Tropical Ecology **57**(2): 255-262, 2016 ISSN 0564-3295

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Spatial extent and conservation status of Banj oak (*Quercus leucotrichophora* A. Camus) forests in Uttarakhand, Western Himalaya

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Abstract: We assessed the conservation status of *Quercus leucotrichophora* (banj oak) forests and identified priority areas for its conservation in Uttarakhand state, India. The methods include mapping by using satellite remote sensing, and phytosociological analysis of dense, open and degraded banj oak forests in different elevational zones in the state. Mapping of banj oak forests was done using IRS P6 AWiFS satellite data in conjunction with altitude information and field knowledge. Canopy density information was generated based on Normalised Vegetation Difference Index (NDVI). Structure, composition and species diversity were quantified within 510 stratified random sample plots distributed in various elevation gradients. The study revealed that banj oak forests constitute 5.24 % (1284 km^2) of total forest cover in the state (45.80 %). Of this, 775 km^2 area falls within reserve forests while 509 km^2 falls in village and private forests. Middle elevation range (1800 - 2200 m asl) represented maximum area (951.7 km^2) under banj oak. Area under dense, open and degraded banj oak forests was estimated at 560.3, 510.62 and 213.68 km^2, respectively. The greatest banj oak tree density was found in dense forests (479 ± 22.35 individual ha^{-1}) between 1500 - 1800 m asl and lowest in degraded banj oak forests (46 ± 19.86 individual ha^{-1}) above 2200 m asl. Mean sapling (585 ± 51 individual ha^{-1}) and seedling (368 ± 37 individual ha^{-1}) density across various forests showed that regeneration is adequate with respect to the mean tree density (337±13.6 individual ha^{-1}) in western Himalaya. Most of the intact banj oak forests in the state occurred between 1800 - 2200 m elevations.

Key words: Banj oak, conservation, Himalaya, remote sensing, Uttarakhand.

Handling Editor: N. Parthasarathy

Introduction

Western Himalaya is endowed with diverse vegetation types, ranging from tropical moist deciduous to temperate and sub-alpine forests, grasslands, alpine scrub and meadows (Champion & Seth 1968). Of these, the temperate broadleaved forests constitute an important natural resource base which is largely dominated by one or the other species of oak (*Quercus* spp.). Oak forest represents climax vegetation between 1000 - 3500 m asl in the region and plays a vital role in conservation of soil, water, native flora and fauna, thereby, providing numerous ecosystem services to

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mankind (Singh & Singh 1992; Upreti *et al.* 1985). Five species of evergreen oaks namely, *Quercus glauca* Thunb. (harinj), *Q. leucotrichophora* A. Camus (banj), *Q. floribunda* Rehder (moru), *Q. lanata* J. E. Sm. (rianj) and *Q. semecarpifolia* Smith (kharsu) grow naturally in the western Himalaya (Troup 1921) and successively replace each other along the increasing elevation in stated order. Among these oak species, banj oak forms most extensive forests between 1000 - 2500 m elevations. Earlier studies (Rana *et al.* 1989; Singh & Rawat 2012; Singh & Singh 1986; Zobel & Singh 1997) have reported the occurrence of banj oak between 1000 - 2500 m elevations, with high abundance around 2000 m elevation. It may be associated with *Q. floribunda* between 2000 to 2500 m elevations, beyond which it disappears.

The agropastoral communities in the Himalayan region, since ages, have inhabited the zone of banj oak forests. The clearing of banj oak forests especially on the south-facing gentle slopes are suitable for agriculture and habitation. The remaining banj oak patches continue to face chronic stress from livestock grazing, lopping, extraction of fuelwood and other biotic pressures. The poor regeneration in banj oak forests is attributed to reduction in acorn production due to heavy lopping and proliferation of alien invasive species (Singh & Singh 1992; Thandani & Ashton 1995). Selective removal of oaks through cutting and burning and changes in soil properties in many parts of western Himalaya have led to invasion of chir pine (*Pinus roxburghii* Sargent) (Saxena & Singh 1982; Singh *et al.* 1984; Tewari 1982).

