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POPULATION STRUCTURE AND REGENERATION DYNAMICS OF TREE SPECIES IN BANJ OAK FORESTS OF TEHRI GARHWAL, WESTERN HIMALAYA

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Forest regeneration is a natural process of forest resource reclamation through production of young ones (saplings and seedlings). Tree species show variable regeneration potential in different associations and response to natural and man-made factors. Banj oak (*Quercus leucotrichophora* A. Camus), one of the important forest forming tree species in western montane Himalaya, is facing regeneration failure in different locations. The present study attempted to assess the population structure and regeneration of *Q. leucotrichophora* and associated tree species in five different stands (sites) of a less explored region (Tehri Garhwal, Uttarakhand, Western Himalaya). To investigate the phytosociological attributes, ten sampling quadrats (400 m^2) were laid in random sampling manner in each forest stand for surveying tree layer, 2 sub-quadrats (25 m^2) for saplings, and 5 sub-quadrats (1 m^2) for seedlings in each sampling quadrat. Among the studied forest stands, tree species richness ranged 8 to 11 (8.8±1.3), total stem density (ind/ha) 750 to 950 (846±85.6), and total basal area (m^2/ha) 18.68 to 29.18 (24.1±3.9). Based on abundance data the banj oak showed 'good' regeneration statuses (density of seedling > saplings > adult trees) in all forests. The distribution of adult tree individuals into different size classes (DBH classes) also indicate 'good' regeneration pattern (higher density in lower size classes and gradual decrease in density towards higher classes or forming a reverse J-shaped pattern). However, majority of the banj oak associated species (e.g. *Prunus cerasoides*, *Pyrus pashia*, *Rhododendron arboreum*, etc.) represented 'fair' regeneration statuses (seedlings > or ≤ saplings ≤ adult trees). Overall, the results of this study shed light on the positive prospects for *Q. leucotrichophora* regeneration and the importance of sustainable coexistence between human communities and these vital forest ecosystems.

Key words: forest composition, population structure, regeneration dynamics, tree diversity

INTRODUCTION

The fragile Himalayan ecosystems (e.g., glaciers, alpine tundra, lakes, rivers, forests, and man-made ecosystems) are unique from biodiversity conservation standpoint. The Himalaya is included in the World's Biodiversity Hotspots list recently as it is home for many endemic and threatened (CR, EN and VU) plants and animals. However, this biodiversity rich landscape is experiencing various changes in its biodiversity patterns due to different natural and man-caused factors. The same is true for the Western Himalayan forests as various changes are appearing in terms of species composition, population structure, and natural regeneration due to global warming, habitat destruction and over-exploitation of forest resources (Gaur 1982, Kumar *et al.* 2004). Therefore, assessment of diversity and regeneration status of tree species in Himalayan forests is important for their sustainable utilisation, management, and conservation (Rawat *et al.* 2018*a*).

The vegetation patterns in the Himalaya vary from one location to another due complexity in climatic, physical and biotic factors (Chawla *et al*. 2008, Pant and Samant 2012). Among the forest types found in Indian Himalaya (Champion and Seth 1968), the broad leaved evergreen banj oak (*Quercus leucotrichophora* A. Camus) forests are most loved and preferred forests in the montane zone (mid elevation belt) of the people of Uttarakhand state. The locals believe that this species maintain their perennial ground water sources hence they will never face drinking water scarcity if dwelling around banj oak forests. Additionally, this species provides green fodder to them during the harsh period, i.e., snow-fall and dry winter (Nautiyal *et al.* 2018, Singh *et al.* 2022). At the mid elevation, the *Q. leucotrichophora* remains member of almost all types of forest compositions. Banj oak (*Q. leucotrichophora*) naturally forms mixed forest stands in association with other broad-leaved (evergreen or deciduous) and coniferous (evergreen) species in the montane zone. However, pure patches are often observed in community-managed forest stands (Van Panchayat) near human habitation or villages. Apart from various anthropogenic disturbances, chir pine (*Pinus roxburghii*) is encroaching on the natural habitats of oak and other broad-leaved species (Rawat *et al.* 2020). Hence, oak-pine forests are extending at a rapid rate in the montane belt of the Western Himalaya. Though *Q. leucotrichophora* forms broad-leaved mixed forests under natural conditions, the composition and dominance of associated tree species are never uniform; these vary from one forest to another.

Recently pure banj oak stands near to village centres or Van Panchayat forests are facing regeneration failure in the state Uttarakhand and other parts of Indian Himalaya (Parveen *et al.* 2017, Singh *et al.* 2021). The human-induced small-scale disturbance (lopping of branches and leaf litter removal) adversely impacts the functioning of banj oak forests of Central Himalaya (Singh *et al.*

2014). The insufficient regeneration of *Q. leucotrichophora* in different parts of the Himalayan forest ecosystem has been reported by earlier workers (Saxena and Singh 1982, Thadani and Ashton 1995). Dhyani *et al.* (2020) in their model predicting found a significant decline in banj oak populations in response to variability in future climate change scenarios in the region.

