COMMUNITY STRUCTURE AND REGENERATION STATUS OF TREE SPECIES IN KYONGNOSLA ALPINE SANCTUARY, EASTERN HIMALAYA, INDIA

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COMMUNITY STRUCTURE AND REGENERATION STATUS OF TREE SPECIES IN KYONGNOSLA ALPINE SANCTUARY, EASTERN HIMALAYA, INDIA. Habitat destruction, over exploitation, monoculture are major reasons for loss of primary forests in Himalaya. Tree population, composition and diversity particularly in the temperate Himalaya play a key role in the maintenance of many ecosystem services and natural biogeochemical cycles. The present study explores composition and regeneration status of tree species in a temperate mixed forest in Kyongnosla Alpine Sanctuary, East Sikkim, India. Two sites at an elevation range of 2800–3800 m were selected and 20 plots of 20 m × 20 m for trees, 80 plots of 5 m × 5 m for saplings, and 160 plots of 1 m × 1 m for seedlings were sampled to study the regeneration status. A total of 17 tree species belonging to 9 genera and 8 families were recorded of which Rhododendron was the most dominant genus with maximum number of species. All the phytosociological attributes, such as relative density, abundance and important value index were calculated. The average species richness of adult trees and saplings was 13.5± 0.7 and for seedlings it was 12.5 ± 0.07. The mean density of seedlings was 3609.77 ± 494.39 individuals ha^{-1}, for saplings 1540 ± 113.13 individuals ha^{-1} and of mature trees 548.75 ± 8.83 individuals ha^{-1}. Total basal area cover ranged from 36.61 to 40.35 m^2 ha^{-1} for trees, from 1.54 to 1.71 m^2 ha^{-1} for saplings. Fair regeneration was observed in 64.72% of total species; good regeneration observed in 17.64% species, 11.76% species exhibited poor regeneration while 5.88% showed no regeneration. Density-diameter distribution exhibited decrease in tree densities towards higher DBH classes. The study not only provides reliable information on the ecosystem's health of the sanctuary but also will help in understanding the complexity of the ecosystem function and an approach to conservation of biota.

Keywords: Eastern Himalaya, India, *Rhododendron*, species richness, temperate mixed forest, tree diversity

STRUKTUR KOMUNITAS DAN STATUS REGENERASI SPESIES POHON DI KYONGNOSLA ALPINE SANCTUARY, HIMALAYA TIMUR, INDIA. Kerusakan habitat, eksploitasi berlebihan, tanaman monokultur adalah penyebab utama hilangnya hutan primer di Himalaya. Populasi, komposisi dan keanekaragaman pohon khususnya di Himalaya yang beriklim sedang memainkan peran kunci dalam pemeliharaan jasa ekosistem dan siklus biogeokimia alami. Penelitian ini mengeksplorasi komposisi dan status regenerasi spesies pohon di hutan campuran beriklim sedang di Kyongnosla Alpine Sanctuary, Sikkim Timur, India. Dua lokasi pada ketinggian 2800–3800 m dipilih dan 20 plot berukuran 20 m × 20 m untuk pohon, 80 plot berukuran 5 m × 5 m untuk pancang, dan 160 plot berukuran 1 m × 1 m untuk bibit diambil sampelnya untuk dipelajari status regenerasinya. Sebanyak 17 jenis pohon dan 9 genus dan 8 famili Rhododendron tercatat sebagai genus yang paling dominan dengan jumlah spesies paling banyak. Semua atribut fitososiologis, seperti kepadatan relatif, kelimpahan dan indeks nilai penting dihitung. Rata-rata keragaman jenis pohon dewasa dan anakan adalah 13,5± 0,7 dan untuk semai adalah 12,5 ± 0,07. Rerata kerapatan semai adalah 3609,77 ± 494,39 individu/ha, untuk pancang 1540 ± 113,13 individu ha^{-1} *dan pohon dewasa 548,75 ± 8,83 individu* ha^{-1}*. Luas dasar total tutupan pohon berkisar antara 36,61 hingga 40,35* m^2 ha^{-1}*, dari 1,54 hingga 1,71* m^2 ha^{-1} *untuk pancang. Regenerasi yang cukup diamati pada 64,72% dari total spesies; regenerasi yang baik diamati pada 17,64% spesies, 11,76% spesies menunjukkan regenerasi yang buruk, sedangkan 5,88% tidak menunjukkan regenerasi. Distribusi kerapatan-diameter menunjukkan penurunan kerapatan pohon menuju kelas DBH yang lebih tinggi. Kajian ini tidak hanya memberikan informasi yang dapat dipercaya tentang kesehatan ekosistem cagar alam tetapi juga membantu dalam memahami kompleksitas fungsi ekosistem dan pendekatan konservasi biota.*

Kata kunci: Himalaya Timur, India, Rhododendron, keragaman spesies, hutan campuran beriklim sedang, keanekaragaman pohon

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I. INTRODUCTION

The community structure, regeneration and stability of a forest are controlled by the density of seedlings, saplings and mature individuals of tree species (Paul, Khan, & Das, 2018). Regeneration is an important process for the survival of tree species in a plant community under the influence of diverse environmental factors and soil conditions. In Himalaya, the regeneration of tree species particularly in sub-alpine and temperate forest ecosystems depends mainly on three factors viz. density of new seedlings at different altitude, competence of seedlings and saplings to endure under varied microclimatic condition and their ability to grow as a mature individual (Mittal, Singh & Tewari 2020). Different tree species exhibit deficiency of adequate regeneration across the Himalayan landscape (Tewari, Bhatt, Mittal, Singh & Tamta, 2016; Tewari, Mittal & Singh, 2017). Therefore, knowledge on the regeneration status of any forest community is prerequisite for its management, restoration and sustainability (Pala, Negi, Gokhale, & Todaria, 2013).

Sikkim, the second smallest state of India having an area of about 7096 km^2 is known as the paradise of naturalists due to its great variety of habitats which sustains a high floral diversity. The state has estimated to have more than 5500 species of flowering plants belonging to 1371 genera under 197 families (Singh & Sanjappa, 2011). All the representative forest-types of eastern Himalaya like sub-Himalayan wet mixed forests, sub-tropical pine forests, wet temperate forests, mixed coniferous forests, eastern oak-Hemlock forests, Oak-fir forests, moist alpine scrubs and dry alpine scrubs are represented in Sikkim (Dash & Singh, 2011). The temperate forest occurs between 1800 and 3500 m asl. It is broadly categorized as broadleaved temperate forest, mixed coniferous temperate forest. The broadleaved temperate forest characterized mostly by *Acer*, *Castanopsis*, *Laurels*, *Magnolia*, *Quercus*, mixed with *Rhododendron* species in different proportions; while the mixed coniferous forests are characterized by mixed population of *Abies–Acer–Betula* with *Rhododendron* species. The important rhododendron species which are found mixed with the coniferous trees are *Rhododendron barbatum* Wall. ex G. Don., *Rhododendron campanulatum* D. Don., *Rhododendron campylocarpum* Hook.f., *Rhododendron falconeri* Hook. f., *Rhododendron griffithianum* Wight, *Rhododendron thomsonii* Hook. f., *Rhododendron wightii* Hook.f. (Lahiri & Dash, 2021).

