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Poor regeneration of Brown Oak (*Quercus semecarpifolia* Sm.) in high altitudes: A case study from Tungnath, Western Himalaya

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This study was carried out in the timberline zone of Tungnath, Chopta region of the Chamoli District in India at eight altitudinal zones from 2,500 to 3,200 m, where the regeneration of Brown Oak was found to be very low. The data were obtained during the rainy season (August-September, 2016) by making counts of mature trees, saplings and seedlings in survey plots (50 × 50 m) at each of the eight altitudes. The results show a low regeneration of Brown Oak (*Quercus semecarpifolia* Sm.*)*. Three of the eight elevation zones (38%) were categorized as having fair regeneration, four (50 %) were categorized as poor, and one site had no regeneration. However, at some elevations, there were substantial numbers of seedlings (such as the highest density of 350,000 ha^{-1} was at an altitude of 2,800 m). This indicates that at this geographic region of Chamoli, where there is increasing annual temperatures and evidence of reduced precipitation, seedlings (though sometimes abundant) fail to survive and mature into saplings; thus, creating a threat to the survival of the Brown Oak in the near future unless remedial action is taken to ensure its conservation.

Key words: Biogeography, climate change, ecology of Tungnath forests, human livelihood, seedling survival, tree conservation.

INTRODUCTION

Across the Indian Himalayan region, over 35 species of Oak (*Quercus* spp.) are reported (Negi and Naithani, 1995). Among these, *Quercus semecarpifolia,* which represents the climax community, forms extensive forests in the high-altitude zones of Western Himalaya. *Quercus semecarpifolia* is a multipurpose tree used to provide fuelwood, fodder, agriculture implements and tannin. The species is also considered to be one of the oldest plants in the region (Shrestha, 2003), which has been over exploited for centuries in the Himalaya (Singh et al., 2011). Given the importance of this species, and other oak species in this region, additional attention has been given to documenting the regeneration capacity of the trees in high altitude forests of the Himalayan region. This

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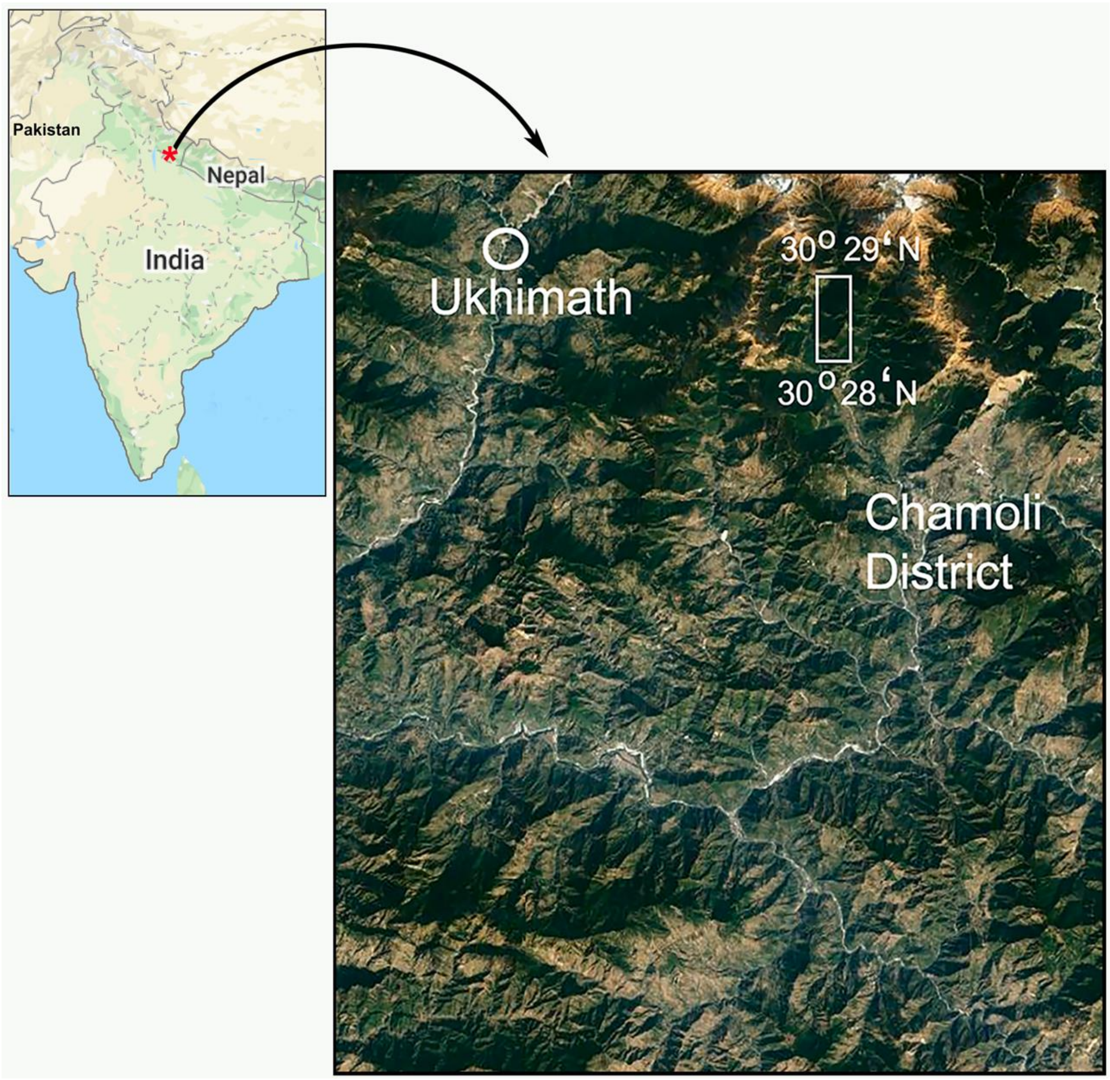

