Introduction

Regeneration is the fundamental process for survival and flourishing to any forest ecosystem. Regeneration potential of tree species decides the future composition of forest in space and time (Henle et al. 2004). The future depends on the number of seedlings, saplings and young trees that gives imminent insight about regeneration status. Successful regeneration depends on the capacity to emerge new seedlings, saplings and their survival as adult trees (Good and Good 1972). Current population structure, growth and fecundity of a forest is an indicator of successful regeneration (Guedje et al. 2003). Thus, population structure could give a better understanding of the future of any forest.

The regenerating behaviour of any species is dependent on habitat conditions which further defines its geographical distribution (Grubb 1977). In any habitat, the interaction between biotic and abiotic factors is highly influential on regeneration of tree seedlings survival and growth (Khan et al. 1986). Vegetation change induced by climax species may lead to change in habitat by altering the microclimatic conditions (like soil properties) and may accelerate forest growth (Van et al. 2017). The change in microclimate also affects the seedlings, saplings and young trees, etc. which are crucial for regeneration of forest (Rahman et al. 2011).

The forest population structure could give a better understanding of the regeneration and future of any stand. By looking at the density-diameter curve one can assume the current reproductive status. This would also give an idea about change in the soil parameters as nutrients of soil is also dependent on the vegetation composition of forest (Jobbágy and Jackson 2000). Thus, change in forest composition may lead to change in the soil properties. This change may also affect the carbon stock of the forest as carbon stock is positively correlated with the trees present in the forest.

The present study is focused on banj oak (Quercus leucotrichophora), a climax species that contribute significantly to both ecological and ecosystem services in this region. Banj oak forests sustain rich biodiversity (Bargali et al. 2015), maintains the quantity and quality of stream water in its proximity (Singh and Singh 1986). Also, banj oak forests are the main source of the three major components in the region i.e., food, fuel and fodder (Singh et al. 2010; Joshi and Negi 2011) and termed as ‘People’s species’ (Singh and Singh 1986). According to Singh et al. (2016), 5.24% i.e. 1284 Km² of the total forest cover of Uttarakhand is contributed by Q. leucotrichophora. Banj oak reported from 1000 to 2500 m, where, between 1000 and 1500 m it is found in very few numbers with other forests, whereas, 1500–1800 m is the pine-oak region, found with mainly pine forests and banj oak forms extensive forests between 1800 and 2200 m in central Himalaya (Singh et al. 2016). Whereas, pine (Pinus roxburghii) forms extensive forest between 900 and 1500 m altitude (Chaturvedi and Singh 1987).
Researches have reported that due to anthropogenic disturbances (like preference of pine trees over banj oak by Britshers in colonial era, logging and lopping by local people, fire, etc.) for last many decades the pine which is generally present in the lower altitude encroached in higher altitude banj oak forest (Semwal and Mehta 1996; Singh et al. 1997; Singh 1998). Additionally, Singh et al. (1984) suggests that climate change is also one of the major factors that induce this vegetation shift. Fire in pine forests are frequent and occur every 3–5 years. Fire eliminates seedlings and saplings of not only pine but also other co-occurring species and affects their regeneration process (Semwal and Mehta 1996). In ecotone zones, these fire reach to adjacent banj oak forests and cause extensive damage to forest composition and pave the way for pine invasion. Saxena and Singh (1984) and Ralhan et al. (1982) suggested long back that banj oak will disappear in near future due to pine invasion in the region. There have been many studies done in the central Himalaya about structure and composition but such regenerating forests have not been reported. However, present study indicates that banj oak is able to reestablish and regenerate on several sites (Figure 1). Encouragingly, Garkoti (2015) also studied regenerating banj oak sites and concluded that protection of a few years could allow banj oak to re-establish in pine invaded areas. Objective of the study is to determine the species composition, population structure of banj oak and pine trees, soil characteristics and carbon stock of these regenerating forests. The present research emphasizes the importance of such regenerating banj oak forests and also recommends the proper management and conservation.

Materials and methods

Site characteristics

After reconnaissance survey, study was conducted in seven regenerating banj oak stands located in Lamgara block of Almora, Uttarakhand (Table 1). The study area falls in the Kumaun region of the Indian central Himalaya. Studied forests are named after adjacent villages. Forests in the study areas are dominated by banj oak and pine. Tree species such as Myrica nagi, Lyonia ovalifolia and Rhododendron arboreum are associated with both banj oak and pine. The study area lies between 29°31’37”N and 29°33’38”N latitudes and between 79°41’30”E and 79°44’52”E longitudes. Altitudes ranged from 1780 m to 1980 m. Aspect of sites are north, north-west, east and west facing with slope varied from 20° to 40° while, no south-facing site is found. Study sites fall in the region of anthropogenic pressure due to dependency of local people on forest resources (Kumar and Ram 2005). These forests are managed and protected by unique village forest council known as ‘Van Panchayat’. This council allows villagers for lopping, wood collection and cattle grazing after certain intervals to control and minimize the human and cattle pressure on forests (Nagahama et al. 2016). As the study sites are located in the Lesser Himalaya, the lithology is mainly Metamorphic. Origin of soil is from slate, phyllite, sandstone and limestone (Raina and Gupta 2009). Texture of soil was predominantly sandy loam and slightly acidic in nature. All sites were chosen on the basis of visible signs of regeneration and area of each site was more than 1 hectare.