Recent studies show that, primary forests of this region have been increasingly under threat due to high anthropogenic disturbance (Grumbine & Pandit 2013; Gairola, Rawal, Todaria, & Bhatt, 2014; Malik, Hussain, Iqbal & Bhatt, 2014; Malik, Pandey & Bhatt, 2016; Negi, Giri & Sekar, 2018; Haq, Rashid, Khuroo, Malik, & Malik, 2019; Ballabha, Kuniyal, Tiwari & Tiwari, 2020). Habitat destruction, burning and slashing agriculture, over exploitation, introduction of monoculture species are identified as major reasons for biodiversity loss (Dash, 2012). Both anthropogenic and natural disturbances are greatly affected the natural ecosystems in terms of their structure, density, composition and also their ecological processes (Allen, Breshears, & McDowell, 2015). Prioritizing different areas for conservation based on useful trees, their mortality or regeneration along with other ecological attributes such as abundance, distribution, and dominance is need of the hour (Paul et al. 2018). Tree population particularly along higher altitudes (timberlines) play a key role in the maintenance of the natural biogeochemical cycles, vital habitats, and ecosystem services for human communities through the different provisions for life sustenance (Cobb et al., 2017). Information on the compositional attributes of vegetation such as the population structure, diversity in temperate forests of western Himalaya is adequately available (Pant & Samant, 2012; Rawat & Chandra, 2012; Khali & Bhatt, 2014; Kumar & Sharma, 2014; Malik & Bhatt, 2015; Dar & Sundarapandian, 2016; Malik & Bhatt, 2016; Malik & Nautiyal, 2016; Meena & Rao, 2016; Kumari, Mehta, Shafi &

Dhiman, 2017; Mir, Masoodi, Geelani, Wani & Sofi, 2017; Sharma, Samant, & Lal, 2017; Bhat et al. 2020; Rawat, Tiwari, Das & Tiwari, 2020; Dasila, Samant & Pandey, 2021), but comprehensive account of the status of forest regeneration particularly in temperate forests in eastern Himalaya are sporadic (Yam & Tripathi, 2016; Pandey, Badola, Rai, & Singh, 2018; Paul et al. 2018; Sinha et al. 2018; Dash et al. 2021). Therefore, to understand the complexity of the ecosystem functions and to establish an integrated approach for conservation, reliable information on the health of these fragile ecosystems is necessary. Keeping all these in mind the present study was conceptualized with an objective to investigate the species richness and diversity, species distribution pattern, different community structure and regeneration status of tree species in temperate mixed forest of Kyongnosla Alpine Sanctuary (KAS), East Sikkim, India.

II. MATERIAL AND METHOD

A. Study Site

The study was carried out during 2016–2019 in Kyongnosla Alpine Sanctuary (KAS), East district, Sikkim, situated between 27°22´ to 27°24´ N latitude and 88°44´ to 88°45´ E longitude. (Figure 1). The sanctuary represents the temperate and alpine vegetation of Sikkim Himalaya and covers an area of 31 km^2 with elevation ranging from 2800 m to 4200 m above mean sea level. *Abies densa*, *Betula utilis*, *Lyonia ovalifolia* and *Rhododendron* spp. are the main components in the mixed temperate forest (Table-1). The main drainage systems of the sanctuary are Byo chu, Rong chu, and Kyongnosla chu, all the rivers are fed by perennial glaciers. Depending on altitude, the sanctuary is divided into three regions viz. Rongchu (2800–3200 m), Goral Rock – Namnang (3200–3800 m) and Helipad–Nakchok area (>3800 m). During the present study, plots were selected