Figure 1. Study site (White rectangle) southeast of Ukhimath in the Chamoli District, State of Uttarakhand, India near the southern border of the Northwestern Himalayas (red asterisk) (Adapted from Google Earth).

includes Nepal (Shrestha, 2003; Vetaas, 2000), Western Himalaya (Bisht et al., 2011, 2013; Kumar et al., 2014; Rai et al., 2013; Singh and Rawat, 2012; Sing et al., 2011) and Northwestern Himalaya (Pant and Samant, 2012).

More recently, particular attention has been given to documenting the relative abundance and likely regeneration of *Q. semecarpifolia* in relation to other tree species in locations such as ridge forests of Western Himalaya (Malik and Bhatt, 2016; Sharma et al., 2016; Tiwari et al., 2018, Tewari et al., 2019). Nearly 70% of such studies have reported very poor regeneration in natural stands. Moreover, *Q. Semecarpifolia* has been reported to be vulnerable to climate change (Bisht et al., 2013), and there is increasing evidence that Western Himalaya is undergoing climate change with increasing annual temperatures in the State of Uttarakhand, and declining precipitation, especially in Chamoli (Yadav et al., 2014). Therefore, the purpose of this research was to document the status of *Q. Semecarpifolia* along an altitudinal range in the Western Himalaya district of Chamoli, and interpret its status in relation to current climate trends in the district.

MATERIALS AND METHODS

Study location

This study was carried out in the timberline zone of Tungnath, Chopta region of the Chamoli District in India (30°27'46.38'' – 30°28'58.30'' N; 79°13'07.80'' – 79°12'53.62'' E) as shown in Figure 1. The Chopta region is 29 km from Ukhimath, 162 km from Rishkesh, and approximately 450 km from the capital (Dehli). Sampling was done at eight altitude zones from 2,500 to 3,200 m, where the regeneration of Brown Oak was found to be very low.

Table 1. Results of the Brown Oak survey reported for each elevation zone.

