

# Quantitative Analysis of Tree Species Diversity in Different Oak (*Quercus* spp.) Dominated Forests in Garhwal Himalaya, India

Gajendra SINGH<sup>1</sup>\*, Gopal S. RAWAT<sup>2</sup>

<sup>1</sup>Wildlife Institute of India, PO Box 18, Chandrabani, 248001 Dehradun, Uttarakhand, India; [gajendrawat@yaboo.com](mailto:gajendrawat@yaboo.com) (\*corresponding author)

<sup>2</sup>International Centre for Integrated Mountain Development, Ecosystem Services, GPO Box 3226, Kathmandu, Nepal

## Abstract

Himalayan broad-leaved forests are mainly dominated by oak (*Quercus* spp.) species. Oak species with other tree species provide numerous ecosystem services and serve as lifeline for local inhabitants. Overall tree diversity and their status in different oak dominated forests viz., *Quercus leucotrichophora* (1500-2200 m), *Q. floribunda* (2201-2700 m) and *Q. semecarpifolia* (2701-3300 m) were studied in Garhwal, Himalaya. A total of 54 tree species (40 genera) in *Q. leucotrichophora*, 43 tree species (30 genera) in *Q. floribunda* and 23 tree species (16 genera) in *Q. semecarpifolia* dominated forests were recorded. Lauraceae was the dominant family in *Q. leucotrichophora* and *Q. floribunda* forests (6 and 8 species respectively), while Ericaceae (3 species) was the dominant family in *Q. semecarpifolia* dominated forests. Pinaceae and Taxaceae were only two gymnospermic family represented by *Pinus roxburghii* at low, *Abies pinrow* at mid, *Abies spectabilis* and *Taxus wallichiana* at higher elevational oak forests. There was no significant variation ( $p=0.8$ ) between overall tree density in different oak forests which ranges from  $337\pm 51$  individual/ha in *Q. semecarpifolia* to  $433\pm 92$  individual/ha in *Q. leucotrichophora* forests. The seedling density has significant variation ( $p=0.01$ ) in different oak forests where highest density was recorded in *Q. leucotrichophora* forests (1981 individual/ha) and lowest in *Q. semecarpifolia* forests (348 individual/ha). The Total Basal Area (TBA) reported from *Q. leucotrichophora* ( $88.06\text{ m}^2/\text{ha}$ ) and *Q. floribunda* ( $110.5\text{ m}^2/\text{ha}$ ) forests was higher than those of earlier reported from the region, while basal area of *Q. semecarpifolia* ( $90.16\text{ m}^2/\text{ha}$ ) was comparable with the forests of western Himalaya.

**Keywords:** associated species, elevation, oak forests, population, regeneration

## Introduction

Oaks (*Quercus* spp.) are the dominant, climax tree species of the moist temperate forests of the Indian Himalayan region (Troup, 1921) where about 35 species of *Quercus* are extensively distributed between 1000-3500 m elevations. Five species of evergreen oaks, namely *Quercus glauca* (phaliyant/harinj), *Q. leucotrichophora* (banj), *Q. lanuginosa* (rianj), *Q. floribunda* (tilonj/moru) and *Q. semecarpifolia* (brown/kharsu) grow naturally in the Uttarakhand state. Except *Q. glauca* and *Q. lanuginosa* three species are widely distributed and forms extensive patches in the Garhwal Himalaya (Singh and Singh, 1992) and each species is replaced by the other to form the climax communities along an increasing elevation. At 2000 m and less *Q. leucotrichophora* exhibits 80% dominance (based on relative basal area), between 2000 to 2200 m it may share dominance with *Q. floribunda* and above 2200 m it generally disappears (Singh and Singh, 1992; Zobel and Singh, 1997). In small patches between 2100-2400 m, *Q. floribunda* may show clear-cut dominance but with further increase in elevation, *Q. floribunda* is replaced by *Q. semecarpifolia*, which may show more than 70-80% domi-

nance in oak forests located above 2700 m a.s.l. (Ralhan *et al.*, 1982).

Oak species assume considerable conservation significance in the Himalayan region as they are providers of numerous ecosystem services and serve as lifeline for the local communities (Saxena and Singh, 1982; Singh and Singh, 1986, 1987; Upreti *et al.*, 1985). The oaks, particularly *Q. leucotrichophora*, *Q. floribunda* and *Q. semecarpifolia* are intricately associated not only with agro-ecosystems but also with the life support systems of the inhabitants of the hills in the Himalaya. The oak forests are source of fuelwood, timber and can be correlated with natural springs and wildlife (Singh, 1981). Himalaya is the home of many unique and diverse human groups, living in river valleys and mountain slopes between 1000-2200 m elevations and subsisting on the Himalayan natural resources for thousands of years. In the recent few decades, with better access to global market and demand for socio-economic development, local people's dependence on natural resources has increased immensely. Therefore, high richness and distribution of associated species is more important for the long term sustainability of these valuable oak species.