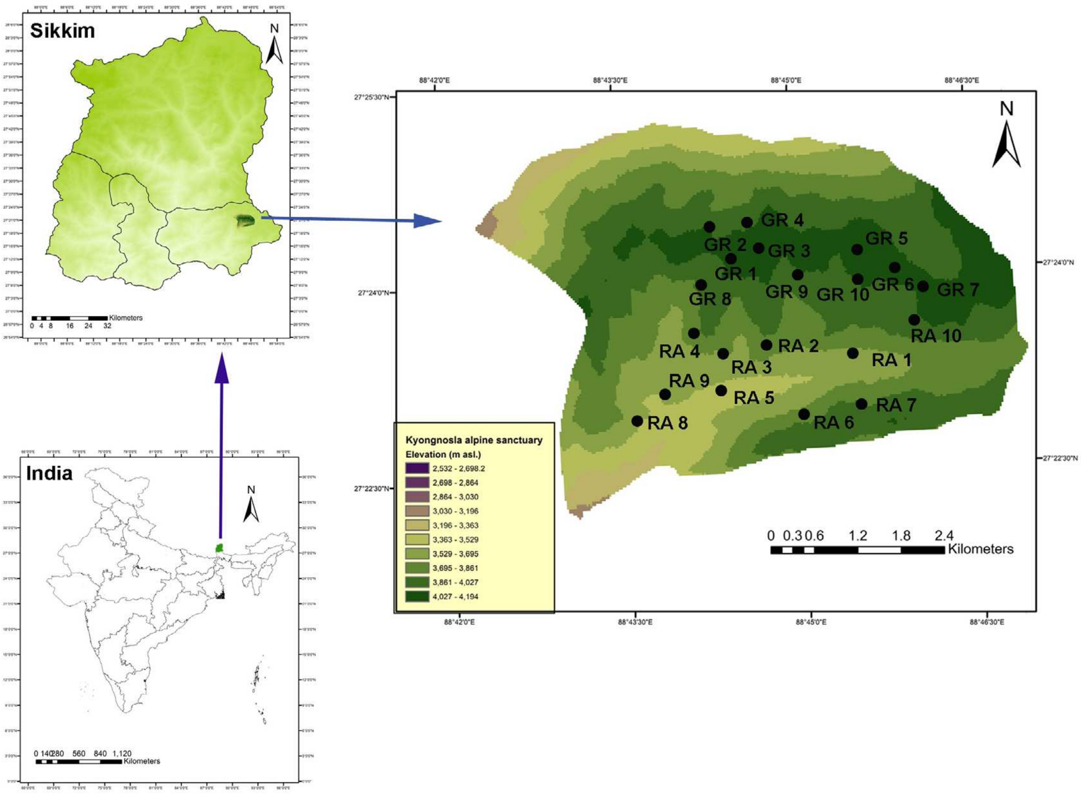


Figure 1. Map showing study site

Table 1. General attributes of the study sites

Sl. No	Study sites (abbreviation)	Altitude (m asl)	Coordination	Five dominant tree species (IVI)
1.	Rongchu Site–1(RA)	2800 –3200	N 27˚22´44.10˝/ E 88˚ 44´05.94˝	*Abies densa* (51.92) *Rhododendron hodgsonii* (33.85) *Acer caudatum* (30.89) *Rhododendron arboreum* (28.89) *Juniperus recurva* (28.88)
2.	Goral rock & Namnang Site–2 (GR)	3400–3800	N27˚22´ 54.71˝/ E 88˚ 43´19.53˝	*Abies densa* (53.54) *Rhododendron hodgsonii* (48.54) *Rhododendron grande* (28.67) *Betula utilis* (26.75) *Acer caudatum* (25.02)

in Rongchu (RA) and Goral Rock – Namnang (GA). Mean monthly temperature fluctuated between 0°C (in January) to 20°C (in June). The average relative humidity varies from 40% to 90% measured by digital hygrometer HTC-8A.

B. Methods

Field visits were undertaken regularly from July 2016 to August 2019. Phytosociological studies were carried out for three growth stages of trees i.e., mature trees, seedlings and saplings using quadrate method. The quadrates were laid in stratified random manner. For the purpose of this study, 20 sample plots i.e., 10 plots at each site of size 20 m × 20 m for trees, 80 quadrates i.e., 40 quadrates at each site of size 5 m × 5 m for saplings and 160 quadrates of size 1 m × 1 m for seedlings (i.e., in 20 tree plots × 8 =160 quadrats nested within each tree plot) were laid down on the forest floor. The correctness of sample size was determined by reaching the point when additional quadrats did not significantly add any new species. Individual tree species having >30 cm circumferences at breast height (CBH i.e., 1.37 m above ground) considered as mature trees and were measured species wise. Individuals having < 10 cm CBH were considered as seedlings and individuals having CBH intermediate in between above two classes are considered as saplings (Malik & Bhatt, 2015). Circumference at breast height (dbh = 1.37 m) was calculated as πr^2 (where r is the radius). Basal area (m^2/ha-) was used to determine the relative dominance of a tree species.

C. Data Analysis

All collected plant specimens were identified with the help of available literature (Bhattacharyya & Sanjappa, 2014; Panda & Sanjappa, 2014; Mao, Dash, & Singh, 2017; Maity, Maiti, & Chauhan, 2018) and also by consulting different herbaria (ARUN, ASSAM, BSHC and CAL). Voucher specimen were prepared following standard procedure (Jain & Rao, 1977) and deposited at Central National Herbarium (CAL). The phytosociological parameters i.e., frequency, density, abundance, total basal area, and their relative values were calculated from pooled quadrate data (Misra, 1968).

Importance value index (IVI) was calculated by summing up the relative values of density (RD), frequency (RF), and total basal (TBA) area (Misra, 1968). If a species contributed ≥50% of the total IVI in a particular site/habitat that site was considered a single species dominated community and if <50% of the total IVI, a mixed community. Species richness was determined as the number of species per unit area (Whittaker, 1972). The distribution pattern was determined by the ratio of abundance to frequency. This ratio indicates regular (<0.025), random (0.025 to 0.05) and contagious (>0.05) distributions (Odum, 1971). Regeneration status of species was totally based on population size of seedlings and saplings (Malik & Bhatt, 2016; Sharma, Mishra, Tiwari, Krishan, & Rana, 2018). Good regeneration is when a species is present in seedlings > saplings > mature stages; fair regeneration, when species is present in seedlings > saplings < mature stage; poor regeneration, when the species is present only in sapling stage, but not as seedlings. When a species is present only in mature stage it is considered as not regenerating. Species is considered as new if the species has no adults but only seedlings or saplings.

The diversity (H') was determined by using Shannon-Wiener information index (Shannon & Weaver, 1963) as:

$H' = - \sum n_i / n \log_2 n_i / n$ ....(1)

where, ni was the IVI value of a species and n was the sum of total IVI values of all species in that forest type. Simpson's diversity index (Simpson, 1949) was calculated as:

$D = 1 – Cd,$ ....(2)

where, D = Simpson's diversity and Cd = Simpson's concentration of dominance = $(\sum ni / n)^2$. Species evenness was calculated using the Shannon evenness index:

$J' = H' / l_n (S)$ ....(3)

where H´ is the Shannon– Wiener diversity index and S is the number of species (Pielou, 1966).

The Shannon evenness index ranges from 0 (when one species is dominant) to 1 (when all species are equally abundant). Beta diversity (Whittaker, 1972) was calculated using the formula:

$\beta\text{–}diversity = (S_1 - c) / (S_2 - c)$ ....(4)

where S1 is the total number of species in site 1 and S2 total number of species in site 2, c is the total number of species occurring in both sites. Species area curve were calculated using PC-CORD V. 7 (McCune & Mefford, 2016). Species area curve was used to evaluate the adequacy of sample size in the plant community.

III. RESULT AND DISCUSSION

A. Species Richness and Diversity

A total of 17 tree species belonging to 9 genera and 8 families were recorded from two sampling sites RA [Site-1] and GR [Site-2] (Table 5). *Rhododendron* with 9 species was the dominant genus. The consolidated phytosociological attributes and diversity indices of studied forest stands are shown in Table 2. Species area curve (Figure 2) revealed that, 10 plots yielded over 14

