	400		980	910	1400		1130	830	1040

Figure 3. Proportionate distribution of trees, saplings and seedlings at different forest sites along the altitude. [BHI, BHII and BHIII represents sub-sites of Barhaini forest region; KDI, KDII and KDIII represents sub-sites of Kaladhungi forest region; MGI, MGII and MGIII represents sub-sites of Mangoli forest region and BPI, BPII and BPIII represents sub-sites of Barapathar forest region]

ACKNOWLEDGEMENTS

Authors acknowledge the forest department of Ramnagar, Nainital and Haldwani forest division for their continuous support and help throughout research work. We also gratefully thank Head Department of Botany Dr. S. D. Tewari for his guidance and providing innovative ideas to mould the research in a positive path.

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