This study aimed to investigate a botanical region primarily composed of banj oak mixed forests in Tehri Garhwal (Uttarakhand, W Himalaya), an area where only a limited number of botanical surveys and forest ecological studies have been conducted. In this study, we investigated the tree species composition, population structure and regeneration dynamics in five different banj oak stands (sites). Our study may fill the knowledge gap (from the area), contribute to understanding regional pattern of banj oak associations; provide base line information on natural regeneration statuses of different species. Such evaluations are also valuable to comprehend the forest ecosystems to further improve conservation and the management planning and execution (Ahmad *et al.* 2020).

MATERIAL AND METHODS

Study area – Tehri Garhwal, a district of Uttarakhand state is situated between the latitudes 30°–31° and the longitudes 78°–79° (Fig. 1). It is bounded

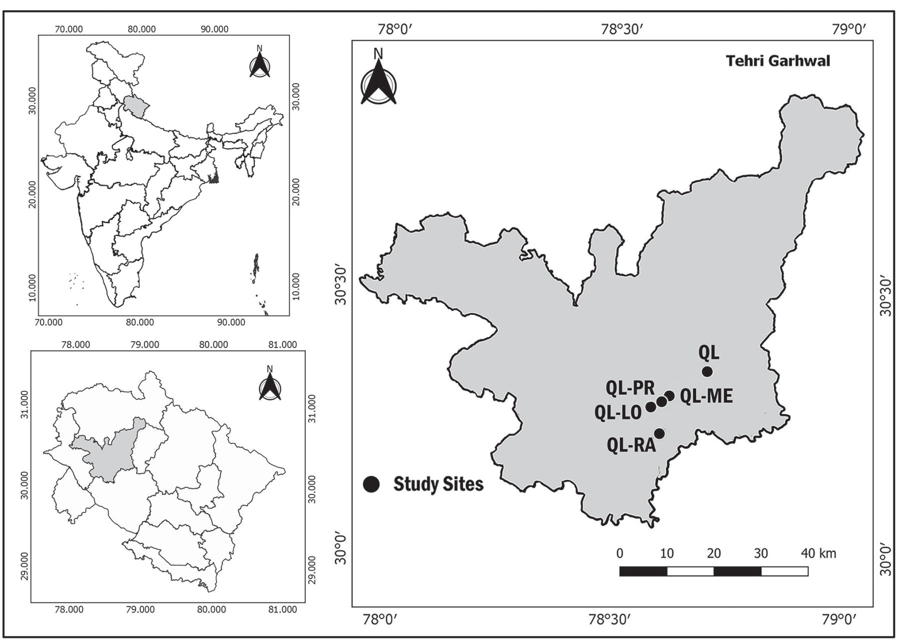

Fig. 1. Map of the study area (labelled circles on the map indicating 5 studied forest communities)

Table 1
Characteristics of five study sites in Tehri Garhwal, Uttarakhand, India

Site	GPS coordinates	Alt	S	A	Common tree species (IVI)	CT
I	30° 13′ 49.17″ E, 78° 35′ 58.75″ N	1,400–1,500	23°	N	*Q. leucotrichophora* (121.68), *R. arboreum* (57.43), *L. ovalifolia* (40.1)	QL-RA
II	30° 18′ 8.43″ E, 78° 37′ 10.48″ N	2,000–2,200	28°	NE	*Q. leucotrichophora* (121.32), *L. ovalifolia* (35.63), *R. arboreum* (34.92)	QL-LO
III	30° 20′ 59.6″ E, 78° 42′ 5.33″ N	1,350–1,550	25°	N	*Q. leucotrichophora* (137.48), *P. roxburghii* (34.64), *R. arboreum* (28.03)	QL-PR
IV	30° 17′ 27.60″ E, 78° 36′ 11.32″ N	1,600–1,800	17°	NE	*Q. leucotrichophora* (122.87), *M. esculenta* (40.74), *R. arboreum* (37.18)	QL-ME
V	30° 16′ 50.14″ E, 78° 34′ 46.5″ N	1,500–1,700	19°	N	*Q. leucotrichophora* (166.93), *R. arboreum* (46.27), *L. ovalifolia* (27.19)	QL

Alt = altitude (m asl) S = slope angle, A = aspect, IVI = importance value index, and CT = community type (based on name code of tree species contributing > 50% in total IVI of trees in that particular site)

by district Dehradun in the west, district Rudraprayag in the east, district Uttarkashi in the north while the river Alaknanda separates it from district Pauri in the south and southeast. Tehri Garhwal (encompassing 3,642 km^2) is the fifth largest among the 13 districts of the state in terms of total geographical area. The climate varies from sub-tropical to cold temperate. The northern and northwestern parts of the district experience sub-zero temperature during the winter. Snowfall is quite common during the winter in the area >2,000 m a.s.l. Agriculture with animal husbandry-based activities is the main source of livelihood for the major population living in the villages of the area. Such population is engaged either in the main occupation of agriculture or its allied practices, dominated by traditional subsistence cereal farming. Several agricultural crops are cultivated on the terraced agricultural fields by the locals in comparatively small scales and self-use. Local people of the region are generally reliant upon forest for their everyday requirements like fuel, fodder and various forests assets.