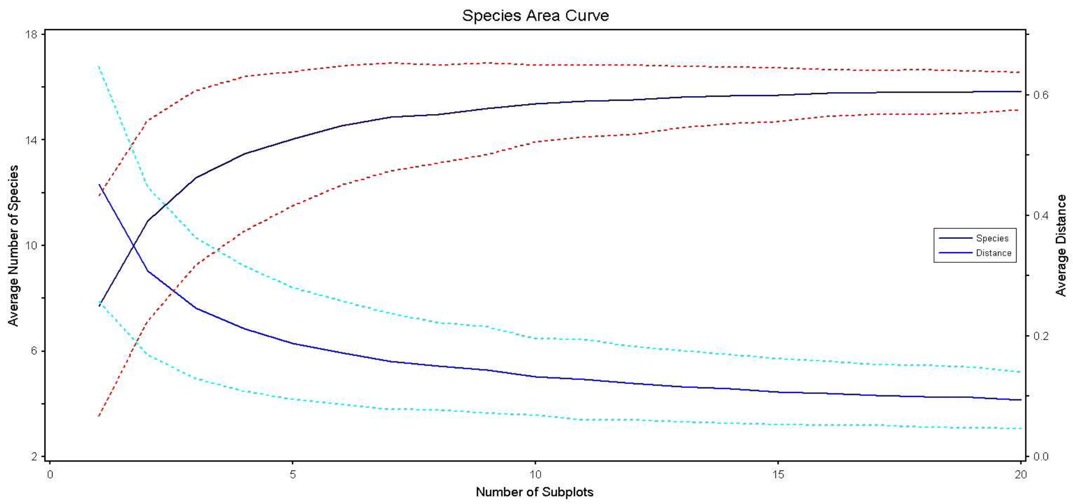


Figure 2. Species area curve based on repeated sub-sampling of a fixed sample (20 sample unit and 17 species)

species, with more plots yielded relatively small increase in the number of species. Similarly, 10 plots yielded a Sorensen distance of less than 0.1 (<10%), measured between the centroid of the subsample and the centroid of the whole sample.

Analysis of phytosociological attributes like density, basal area (BA), importance value index (IVI) for each growth form such as trees, saplings and seedlings (Table-3) for each site revealed that, species richness of trees varied from 13–14 (13.5 ± 0.70), saplings 13–14 (13.5 ± 0.70) and seedlings 13–12 (12.5 ± 0.70). Total tree density was minimum and varied between 542.5–555 ha^{-1} (548.75 ± 8.83), saplings density was moderate and varied between 1460–1620 ha^{-1} (1540 ± 113.13), while the seedlings density was maximum with 3115.38–4104.16 ha^{-1} (3609.77 ± 494.39). Tree basal area recorded a maximum (40.35 m^2 ha^{-1}) at site 1 (RA) and minimum (36.61 m^2 ha^{-1}) at site 2 (GR). Average basal area per site for trees, saplings and seedlings were 38.48 ± 2.64 m^2 ha^{-1}, 1.62 ± 0.12 m^2 ha^{-1} and 0.86 ± 0.04 m^2 ha^{-1}, respectively. These values obtained during the present study are comparable to earlier studies carried out in other Himalayan ecosystems.

Gairola et al., (2008), reported tree density of 552.88 ± 57.92 individuals ha^{-1}, sapling density 4935.44 ± 706.62 individuals ha^{-1} and seedling density 3375.51 ± 1125.17 individuals ha^{-1} in subalpine forest dominated by abies-quercus community in Western Himalaya. Rawat et al., (2018), reported tree density of 248.5 ± 22.79 individuals ha^{-1}, sapling density 840 ± 141.07 individuals ha^{-1}, and seedling density 32278.6 ± 3712.1 individuals ha^{-1} from mixed type subtropical forest of eastern Himalaya that is smaller value than present reported value which indicates that high mortality rate of saplings in subtropical forest might be due to dense canopy coverage. Singh et al. (2016), who were studying regeneration status of tree species of temperate oak dominated forest of Garhwal Himalaya recorded seedling density ranging from 1376–9600 individuals/ha. Deb and Sundriyal (2008) reported seedling density of 8619 ± 4106.86 individuals ha^{-1} from sub-tropical forest of Namdapha National Park.

The total basal area ranged from 36.61 ± 0.87 m^2 ha^{-1} (GR) to 40.35 ± 0.77 m^2 ha^{-1} (RA). These values are much higher to similar studies conducted in western Himalaya, viz., 8.94–69.84 m^2 ha^{-1} as reported by Gairola et al. (2008); 18 ±

Table 2. Phytosociological attributes and diversity indices of the study sites

Variables	Trees		Saplings		Seedlings	
	Site-1 (RA)	Site-2 (GR)	Site-1 (RA)	Site-2 (GR)	Site-1 (RA)	Site-2 (GR)
No. of plots	10	10	40	40	80	80
Size of plots (m^2)	400	400	25	25	01	01
Actual sampled area (ha)	0.80	0.80	0.10	0.10	0.008	0.008
No. of species	14	13	14	13	13	12
No. of genera	7	9	7	7	6	7
No. of families	7	8	7	7	6	6
Density (individuals ha^{-1})	555	542.5	1620	1460	40500	49250
Basal Area (m^2 ha^{-1})	40.35	36.61	1.11	1	0.89	0.83
Diversity index	0.55	0.51	0.60	0.58	0.57	0.52
Beta diversity (β- Div.)	1.64	1.52	1.64	1.30	1.52	1.41
Concentration of dominance (Cd)	0.095	0.10	0.077	0.079	0.082	0.094
Evenness (e)	0.48	0.46	0.52	0.52	0.51	0.48

Table 3. Phytosociological attributes of two study sites of Kyongnosla Alpine Sanctuary

Trees

	RA (Site–1)						GR (Site–2)					
	D ha^{-1}	A	RF	RD	Rdo	IVI	D ha^{-1}	A	RF	RD	Rdo	IVI
ACCA	45	3	6.81	8.10	15.96	30.89	35	3.5	5.9701	6.45161	12.6061	25.027
ABDE	80	3.2	11.36	14.41	26.14	51.92	77.5	5.166	8.9552	14.2857	30.3061	53.547
BEUT	17.5	1.4	5.68	3.15	2.64	11.47	55	4.4	7.4626	10.1382	9.15015	26.751
JURE	62.5	2.77	10.22	11.26	7.39	28.88	42.5	2.833	8.9552	7.83410	5.53983	22.329
LYOV	–	–	–	–	–	–	30	3	5.9701	5.52995	1.54360	13.043
PRCO	–	–	–	–	–	–	27.5	3.666	4.4776	5.06912	1.50930	11.056
RHAR	47.5	2.375	9.09	8.55	11.23	28.88	–	–	–	–	–	–
RHCA	22.5	2.25	4.54	4.05	1.50	10.10	55	3.142	10.447	10.1382	4.05625	24.642
RHCI	27.5	2.2	5.68	4.95	1.75	12.39	35	2.8	7.4626	6.45161	2.46119	16.375
RHFU	10	2	2.27	1.80	0.59	4.66	7.5	1.5	2.9850	1.38248	0.48880	4.8563
RHGR	45	2.25	9.09	8.10	6.86	24.06	47.5	2.375	11.940	8.75576	7.98387	28.679
RHHO	67.5	3.375	9.09	12.16	12.60	33.85	90	4	13.432	16.5898	18.5232	48.545
RHLA	12.5	2.5	2.27	2.25	1.06	5.59	–	–	–	–	–	–
RHTH	52.5	2.33	10.22	9.45	4.49	24.18	–	–	—	–	–	–
SOMI	35	2	7.95	6.30	5.17	19.43	30	2	8.9552	5.52995	4.88808	19.373
VIER	30	2.4	5.68	5.40	2.56	13.65	10	2	2.9850	1.84331	0.94331	5.7717