Ecological studies covering community structure and phytosociology of the oak forests are largely confined to Kumaun Himalaya (Ralhan *et al.*, 1982; Singh and Singh, 1987, 1992). These authors have found that throughout the elevational gradient, evergreen *Quercus* spp. are the dominant tree species sharing dominance with evergreen and deciduous species *viz.*, *Alnus nepalensis*, *Carpinus viminea*, *Lyonia ovalifolia*. Through aerial photo-analysis Tiwari and Singh (1984) described four different oak forests in the Kumaun region, where *Q. leucotrichophora* occupied maximum area, while *Q. floribunda* occupied the minimum. Total basal area for the central and western Himalayan oak forests were reported to range between 29.8 to 83.8 m<sup>2</sup>/ha (Saxena and Singh, 1982; Singh and Singh, 1986, 1987; Tewari and Singh, 1984). In the forests where oaks were prevalent the total basal cover ranged between 29.3 to 39.2 m<sup>2</sup>/ha (Rawat and Singh, 1988; Upreti *et al.*, 1985). These authors also reported that in natural banj oak forests the species richness is low, where generally one or two species predominate. Several studies on diversity, population structure, regeneration status and causes of degradation of the central Himalayan oak forests concluded that excessive dependency and exploitation is the major concern for rapid degradation (Chandra *et al.*, 1989; Gupta and Singh, 1962; Rikhari *et al.*, 1989; Saxena and Srivastava 1973; Singh and Singh 1987). The literature review reveals that a few studies are available in complete quantification of tree species diversity and status in various oak forests from the Garhwal Himalaya. The present study describes: 1) tree species diversity in various oak forests, 2) population status of oaks and its associated species in these oak dominated forests within an elevational range of 1400-3300 m in Garhwal, Himalaya.

## Materials and methods

### Study area

The study was conducted in the outer fringes of Kedarnath Wildlife Sanctuary (KWS) in Chamoli and Rudraprayag districts, Garhwal Himalaya. Historically, the area has been a famous place of pilgrimage for Indian devotees for many centuries. A motorable road connects this area to the nearby national highway and other religious places (Kedarnath, Badrinath, Gangotri and Yamunotri). The area is characterized by undulating topography, wide variation in altitude, rainfall, temperature and soil conditions. The area is an important wintering range of several high altitude animals and is used by a large number of local agro-pastoral and migratory community (gujjars) besides tourists and pilgrims during summer. The intensive study area (~975 km<sup>2</sup>) covers a wide elevational range from 1400-3680 m above sea level with a varying mean annual temperature range (-4 to 34°C). The local inhabitants are settled in scattered villages along lower fringes (<2200 m) and are basically agro-pastoralists. Livestock production and tourism are the main landuse practices across different

elevational zones in the region. The area was selected as it has a wide elevational range, different habitat and vegetation types mainly dominated by the oaks, varied aspect and slope categories. According to Champion and Seth (1968) broad vegetation classes in the study area are Temperate Oak Forest, Maple Forest, Sub- Alpine Oak Forest, Fir Forest, Birch- Buransh Forest, Alpine scrub, and Alpine meadows.

### Methods

The field surveys were carried out to study the tree species across various oak forests in the outer fringes of Kedarnath WS during 2006 to 2010. Based on six months of extensive reconnaissance survey and dominance of oak species, three types of forests *viz.*, *Q. leucotrichophora* (1400-2200 m), *Q. floribunda* (2201-2700 m) and *Q. semecarpifolia* (2701-3300 m) were taken up for the vegetation analysis (Fig. 1). Vegetation sampling procedures were determined following Mishra (1968) and Kershaw (1973). Avoiding main motorable road, permanent foot paths and fodder collection trails, various forested and other habitats in each oak forests were identified and marked. Transects were laid within these forests covering various altitude, aspects and slope categories. 10 sample plots were taken in each transect, at an interval of 200 m depending upon the accessibility. Overall, 287 circular plots were laid in three oak forests. Although maximum efforts were made to include all the representative areas of oak forests but some of the inaccessible areas were difficult to cover due to steep slopes (>60°). Within each plot, circumference at breast height (CBH) of each tree, height, species name and number were recorded. A nested plot of a 5 m radius (78.5 m<sup>2</sup> area) was laid within the larger plot to record regenerating individuals (seedlings and saplings). Identification of plants was made with the help of florulas, research papers and reports (*e.g.*, Naithani, 1984; Polunin and Stainton, 1984; Osmaston, 1927). Unidentified plants were collected and preserved following Jain and Rao (1976) and brought to Wildlife Institute of India (WII) Dehra Dun for further examination and identification. Herbarium of WII, Botanical Survey of India, Northern circle Dehra Dun (BSI) and Forest Research Institute Dehra Dun (DD) were consulted to cross-check the identity of various species. A set of duplicate specimens were collected for