About 50% area of the district is forest covered. The vegetation of the district can be divided into six categories following classification by Bahuguna *et al*. (2016), viz., (i) Himalayan sub-tropical pine forest, (ii) Western Himalayan broadleaved temperate forest, (iii) Western Himalayan deodar forest, (iv) Western Himalayan mixed coniferous forest, (v) Western Himalayan dry temperate coniferous forest, and (vi) Western Himalayan alpine pasture. A larger part of the district is surrounded by thick wilderness of pure or mixed stands of endemic (evergreen and deciduous) trees.

Site selection – Five oak (*Quercus leucotrichophora*) forests varying in their species composition and dominance were selected as study sites (Fig. 1, Table 1).

These sites are located *ca* > 10 km far from each other. Each of the selected sites is reachable from nearby human settlements (villages) situated about 1–3 km distance. These forests often experience man-caused forest fires (from March to June) and other anthropogenic pressures (cattle grazing, folder collection, timber collection, etc.). The locality factors including coordinates, elevation, and aspect of selected sites were measured during the field surveys by GPS (Garmin, Rino-130) while the slope angle was measured using a digital inclinometer. Map of the study area was prepared using QGIS software (Ver. 3.32).

The importance value index (IVI) is a numerical measure used in ecology to assess the relative importance of different species within a particular ecosystem or community. It takes into account various factors such as the frequency, density, and dominance of species to determine their importance. For the better presentation and easy discussion, the five study sites were considered as tree communities and standard code (abbreviations) was given to each site based on the IVI of the first species (represented > 50% of the total IVI of the site) e.g. QL (*Quercus leucotrichophora*) or IVI of first two species e.g. QL-RA (*Q. leucotrichophora-Rhododendron arboreum*), QL-LO (*Q. leucotrichophora-Lyonia ovalifolia*), QL-PR (*Q. leucotrichophora-Pinus roxburghii*), and QL-ME (*Q. leucotrichophora-Myrica esculenta*) community.

Data collection and analysis – Field surveys were conducted to collect the specimens (for identification purposes) of tree species and field data during 2021–2022. The tree specimens were collected in their reproductive stage (flowering or fruiting stage) while tree community data were collected during the post-monsoon season (September and October 2022). The identification of species was done with the help of existing taxonomic literature (Gaur 1999, Naithani 1984–1985, Pusalkar and Singh 2012). The identified tree samples were deposited in the Herbarium of the Department of Botany, HNB Garhwal University Srinagar (GUH). The species composition of each site was analysed by nested quadrat methods (Kent and Coker 1992). A total of 10 quadrats of size 400 m^2 (20 m × 20 m) were randomly laid in each site to collect adult tree data. Within each large quadrat, two sub-quadrats (size 5 m × 5 m) were nested for saplings and five sub-quadrats (size 1 m × 1 m) for seedlings. Metallic nails and nylon ropes of different lengths (i.e., 20 m, 5 m and 1 m) were used to establish sampling units (quadrats). Circumference was measured with the help of graduated tape or ruler scale and thread (for small individuals). Circumference (C) was used to differentiate tree life stages into adult trees (C > 30 cm at 1.37 m above ground level), saplings (C = 10–30 cm) and seedlings (C < 10 cm). The adult tree data were analysed for frequency, density, and basal area (Curtis 1956, Misra 1968) while the saplings and seedlings for density only to depict the regeneration status.

Frequency (%) = ((Total no. of quadrates in which a species occurs) / (Total no. of quadrates studied)) × 100
Density = (Total number of individuals of a species) / (Total no. of quadrates studied)

Basal area (BA) is the cross-sectional area of a tree trunk at breast height. The mean basal area (MBA) was calculated by dividing the average square circumference of each species by 4π. The MBA was multiplied by the respective densities of particular tree species to obtain the total basal area (TBA). The importance value index (IVI) was calculated as per (Phillips 1959).

IVI = RD% + RF% + RTBA%

where, RF = relative frequency, RD = relative density and RTBA = relative total basal area.

Relative frequency (RF) is a measure that indicates the proportion of times a particular species is encountered in a sample or study area relative to the total number of encounters of all species. Relative density (RD) represents the abundance of a specific species in relation to the total number of individuals or organisms in a sample or area. Relative total basal area (RTBA) is a measure of the contribution of a specific tree species to the total basal area in a forest stand.