Zone S/N	Elevation zone (m)	Latitude (N)	Longitude (E)	Trees (ind. ha^{-1})	Saplings (ind. ha^{-1})	Seedlings (ind. ha^{-1})	Regeneration pattern
1	2,500	30°27'46.38"	79°13'07.80"	123	0	13,833	Poor
2	2,600	30°27'58.67"	79°13'00.97"	120	13	7500	Fair
3	2,700	30°28'00.39"	79°33'10.44"	143	0	128,333	Poor
4	2,800	30°28'14.35"	79°33'12.38"	293	20	350,000	Fair
5	2,900	30°28'46.92"	79°12'35.82"	403	0	133,333	Poor
6	3,000	30°28'45.90"	79°12'46.59"	276	0	173,333	Poor
7	3,100	30°28'54.28"	79°12'53.63"	443	10	50,000	Fair
8	3,200	30°28'58.30"	79°12'53.62"	10	0	0	None

No. = number, N = North, E = East, ind. = individuals.

The data were obtained during the rainy season (August-September, 2016).

Sampling design and methods

For tree vegetation sampling at each of the eight elevation zones, three 50 × 50 m plots were identified that were representative of the forest vegetation at each zone. Within each plot, ten square sub-plots (10 × 10 m) were randomly placed for a total of 30 sub-plots. The size and number of sub-plots were determined according to Misra (1968), and Ellenberg and Mueller-Dombois (1974). Tree circumference at breast height (cbh) at 1.37 m height from the ground was measured in each sub-plot. Individuals > 31.5 cm cbh were considered trees, 31.5-10.5 cm cbh as saplings, and individuals <10.5 cm cbh (less than 1 m height) were considered as seedlings. To assess the current regeneration status, the method given in Kumar et al. (2014) was used, and their four categories of regeneration were applied to categorize the stands of *Q. Semecarpifolia* as follows: (i) *Good regeneration* - Seedling > Sapling > Adults, (ii) *Fair regeneration* - Seedling > Sapling ≤ Adults, (iii) *Poor regeneration* -Seedling and Adult trees only (Saplings absent), and (iv) *None* (no regeneration).

Additional data on changes in temperature and precipitation (www.carbonbrief.org; Yadav et al., 2014) have been included and used to interpret the results of this study, as reported in the Results and Discussion section. Data were entered in Excel files, tables were created to list numerical data, and column graphs were made to display densities of trees and seedlings at each sampling elevation. Chi-square analysis (http://quantpsy.org) was used to analyze tree density data within each altitudinal zone and to compare seedling densities with mature tree densities across the eight altitudinal zones. Correlation coefficients were calculated using an online calculator (socscistatistics.com).

RESULTS AND DISCUSSION

With respect to regeneration (Table 1), three of the elevation zones (38%) were categorized as having fair regeneration (altitude zones 2, 4 and 7) with negligible densities of saplings in the range of 10 to 20 individuals ha^{-1}. Four altitude zones (50%) were categorized as poor, with absence of saplings (altitude zones 1, 3, 5, and 6). One zone (altitude zone 8) had no evidence of regeneration and was categorized as none. This indicates that in some cases, the seedlings apparently fail to survive and mature into saplings. However, at some elevations there were substantial numbers of seedlings (the highest density of 350,000 ha^{-1} at altitude zone 4), although the density of samplings at this altitude zone was relatively low (20 individuals ha^{-1}).

The densities of mature trees and of seedlings are plotted as column graphs in Figure 2 to more clearly display the pattern of the densities, comparatively, in relation to elevation. In general, mature-tree densities (Figure 2A) are less at elevations of 2,500 to 2,700 m, but are substantially denser at elevations of 2,800 to 3,100 m. However, they are markedly less at 3,200 m. In contrast, seedlings (Figure 2B) are most dense in the range of 2,700 to 3,000 m, with a peak density in zone 4 (2,800 m); but even here, the number of saplings is not large (20 individuals ha^{-1}) as reported in Table 1.