Climate

Climate data were collected from the nearest weather station i.e. Almora. Mean annual, mean maximum and mean minimum temperature of 2014 was 17.85°C, 23.89°C and 11.82°C respectively and the mean annual precipitation was 97.88 cm (VPKAS 2017). The whole year can be separated into three major seasons i.e., cold and dry winter (December to February-end), warm and dry summer (April to mid-June) and rainy (mid-June to September). Autumn (October to November) and spring (February to March) are transition periods. Snowfall normally occurs from the end of December to the beginning of February.

Sampling and data analysis

Phytosociology

Phytosociological study was conducted in each forest using ten 10 m x 10 m random quadrats and species-area curve was used to determine the number and size of quadrats (Misra 1968). Circumference at breast height (cbb) of all individuals was measured and converted into diameter at breast height (dbh) in each

Figure 1. Representation of banj oak regenerating site in pine invaded area in Almora district, central Himalaya.
quadrat. Trees with \( \geq 10 \text{ cm dbh} \) (diameter at breast height i.e., 1.37 m above the ground) were considered as trees, individuals with \(< 10 \text{ cm dbh} \) were considered as saplings and individuals \(< 1 \text{ m in height} \) were considered as seedlings (Dhar et al. 1997). According to the field data, the following girth classes (dbh) for trees were established: seedlings (A), saplings (B), 10–20 cm (C), 20–30 cm (D), 30–40 cm (E), 40–50 cm (F), \( > 50 \text{ cm} \) (G). Based on the established girth classes population structures were drawn for all the seven sites.

Quantitative analysis of vegetation (density, frequency and abundance) was done by following Curtis and McIntosh (1959). Relative values of density, frequency and dominance were also calculated (Phillips 2016) and summed to get Importance value index (IVI) of individual species (Curtis 1959). Distribution pattern was determined by the ratio of abundance to frequency (A/F). Distribution is considered as regular when A/F \( < 0.025 \), random when A/F = 0.025–0.05 and contagious when A/F > 0.05 (Cottam and Curtis 1956).

Regeneration status of tree species was determined on the basis of population size of seedlings, saplings and adults. Population was divided into different regenerating classes following previous studies (Khan et al. 1986; Malik and Bhatt 2016). Population is considered as 'good regeneration' when seedling > sapling > adults. Population is said to be 'fair regeneration' if (i) seedlings > sapling \( \leq \) adults and (ii) seedling \( \leq \) sapling > adult. If the population consists of saplings, but no seedlings (saplings may be <, > or = adults) then it is termed as 'poor regeneration'. When both seedlings and saplings are absent and only adults are found then it is called as 'no regeneration'. When only seedlings and saplings are found without any adult, it is considered as 'new arrival'.

**Diversity indices**

Species diversity \( (H') \) was calculated using Shannon-Weiner index (Shannon and Weaver 1963) and species dominance was calculated by Simpson dominance index \( (C_{d}) \) (Simpson 1949). Tree species richness index (d) was calculated using the formula given by Margalef (1958). The equitability \( (E) \) or evenness of distribution of individuals between species was calculated by the following formula

\[
E_r = H' / H_{\text{max}}
\]  

Where, \( H_{\text{max}} \) is maximum species diversity, which occurs if all the species are of equal abundance, i.e. \( H_{\text{max}} = \log_2 S \) (Krebs 1972) where, S is the number of species.

### Soil characteristics

Three soil samples were collected from three depths 0–10 cm, 10–20 cm and 20–30 cm at all the site. Physical (bulk density, texture, porosity) and chemical parameters (pH, organic carbon, total nitrogen, available phosphorus, available potassium) were estimated by following Okalebo et al. (2002) and Osman (2013).

### Biomass and carbon stock

Biomass of Forest was analyzed by following allometric equation

\[
\ln(y) = a + b \ln(x)
\]  

Where, \( y \) is dry weight biomass, \( x \) is circumference at breast height (cbh), \( a \) is the y-intercept and \( b \) is the slope or regression coefficient. Using the calculated values of intercept and slope for different species, biomass was calculated of all species. Biomass for Q. leucotrichophora, R. arboreum and M. nagi was calculated according to Rawat and Singh (1988) while biomass for P. roxburghii was determined according to Chaturvedi and Singh (1987). Carbon stock was calculated by multiplying obtained biomass by a function of 0.47 (Eggleston et al. 2006).