The diversity index (Shannon–Wiener index) (Shannon and Wiener 1963), dominance index (Simpson index) (Simpson 1949) and evenness index (Pielou's evenness index) (Pielou 1966) calculated as follows:

$$\text{Shannon–Wiener diversity index } = \sum_{i=1}^{s} pi \ln pi$$

$$\text{Dominance index } = \sum_{i=1}^{s} (pi^2)$$

$$\text{Pielou evenness index} = H' / H'_{max}$$

where, *pi* is the proportion of individuals of i^{th} species and total number of individuals of all species; H′ is the Shannon–Wiener index; H_{max} is the Shannon maximum diversity index (H_{max} – ln (S).

The Shannon–Wiener index measures overall diversity, taking into account both the number of species and how evenly they are distributed. The dominance index (Simpson index) measures the concentration of individuals within a few dominant species. It is the inverse of diversity, meaning that higher values of the Simpson index indicate lower diversity. Pielou's evenness index quantifies the evenness of species distribution within a community. It complements the Shannon–Wiener index by providing a measure of evenness alone, without considering species richness.

Chord diagram of tree species composition of different study sites based on absence and presence species data matrix was prepared using R software

Table 2
Criteria for tree regeneration status allocation

Criteria	Regeneration status
Seedlings > saplings > adult trees	Good (G)
Seedlings > or ≤ saplings ≤ adult trees	Fair (F)
Tree species surviving only in the sapling stage with no seedling, saplings may be <, > or = adult trees	Poor (P)
Tree species found only in the adult form (CBH > 30 cm) without sapling and seedling	Not regenerating (NO)
Species with no adult tree representatives; found at sapling and/ or seedling stages only	New recruiting (NW)

(Ver. 4.3.1.). The density-diameter curves (d-d curves) prepared by dividing tree individuals into six diameter classes (DBH classes) i.e., 10–20 cm (D1), 21–30 (D2), 31–40 (D3), 41–50 (D4), 51–60 (D5) and >60 cm (D6) (Fig. 3). The diameter (DBH) was calculated from circumference (CBH) data collected during field study. The regeneration status, viz., 'Good' (G), 'Fair' (F), 'Poor' (P), 'Not' regenerating (NO) and 'New' recruiting (NW) was determined as per the criteria given in Table 2 (Khan and Tripathi 1986, Shankar 2001).

RESULTS

A total of 16 tree species belonging to 14 genera and 12 families were recorded from five sampling sites (50 tree quadrats; 10 quadrats in each site) (Fig. 2). Adult tree (CBH > 30 cm) species richness was observed highest (11 spp.) in QL-ME community followed by QL-LO (9 spp.), QL-RA, QL-PR, and QL communities (8 spp. each). Tree stem density ranged from 750 ind/ha in QL-ME to 950 ind/ha in QL-PR community while the total basal area varied from 18.68 m^2/ha in QL to 29.18 m^2/ha in QL-PR community (Table 3). Tree diversity index (Shannon–Wiener index) values ranged from 1.17 in QL to 1.73 in QL-ME community and tree dominance index (Simpson index) reported between 0.28 (QL-ME) to 0.48 (QL community). Tree evenness (Pielou's evenness index) was found to be lowest (0.56) in QL community and highest (0.75) in QL-RA community.

Stem density of saplings (tree individuals with circumference in between 10–30 cm) varied between 870 ind/ha (QL) and 2120 ind/ha (QL-RA) (Table 3). The total basal area of saplings was recorded minimum (0.67 m^2/ha) in QL and maximum (2.10 m^2/ha) in QL-PR community. Sapling species richness was the highest (7 spp.) in QL-ME community and the lowest (4 spp.) in QL-PR community. Sapling diversity index varied from 0.85 (QL-LO) to 1.25 (QL-ME), while dominance index value ranged from 0.38 (QL-ME) to 0.60 (QL-LO). Sapling evenness index value was found to be the lowest (0.47) in QL-LO community and the highest (0.69) in QL-PR community.

Density of seedlings (tree individuals with circumference < 10 cm) ranged from 2,020 ind/ha in QL-ME community to 3,810 ind/ha in QL-RA community (Table 3). Seedling species richness was high in QL-LO and QL-ME community (9 spp. each) and low in QL-PR and QL mixed community (7 spp. each). The values of diversity index for seedlings ranged from 0.75 in QL community to 1.19 in QL-PR community, while dominance index values ranged from 0.38 in QL-PR to 0.68 in QL community. Evenness index value was found to be the lowest (0.39) in QL community and the highest (0.61) in QL-PR community.