By comparison, the mature tree density peaked at 3,100 m elevation (Figure 2A), while the seedling density at 3,100 m was among the lowest densities recorded at this site (Figure 2B). Overall, both mature trees and seedlings were least abundant in zone 8 (3,200 m). Most of the sampling zones occurred in locations that were either an approximate plateau or with a gently sloping terrain. However, zone 4 (2800 m) was a rather steep south-east facing slope extending for over 300 m from the base up to a small ridge at the top that marked the beginning of the next rather gentle sloping plateau where zones 5 through 8 were located. The presence of a peak in seedling densities (350,000 ha^{-1}) in zone 4 is likely due to the inaccessibility of this terrain to cattle and other grazing animals. Overgrazing and trampling on seedlings and young saplings by animals has been widely recognized as one of the threats to regeneration of *Q. semecarpifolia* more broadly in Western Himalaya (Shrestha, 2003).

The densities of mature trees in elevation zones 1 to 8 (Figure 2A) were statistically different from one another based on one-way chi-square analysis (X^2 = 710.3, df = 7, p < 0.001). Likewise, the densities of seedlings in the eight elevation zones (Figure 2B) were statistically

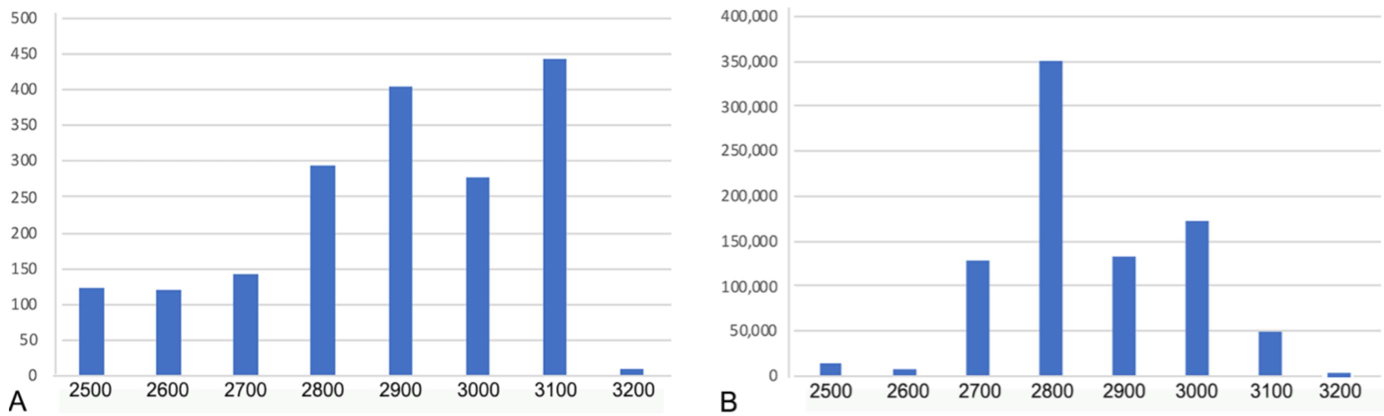

Figure 2. Column graphs comparing densities (number ha^{-1}, ordinate) of mature trees (A) and seedlings (B) across the eight altitude zones 2,500 to 3,200 m (abscissa).

different (X^2 = 914.4, df =7, p < 0.001). Furthermore, a two-way chi-square analysis of the densities of the mature trees compared to the densities of the seedlings across the eight elevation zones was statistically significant (X^2 = 3,523, df = 7, p < 0.001), suggesting a lack of correlation between densities of mature, seed-producing trees and densities of seedlings at the eight elevation zones. A correlation analysis of the densities of mature trees and the densities of seedlings at the eight altitude zones was used to further examine the pattern of relationships. There was no statistically significant correlation between densities of mature trees and the densities of seedlings (r = 0.42, p = 0.30, df = 7). Given the very low densities of saplings across all altitudinal zones, no further statistical analyses were made with this data. Overall, these data indicate that the densities of seedlings are not significantly related to the densities of mature, acorn-bearing trees in these eight elevation zones in the Chamoli District; and this suggests that other factors such as animal predation, environmental stress and climatic forcing functions may account for some of the poor regeneration in the region.