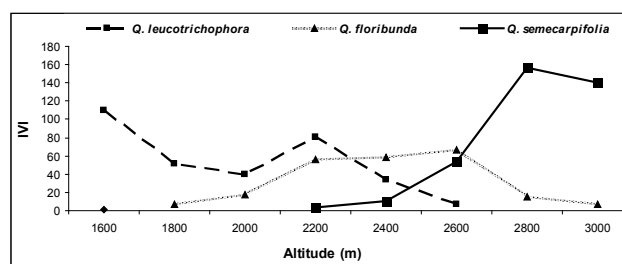


Fig. 1. Dominance (IVI) of oak species at different altitude in Kedarnath WLS, Garhwal Himalaya

Tab. 1. Number of tree species and their density (individuals/ha) of important families in various oak forests

Families	<i>Q. leucotrichophora</i> forest		<i>Q. floribunda</i> forest		<i>Q. semecarpifolia</i> forest	
	No. of Species	Density (ind./ha)	No. of Species	Density (ind./ha)	No. of Species	Density (ind./ha)
Aceraceae	2	1.38	4	18.05	2	0.85
Anacardiaceae	3	3.46	1	0.27	-	-
Aquifoliaceae	1	3.46	1	19.11	1	2.97
Betulaceae	4	43.27	3	15.13	1	0.42
Buxaceae	-	-	1	1.33	-	-
Celastraceae	-	-	1	2.12	-	-
Cornaceae	2	1.04	-	-	-	-
Ericaceae	2	118.73	1	164.81	3	136.73
Euphorbiaceae	3	32.19	-	-	-	-
Fagaceae	3	88.27	3	117.30	2	146.92
Hippocastanaceae	-	-	1	4.25	-	-
Lauraceae	6	67.16	8	40.07	2	2.55
Meliaceae	2	1.04	1	0.27	-	-
Moraceae	3	0.69	-	-	-	-
Myricaceae	1	11.42	-	-	-	-
Oleaceae	-	-	2	0.80	-	-
Pinaceae	1	1.38	2	10.88	2	32.27
Rhamnaceae	1	0.35	-	-	1	0.42
Rosaceae	4	15.23	2	6.63	2	6.79
Sabiaceae	2	5.88	1	0.53	-	-
Simaroubaceae	-	-	1	-	-	-
Symplocaceae	2	16.27	3	19.37	1	1.27
Taxaceae	-	-	1	1.06	1	2.12
Others	12	22.48	5	11.18	5	4.66
Total	54	433.72	43	433.15	23	337.99

less known and unidentifiable species preserved at WII's herbarium.

#### Data analysis

The field data was quantitatively analysed for frequency, density and basal area following the standard ecological methods (Muller-Dombois and Ellenberg, 1974). The Importance Value Index (IVI) for tree species was deter-

mined as the sum of relative frequency, relative density, and relative basal area (Mishra, 1968). Species richness, the number of species per unit area (Whittaker, 1972), Shannon-Wiener Index of diversity ( $H'$ ) (Shannon and Weaver, 1972) and the mostly used Pielou's Evenness Index (Pielou, 1966) for the Himalayan region were also calculated. One way ANOVA was performed to test whether the densities of trees and regenerating individuals in the different oak forests are significantly different.

#### Results

##### Species richness, diversity and distribution

A wide range of tree species was recorded in the systematically surveyed three oak forests along the altitudinal gradient. A total of 54 tree species belonging to 40 genera and 26 families were recorded in *Q. leucotrichophora* dominated forests, while only 32 species (59%) were recorded during the sampling (Fig. 2). Lauraceae with 6 species was the dominant family followed by Betulaceae and Rosaceae (4 species each). In *Q. floribunda* dominated

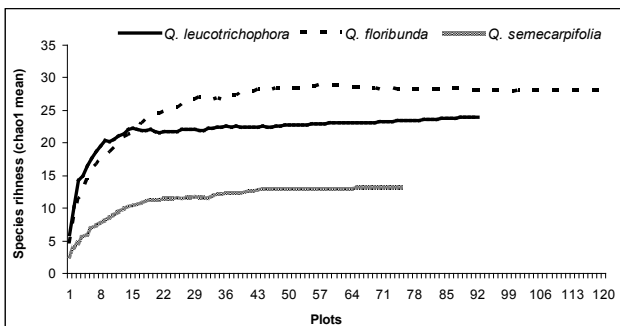


Fig. 2. Rarefaction graph of species richness across various oak forests

Tab. 2. Summary of plant diversity and forest characteristics of tree species across various oak forests