The site-wise density-diameter distribution (d-d curve) of adult tree individuals (CBH > 30 cm) is depicted in Figure 3. The d-d curves are also given for first three dominant species at each site. The first two smaller size DBH classes, viz. D1 (10–20 cm) and D2 (21–30 cm) showed high density in comparison to larger sized DBH classes (D3–D6). A majority of tree species (including *Q. leucotrichophora*, *P. roxburghii*, *L. ovalifolia* and *M. esculenta*) exhibited the reverse J-shaped d-d curves. *Rhododendron arboreum* also showed interrupted d-d curves at QL-RA and QL communities.

The regeneration statuses of tree species vary from community to community. The percentage ‘good’, ‘fair’, and ‘poor’ regeneration status species at various sites are depicted in the Table 3, while species wise regeneration

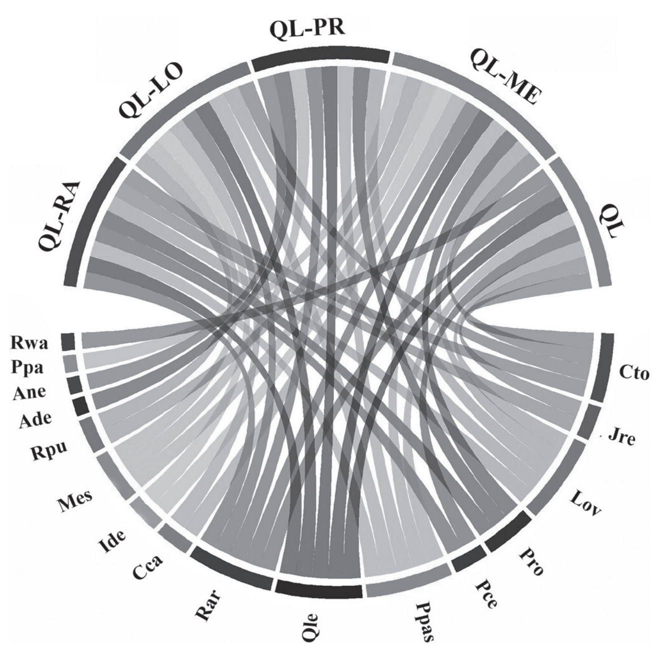

Fig. 2. Composition of tree species in different communities (lower half of chord diagram showing tree species and upper half showing communities). Abbreviations for tree names as per Table 5

Table 3
Phytosociological attributes for tree, sapling, and seedling layers at the five study sites

Parameters	Tree community				
	QL-RA	QL-LO	QL-PR	QL-ME	QL
Tree layer					
Total stem density (ind/ha)	820	920	950	750	790
Total basal area (m^2/ha)	26.24	22.65	29.18	23.66	18.68
Species richness	8	9	8	11	8
Diversity index	1.56	1.61	1.47	1.73	1.17
Dominance index	0.30	0.32	0.35	0.28	0.48
Evenness index	0.75	0.74	0.71	0.72	0.56
Sapling layer					
Total stem density (ind/ha)	2120	1260	1590	1050	870
Total basal area (m^2/ha)	1.83	0.98	2.10	1.10	0.67
Species richness	6	6	4	7	5
Diversity index	1.14	0.85	0.95	1.25	0.95
Dominance index	0.42	0.60	0.49	0.38	0.53
Evenness index	0.64	0.47	0.69	0.64	0.59
Seedling layer					
Total stem density (ind/ha)	3810	2350	2670	2020	2090
Species richness	9	9	7	9	7
Diversity index	1.10	1.05	1.19	1.14	0.75
Dominance index	0.45	0.55	0.38	0.41	0.68
Evenness index	0.53	0.48	0.61	0.52	0.39

status are given in the Table 6. Two species (*Alnus nepalensis* and *Pinus patula*) were recorded at adult tree stage only in the region ('no' regeneration status). Similarly, *Cupressus torulosa* and *Ilex dipyrena* also showed 'no' regeneration

Table 4
Percentage of tree species showing various regeneration statuses

Tree regeneration status	QL-RA	QL-LO	QL-PR	QL-ME	QL
G	44.4	22.2	50.0	54.6	37.5
F	44.4	77.8	25.0	27.3	50.0
P	–	–	12.5	–	–
NW	11.1	–	–	–	–
NO	–	–	12.5	18.2	12.5

Abbreviations for tree regeneration status as per Table 1

Table 5
Phytosociological attributes of adult tree species at different forest sites