### Statistical analysis

All the statistical analysis was done by using R 3.5.0 version (R core team 2018). Normality of the data was checked by using Shapiro-Wilk’s test, if normality was not met, data were transformed in log values. F test and Leven’s test was used to calculate the homogeneity of variance of the data. Difference between means was estimated by using t-test and ANOVA, in case, data was not found homogenous Welch t-test and Welch one-way test were used. Principal component analysis and correlation were calculated to understand the associations of variables.

### Results

#### Floristic composition

A total of five tree species were found, of which Q. leucotrichophora, P. roxburghii, M. nagi, and R. arboreum were common and P. pashia was found at one site only i.e. Toli A (Table 2). Among all the study sites, frequency of banj oak was found to be 70–100% while for pine it was 60–90%. Whereas, frequency of M. nagi, R. arboreum and P. pashia was found 10–60%, 10-30% and 0-10%, respectively. Distribution pattern
was calculated on the basis of abundance and frequency ratio and found banj oak varied from regular to contagious and pine was present randomly in most of the sites. *M. nagi* and *R. arboreum* were co-occurring with banj oak and pine in contagious or random distribution pattern. Total tree density varied from 390 trees ha\(^{-1}\) (Toli A) to 1550 trees ha\(^{-1}\) (Hathikhan B), out of which, banj oak and pine varied between 260 trees ha\(^{-1}\) (Toli A) – 1200 trees ha\(^{-1}\) (Hathikhan B) and 90 trees ha\(^{-1}\) (Toli A) – 300 trees ha\(^{-1}\) (Hathikhan A), respectively. Density of other three species *M. nagi*, *R. arboreum* and *P. pashia* were reported between 30 – 150 trees ha\(^{-1}\), 20 – 110 trees ha\(^{-1}\) and 10 trees ha\(^{-1}\), respectively. Total basal area of trees varied from 17.0 m\(^2\) ha\(^{-1}\) (Toli A) to 49.1 m\(^2\) ha\(^{-1}\) (Hathikhan B). For banj oak, it was found to be between 5.5 m\(^2\) ha\(^{-1}\) (Toli B) and 21.0 m\(^2\) ha\(^{-1}\) (Hathikhan B) and for pine, it was between 6.4 m\(^2\) ha\(^{-1}\) (Toli A) and 26.0 m\(^2\) ha\(^{-1}\) (Hathikhan B). Correlation between basal area and tree density was calculated and found that density of both banj oak and pine was highly correlated (\(R^2=0.85\)) but their basal area were not strongly correlated (\(R^2=0.64\)). IVI values of banj oak (127–168.2) and pine (100.2–128.1) suggested that banj oak is the dominant species at all sites studied.

Presence of seedlings and saplings of banj oak and pine were studied. Density of banj oak seedlings ranged from 130 seedlings ha\(^{-1}\) (Asota) and 960 seedlings ha\(^{-1}\) (Takoli band). Compared to banj oak, pine exhibited lower seedling density, 0 seedlings ha\(^{-1}\) in Hathikhan A and Hathikhan B to 30 seedlings ha\(^{-1}\) in Toli A, Toli B and Asota. Whereas, banj oak saplings density ranged from 310 saplings ha\(^{-1}\) (Asota) to 630 saplings ha\(^{-1}\) (Takoli band) and pine sapling density was between 0 saplings ha\(^{-1}\) (Hathikhan A and Hathikhan B) to 90 saplings ha\(^{-1}\) (Asota).

Shannon Weiner diversity varied from 0.77 to 1.23; highest was found at Hathikhan B site and lowest was found at Asota site. The calculated Simpson dominance index was between 0.41 and 0.67, highest at Hathikhan B and lowest at Toli B. Species richness varied from 1.00 (Thath) – 1.98 (Toli A) and species evenness varied between 0.42 (Hathikhan A) – 0.61 (Hathikhan B).

### Population structure and regeneration status

Population structure was constructed on the basis of densities of seedlings, saplings and different girth classes of trees ([Figure 2](#)). Banj oak trees were found mostly in the 10–20 cm dbh class, while pine was mostly present in >10–20 cm dbh class. In most of the sites, banj oak was found lower in seedling and sapling class than 10–20 cm dbh class whereas, at Takoli band