Parameters	<i>Q. leucotrichophora</i> forest	<i>Q. floribunda</i> forest	<i>Q. semecarpifolia</i> forest
Number of families	26	20	12
Number of genera	40	30	16
Species richness	54	43	23
Tree Density (ind./ha)	415	422	333
Total Basal Area (m <sup>2</sup> /ha)	88.06	110.5	123.8
Tree Seedling Density (ind./ha)	1981	1475	348
Tree Sapling Density (ind./ha)	513	338	253
Diversity indices (Tree):			
Shannon diversity index	2.66	2.53	1.41
Pielou's evenness index	0.67	0.67	0.45

forests, 43 tree species (30 genera and 20 families) were found in systematic survey, while 34 species (79%) were recorded during the sampling in the region. Lauraceae (8 species) was the dominating family in *Q. floribunda* forests followed by Aceraceae (4 species), Betulaceae, Fagaceae and Symplocaceae (3 species each). In *Q. semecarpifolia* dominating forests a total of 23 tree species belonging to 16 genera and 12 families were recorded, where 17 species (74%) were recorded during the sampling. Ericaceae (3 species) was the dominating family followed by Aceraceae, Rosaceae and Pinaceae (2 species each). Pinaceae and Taxaceae were only two gymnospermic family represented by *Pinus roxburghii* in *Q. leucotrichophora*, *Abies pindrow* in *Q. floribunda*, *A. spectabilis* and *Taxus wallichiana* in *Q. semecarpifolia* dominated forests (Tab. 1). Shannon-Wiener's Diversity Index varied from a minimum of 1.41 in *Q. semecarpifolia* forests at 2700-3300 m altitude to a maximum of 2.66 in *Q. leucotrichophora* dominated forests at 1400-2200 m elevation, similarly Pielou's Evenness Index varied from a minimum of 0.45 in *Q. semecarpifolia* forests to 0.67 in *Q. floribunda* and *Q. leucotrichophora* forests (Tab. 2).

#### Density

The overall tree density across various oak forests was estimated; where maximum tree density was recorded in *Q. leucotrichophora* and *Q. floribunda* dominated forests (433 individuals/ha each) followed by *Q. semecarpifolia* (335 individuals/ha) forests. In *Q. leucotrichophora* dominated forests, *Q. leucotrichophora* (65 individuals/ha), *Rhododendron arboreum* (60 individuals/ha) and *Lyonia ovalifolia* (57 individuals/ha) had the highest density and together accounted 43% of the total forest density. In *Q. floribunda* dominated forests *R. arboreum* (101 individuals/ha), *L. ovalifolia* (61 individuals/ha), *Q. floribunda* (50 individuals/ha), and *Q. semecarpifolia* (43 individuals/ha) accounted for 60% of the forest density, while in *Q. semecarpifolia* dominated forests only *Q. semecarpifolia* (142 individuals/ha) and *R. arboreum* (129 individuals/ha) accounted 80% of the total forest density (Tab. 3).

#### Regeneration and population structure

Overall density of regenerating individuals decreases with increasing elevation, where maximum seedlings (1981 individuals/ha) and saplings (513 individuals/ha) were recorded in *Q. leucotrichophora* forests followed by *Q. floribunda* (1475 individuals/ha seedlings, 338 individuals/ha saplings) and *Q. semecarpifolia* (348 individuals/ha seedlings, 253 individuals/ha saplings) forests. In *Q. leucotrichophora* forests *Neolitsea cuipala* (362 individuals/ha) and *Q. leucotrichophora* (322 individuals/ha) had highest seedling density and together accounted for 34% of the forest seedling density, whereas in *Q. floribunda* forests highest seedling density shown by *Symplocos ramosissima* (341 individuals/ha) and *Neolitsea pallens* (278 individuals/ha) accounted for 41% of the forests. At higher altitude, *Q. semecarpifolia* (232 individuals/ha) accounted for highest (66%) seedling density to its own forests (Tab. 4). The different girth class trees of various oak forests showed