Mapping the extent and spatial distribution of keystone species and major forest formations is essential for further conservation planning. Satellite remote sensing technology has been proven as effective tool for assessment and monitoring the extent, distribution and status of forests from local to global scale (Kushwaha 1990; Lillesand & Kiefer 2000; Rathore *et al.* 1997). It is a tool for monitoring vegetation status, specially in forests, because the hilly or swampy terrain is inaccessible (Chellamani *et al.* 2014). Previous attempts on mapping of vegetation types in the Himalayan region have yielded limited information on the status of banj oak forests (Pant & Kharkwal 1995; Pant & Singh 1992; Tiwari & Singh 1984; Tiwari & Singh 1987). So far, there has not been any quantitative study on the spatial distribution and phytosociology of banj oak forests at a landscape level covering different elevation zones, management regimes (reserve, village and private forests) and disturbance levels (dense, open and degraded forests). Strategies for species management programmes vary with the species in consideration, their total population size, number of subpopulations, number of viable populations, etc. (Ramachandran *et al.* 2014). This study fills the information gap mentioned above and utilizes satellite remote sensing data, topographical information and extensive ground truth data to generate precise information on the banj oak dominated forests in the state of Uttarakhand, India. This paper deals with the current distribution of banj oak forests, population and regeneration status to suggest priority areas for conservation.

Material and methods

Study area

The study was conducted in the state of Uttarakhand (India) that forms part of western Himalaya. The state lies between latitude 28° 43' and 31° 28' N and longitude 77° 34' and 81° 03' E occupying an area of 53,483 km^2. Physiographically, the state is divisible into three broad zones, *viz.,* the Terai, the Shivalik and the Greater Himalaya, representing tropical, sub-tropical and temperate-alpine climate respectively. The recorded forest area in the state is 34,651 km^2 that constitutes 64.79 % of its geographical area. Total forest cover is 24,495 km^2, which is 45.80 % of the state's geographical area (Anonymous 2009). About 7,645.96 km^2 (14.29 % of state geographic area) is under six national parks, seven wildlife sanctuaries and three conservation reserves (Anonymous 2012).

Satellite data

Cloud-free geocoded IRS P6 AWiFS (Advance Wide Field Sensor) satellite data of 2nd May 2009 was used for geospatial analysis. AWiFS has 56 m pixel size at nadir and four spectral bands in green, red, near infrared and shortwave infrared region. The large swath of AWiFS (700 km) covered the entire study area in single scene and hence evaded scene to scene spectral variability that arises while mosaicing multiple smaller scenes. The occurrence of profuse leafing and flowering in banj oak forests during summer offered high spectral contrast.

Pre-processing of satellite data

Dark pixel subtraction (DPS) technique was used to reduce the effect of haze on the satellite data. DPS is a haze correction method in which the reflectance over dark areas in the satellite image (e.g., water body) is considered as effect of haze. Subtraction of the reflectance value picked from water bodies from all the bands in the image enhances the image quality. The satellite data was in UTM projection and WGS 84 datum.

Classification of forests in the zone of banj oak

Using maximum likelihood classification technique, seven vegetation classes were identified and mapped in the zone of banj oak (1000 - 2500 m asl), viz., banj oak, broadleaved mixed, secondary scrub, Deodar/*Cupressus*, deciduous/scrub, chir pine and hillside grasslands. Information from satellite data alone was insufficient for precise delineation of banj oak. Hence, elevation information derived from ASTER satellite based digital elevation model was utilized to refine classification. A rule based classification was devised based on Boolean logic to integrate elevation information in classified image using ERDAS Imagine image processing software. For example, elevational zone between 1000 to 1500 m shows predominance of chir pine, 1500 to 1800 m asl comprises mixed patches of chir pine and banj oak, while elevation range of 1800 to 2200 m asl is dominated by banj oak. The upper limit of banj oak forests lies between 2200 to 2500 m asl. Due to moderate spatial resolution of AWiFS satellite data, the patches of banj oak less than one hectare in area could not be delineated. However, extensive field work helped in identification of many small patches of banj oak forests which were included in the final map generated for the state.