#### Table 2. Species composition of tree species present in all the sites.

| Species       | Trees ha\(^{-1}\) | Total basal area m\(^2\) ha\(^{-1}\) | IVI  | Saplings ha\(^{-1}\) | Seedlings ha\(^{-1}\) |
|---------------|-------------------|-----------------------------------|------|----------------------|---------------------|
| **Toli A**    |                   |                                   |      |                      |                     |
| *Q. leucotrichophora* | 260              | 9.7                               | 158.8| 390                  | 310                 |
| *P. roxburghii*      | 90                | 6.4                               | 100.2| 50                   | 30                  |
| *M. nagi*           | 30                | 0.6                               | 30.5 | 10                   | 0                   |
| *P. pashia*         | 10                | 0.3                               | 10.5 | 0                    | 0                   |
| **Total**         | 390               | 17.0                              | 300.0| 450                  | 340                 |
| **Toli B**        |                   |                                   |      |                      |                     |
| *Q. leucotrichophora* | 360              | 5.5                               | 127.0| 390                  | 280                 |
| *P. roxburghii*     | 100               | 11.4                              | 108.1| 40                   | 30                  |
| *M. nagi*           | 40                | 0.4                               | 17.0 | 10                   | 0                   |
| *R. arboreum*      | 110               | 3.6                               | 47.9 | 0                    | 10                  |
| **Total**         | 610               | 21.0                              | 300.0| 440                  | 320                 |
| **Asota**         |                   |                                   |      |                      |                     |
| *Q. leucotrichophora* | 420              | 7.3                               | 159.1| 310                  | 130                 |
| *P. roxburghii*     | 170               | 11.4                              | 128.1| 90                   | 30                  |
| *M. nagi*           | 30                | 0.4                               | 12.8 | 10                   | 20                  |
| **Total**         | 620               | 19.1                              | 300.0| 410                  | 180                 |
| **Takoli band**   |                   |                                   |      |                      |                     |
| *Q. leucotrichophora* | 540              | 12.5                              | 137.3| 630                  | 960                 |
| *P. roxburghii*     | 260               | 13.5                              | 101.2| 70                   | 0                   |
| *M. nagi*           | 130               | 6.7                               | 61.6 | 60                   | 0                   |
| **Total**         | 930               | 32.7                              | 300.0| 760                  | 960                 |
| **Thath**         |                   |                                   |      |                      |                     |
| *Q. leucotrichophora* | 680              | 12.3                              | 149.1| 420                  | 200                 |
| *P. roxburghii*     | 190               | 17.0                              | 110.9| 50                   | 20                  |
| *M. nagi*           | 140               | 1.7                               | 40.1 | 230                  | 140                 |
| **Total**         | 1010              | 31.2                              | 300.0| 700                  | 360                 |
| **Hathikhan A**   |                   |                                   |      |                      |                     |
| *Q. leucotrichophora* | 1080             | 18.1                              | 153.0| 600                  | 670                 |
| *P. roxburghii*     | 300               | 21.4                              | 106.0| 0                    | 0                   |
| *M. nagi*           | 150               | 3.2                               | 33.9 | 90                   | 0                   |
| *R. arboreum*      | 20                | 0.8                               | 7.2  | 0                    | 0                   |
| **Total**         | 1550              | 43.6                              | 300.0| 690                  | 670                 |
| **Hathikhan B**   |                   |                                   |      |                      |                     |
| *Q. leucotrichophora* | 1200             | 21.0                              | 168.2| 490                  | 660                 |
| *P. roxburghii*     | 250               | 26.0                              | 110.7| 0                    | 0                   |
| *M. nagi*           | 30                | 1.1                               | 13.4 | 10                   | 0                   |
| *R. arboreum*      | 20                | 0.8                               | 7.7  | 0                    | 0                   |
| **Total**         | 1500              | 49.1                              | 300.0| 500                  | 660                 |
site trees in 10–20 cm dbh density was lower than seedlings and saplings. Pine trees were found in wide range of dbh classes from seedlings to >50 cm dbh. Population structure of pine exhibited discontinuity at some of the sites whereas, banj oak showed discontinuity at only Toli A site. On the basis of density of trees, saplings and seedlings, we have categorized banj oak and pine into four regenerating classes. In four forests (Asota, Thath, Toli B and Toli A) both banj oak and pine fell under the category of 'Fair regenerating' status whereas, in Takoli Band forest, banj oak and pine were categorized as 'Good regenerating' and 'Poor regenerating' status, respectively. In Hathikhan A and Hathikhan B forests with highest density and total basal area, banj oak was grouped under 'Fair regenerating' and pine was under 'Not regenerating'.