Tree species (Code given)	QL-RA		QL-LO		QL-PR		QL-ME		QL	
	Den.	IVI	Den.	IVI	Den.	IVI	Den.	IVI	Den.	IVI
Acacia dealbata (Ade)*	–	–	–	–	60	27.09	–	–	–	–
Alnus nepalensis (Ane)	–	–	–	–	30	14.83	–	–	–	–
Cornus capitata (Cca)	–	–	50	18.37	–	–	20	08.76	–	–
Cupressus torulosa (Cto)	30	16.84	50	28.82	–	–	20	13.76	20	15.91
Ilex dipyrena (Idi)	–	–	20	7.92	–	–	10	4.85		
Juglans regia (Jre)	30	18.99	–	–	–	–	–	–	10	7.61
Lyonia ovalifolia (Lov)	90	40.10	100	35.63	60	24.65	60	26.36	50	27.19
Myrica esculenta (Mes)	–	–	60	24.92	50	16.64	100	40.74	–	–
Pinus patula (Ppa)*	–	–	–	–	–	–	10	4.45	–	–
Pinus roxburghii (Pro)	20	08.72	–	–	150	34.64	30	14.69	–	–
Prunus cerasoides (Pce)	40	16.01	–	–	–	–	–	–	30	15.8
Pyrus pashia (Ppas)	50	20.24	40	15.96	40	16.64	40	17.61	30	15.32
Quercus leucotrichophora (Qle)	400	121.68	490	121.32	530	137.48	370	122.87	530	166.93
Rhododendron arboreum (Rar)	160	57.43	80	34.92	30	28.03	70	37.18	110	46.27
Rhus pujabensis (Rpu)	–	–	30	12.14	–	–	20	8.73	–	–
Rhus wallichi (Rwa)	–	–	–	–	–	–	–	–	10	4.97
Total	820	300	920	300	950	300	750	300	790	300

Den. = density (ind/ha), and IVI = importance value index. * = introduced and planted species status at QL-ME and QL community, respectively. At QL-RA, *Ilex dipyrena* was observed at seedling stage only ('new' regeneration status).

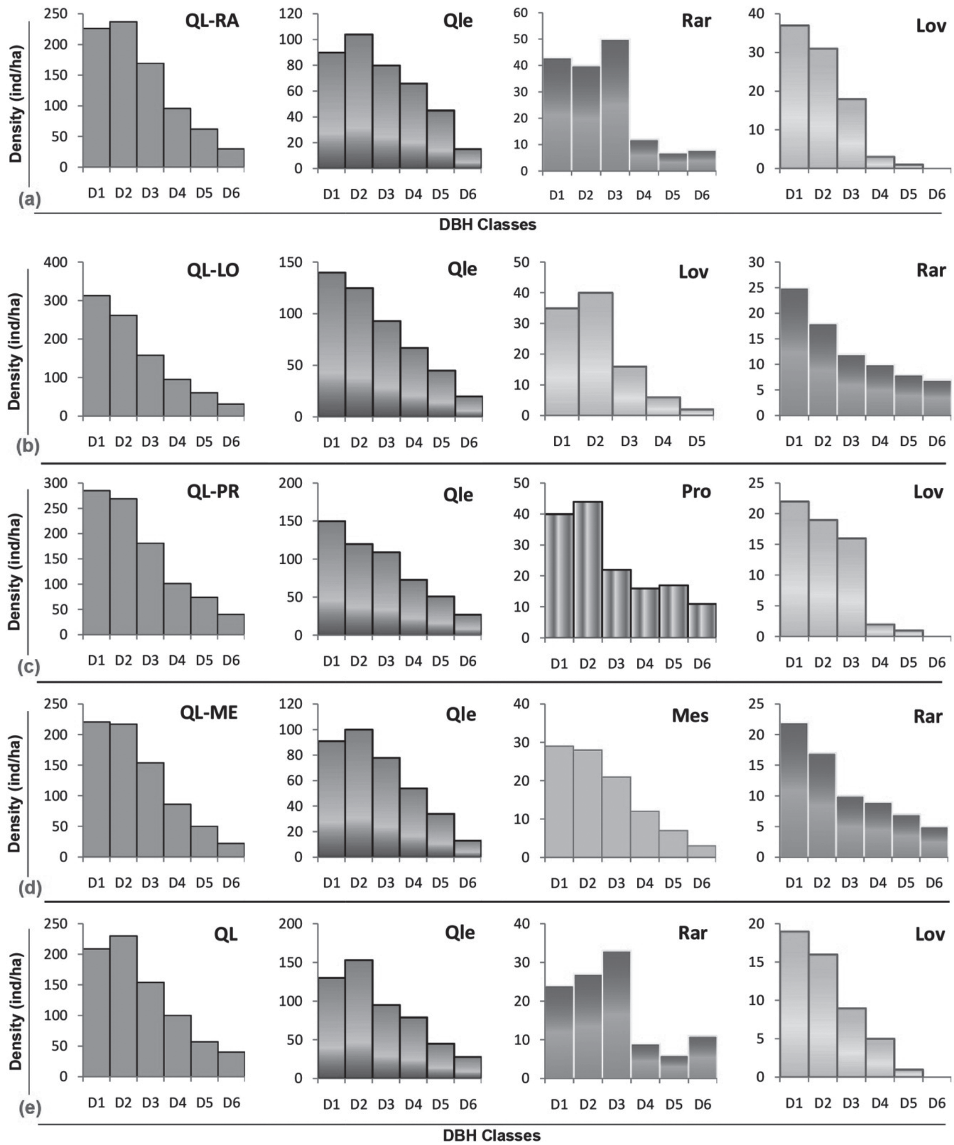

Fig. 3. Density-Diameter distribution all and first three dominant species: (a) QL-RA, (b) QL-LO, (c) QL-PR, (d) QL-ME, and (E) QL community. DBH (diameter at breast height) class: D1 (10–20 cm), D2 (21–30 cm), D3 (31–40 cm), D4 (41–50 cm), D5 (50–60 cm) and D6 (> 60 cm). Abbreviations for tree names as per Table 5