Banj oak forests were categorised into dense (above 40 %), open (between 40 % to 20 %) and degraded (less than 20 %) based threshold of normalised vegetation difference index (NDVI) calculated from AWiFS satellite data. Threshold of NDVI values was done considering the canopy density information collected in vegetation sample plots.

Field sampling

Field sampling was carried out in the entire banj oak zone (1000 to 2500 m asl) during 2009-2010. A total of 510 circular vegetation plots (< 1500 m = 62, 1500 - 1800 m = 125, 1800 - 2200 m = 255 and > 2200 m = 68) of 10 m radius were randomly laid considering the probability proportional to size of banj oak forests in different elevation zones (Fig. 1). Circular plots of 10 m radius (314 m^2 area) were preferred over 10 m × 10 m square plots to cover more area, easy to lay, less time consuming, required less man power and covered enough area to look at the micro-habitat parameters. Within each plot, girth at breast height (GBH) of each tree, height, species name and number were recorded. A nested plot of 5 m radius was laid within the larger plot to record seedlings and saplings. Although all efforts were made to include all the representative areas of banj oak forests, some of the inaccessible areas were difficult to cover due to steep slopes.

Phytosociological analysis

The field data was quantitatively analysed for frequency, density and basal area following Mueller-Dombois & Ellenberg (1974). The importance value index (IVI) for tree species was determined as the sum of relative frequency, relative density and relative basal area (Misra 1968). Shannon-Wiener Index of Diversity (H') (Shannon & Weaver 1949) was calculated across various oak forests.

Results

Based on detailed analysis, the total extent of banj oak forest in the state comes to 1284.60 km^2 (5.24 % of total forest cover of the state). About 774.93 km^2 of banj oak forest lies within reserved forest while the remaining 509.66 km^2 lies in unclassified and village forests (Table 1). Garhwal region has larger area under banj oak forests (840 km^2) compared to Kumaun region (444.7 km^2). The largest area under banj oak was in Tehri district (9.62 %), followed by Pithoragarh (7.09 %), Uttarkashi (6.65 %), Pauri (3.25 %), Nainital (3.55 %), Almora (4.23 %) and Champawat (4.5 %) districts (Fig. 2). The areas under banj oak forests in different elevation zones with their phytosociological characteristics are described below:

Banj oak forests below 1500 m: This elevation zone was largely dominated by chir pine forests, where patches of banj oak showed scattered distribution occupying a total area of 38.20 km^2. The greatest tree density was recorded in dense forests (358.28 ± 22.35 individual ha^{-1}) with maximum total basal area (13.77 m^2 ha^{-1}). In terms of regenerating individuals across various