**Soil characteristics**

Both physical and chemical parameters of soils were analysed for all the sites (Table 3). Bulk density of the studied sites varied from 1.4 to 1.6 g cm⁻³. Soil porosity was calculated between 38% and 46% throughout all the sites. Both bulk density and porosity not varied significantly throughout the sites and depths (p < 0.05), although bulk density was lowest and porosity was highest in upper layer (0–10 cm) of soil. Texture of soil was found sandy loam throughout the sites. Soil was found slightly acidic in nature and pH was found between 5 and 5.7 and varied significantly through the sites (p < 0.001). Organic carbon varied significantly (p < 0.001), both depth and site wise and found between 0.91% to 1.83%, lowest at Toli A site and highest at Hathikhan B site. Total nitrogen of soil was found lowest at Toli A site (0.12%) and highest at Hathikhan B site (0.18%) among sites and depths (p > 0.05). Value of available phosphorus varied (p > 0.05) from 0.003% to 0.006% while available potassium varied (p < 0.001) from 0.03% to 0.06%. Soil carbon stock was estimated between 38.98 Mg ha⁻¹/30 cm (Toli A) and 84.86 Mg ha⁻¹/30 cm (Hathikhan B). Whereas, soil nitrogen stock per hectare was estimated from 5.31 Mg ha⁻¹/30 (Toli A) cm to 8.15 Mg ha⁻¹/30 cm (Hathikhan B). Both carbon and nitrogen stock were found significantly different at depths and sites (p < 0.001). Carbon/nitrogen ration was found between 6.91 and 11.02 at Asota and Hathikhan B sites respectively (p > 0.05).

**Biomass and carbon stock**

Total biomass of forests varied from 145.30 to 503.80 Mg ha⁻¹ and total carbon density was found to be between 68.29 and 247.61 Mg ha⁻¹. Carbon density of banj oak varied between 46.96 and 167.36 Mg ha⁻¹ while for pine it varied from 17.18 to 72.95 Mg ha⁻¹. Whereas, carbon density calculated for *M. nagi* and *R. arboresum* was 3.44–20.14 Mg ha⁻¹ and 0.0–8.26 Mg ha⁻¹ respectively. In overall species, highest carbon
density was contributed by banj oak (64.4%) followed by pine (28.2%), \textit{M. nagi} (6.3%) and \textit{R. arboreum} (1.1%). Carbon stock of banj oak and pine was divided on the basis of size classes. Carbon stock of banj oak was found maximum in 10–20 cm dbh size class (11.29–21.42 Mg ha\(^{-1}\)) followed by 20–30 cm dbh (7.05–17.59 Mg ha\(^{-1}\)). Whereas, carbon stock of pine was distributed in wide range of size class, from 0.6–7.1 Mg ha\(^{-1}\) in 10–20 cm dbh, 0.0–13.3 Mg ha\(^{-1}\) in 20–30 cm dbh, 5.0–56.9 Mg ha\(^{-1}\) in 30–40 cm dbh, 0.0–83.4 Mg ha\(^{-1}\) in 40–50 cm dbh, 0.0–32.1 Mg ha\(^{-1}\) in 50–60 cm dbh, 0.0 Mg ha\(^{-1}\) in 60–70 cm dbh and 0.0–38.6 Mg ha\(^{-1}\) in 70–80 cm dbh. Correlation of basal area and carbon density was also calculated and found to be highly correlated (\(R^2 = 0.9\)).

**Discussion**

The regeneration of forest is an important phenomenon in which old trees are regularly replaced by younger ones. Consequently, prosperity of forest (i.e. health, species composition etc.) predominantly depends on regeneration of a forest in a given time and space (Jones et al. 1994). The present study focuses on the regeneration status of seven banj oak forests.

Distribution pattern of trees showed that banj oak was predominantly found in contiguous distribution whereas, pine was present in random distribution and no tree species was found in regular distribution. Contagious distribution is most common distribution in nature whereas random distribution is found in relatively uniform distribution (Odum 1971). Here, reason behind different distribution by banj oak and pine in the same habitat is not clear but this may be due to their strategy to adapt in the present environment.

Density of banj oak was found higher than pine but basal area of pine was found higher than banj oak. Few pine trees with higher basal area were present whereas, more banj oak trees were found with lower basal area. Density of banj oak (260–1200 trees ha\(^{-1}\)) were found similar to the studies done in banj oak forests by Dhar et al. (1997) (1100 trees ha\(^{-1}\)) and higher than Singh and Singh (1986) (551 trees ha\(^{-1}\)), Rawat and Singh (1988) (490 trees ha\(^{-1}\)) and Thadani and Ashton (1995) (617 trees ha\(^{-1}\)). The values were higher than study done in banj oak-pine forest by Ram et al. (2004) (340 trees ha\(^{-1}\)) in central Himalaya. Whereas, density of pine trees (90–300 trees ha\(^{-1}\)) was found lower than studies done in pine forests by Rawal and Pangtey (1994) (580 trees ha\(^{-1}\)), Singh et al. (1994) (700 trees ha\(^{-1}\)) and Dhar et al. (1997) (616 trees ha\(^{-1}\)). Density of pine trees were higher than values for banj oak-pine forest (Ram et al. 2004) (100 trees ha\(^{-1}\)). Ram et al. (2004) reported lower value of both banj oak and pine, this may be due to the forests taken for the study were highly disturbed by anthropogenic activities. Basal area of banj oak (5.5–210.0 Mg ha\(^{-1}\)) was found lower than earlier studies done in banj oak forests viz. Singh and Singh (1986) (31.69 Mg ha\(^{-1}\)), Rawat and Singh (1988) (33.28 Mg ha\(^{-1}\)), Thadani and Ashton (1995) (39.2 Mg ha\(^{-1}\)) and Dhar et al. (1997) (35.3 Mg ha\(^{-1}\)). Basal area of pine (6.4–26.0 Mg ha\(^{-1}\)) was also found lower than the previous studies done in the pine forests viz. Rawal and Pangtey (1994) (37.1 Mg ha\(^{-1}\)), Singh et al. (1994) (45.4 Mg ha\(^{-1}\)) and Dhar et al. (1997) (43.9 Mg ha\(^{-1}\)). All the previous studies have been done in mature banj oak and pine forests, so this may be a reason for their higher basal area in comparison to present study. We found that relative density and relative frequency of banj oak was higher than pine at each stand. However, relative dominance of pine was higher than banj oak, due to its higher basal area. By summing all these parameters, IVI was calculated, which showed that banj oak was the dominant species in all the sites.