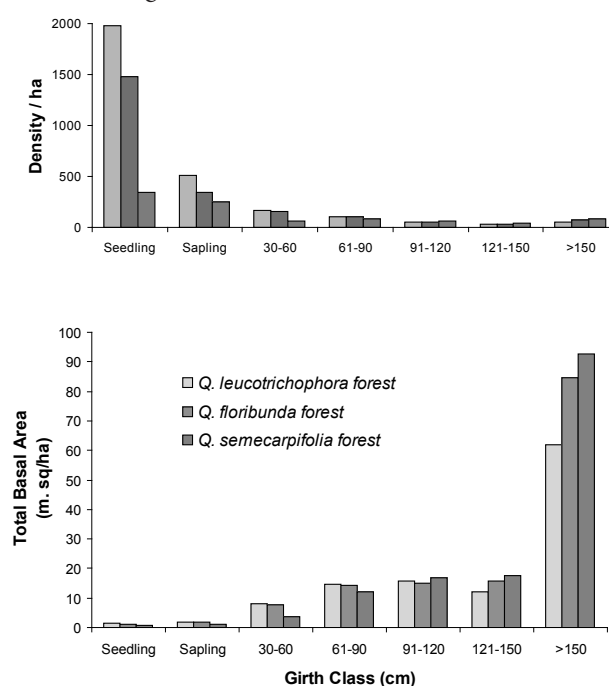


Fig. 3. Distribution of species density and total basal area in different girth classes in various oak forests

Tab. 3. Density and Total Basal Area (TBA) with average height (Av. ht) of dominant tree species across various oak forests

Species	<i>Q. leucotrichophora</i> forest		<i>Q. floribunda</i> forest		<i>Q. semecarpifolia</i> forest	
	Mean D/ha $\pm$ SE	TBA (m)	Mean D/ha $\pm$ SE	TBA (m)	Mean D/ha $\pm$ SE	TBA (m)
<i>Abies pindrow</i>	-	-	10.88 $\pm$ 2.91	12.51	17.83 $\pm$ 4.64	6.42
<i>Abies spectabilis</i>	-	-	-	-	14.44 $\pm$ 4.49	7.69
<i>Acer pictum</i>	-	-	13.54 $\pm$ 5.12	3.83	0.85 $\pm$ 0.67	1.11
<i>Acer sterculiaceum</i>	1.38 $\pm$ 1.38	0.91	3.72 $\pm$ 1.87	0.61	-	-
<i>Aesculus indica</i>	0.69 $\pm$ 0.69	0.68	4.25 $\pm$ 1.41	4.46	-	-
<i>Alnus nepalensis</i>	24.92 $\pm$ 5.11	13.19	3.18 $\pm$ 2.01	3.77	-	-
<i>Betula alnoides</i>	4.15 $\pm$ 1.41	3.00	2.92 $\pm$ 1.13	0.45	-	-
<i>Betula utilis</i>	-	-	-	-	0.42 $\pm$ 0.34	0.06
<i>Carpinus viminea</i>	14.19 $\pm$ 3.09	3.41	9.02 $\pm$ 3.38	1.37	-	-
<i>Dodecadenia grandiflora</i>	4.50 $\pm$ 2.06	-	5.31 $\pm$ 1.9	0.75	2.55 $\pm$ 1.15	0.18
<i>Eurya acuminata</i>	5.88 $\pm$ 2.41	0.53	18.31 $\pm$ 4.24	1.28	-	-
<i>Ilex dipyrrena</i>	3.46 $\pm$ 1.15	0.45	19.11 $\pm$ 3.34	2.41	2.97 $\pm$ 0.98	0.42
<i>Litsaea lamuginosa</i>	48.12 $\pm$ 8.56	3.77	15.39 $\pm$ 4.86	1.17	-	-
<i>Lyonia ovalifolia</i>	58.16 $\pm$ 9.22	13.18	63.69 $\pm$ 9.95	9.42	4.67 $\pm$ 2.17	0.49
<i>Meliosma pungens</i>	5.88 $\pm$ 2.2	0.60	0.53 $\pm$ 0.53	0.01	-	-
<i>Neolitsea cuipala</i>	10.38 $\pm$ 2.5	1.68	6.90 $\pm$ 1.90	0.74	-	-
<i>Neolitsea pallens</i>	1.04 $\pm$ 1.04	0.02	1.33 $\pm$ 0.84	0.04	-	-
<i>Prunus cornuta</i>	-	-	3.18 $\pm$ 1.62	0.59	1.27 $\pm$ 0.75	0.14
<i>Pyrus pashia</i>	14.89 $\pm$ 3.13	1.68	2.65 $\pm$ 1.04	0.59	-	-
<i>Quercus floribunda</i>	11.42 $\pm$ 3.74	6.78	50.69 $\pm$ 7.29	23.73	4.67 $\pm$ 2.38	1.11
<i>Q. lauca</i>	9.69 $\pm$ 3.61	3.59	-	-	-	-
<i>Q. leucotrichophora</i>	66.81 $\pm$ 10.95	15.76	19.90 $\pm$ 5.28	5.83	-	-
<i>Q. semecarpifolia</i>	-	-	43.79 $\pm$ 6.78	16.82	142.25 $\pm$ 12.36	51.21
<i>Rhododendron arboreum</i>	60.58 $\pm$ 12.28	10.47	101.11 $\pm$ 12.23	16.89	132.06 $\pm$ 13.97	18.53
<i>Sorbus cuspidata</i>	-	-	0.80 $\pm$ 0.46	0.06	3.40 $\pm$ 1.76	1.44
<i>Symplocos chinensis</i>	3.46 $\pm$ 2	0.25	5.57 $\pm$ 1.58	0.36	-	-
<i>Symplocos racemosa</i>	9 $\pm$ 3.1	0.43	13.80 $\pm$ 4.46	0.82	-	-
<i>Taxus baccata</i>	-	-	1.06 $\pm$ 0.52	1.14	2.12 $\pm$ 0.87	1.09
Other	75.12 $\pm$ 13.5	7.68	12.48 $\pm$ 5.46	0.83	8.49 $\pm$ 4.5	0.27
*Total	433.72 $\pm$ 93.13	88.06	433.15 $\pm$ 92.11	110.47	337.99 $\pm$ 51.03	90.16