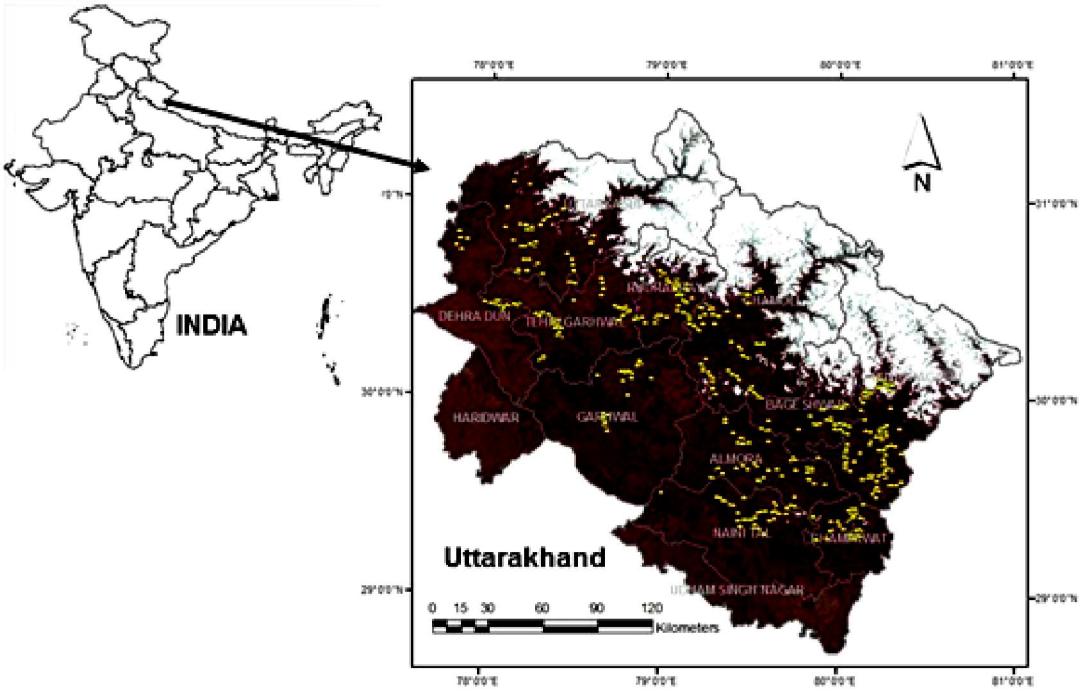

Fig. 1. Location map of study area and field sample plots superimposed on AWiFS false color composite.

Table 1. Area under banj oak forests in different districts and reserve forests in Uttarakhand.

Districts	District area (km^2)	*Forest cover in 2007	Forest cover (%)	Total Banj oak area (km^2)	Bnaj oak in RF (km^2)	Banj oak outside RF (km^2)	(%) respect to forest cover	(%) respect to geographical area
Kumaun region								
Almora	3139	1577	50.24	66.74	39.01	27.73	4.23	2.13
Bageshwar	2246	1381	61.49	66.25	32.70	33.55	4.80	2.95
Champawat	1766	1181	66.87	53.15	21.72	31.44	4.50	3.01
Nainital	4251	3093	72.76	109.93	52.78	57.16	3.55	2.59
Pithoragarh	7090	2094	29.53	148.49	56.46	92.03	7.09	2.09
Garhwal region								
Chamoli	8030	2695	33.56	138.01	101.08	36.93	5.12	1.72
Dehradun	3088	1607	52.04	104.69	38.91	65.78	6.51	3.39
Pauri	5329	3289	61.72	106.86	63.90	42.96	3.25	2.01
Rudraprayag	1984	1125	56.70	74.71	47.29	27.41	6.64	3.77
Tehri	3642	2147	58.95	206.68	164.81	41.88	9.62	5.67
Uttarkashi	8016	3145	39.23	209.08	156.29	52.79	6.65	2.61
Total	53483	24495	45.80	1284.60	774.93	509.66	5.24	2.40

(FSI) Forest Survey of India Report 2009, (RF) Reserve Forests, U. S. Nagar and Haridwar districts does not have banj oak forests.

forests, dense forests had maximum saplings (780.25 individual ha^{-1}) and seedlings (684.7 individual ha^{-1}) followed by open and degraded forests. Species richness varied between 4 (degraded) to 9 (dense) species across various forests, whereas, the IVI of banj oak was below 50 in the region.

Banj oak forests between 1500 - 1800 m: This zone was mainly represented by chir pine and banj oak mixed forests where 240.8 km^2 area was under banj oak forests. In this zone, banj oak was found mixed with pioneer seral species i.e., *Alnus nepalensis* D. Don, *Carpinus viminea* Lindl. and *Betula alnoides* Buch.-Ham. ex D. Don along river valleys and in old landslide areas. The tree density (479.03 ± 22.35 individual ha^{-1}) and total basal area (19.38 m^2 ha^{-1}) of banj oak was greatest in dense forests representing maximum tree density and basal area of the state. In the region highest saplings (758.54 individual ha^{-1}) and seedlings (403.4 individual ha^{-1}) were recorded in open and degraded forests respectively. The IVI of banj oak ranges 50 - 140 in the region.