Considering the variations among study sites, we found total basal area as one of the important factors in the forest structure. Density of trees, saplings and seedlings increased with total basal area of forest. Number of both banj oak and pine individuals were positively correlated (\(R^2 = 0.8\)) with basal area but number of banj oak trees increased remarkably than pine trees with increase in their respective basal area, indicating the better growth of young banj oak trees (Figure 3). Pine tree density was found to be very low with presence of individuals in higher age classes suggesting the old pine trees in the study sites. The gradual increase in the number of banj oak individuals with total basal area indicated that the change in species composition could be due to local favourable

**Table 3.** Soil characteristics of all the sites (n = 3, mean ± se).

| Site name         | Tolli A | Tolli B | Asota | Takoli band | Thath | Hathikhkan A | Hathikhkan B |
|-------------------|---------|---------|-------|-------------|-------|--------------|--------------|
| Sand (%)          | 60.0 ± 5.2 | 60.7 ± 6 | 61.2 ± 4.9 | 59.8 ± 6.1 | 60.7 ± 5.7 | 58.2 ± 7.2 | 56.7 ± 4.7 |
| Clay (%)          | 11.33 ± 1.8 | 13.5 ± 2 | 13.2 ± 2.3 | 13.0 ± 1.6 | 10.5 ± 1.2 | 14.9 ± 1.5 | 13.2 ± 1.4 |
| Silt (%)          | 28.63 ± 2.3 | 25.7 ± 3.3 | 25.58 ± 3.4 | 27.02 ± 2.5 | 28.7 ± 4.1 | 27.1 ± 2.8 | 29.7 ± 3.4 |
| Bulk density (g cm\(^{-1}\)) | 1.4 ± 0.06 | 1.6 ± 0.15 | 1.6 ± 0.05 | 1.6 ± 0.07 | 1.5 ± 0.08 | 1.6 ± 0.39 | 1.6 ± 0.08 |
| Porosity (%)      | 45.85 ± 4.76 | 38.34 ± 4.98 | 40.93 ± 3.84 | 39.7 ± 4.23 | 41.53 ± 5.57 | 39.68 ± 3.91 | 39.44 ± 3.53 |
| pH                | 5.0 ± 0.09 | 5.5 ± 0.16 | 5.2 ± 0.14 | 5.4 ± 0.12 | 5.2 ± 0.16 | 5.7 ± 0.08 | 5.0 ± 0.12 |
| Organic carbon (%)| 0.91 ± 0.07 | 0.93 ± 0.06 | 1.02 ± 0.10 | 1.16 ± 0.20 | 1.30 ± 0.14 | 1.62 ± 0.26 | 1.82 ± 0.19 |
| Total nitrogen (%)| 0.12 ± 0.01 | 0.13 ± 0.2 | 0.13 ± 0.01 | 0.14 ± 0.02 | 0.14 ± 0.01 | 0.16 ± 0.02 | 0.18 ± 0.01 |
| Available P (%)   | 0.006 ± 0.0007 | 0.004 ± 0.0006 | 0.004 ± 0.0006 | 0.003 ± 0.0005 | 0.005 ± 0.0009 | 0.006 ± 0.0003 | 0.006 ± 0.0006 |
| Available K (%)   | 0.004 ± 0.0009 | 0.003 ± 0.0009 | 0.006 ± 0.0006 | 0.003 ± 0.0004 | 0.003 ± 0.0008 | 0.006 ± 0.0004 | 0.004 ± 0.0006 |
| Soil organic carbon stock (Mg ha\(^{-1}\) / 30 cm) | 38.98 ± 1.79 | 45.76 ± 2.31 | 47.77 ± 1.79 | 53.81 ± 1.82 | 58.40 ± 3.00 | 74.26 ± 3.57 | 84.86 ± 3.42 |
| N stock (Mg ha\(^{-1}\) / 30 cm) | 5.31 ± 0.46 | 6.31 ± 0.91 | 6.88 ± 0.68 | 6.34 ± 1.00 | 6.33 ± 0.81 | 7.54 ± 1.19 | 8.15 ± 0.84 |
| C/N               | 7.21 ± 0.87 | 7.47 ± 0.34 | 6.91 ± 0.94 | 6.51 ± 0.81 | 9.27 ± 0.39 | 10.43 ± 0.76 | 11.02 ± 0.84 |
conditions, such as change in soil characteristics, nutrient availability, canopy cover etc. of forest that controls the growth of a species. Singh and Singh (1992) showed the capacity of banj oak to ameliorate its surrounding for growth of its own species after establishment. Thadani and Ashton (1995) reported that in several young banj oak sites, presence of adult banj oak trees help in the regeneration of banj oak. Therefore, it could be inferred that banj oak dominance has changed the local environment of forest that enabled banj oak to grow better than pine. M. nagi, a nitrogen fixing tree that enriches the soil with nitrogen could also help in the regeneration of banj oak as it is high nitrogen demanding species.