$p > 0.05$  (not significant) (one way ANOVA)

that, 41% of the total stem in *Q. leucotrichophora* and 37% of stem in *Q. floribunda* dominated forests were between 30-60 cm girth class, whereas, in *Q. semecarpifolia* forest only 19% of the total stem were in 30-60 cm girth class.

The density-diameter distribution yielded reverse J-shaped curves in all three forest types. Despite the density of seedlings, saplings and lower girth class trees being very high, their total basal area was much less than the basal area of the matured and old growth trees, thereby resulting in J-shaped distribution of basal area (Fig. 3).

## Discussion

At elevations ranging from 1000 m to the timber line (approx. 3500 m) in the Garhwal Himalaya, one or the other species of oak (*Quercus* spp.) forms the climax vegetation (Champion and Seth, 1968; Troup, 1921). The natural oak forests of the Garhwal Himalaya are multilayered temperate evergreen forests, composed of large and

small trees distributed in two distinct strata. The canopy and under-canopy tree layers were composed of large (>15 m height) and small (<15 m height) trees. The high species richness and density of the under-canopy tree layer is attributed to the presence of overhead canopy. These are either young or whose growth was arrested due to heavy shade by the overhead canopy in the lower altitudinal region. A total of 54 tree species in *Q. leucotrichophora*, 43 tree species in *Q. floribunda* and 23 tree species in *Q. semecarpifolia* dominated forests were recorded. The presence of higher number of tree species in *Q. leucotrichophora* and *Q. floribunda* dominated forests indicates the importance of wide range of distribution of many woody species and availability of high mesic condition. Whereas, *Q. semecarpifolia* dominated forests were inhabited in a wide range of distribution but in less favourable microclimatic condition. It is well-known that in the sub-alpine (2700-3300 m) zone microclimate has a greater role in the distribution of the species than the climate of the region (Ludwig and

Tab. 4. Density of regenerating individuals (individuals/ha) of dominant tree species across various oak forests

Species	<i>Q. leucotrichophora</i> forest		<i>Q. floribunda</i> forest		<i>Q. semecarpifolia</i> forest	
	Seedlings (ind./ha)	Saplings (ind./ha)	Seedlings (ind./ha)	Saplings (ind./ha)	Seedlings (ind./ha)	Saplings (ind./ha)
<i>Abies spectabilis</i>	-	-	-	-	1.70	3.40
<i>Acer pictum</i>	-	-	69.00	9.55	1.70	-
<i>Aesculus indica</i>	36.00	-	9.55	-	-	-
<i>Daphniphyllum himalayense</i>	34.62	24.92	-	-	-	-
<i>Dodecadenia grandiflora</i>	38.77	16.62	-	-	-	-
<i>Eurya acuminata</i>	60.92	5.54	38.22	13.80	-	-
<i>Ilex dipyrrena</i>	23.54	2.77	154.99	23.35	28.87	28.87
<i>Lyonia ovalifolia</i>	12.46	30.46	16.99	7.43	-	3.40
<i>Meliosma pungens</i>	27.69	12.46	-	-	-	-
<i>Myrica esculenta</i>	42.92	8.31	-	-	-	-
<i>Neolitsea cuipala</i>	362.78	77.54	92.36	22.29	-	1.70
<i>Neolitsea pallens</i>	256.16	16.62	278.13	98.73	-	-
<i>Persea odoratissima</i>	55.39	2.77	-	-	-	-
<i>Pyrus pashia</i>	67.85	27.69	9.55	4.25	-	-
<i>Quercus floribunda</i>	78.93	2.77	205.94	12.74	-	-
<i>Quercus glauca</i>	132.93	4.15	-	-	-	-
<i>Quercus leucotrichophora</i>	322.63	70.62	23.35	13.80	-	-
<i>Quercus semecarpifolia</i>	-	-	77.49	81.74	232.70	52.65
<i>Rhododendron arboreum</i>	74.77	27.69	49.89	18.05	81.53	139.28
<i>Symplocos ramosissima</i>	261.70	112.16	341.83	21.23	-	-
Others	91.39	70.62	108.28	11.68	1.70	23.78
*Total	1981.45	513.71	1475.58	338.64	348.20	253.08