Saplings

	RA (Site–1)						GR (Site–2)					
	D ha^{-1}	A	RF	RD	Rdo	IVI	D ha^{-1}	A	RF	RD	Rdo	IVI
ACCA	90	1.28	5.55	5.83	7.72	19.11	80	1.33	6.59	5.47	8.53	20.61
ABDE	130	1.18	8.02	9.16	10.97	28.16	150	1.66	9.89	10.27	12.13	32.29
BEUT	140	1.55	8.64	7.5	6.91	23.05	110	1.37	8.79	7.53	7.64	23.96
JURE	160	1.14	9.87	11.66	6.09	27.64	130	1.85	7.69	8.90	6.74	23.33
RHAR	110	1.375	6.79	6.66	8.13	21.58	–	–	–	–	–	–
RHCA	90	1.28	5.55	5.83	7.31	18.70	130	1.44	9.89	8.90	8.08	26.88
RHCI	90	1.5	5.55	5	6.50	17.05	80	1.33	6.59	5.47	7.19	19.26
RHFU	110	1.22	6.79	7.5	5.69	19.98	90	2.25	4.39	6.16	6.29	16.85
RHGR	140	2	8.64	5.83	5.69	20.16	140	1.75	8.79	9.58	6.29	24.67
RHHO	170	1.133	10.49	12.5	9.34	32.34	140	1.55	9.89	9.58	10.33	29.81
RHLA	110	2.2	6.790	4.16	7.11	18.07	110	1.57	7.69	7.53	7.86	23.09
RHTH	190	1.18	11.72	13.33	5.081	30.14	100	1.25	8.79	6.84	5.61	21.25
SOMI	60	1.5	3.70	3.33	7.52	14.55	90	1.8	5.49	6.16	8.31	19.7

Seedlings

	RA (Site–1)						GR (Site–2)					
	D ha^{-1}	A	RF	RD	Rdo	IVI	D ha^{-1}	A	RF	RD	Rdo	IVI
ACCA	2125	1.41	5.50	5.24	8.14	18.89	3000	1.14	7.55	6.09	8.75	22.39
ABDE	3875	1.192	11.92	9.56	9.82	31.31	7250	1.34	15.46	14.72	10.55	40.73
BEUT	1875	1.66	4.12	4.62	7.58	16.34	2625	2.33	3.23	5.32	8.15	16.72
JURE	5875	1.424	15.13	14.5061	7.47767	37.1214	7625	1.41	15.46	15.48	8.03	38.98
PRCO	–	–	–	–	–	–	2375	1.35	5.03	4.82	8.27	18.13
RHAR	3625	1.611	8.25	8.95061	7.8125	25.0199	–	–	–	–	–	–
RHCA	3250	2.166	5.50	8.02469	7.36607	20.8953	3625	1.61	6.47	7.36	7.91	21.74
RHCI	4625	1.275	13.30	11.4197	7.03125	31.7537	3250	2.166	4.316	6.59	7.55	18.46
RHFU	2625	1.909	5.045	6.48148	6.69642	18.2237	–	–	–	–	–	–
RHGL	–	–	–	–	–	–	2525	1.5	5.03	5.32	7.55	17.91
RHGR	2375	1.357	6.422	5.86419	7.92410	20.2103	4625	1.27	10.43	9.39	8.51	28.33
RHHO	2000	1.6	4.587	4.93827	8.14732	17.6727	7000	1.14	17.62	14.21	8.75	40.59

Table 3. Continued

	RA (Site–1)						GR (Site–2)					
	D ha^{-1}	**A**	**RF**	**RD**	**Rdo**	**IVI**	**D ha^{-1}**	**A**	**RF**	**RD**	**Rdo**	**IVI**
R**H**LA	3250	1.625	7.339	8.02469	7.14285	22.5069	–	–	–	–	–	–
R**H**TH	2625	1.5	6.422	6.48148	6.91964	19.8231	2000	1.6	3.59	4.06	7.43	15.09
S**O**MI	2375	1.357	6.422	5.86419	7.92410	20.2103	3250	1.62	5.75	6.59	8.51	20.86

Abbreviations: *Abies densa* :- ABDE, *Acer caudatum* = ACCA, *Betula utilis* = BEUT, *Juniperus recurva* = JURE, *Lyonia ovalifolia* = LYOV, *Prunus cornuta* = PRCO, *Rhododendron arboreum* = RHAR, Rhododendron campylocarpum = RHCA, *Rhododendron cinnabarinum* = RHCI, *Rhododendron fulgens* = RHFU, *Rhododendron glaucophyllum* = RHGL, *Rhododendron grande* = RHGR, *Rhododendron hodgsonii* = RHHO, *Rhododendron lanatum* = RHLA, *Rhododendron thomsonii* = RHTH, Sorbus microphylla = SOMI, *Viburnum erubescens* = VIER, A= Abundance, D ha^{-1}= Density (individuals ha^{-1}), RF= Relative frequency, RD= Relative density, Rdo= Relative dominance, IVI= Important value index

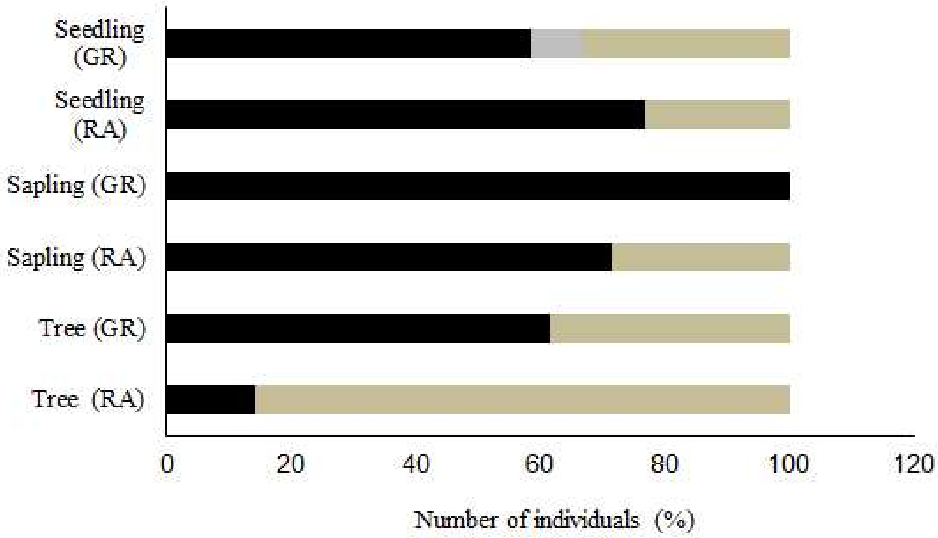


Figure 3. Distributions pattern of trees, saplings and seedlings at both study sites