The density-diameter (d-d) curve is being used by various researchers to represent the population structure of a forest stands (Jacques 1980; Westphal et al. 2006). The population structure indicates the number of seedlings, saplings and adults in any population at a time. This shows the successful or unsuccessful regenerating behaviour of a stand. In the present study, highest density of the banj oak trees was present in lower size classes and density declined gradually as age classes increased. On the other hand pine was found mostly in the higher age classes. The presence of banj oak in lower age classes showed young stage of the species while pine’s presence in mostly higher age classes indicated declining stage (Figure 4). In our study, banj oak population structure was found mostly in zig-zag pattern due to less number of seedlings and saplings than young trees, this may be due to human disturbance such as lopping, wood collection and cattle grazing (Singh 1998). Whereas, Takoli band was exception as higher number of seedlings were reported followed by saplings and trees. At Toli A site, we found wide range of size class but this was also only site were discontinued population structure was reported due to missing 40–50 cm dbh size class. This may be due to death of trees in particular size class or logging. Pine population was spread in various diameter classes from seedling to >50 cm dbh. Toli A, Toli B and Asota reported discontinued structure whereas, at Hathikhan A and Hathikhan B no seedlings and saplings were found. Less number of seedlings and saplings of pine in the study area could be due to less number of pine trees. For the better understanding of regeneration, sites were categorized into four status based on their seedlings, saplings and trees. Although four study sites (Asota, Thath, Toli A and Toli B) indicated a ‘Fair regeneration’ status for both banj oak and pine, the number of young individuals (seedlings, saplings and trees in 10–20 cm dbh size class) for pine was found to be very less in comparison to banj oak, suggesting the lower recruitment of young pine population. At sites Hathikhan A and Hathikhan B, with higher total basal area, the status of banj oak was found ‘Fair regeneration’ but pine was found to be in ‘No regeneration’ stage. In those two sites, pine seedlings and saplings were absent indicating its possible replacement by banj oak in future.

Species diversity is often calculated in the form of an index and measures the biological variety in an ecosystem at species level and also used to investigate ecological change (Singh et al. 2014). Species diversity is affected by stability of community that affects the both microclimate and macroclimate which regulate the diversification of the community (Verma et al. 2004). The species diversity in our study sites (0.77–1.23) is comparable with the values (0.4–2.8) reported by Singh et al. (1994) in Kumaun Himalaya. The values are also comparable with various other studies done in the different parts of Uttarakhand like Uniyal et al. (2010) (0.70–3.08), Pant and Sammant (2012) (0.74–2.66), Singh et al. (2014) (0.66–2.69) and Singh et al. (2016) (1.49–1.86). Simpson dominance index (Cd) values of our sites (0.41–0.67) were comparable with Tiwari and Singh (1985) (0.11 and 0.93) in Kumaun Himalaya. In other parts of Uttarakhand, Cd has been reported by various researchers, Gairola et al. (2011) found 0.12–0.25 in Mandal chopta and Raturi (2012) reported 0.09–0.63 in Rudraprayag. In Western Himalaya Malik and Bhatt (2015) reported between 0.09–0.63. Both Simpson dominance and species diversity indices are inversely related and followed the same in our study sites. Species richness and evenness in the studied sites were not varied much as only few species were present in all the sites. The value is similar to the study done in the Kumaun region by Singh and Singh (1986).