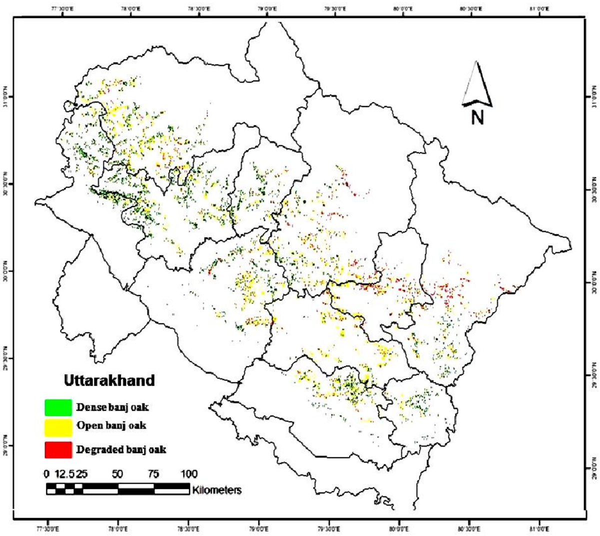

Fig. 2. Spatial distribution and canopy density of banj oak forests.

*Banj oak forests between 1800 - 2200 m***:** This elevation zone represents maximum area i.e., 951.7 km^2 under banj oak forests in the state. In the shady moist less disturbed slopes, shrub layer was formed by *Sinarundinaria falcata* (Nees) Chao & Renv. (hill bamboo), *Daphne papyracea* Wall. ex Steud., *Berberis lycium* Royle and *Myrsine africana* Linn. were common understory species, where tree density ranged between 146.12 ± 19.86 individual ha^{-1} (degraded) to 382.17 ± 19.86 individual ha^{-1} (dense). Maximum total basal area was recorded in open forests (13.51 m^2 ha^{-1}). This zone exhibited maximum regenerating individuals where maximum sapling (1118.6 individual ha^{-1}) and seedling density (517.5 individual ha^{-1}) were recorded in open forests. Maximum species richness (20) was recorded in dense forests in this zone. The IVI of oak species in this zone was above 200.

Banj oak forests above 2200 m: This elevation zone represents upper limit of banj oak forests in the western Himalaya. About 53.69 km^2 area was mapped under banj oak forests in this zone, mixed with other broadleaved species such as *Quercus floribunda* Rehder, *Neolitsea cuipala* (Buch.-Ham. ex D. Don) Kost., *Neolitsea pallens* (D. Don) Mom. & Hara, *Rhododendron arboreum* Smith, *Lyonia ovalifolia* (Wall.) Drude, *Betula alnoides* Buch.-Ham. ex D. Don, *Carpinus viminea* Lindl., *Pyrus pashia* Buch.-Ham. ex D. Don and *Symplocos* spp. etc. Dense forests had highest banj oak tree density (301.49 ± 19.86 individual ha^{-1}) with maximum total basal area (13.95 m^2 ha^{-1}) in the region. Dense forests also represent highest sapling (416 individual ha^{-1}) and seedling (348 individual ha^{-1}) density in the zone.

Discussion

In the western Himalaya, oaks generally form gregarious forest patches while they also occur in mixed formations with other broadleaved species particularly in elevational transition zones. Extant oak patches occur only on uncultivable, steep terrain for most of the ideal oak habitats have long been converted into habitation and cultivation. Hence, such areas pose big challenges while mapping based on remote sensing techniques. Use of May month AWiFS data provided best spectral contrast between banj oak and other associated vegetation types. Also, the high sun elevation during May month helped in reducing the effect of shadow in the image. Extensive ground truth knowledge along with elevation information from digital elevation model helped in classifying banj oak forests in sun shadow affected areas.