\* $p < 0.05$  for seedlings and  $p > 0.05$  for saplings (One way ANOVA)

Reynolds, 1988). Similar observations have been also reported from other temperate forests of the Western Himalaya (Singh and Singh, 1992; Zobel and Singh, 1997) and mountain humid forests of Meghalaya, northeast India (Jamir *et al.*, 2006; Mishra *et al.*, 2005).

Species diversity is one of the most important measures of community structure and it has been related to succession, stability and primary productivity. The diversity of trees is fundamental to forest diversity because they provide resources and habitats for almost all other species (Huston, 1994). Tree species diversity along the altitudinal gradient in various oak forests varied from a minimum of 1.41 in *Q. semecarpifolia* forests at 2700-3300 m altitude to a maximum of 2.66 in *Q. leucotrichophora* dominated forests. The lower species diversity in *Q. semecarpifolia* forests indicates heterogeneous distribution of the species. The dominance of *Q. semecarpifolia* indicates a suitable habitat for only this species and other species have existed only in very small patches, while in *Q. leucotrichophora* dominated forests undulating gentler terrain supports a greater number of species to distribute evenly and also increases species diversity. The lower diversity in *Q. semecarpifolia* forested region could be due to lower rate of evolution and diversification of communities (Simpson, 1965) and severity in the environment (Connell and Orias, 1964). The species richness and diversity index values in the Kedarnath WS fall within the range of values (tree species richness

9-28 and species diversity 0.8-3.4) recorded by Ralhan *et al.* (1982), Saxena and Singh (1982), Tewari (1982) and Upreti *et al.* (1985) for temperate forests of the Himalaya and are less than those (species diversity 3.5-5.4) recorded for moist tropical forests by Mishra *et al.* (2005) and Singh *et al.* (1981).

Lauraceae and Betulaceae in *Q. leucotrichophora*, Lauraceae and Aceraceae in *Q. floribunda* dominated forests were the dominant and co-dominant tree species families, while in *Q. semecarpifolia* forests the Ericaceae was the dominant family. This corroborates the result of Uniyal (2001) in Bhagirathi catchment, Uttarakhand, Singh (1999) in GHNP, Himachal Pradesh and Upadhaya *et al.* (2003) in Jainta hills in Meghalaya, who also recorded these families as dominant and co-dominant in the region.

*Q. leucotrichophora* and *Q. floribunda* dominated forests between 1400-2700 m altitude exhibit the maximum tree density (433 individuals/ha). *Q. leucotrichophora* was greatest at the hill base and lowest on the hill top. Whereas, *Q. floribunda* does not form mono stand and mixed with member of Lauraceae and Symplocaceae families. The lowest density (337 individuals/ha) of tree species was recorded in the *Q. semecarpifolia* forests at high altitude (>2700 m) region. *Q. semecarpifolia* (132 individuals/ha) with associations of *Rhododendron arboreum* (132 individuals/ha) dominating the forests. There was no signifi-

Tab. 5. Data on tree density and total basal area (TBA) of oak forest in the Uttarakhand Himalaya