Estimating the different soil parameters revealed the changes in soil characteristics throughout the sites and depths. Organic carbon, organic matter, total nitrogen, C/N ratio, carbon stock and nitrogen stock increased with increase in basal area and density of trees. This increase in soil characteristics could be the result of better nutrient input through litterfall and increase in regenerating banj oak trees. Our values are comparable with various studies done in the Kumaun Himalaya, viz. Khanna and Singh (1984), Thadani and Ashton (1995) and Pandey et al. (2018). The values are also similar to the studies done in other parts of Uttarakhand consisting banj oak and pine forests viz. Gairola et al. (2012) and Joshi and Negi (2015).

Principal component analysis was done to find out the

![Figure 3. Basal area of banj oak and pine with their respective tree density.](image-url)
key information from the multivariate dataset by plotting all the data along with first two principal components (Figure 5). PCA revealed that most of the soil parameters were varied in similar ways except bulk density and porosity which was found in exact opposite direction. Correlation was also calculated to understand the relationship between two or more variables (Figure 6). We found few of the parameters to be highly correlated with each other while others were less or no and sometimes negatively correlated with each other. Organic carbon was significantly correlated with total nitrogen of soil indicated both the important component were increasing simultaneously. Organic carbon and total nitrogen of soil also showed significant correlation with basal area and density of forests sites indicating the increase might be driven by changing vegetation composition in these sites.

Size hierarchy of the present study follows Weiner and Solbrig (1984) that suggests, a few large plants often have greater contribution in forest population’s biomass. This could be easily seen in our study for the pine vegetation, where few old large pine trees contributed significantly in biomass and basal area whereas, in case of banj oak, mostly young trees contributed for
the same. This kind of contribution by banj oak in population makes it positively skewed because of high number of young individuals on right side and less old individuals towards tail. Studies have also shown density and skewness relationship (Obeid et al. 1967; Ford 1975), indicating higher density of young individuals tending towards positively skewed population. This skewness will move towards negative side with time when density in higher girth class will increase.

According to Hu et al. (2015), biomass and carbon density are dependent on the vegetation composition of the forest and it is mostly dependent on trees whereas seedlings and saplings have very less contribution. The regeneration will not only affect the vegetation pattern of the forest but also the biomass and carbon stock. In the present study, total tree carbon density and biomass was higher for banj oak than pine at all the sites (Figure 7). Higher number of banj oak individuals enabled Hathikhan A and Hathikhan B sites to consist highest basal area and carbon stock. Whereas, lowest carbon stock was reported in Toli A site due to its lowest tree density and basal area. Carbon density of banj oak was 55–71% followed by pine 25–32%. Allocation of biomass and carbon stock in both banj oak and pine was very different. In banj oak, above ground biomass (AGB) consists 70% biomass, out of which 33% distributed in bole, 21% to branches and remaining in twigs, foliage and reproductive parts. Whereas in pine, AGB biomass was 80% out of which in bole it was allocated almost double of the banj oak i.e. 62%, it was followed by first order branches that consisted 12% and rest of the biomass was allocated to the second order branches, foliage and reproductive parts. As banj oak has a more developed and much deeper root system than pine, its root system consists 30% of the total biomass while for pine, it is only 20%. Percentage of biomass and carbon stock in banj oak varied from 78% in young 10–20 cm dbh class to 2% in 30–40 cm dbh size class showed the distribution of maximum biomass in young trees. Whereas, in pine trees, maximum biomass (87%) was distributed in greater than 30 cm dbh size class indicating more carbon stock distribution in higher size classes.

Large number of seedlings and saplings indicated that forest has high capacity of regeneration of banj oak and consists continuous source of biomass and carbon stock in near future. The carbon density (47.90–171.40 Mg ha$^{-1}$) was comparable to Jina et al. (2009) who reported 173.3–262.6 Mg ha$^{-1}$ carbon stock in banj oak-pine forests in central Himalaya. Additionally, Rana et al. (1989) calculated 166.80–440.10 Mg ha$^{-1}$ in seven forests and Singh and Singh (1992) reported carbon stock of whole central Himalayan forest to be 250–300 Mg ha$^{-1}$. Our study indicated that present forests consist substantial amount of carbon stock in regenerating banj oak forest and play as an important sink for atmospheric CO$_2$.

**Conclusion**

In our study, we found that banj oak population is expanding and with higher density of young trees,
saplings and seedlings it will thrive in the region. On the other hand, young pine population is declining with lower number of seedlings, saplings and young trees and indicates difficulties ahead for the species. The changing soil parameters (especially carbon and nitrogen) are also playing important role to facilitate the banj oak regeneration. Carbon stock value is also high for the studied forest making them very important for the carbon accumulation. Other studies like nutrient and microbial dynamics in these forests are required to understand the whole phenomena. It is highly suggested that proper protection and management is required to protect these forests.

Acknowledgements

We are highly thankful to the University Grant Commission (UGC) for providing financial assistance. Work has been fulfilled under UGC project F. No. 42-436/2013 (SR) and UGC-BSR fellowship.

Disclosure statement

No potential conflict of interest was reported by the authors.

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