The palaeoecological evidences suggest that banj oak forests were most dominant between 1000 - 2000 m elevations in western Himalaya (Tewari 1982). Tiwari & Singh (1987) reported excessive transformation and exploitation of oak harbouring broadleaved forests during the early British colonial period (1816 - 1890). Though the natural limit of banj oak is between 1000 - 2500 m asl, but most of banj oak bearing forests were distributed between 1800 - 2200 m (951 km^2 out of 1284 km^2). However, throughout its entire distribution range, banj oak forests were highly fragmented, partly due to its natural occurrence patterns and largely due to anthropogenic pressure. In general, the major causes of loss and degradation of banj oak forests are excessive dependency for fodder and fuelwood, invasion of chir pine and construction of roads.

Table 2. Phytosociological attributes – density of banj oak in dense, open and degraded forest categories in different elevation zones.

Elevational zone (area under banj oak forests)	Forest category	Tree (ind ha^{-1}) (mean ± SE)	Total Basal Area (m^2 ha^{-1})	Sapling (ind ha^{-1})	Seedling (ind ha^{-1})	Diversity (Tree)	Richness (Tree)
1000-1500 (38.2)	Dense forest	358.28 ± 22.35	13.77	780.25	684.71	1.05	9
	Open forest	339.70 ± 26.39	11.64	679.41	467.09	1.07	5
	Degraded forest	111.46 ± 19.86	9.7	127.39	191.08	1.03	4
1500-1800 (240.82)	Dense forest	479.03 ± 22.35	19.38	376.86	366.24	0.83	10
	Open forest	370.58 ± 26.39	14.28	758.54	335.84	1.02	15
	Degraded forest	183.12 ± 19.86	8.25	297.24	403.4	0.9	8
1800-2200 (951.7)	Dense forest	382.17 ± 22.35	12.71	611.47	315.92	1.47	20
	Open forest	308.52 ± 26.39	13.51	1118.63	517.52	1.5	18
	Degraded forest	146.12 ± 19.86	8.37	276.01	162.77	1.21	8
2200-2500 (53.69)	Dense forest	301.49 ± 22.35	13.95	416.14	348.19	1.72	15
	Open forest	213.83 ± 26.39	12.15	291.17	218.38	1.03	5
	Degraded forest	46 ± 19.86	7.41	382.17	56.62	1.03	4
Forest type wise	*F*	19.38	8.43	3.69	2.49	0.66	2.26
	df	2, 194	2, 9	2, 9	2, 9	2, 9	2, 9
	P	0.000	0.009	0.067	0.14	0.54	0.16

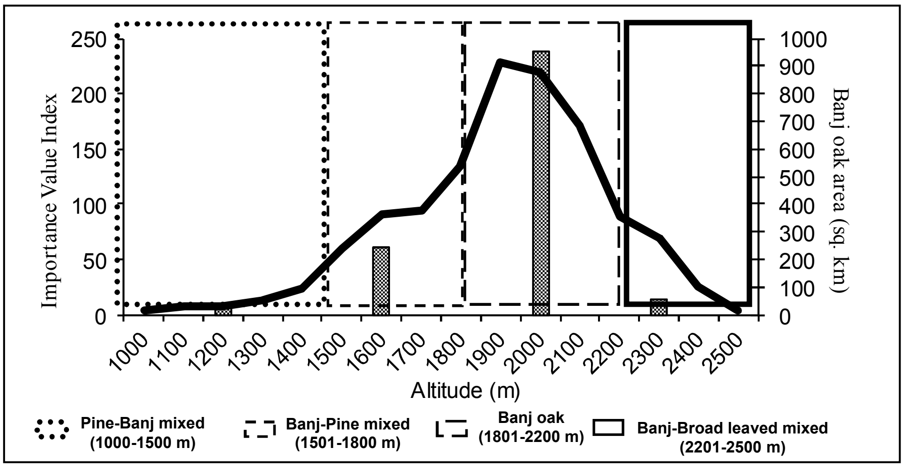

Fig. 3. Distribution of banj oak forest area and importance value index in different elevation zones.