Currently, there is increasing evidence of climate change in the Western Himalayas. For example, there has been a 1.1°C warming as of 2020, in the State of Uttarakhand where the District of Chamoli is located (https://www.carbonbrief.org); and based on an analysis of 41 years of data, there has been a statistically significant decrease in the annual precipitation in the District of Chamoli, particularly during the post-monsoon and winter seasons (Yadav et al., 2014). *Q. Semecarpifolia* is a viviparous oak; the acorns begin germination before or during their deposition on the ground (Tewari et al., 2019). This makes them particularly sensitive to possible stress during the post-monsoon and subsequent winter seasons, when the seedlings are becoming established. Tewari et al. (2019), who studied acorn maturation and regeneration in *Q. Semecarpifolia* in the Western Indian Himalayan region, reported that acorn maturation and regeneration are particularly dependent on moisture. They noted the presence of a large number of fallen seeds with dried emerged radicals, varying in length between 2 and 6 cm, and stated this was a clear indicator that intermittent patterns of rainfall, followed by long stretches of rainless periods, resulted in drying of radicals and ultimate mortality of seeds. Furthermore, the seedlings of *Q. Semecarpifolia* are light-demanding, and any change in canopy tree species with possible increased shade could result in further decreased regeneration of this species (Singh and Singh, 1987).

The study is consistent with most of the previous reports, suggesting failure of Brown Oak regeneration in the Himalaya region (Tewari et al., 2019), but it provides additional information on the status of seedlings and likely regeneration potential of Brown Oak across a much broader altitudinal range (2,500 to 3,200 m) up to the timberline; particularly in the District of Chamoli, where there is evidence of declining patterns of precipitation. An earlier study by Saran et al. (2010) concluded that there can be a reduction of 40% or as much as 76% in the stands of *Q. semecarpifolia* in present habitats; if there is a 1 or 2°C global temperature rise, respectively, as predicted (IPCC, 2014). Evidence also indicates a relatively higher rate of temperature rise in some regions of the Himalayas (1.5°C) in recent decades compared to the global average (Shrestha et al., 2012), suggesting that the pressure on survival of *Q. semecarpifolia* may be even more severe than predicted by some conservative estimates. Increasing temperatures, particularly during night, places additional respiratory demands on seedlings and saplings; thus, contributing to potential declines in their carbohydrate reserves, especially if increased temperatures are coupled with decreasing precipitation that may result in water stress and lower stomatal conductance producing less photosynthetic gains during the day. This scenario of seedlings' failure to establish calls for more dedicated attention to conservation of the species, including more diligence in reducing anthropogenic sources of stress such as predation by domesticated animals, and excessive harvesting of the trees for lumber and other practical uses, especially at higher elevations. *Q. semecarpifolia* is an important component of high-altitude forest ecosystems, and changes in its dominance could have wide-ranging implications for regional ecology and human livelihoods.

Conclusions

Regeneration of Brown oak (*Q. semecarpifolia*) across eight altitudinal zones (2,500 - 3,200 m) in the Chamoli District of the state of Uttarakhand shows evidence of serious decline, ranging from no regeneration at the highest altitude (3,200 m) to *poor* or *fair* at the seven other lower altitudes. In addition to possible anthropogenic effects (cutting the forests and damage due to invading domestic animals), a changing climate (including increased temperatures and declining precipitation, particularly in the Chamoli District) may adversely affect regeneration of Brown Oak more broadly in Uttarakhand. Given the changing stress due to climate change, more earnest attention should be given to conservation of the Brown Oak, especially at higher altitudes, with particular attention to reducing anthropogenic sources of damage such as limiting grazing by domesticated animals and regulating cutting of trees for lumber and other practical uses.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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