10.69 m^2 ha^{-1} as reported by Rawat et al., (2018) and higher to the result in ridge forests of the western Himalaya Tiwari et al. (2018) 61.09 ± 9.35 m^2 ha^{-1}). The higher value might be due to the high floral diversity particularly the broad leaved elements in eastern Himalaya. This also substantiate the fact that, in the temperate to subalpine forests of Sikkim Himalaya (2800–3800 m asl.) high density of low girth class tree species such as *Rhododendrons*, *Sorbus*, *Viburnum* etc. record maximum diversity in the middle storey while in the top storey just a limited number of coniferous such as *Abies densa* is found. Beside the altitudinal variation; species composition, age structure and successional stage of the forest also affect the basal area of the tree species. Concentration of dominance (cd) ranged from 0.09 (RA)–0.10 (GR) in tree, 0.07 in sapling and 0.08–0.09 in seedling layer. In the present study concentration of dominance of the entire landscape community is strongly influenced by the important value index of the first three relatively important species as similarly observed in western Himalayan subtropical forest (Malik & Bhatt, 2015). This is because of the concentration of the dominance is generally inversely proportionate to species diversity and species richness.

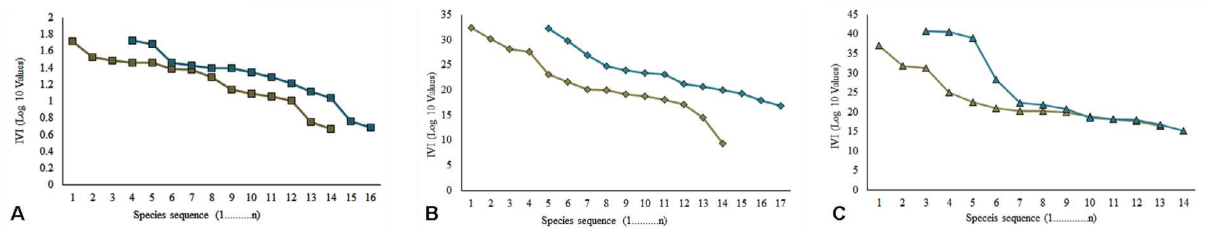
B. Species Distribution Pattern

Abundance to frequency (A/F) ratio for the tree stratum indicated that majority of the tree species in all growth stages showed contiguous distribution pattern (Figure 3), while most of the random distribution pattern recorded in site–1 but only few species among seedlings at site–2 (GR) shows random distribution (Figure 3). *Abies densa* was the dominant tree species in both study area Rongchu (RA) (Site-1) and Goral rock (GR) (Site–2) with important value index 51.92 and 53.54 respectively. The other dominant species in RA were *Rhododendron hodgsonii* (IVI: 33.85) followed by *Acer caudatum* (IVI: 30.89), *Juniperus recurva* (IVI: 28.88), *Rhododendron arboreum* (IVI: 28.88) and in GR *Rhododendron hodgsonii* (IVI: 48.54) followed by *Rhododendron grande* (IVI: 28.68), *Betula utilis* (IVI: 26.75), *Acer caudatum* (IVI: 25.02), *Rhododendron campylocarpum* (IVI: 24.64).

In saplings stratum, *Rhododendron hodgsonii* (IVI: 32.34) was the dominant species at RA and *Abies densa* (IVI: 32.29) at GR. Similarly, among seedlings, *Juniperus recurva* had maximum spread out (IVI: 37.1) at RA followed by *Rhododendron cinnabarinum* (IVI: 31.8), *Abies densa* (IVI: 31.3), *Rhododendron arboreum* (IVI: 25). *Abies densa* was the most dominant (IVI: 40.74) species at GR followed by *Rhododendron hodgsonii* (IVI: 40.59), *Juniperus recurva* (IVI: 38.98), *Rhododendron grande* (IVI: 28.33). *Rhododendron glaucophyllum* (IVI: 17.91) was observed only in seedling stage at GR. The dominance-diversity curve (d-d curve) in all three stages i.e., mature tree, sapling and seedling layers (based on log 10 value of IVI) were of normal log series (Figure 4).

Shannon–Wiener diversity index (H´) of tree species ranged from 0.51 (GR) to 0.55 (RA), for sapling H´ ranged from 0.58 (GR) to 0.60 (RA) and for seedling it ranged from 0.52 (GR) to 0.57 (RA). Lower diversity indices imply that temperate to sub- alpine forest of Kyongnosla Alpine Sanctuary is homogeneous. It is mainly dominated by different species of *Rhododendron* and *Abies*. It also indicates that species may not coexist in an overlapping habitat that in turn gives lower stability of the forest. These values of H´ are smaller than values reported from temperate forest of Khokhan Wildlife Sanctuary, north–western Himalaya (Pant & Samant, 2012), which might be due to difference in altitudinal gradient, vegetational composition suitability to habitats. In the timberline zone of Khangchendzonga National Park, Sikkim, H´ value for tree was observed between 0.77–1.47 and 1.2–1.9 respectively (Pandey, Badola, Rai, & Singh, 2018; Pandey, Rai, & Kumar, 2018) which were higher value than in the present study. The lower value of the present study may be attributed to the presence of homogeneous forest in eastern part of Sikkim Himalaya than in the western part. The Bhutanese affinities of plant in the eastern part and central Nepalese affinities in the western part also play a role in topography and local landscape label. As compared in *Quercus-Cedrus* dominated ridge temperate forest in western Himalaya H´ the diversity was 0.51 ± 0.05 (Tiwari et al., 2018).

The values of Pielou equitability ranged from 0.46 to 0.48 in tree layer, 0.52 in sapling layer and 0.48 to 0.51 in seedling layer which is larger than (0.30–0.36 for trees, 0.3–0.40 for saplings, and 0.32–0.41 for seedlings) of mixed forest of Western Himalaya for the same functional group (Tiwari et al., 2018); while lower than (1.15 ± 0.20 for tree, 1.24 ± 0.03 for sapling and 1.21 ± 0.04 for seedlings) in the



A. Trees B. Saplings and C. Seedlings

Figure 4. Dominance-diversity curves (d-d curve)

temperate forest of eastern Himalaya (Rawat et al., 2018). The moderate value for this evenness index can be attributed to the higher diversity of one genus *Rhododendron* in Site 1 (RA) and diversification or low diversity assemblage of the same genus in Site 2 (GR).