During the field survey, excessive lopping of banj oak forests was observed below 1500 m and above 2200 m elevation zone in the state, where degraded banj oak forests had least tree density. In several places owing to excessive lopping/ logging and browsing by livestock, banj oak forests have become stunted scrublands. Large scale fragmentation of contiguous banj oak forests due to expansion of orchards was also observed in few places below 1500 m elevation. Unavailability of alternative fodder yielding species has led large scale degradation of banj oak forests in some of the districts. Old growth stands of banj oak were generally lacking regeneration as compared to young growth stands which on the contrary were better in regeneration status. The low diversity of banj oak forests is attributed to the biotic disturbance due to excessive grazing by cattle and frequent lopping by local communities (Ralhan *et al.* 1982; Singh & Singh 1987; Upreti *et al.* 1985). Ingression by chir pine and *Eupatorium adenophorum* Spreng. along the fringes hamper the regeneration of banj oak and others associated native species. Many of the large banj oak forest patches are in areas managed by military cantonment, private estates and where people have shown interest in management.

Although, banj oak forests in the western Himalayan region are similar in their physiognomy and composition across various regions, their structure and composition varies significantly across management regimes (P = 0.001) (Table 2). The mean tree density (337 ± 13.6 individual ha^{-1}) is comparable to some of the past studies in banj oak forests (total tree density of forest) of Kumaun and Garhwal region (Dhanai *et al.* 2000; Ghildiyal *et al.* 1998; Ralhan *et al.* 1982; Saxena *et al.* 1984). Total basal area (TBA) ranged between 7.41 ± 4.58 m^2 ha^{-1} (degraded) to 19.38 ± 10.15 m^2 ha^{-1} (dense). The study reveals that basal area of banj oak trees decreased with increasing elevation, while, density and species diversity increased which was also reported by Bormann *et al.* (1970). However, at some localities at elevation above 2200 m *viz*., Ransi (Rudraprayag), Sankari (Uttarkashi) and Mussoorie (Dehradun), girth size was more than 250 cm, whereas majority of patches in the study area ranged between 60 - 120 cm girth classes (P < 0.05).

It is apparent from the mean density of saplings (585 ± 51 individual ha^{-1}) and seedlings (368 ± 37 individual ha^{-1}) across various elevational gradients that regeneration is adequate with respect to the mean tree density (337 ± 13.6 individual ha^{-1}) in western Himalaya. There was no significant (P > 0.05) difference in the availability of regenerating individuals across the elevations. However, in many forest patches grazing by domestic animals and frequent lopping by local communities has been cited as the cause of low banj oak regeneration in the state (Ralhan *et al.* 1982).

Conclusions

Despite a considerable area (45 %) under forest cover, the state of Uttarakhand is left with a very small proportion (5.24 %) under banj oak forests. Most of the intact banj oak forests were recorded between 1800 - 2200 m elevations. Whereas fringes of banj oak forests between 1500 - 1800 m elevations zone were heavily invaded by *Eupatorium adenophorum* and chir pine, which hamper the regeneration of oaks and associated native species. Very few banj oak patches were recorded below 1000 m asl and such patches form interesting ecological transition and need special conservation efforts.

Acknowledgements

The authors acknowledge Director and Dean, Wildlife Institute of India, Dehradun, and Uttarakhand Forest Department for support in carrying out the project on banj oak. The financial support from Uttarakhand State Council for Science and Technology (UCOST) and Department of Science and Technology, New Delhi, are duly acknowledged.

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(Received on 13.08.2013 and accepted after revisions, on 30.07.2014)