Locality	Density/ha	TBA (m <sup>2</sup> /ha)	Author and year
<i>Q. leucotrichophora</i> forests			
Maheshkhan (Nainital)	940	39.4	Saxena and Singh 1982
Chambhi (Nainital)	416	32.71	Ralhen <i>et al.</i> 1982
Kunjakharak (Nainital)	830	30.69	Rikhari <i>et al.</i> 1991
Siahidevi (Almora)	1260	31.7	Rana <i>et al.</i> 1985
Shitalakhet (Almora)	880	56.37	Pandey 2003
Mandal (Chamoli)	340	25	Ghildiyal <i>et al.</i> 1998
Pauri (Pauri Garhwal)	730	43.96	Srivastava <i>et al.</i> 2005
Pauri (Pauri Garhwal)	390	17.27	Dhanai <i>et al.</i> 2000
Buvakhal (Pauri Garhwal)	790	35.39	Kusumlata and Bisht 1991
Mussoorie (Dehradun)	640	-	Joshi <i>et al.</i> 1985
Dhanolti (Dehradun)	140	13.55	Singhal and Soni 1989
Mandal-Tungnath (Chamoli)	433	88.06	Present study
<i>Q. floribunda</i> forests			
Maheshkhan (Bhawali)	1300	83.77	Saxena and Singh 1982
Garhwal Himalaya (Pauri)	220-640	23.53-43.24	Sharma <i>et al.</i> 2001
Dudhatoli region (Dehradun)	250-340	18.45-38.25	Baduni and Sharma 1996
Kumaun region	320-1960	37-95	Singh <i>et al.</i> 1994
Dhakuri (Pindari)	1060	98.49	Kalakoti <i>et al.</i> 1986
Mandal-Tungnath (Chamoli)	433	110.47	Present study
<i>Q. semecarpifolia</i> forests			
Chakrata (Dehradun)	320	29.19	Singhal <i>et al.</i> 1986
Binsar Mahadev (Pauri)	310-520	31.50-57.33	Baduni and Sharma 1996
Kumaun region	250-2070	5-114	Singh <i>et al.</i> 1994
Pindari (Bageshwar)	480	73.4	Adhikari <i>et al.</i> 1995
Askot WS (Pithoragarh)	550	50.8	Dhar <i>et al.</i> 1997
Kedarnath WS (Chamoli)	340-810	30.1-62.2	Rai <i>et al.</i> 2012
Mandal-Tungnath (Chamoli)	337	90.16	Present study

cant variation (one way ANOVA,  $p=0.8$ ) between overall tree density in different oak forests. The total basal area of *Q. leucotrichophora* (88.06 m<sup>2</sup>/ha), *Q. floribunda* (110.47 m<sup>2</sup>/ha) and *Q. semecarpifolia* (90.12 m<sup>2</sup>/ha) dominated forests with low tree density of 433.72, 433.15 and 337.99 individuals/ha respectively, showed that there were high density of higher girth class trees in the region. The total basal area reported in all the three oak dominated forests were slightly higher than those of earlier values (35.0 to 83.8 m<sup>2</sup>/ha) reported by various authors (Tab. 5) for the Himalayan forests.

The density-distribution curve of the tree species showed that there are higher numbers of seedlings in *Q. leucotrichophora* and *Q. floribunda* forests than in the *Q. semecarpifolia* forests, which is comparable to the other studies of the Himalayan region (Thadani and Ashton, 1995). Low number of seedlings (348 individuals/ha) and saplings (253 individuals/ha) in *Q. semecarpifolia* forests could be due to excessive grazing by local as well as migratory livestock in the region (Singh, 2008; Singh *et al.*, 2010). The seedlings density has significant variation ( $p=0.01$ ) in different oak forests. Highest seedling density was recorded in *Q. leucotrichophora* forest (1981 individuals/ha) and lowest in *Q. semecarpifolia* forests (348 indi-

viduals/ha). Sapling density did not show any significant variation ( $p>0.05$ ) across various oak forests in the region with highest density recorded in *Q. leucotrichophora* forests (1981 individuals/ha) and lowest in *Q. semecarpifolia* forests (348 individuals/ha).

Based on this distribution curve one can predict the species showing expanding or stable type of population structure, since they have a sufficient number of individuals in younger classes to replace those in older classes. Comparison of total basal area and girth classes distribution showed that, high basal area cover was recorded in the higher girth class trees of all the three oak dominated forests.

## Conclusions

Among all the oak forests of the region, *Q. leucotrichophora* dominating forests are slightly richer in terms of tree species richness and diversity than *Q. floribunda* and *Q. semecarpifolia* forests. The distribution of tree species (54 tree spp. in *Q. leucotrichophora*, 43 tree spp. in *Q. floribunda* and 23 tree spp. in *Q. semecarpifolia* dominated forests) in these forests stands was governed mainly by the gradient of altitude. Member of Lauraceae family were the

most dominant tree species in the *Q. leucotrichophora* and *Q. floribunda* forests. The regenerating individuals and higher girth class trees were high in these forests because of mesic condition. Although the entire forested area seems protected and natural, the low seedling/sapling density in *Q. semecarpifolia* forests is a matter of concern and needs some protection from grazing in the early stage of plant growth.

#### Acknowledgements

We are thankful to UCOST, Govt. of Uttarakhand and Department of Science and Technology, Govt. of India for funding (No. SR/FT/LS-054/2009).

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