The extent of species replacement or species turnover along environmental gradient in the studied area determinates its beta diversity. The study shows that the beta diversity for tree layer ranged from 1.21 to 1.52; for sapling 1.64 (RA) to 1.52 (GR). Low differences in the values of beta diversity among different sites indicate that different growth form respond in a similar fashion and species composition does not vary significantly across different forest types (Adhikari, Rikhari, Rawat, & Singh, 1991). The species composition of Conifers- *Rhododendron* mixed temperate or subalpine forest shows the uniform community assembly because of their inclination to grow in pure patches or availability of limited number of broad-leafed elements in mixed forest across the study area.

C. Regeneration Status

The regeneration status of each tree species at different study sites are presented in Table 5. Proportion of regeneration status is shown in Figure 5. Fair regeneration status was recorded for maximum species at both sites. Density-diameter distribution exhibited decrease in tree densities towards higher DBH classes. Maximum tree individuals (64.7%) were observed in the fair regeneration area, followed by 17.64% of good regeneration, 11.76% of poor regeneration and 5.88% as new. Most tree individuals (45.82%) were observed in the least DBH class (<10 cm), followed by >30 cm (28.58%) and 10–30 cm (25.59%) (Figure 6). Regeneration is not observed in *Viburnum erubescens* in all sites probably due to poor seed viability or non-conducive habitat.

Overall regeneration status of the studied temperate mixed forest in Kyongnosla Alpine Sanctuary possesses fair regeneration rate which varied from 14.28% (RA) to 76.92% (GR). *Abies densa* is the dominant tree species in both sites and shows fair regeneration. *Lyonia ovalifolia* and *Rhododendron fulgens*, *R. hodgesonii* and *Viburnum erubescens* at GR show poor regeneration. *Viburnum erubescens* was not regenerating at all at RA while *Rhododendron glaucophyllum* at GR was found only in seedling stage. The high density of *Abies* and *Rhododendron* in both the studied

Table 5. Regeneration status of tree species in study area

Name of species	Study sites	
	Site-1 (RA)	Site-2 (GR)
Abies densa Griff.	No	Fair
Acer caudatum Wall.	No	Fair
Betula utilis D. Don	Good	Fair
Juniperus recurva Buch. -Ham. ex D. Don	Fair	Fair
Rhododendron arboreum Sm.	Fair	-
Rhododendron campylocarpum Hook. f.	Good	Fair
Rhododendron cinnabarinum Hook. f.	Fair	Fair
Rhododendron fulgens Hook. f.	Good	Poor
Rhododendron glaucophyllum Rehder	-	New
Rhododendron grande Wight	Fair	Fair
Rhododendron hodgsonii Hook. f.	No	Fair
Rhododendron lanatum Hook. f.	Good	New
Rhododendron thomsonii Hook. f.	Good	No
Sorbus microphylla (Wall. ex Hook.f.) Wenz.	Fair	Fair
Lyonia ovalifolia (Wall.) Drude	-	Good
Prunus cornuta (Wall. ex Royle) Steud.	-	Poor
Viburnum erubescens Wall.	No	No

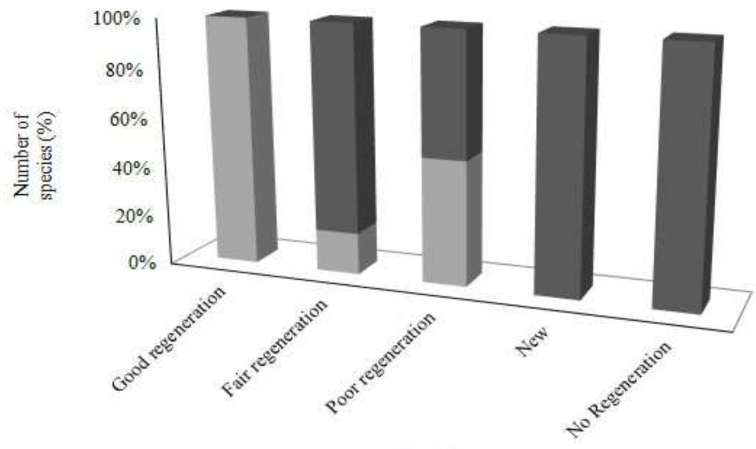


Figure 5. Regeneration status of tree species at various study sites

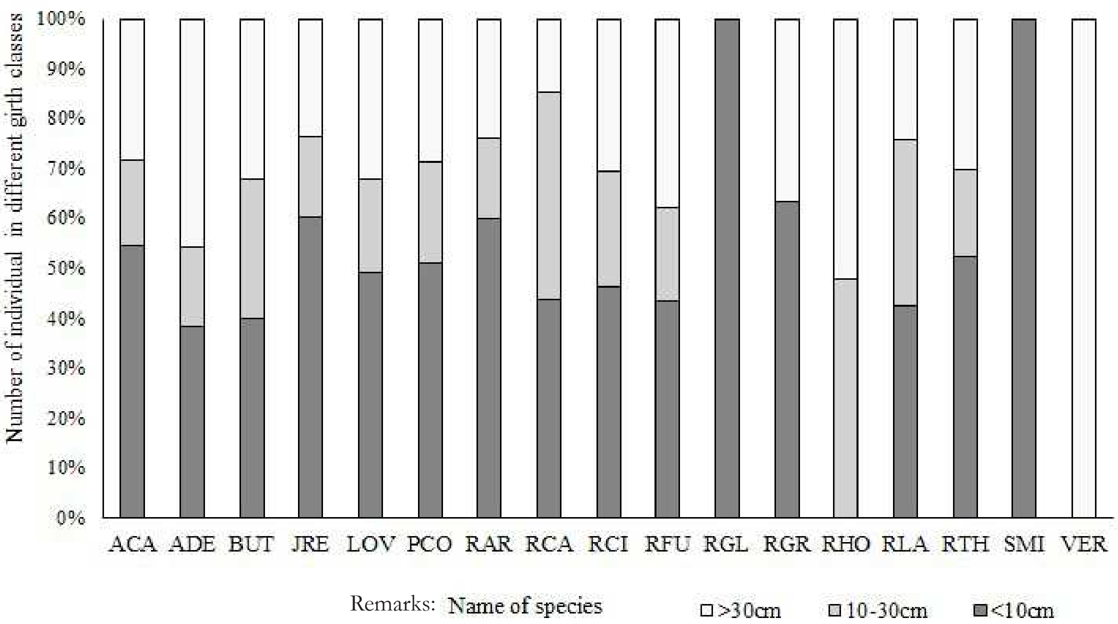


Figure 6. Distributions of tree individuals in different diameter classes

sites may be attributed to the optimal pH value (nearer to 5.5) of the soil for the growth of these two species (Sundriyal & Bisht, 1988).