Table 6
Regeneration status of tree species in different study sites in Tehri Garhwal, Uttarakhand, India

Tree community	Attribute	Density (ind/100 m²)															
		Ade	Ane	Cca	Cto	Idi	Jre	Lov	Mes	Ppa	Pro	Pce	Ppas	Qle	Rar	Rpu	Rwa
QL-RA	TR	–	–	–	0.3	–	0.3	0.9	–	–	0.2	0.4	0.5	4.0	1.6	–	–
	SP	–	–	–	0	–	0	4.7	–	–	0.6	0.2	0.6	12.6	2.5	–	–
	SD	–	–	–	0.2	1.0	0.3	7.2	–	–	0.7	0.4	0.4	23.4	4.5	–	–
	RS	–	–		F	NW	F	G	–	–	G	F	F	G	G	–	–
QL-LO	TR	–	–	0.5	0.5	0.2	–	1.0	0.6	–	–	–	0.4	4.9	0.8	0.3	–
	SP	–	–	0	0	0.1	–	1.6	0.7	–	–	–	0.3	9.6	0.3	0	–
	SD	–	–	0.8	0.3	0.3	–	2.7	0.4	–	–	–	1.1	17.1	0.7	0.1	–
	RS	–	–	F	F	F	–	G	F	–	–	–	F	G	F	F	–
QL-PR	TR	0.6	0.3	–	–	–	–	0.6	0.5	–	1.5	–	0.4	5.3	0.3	–	–
	SP	0	0	–	–	–	–	1.1	0.9	–	3.4	–	0	10.5	0	–	–
	SD	0.1	0	–	–	–	–	1.9	1.4	–	8.9	–	0.3	13.7	0.4	–	–
	RS	P	NO	–	–	–	–	G	G	–	G	–	F	G	F	–	–
QL-ME	TR	–	–	0.2	0.2	0.1	–	0.6	1.0	0.1	0.3	–	0.4	3.7	0.7	0.2	–
	SP	–	–	0	0.3	0.2	–	1.2	2.4	0	0.5	–	0.1	5.8	0	0	–
	SD	–	–	0	0.4	0.3	–	1.7	3.9	0	0.7	–	0.3	12.1	0.4	0.4	–
	RS	–	–	NO	G	G	–	G	G	NO	G	–	F	G	F	F	–
QL	TR	–	–	–	0.2	–	0.1	0.5	–	–	–	0.3	0.3	5.3	1.1	–	0.1
	SP	–	–	–	0	–	0.2	1.1	–	–	–	0.6	0	6.1	0.7	–	0
	SD	–	–	–	0	–	0.3	1.8	–	–	–	0.4	0.4	17.1	0.6	–	0.3
	RS	–	–	–	NO	–	G	G	–	–	–	F	F	G	F	–	F

TR = tree density (ind/100 m²), SP = sapling density (ind/100 m²), SD = seedling density (ind/100 m²), RS = regeneration status, F = fair, G = good, NO = no regeneration, NW = new, and P = poor. Abbreviations for tree names as per Table 5

DISCUSSION

In this study, five oak (*Quercus leucotrichophora*) mixed communities were analysed in part of Western Himalaya, India. Banj oak (*Q. leucotrichophora*) is one of the large forest-forming tree species in the Western Himalaya (Bagri *et al.* 2022, Ghildiyal *et al.* 1998, Tewari and Singh 1985, Thakur *et al*. 2021). Mixed forests naturally form in the montane zone, but pure patches often occur near human habitation due to chir pine encroachment, leading to the rapid expansion of oak-pine forests in the Western Himalaya, with varying tree species composition and dominance (Bhandari *et al.* 2000, Gaur 1999, Rawat *et al.* 2021, Singh *et al.* 1984, Tiwari 2005). Five oak mixed forests (growing between 1,350 and 2,200 m a.s.l.), which are investigated in this study (Table 1, Fig. 2) are dominated by *Q. leucotrichophora*, but the associated species vary in both composition and dominance.