The variations in phytosociological attributes in different Himalayan Forests can be attributed to the influence by large number of environmental variables e.g., soil conditions, slope angle, species composition, elevation, regional climate, topography and anthropogenic interferences (Das et al., 2020). The variations in the different successional stages of the studied sites can be ascribed to both locality and landscape-level variations in forest attributes, thus producing spatial heterogeneity (Rawat et al., 2020). In the present study, we have also observed that, species richness of trees and saplings was recorded a maximum at Study site 2 (GR); tree density, species richness and basal area followed a trend of decreasing (from RA-GR) with increasing altitude. Maximum basal area of trees and saplings were recorded at lower altitude (RA) and minimum at upper altitude (GR).

The general regeneration pattern of tree species in the study area was fairly high. The study sites are also part of one of the highly diversified alpine forests of Sikkim Himalaya, and it is covered under the protected area network. However, the rich floristic resources of the area have considerably depleted both quantitatively as well as qualitatively in the recent times owing to the illegal encroachments, influx of tourism, unscientific over exploitation of medicinal plants, and heavy grazing. During the study, it has also been observed that, plants are highly effected due to overuse grazing and browsing by taks of adjacent villages, many plants species have suffered with depleted regeneration. Therefore, keeping view of the sustainability of the alpine sanctuary and to preserve the plant wealth, the forest department of Sikkim have already been implementing various conservation programmes such as controlled grazing, development of soil seed bank, complete ban on collection of medicinal plants, fuelwoods, protection of species-specific habitats, and livestock management in adjacent villages. The study further recommends the use of alternative non-conventional source of energy such as LPG or solar in the local communities which could diminish the burden on adjacent forests.

IV. CONCLUSION

Assessment of tree species diversity, density and regeneration pattern under prevailing microenvironment is important for their sustainable utilization, management and conservation. The present study shows that on the whole regeneration status of tree species in the study area is fair and it may be due to ambient environment, biotic and abiotic factors that greatly affected the endurance of the seedlings. Moreover, regeneration pattern of four species shows poor or no regeneration that was affected by microenvironment and nature of local canopy, because germination and survival of these seedlings and sprouts mostly depend on the above two factors. However, rest of the species of the study sites were regenerating and their seedlings and sprouts have managed to survive because of their broad ecological amplitude and greater adaptability against biotic interferences. Overall, the studied forest area shows fair regeneration (35.71% in RA, 56.25% in GR) followed by good regeneration (35.71% in RA, 6.25% in GR), not regenerating (28.57% in RA, 12.5% in GR) and poor regeneration (12.5% only in GR). Therefore, the result of the present study on tree species diversity and its regeneration status in Kyongnosla Alpine Sanctuary provide a better scope for future researchers and policy makers who want to obtained more accurate data on forest inventory and its implication on further conservation strategies.

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APPENDICES

Table 4. Comparison of earlier reported phytosociological attributes of Himalayan Forest with the results of the present study

Forest type (no. of stands studied)	Altitude range (m asl)	SR	Density (individuals/ ha)	Basal Area (m^2 /ha)	H′	B–div	Cd	Ref. **
			Tree Layer					
Present Study	2800–3750	13.5±.70	548.75±8.83	38.48±2. 64	0.53±.028	1.58±.08	0.095±.005	
Garhwal Himalaya, India	2000–2550	5.375±1.18	35–930	2.21–87.07	1.54±.18	–	–	Ref.1
Sub–alpine zone of west Himalaya, India	3000–3200	–	552.88±57.92	–	–	–	–	Ref.2
Namdapha National Park, north–east India	300–600	57.33± 22.5	351± 53.61	–	–	–	–	Ref.3
Western Himalaya, India	1450–3540	14.66±1.20	661.5 ± 32.37	61.09± 9.35	0.44±.02			Ref.4
Temperate forest, Neora Valley National Park	2156–2845	15.67±4.04	248.5±22.79	18±10.69	2.19±0.57	3.28±0.54	0.2±0.14	Ref. 5
Timberline forest, KNP, Sikkim Himalaya	3787–3989	20	120 to 374	–	0.77–1.47	–	–	Ref. 6
Timberline in Khangchendzonga National Park, Sikkim	3000–4000		1,504±209	0.93–52.52	1.26–1.86			Ref. 7
			Sapling Layer					
Present Study	2800–3750	13.5±.70	1540±113.13	1.62±0.12	.59±.014	1.47±.24	.078±.0014	
Garhwal Himalaya, India	2000–2550	5.875±1.18	167–1,296	–	1.79±.78	–	–	Ref.1
Sub–alpine zone of west Himalaya, India	3000–3200	–	4935.44±706.62	–	–	–	–	Ref.2
Namdapha National Park, north–east India	300–600	42.66±15.3	2897.66±1276.29	–	–	–	–	Ref.3
Western Himalaya, India	1450–3540	12.5±1.19	3845.5 ± 454.58	–	0.438±.04	–	–	Ref.4

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Forest type (no. of stands studied)	**Altitude range (m asl)**	**SR**	**Density (individuals/ ha)**	**Basal Area (m^2 /ha)**	**H´**	**B–div**	**Cd**	**Ref. ****
Temperate forest, Neora Valley National Park	2156–2845	14±3.61	840±141.07	1.75±0.37	2.25±0.24	28.72±2.95	0.13±0.03	Ref. 5
Timberline in Khangchendzonga National Park, Sikkim	3000–4000	–	1,601±272	–	–	–	–	Ref. 7
			Seedling Layer					
Present Study	2800–3750	12.5±.70	44875±6187.18	–	.54±.03	1.46±.077	.08±.007	
Garhwal Himalaya, India	2000–2550	–	1,376–9,600	–	1.6025±.54	–	–	Ref.1
Sub–alpine zone of west Himalaya, India	3000–3200	–	3375.51±1125.17	–		–	–	Ref.2
Namdapha National Park, north–east India	300–600	19.66± 9.52	8619± 4106.86	–	–	–	–	Ref.3
Western Himalaya, India	1450–3540	12.66±1.66	46,683±9524.17	–	0.40± .03	–	–	Ref.4

**Remarks: Ref.1= Singh et al., (2016); Ref.2= Gairola et al., (2008); Ref.3= Deb & Sundriyal, (2008); Ref.4= Tiwari et al., (2018); Ref. 5= Rawat et al., (2018); Ref. 6 & 7= Pandey et al., (2018, 2018), Concentration of dominance (Cd), Shannon–Wiener diversity index (H´); beta diversity (B-div.); References (Ref.)