In this study, the adult tree (CBH > 30 cm) species richness ranged from 8–11 and stem density 750–950 ind/ha (Table 3). These resulted values are found in agreement with earlier reports from other nearby Himalayan forests. The species richness of oak dominant forests of Garhwal Himalaya were reported between 4 and 11 by Saha *et al*. (2016, Dhanaulti region), Gairola *et al*. (2011, Mandal forest), and Rawat *et al*. (2021, western Ramganga valley). The tree stem density reported in earlier studies ranged 790–1,260 ind/ha (Kusum Lata and Bisht 1991), 1,570–1,785 ind/ha (Bhandari *et al*. 2000), 760–1,110 ind/ha (Kumar and Bhatt 2006), 652 to 1,028 ind/ha (Kumar *et al.* 2009) 380–1,470 ind/ha (Gairola *et al.* 2011), and 400–933 ind/ha (Rawal *et al.* 2012). The resulted total basal area (TBA) i.e., 18.68–29.18 m^2/ha (Table 3) found comparable to earlier studies from the other parts of the Uttarakhand (Kumar *et al.* 2009, Kusum Lata and Bisht 1991, Malik and Bhatt 2016).

The regeneration statuses of tree species vary from community to community. All the studied community showed higher number of adult tree individuals into lower size classes viz., D1 (10–20 cm) and D2 (21–30 cm) and uneven distribution in higher size classes. This indicates these that communities are unevenly aged and young growth forests and showed 'reverse J-shaped' d-d curves. Reverse J-shaped d-d curves were reported in the forest stands where a higher number of small individuals with fewer large ones is present. Such pattern of density-diameter distribution in natural forest stands indicates stable population with good regeneration (Dash *et al.* 2021, Khan *et al.* 1987). Typically, young forests exhibit a normal or Gaussian distribution, but in this study, these forest communities displayed a reverse J-shaped curve. This phenomenon can be attributed to the continuous utilisation of saplings by humans, which resulted in a lower number of individuals in larger diameter classes. Prasad *et al*. (2015) similarly documented a 'reverse J-shaped curve' in moderately disturbed *Q. leucotrichophora* forests.

Two species (*Alnus nepalensis* and *Pinus patula*) were reported at adult tree stage only in the region ('no' regeneration status). *Pinus patula* is a recently introduced (planted) species in the region that has achieved reproductive stage (producing cones with seeds) but the natural germination of seed was not seen yet. That is why the species may not observed at seedling/sapling stages. The studied communities located on mountain slopes far from the stream/river hence no regeneration of *Alnus nepalensis* in these is not a serious matter of concern because it naturally and abundantly occurred in stream/river side and moist broad-leaved forest habitats (Das *et al.* 2021, Rawat *et al.* 2021). *A. nepalensis* is a fast-growing early successional species, which often forms pure stands in post-disruption (landslides/ landslips) in most montane Himalayan forests (Rana *et al*. 2018). *Ilex dipyrena* and *Cupressus torulosa* are more common in upper temperate regions and *C. torulosa* is often planted in the lower temperate regions of the Uttarakhand. It is evident from Tables 3 and 5 that the majority of the tree species showed 'good' and 'fair' regeneration pattern in the study area. The majority of the tree species represented 'fair' regeneration status in mid elevations (1,200 and 3,100 m a.s.l.) in Uttarakhand (Rawat *et al.* 2018*b*).

The frequent human-ignited fires and cattle grazing may be serious threats to the natural regenerations of banj oak, *Rhododendron arboreum* and other broad-leaved species because these factors not only injure the seedlings and saplings but also reduce the germinating capacity of freshly dispersed seeds on the ground surface by heating effects and physical damage. However, in present study *Q. leucotrichophora* showed good regeneration in all the forest communities, which indicates that forest composition in not a factor, which affects the regeneration of *Q. leucotrichophora.*

CONCLUSIONS

In conclusion, the primary objective of this study was to evaluate the influence of forest composition on the regeneration of *Q. leucotrichophora*. Our findings reveal that, in the context of this study, Q. *leucotrichophora* demonstrated healthy regeneration across various studied forest communities. This suggests that forest composition may not be a significant factor affecting the regeneration of *Q. leucotrichophora* in the examined region. It is worth noting that the presence of oak forests near human settlements has long been established, as highlighted by Champion and Seth (1968). *Q. leucotrichophora* holds a crucial role in the lives of the local population in the mid-elevation areas of Garhwal Himalaya, serving as a vital source of fuel, fodder, and leaves for fertilising cultivated lands. The sustainable utilisation of this species by the local communities may have contributed to the uneven diameter distribution observed in these forests. Furthermore, our findings align with those of Prasad *et al.* (2015), who reported that *Q. leucotrichophora* exhibits robust regeneration under moderate to mid-level disturbance. This underscores the resilience of the species and its ability to adapt to varying ecological conditions. Adopting plantations using several native and site-adapted tree species with protection from grazing and fire at early growth stages; awareness among locals towards sustainable utilisation of forest resources; provided alternatives of resources extracted from forests may be helpful in the maintenance and management of these forests for future needs.

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