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Tree Regeneration and Vegetation Structure in High Altitudes of Uttarakhand Himalaya, India

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ABSTRACT
The present paper is unique because of the use of modern statistical techniques to assess the species composition, distribution, and regeneration pattern at high altitude Himalayas. Threats to the forest community were also assessed at different survey sites. Stratified random sampling was carried out at 13 high altitude sites of Uttarakhand, from east to west at altitudinal range from 2500m to 4000m a.s.l., irrespective of protected areas. The tree species density was found maximum at Saukherk (665.5±192.3) followed by Mulakherk (586.2±367.7). A total of 16 regenerating tree species were recorded from 13 surveyed sites. The densities of regeneration tree species were low at all the surveyed sites especially towards the glacier; however, saplings were recorded maximum at Hitoli (5176.2±3690.4). PCA was performed to understand the patterns of relationship among various surveyed sites at the landscape level. The tree cover, density, diversity, and richness play a powerful role in discriminating the sites at PC I while the second PC is a gradient of grass and disturbances. The high altitude Himalayas have the anthropoegenic pressure due to tree cutting, lopping, cattle grazing etc. The mean tree cutting, lopping, cattle dung, grazing, and impact of the fire were assessed at different surveyed sites and threat scores were calculated. The Saukherk, Dungiadong are the least threatened sites while the Liwari, Mulakherk and Hitoli are the most threatened sites.

Key words: Vegetation composition, tree species regeneration, Principal Component Analysis.

INTRODUCTION

The vegetation studies in the Himalayan region develop the understanding of the different aspects of forest ecosystem such as species composition, species distribution, regeneration pattern, etc. It is possible to study markedly dissimilar environments and related species in a close range of space in the Himalayan region. The high altitude represents a good deal of variation in altitudinal gradient, topography, and climatic condition. There is vast volume of literature on forest ecosystem in Uttarakhand Himalaya. In forested area, Singh et al. (2015) has carried out vegetation status and plant diversity of chandrabadani oak forest along anthropogenic disturbance gradient in Garhwal Himalaya, Uttarakhand, India. In Kempty range of Mussoorie forest division, Raina et al. (2009) has studied soil and vegetation in relation to parent material of Garhwal Himalayas. Kumar et al. (2010) has conducted a study in *Pinus roxburghii* forest in the district of Tehri Garhwal to assess the effect of altitude on soil characterstics, species composition and volume. With reference to subtropical forest, Kharkwal and Rawat (2010) have investigated the vegetation structure and composition of Nainital catchment in Kumaun region of central Himalaya. A detailed study was conducted in the Haat Kali sacred grove in Pithoragarh district (Singh et al. 2010). In 2011, the impact of *Lantana camara* invasion on basal area cover, density, frequency and abundance of various plant species was evaluated by Dobhal et al. (2011) on riparian vegetation of Nayar region in Garhwal Himalaya. On the basis of canopy cover, tree density and light attenuation, Pokhriyal et al. (2012) assessed the disturbance level in Saklana forest range of Tehri Garhwal and analysed its impact on species composition and diversity. Similarly, Singh et al. (2015) has carried out a study of vegetation status and plant diversity of an oak forest along anthropogenic disturbance gradient in Garhwal Himalaya. In order to provide a better management, Pandey and Lodhiyal (2015) have studied that deals with the vegetation structure and regeneration of van panchayat forests in Kumaun Himalaya. For mapping the spatio-temporal patterns in vegetation trends, Mishra and Chaudhuri (2015) conducted seasonal trend analysis on MODIS NDVI time series data (2000-2014), also examined its association with altitudinal gradient and land use land cover

dynamics. The anthropogenic disturbances and their impacts on the vegetation in Kedarnath wildlife sanctuary, Western Himalaya has been assessed by Malik et al. (2016) with reference to disturbance parameters such as density, total basal area of cut stumps, lopping percentage and grazing intensities. In contrast, Bhat et al. (2020) has estimated the phytosociological attributes of woody vegetation along altitudinal gradient of Kedarnath wildlife sanctuary in western Himalaya, India. These intensive studies have largely been conducted at specific sites in smaller forest stands and therefore many findings may have limited application in exploring relationships between different attributes of vegetation at the landscape level.

General understanding of vegetation and also of patterns, if any, in different vegetation attributes at the landscape level is of fundamental importance not only from the point of view of plant ecology but also from the perspective of gaining an understanding of patterns in relationships between plant and animal communities. It is, therefore, desirable that ecological studies which attempt to explore the factors governing abundance and distribution of different animal species at the micro or macro level should also take into consideration underlying factors governing the plant communities and their different attributes.

Field surveys, conducted at 13 high altitude forest patches to assess the vegetation structure and provided an opportunity to gather extensive data on vegetation, which could be used to develop an understanding of variation in general vegetation across different sites. It was presumed that such an understanding would help explore patterns of vegetation distribution at the landscape level. The present study was designed to understand the vegetation structure at the higher altitude of the Himalaya. The data presented are unique in the sense that such extensive vegetation sampling at 13 sites spread over an area of 51033 km^2 has been attempted for the first time in Uttarakhand and very occasionally in India.

STUDY AREA

The vegetation study was carried out from east to west, at a higher altitude ranging from 2500 m-4000 m a.s.l. irrespective of the protected areas. Data were collected from October 2003 to December 2006 in 13 forest patches of Chamoli, Bageshwar and Uttarkashi districts of Uttarakhand state (77° 34' 27" E to 81° 02' 22" E and 28° 53' 24" N to 31° 27' 50" N; Fig. 1 and Table 1). The surveyed sites are having a temperate climate. Maximum rainfall occurs from mid-June to September, and during August highest rainfall is recorded. Vegetation of these sites was classified into five categories: (1) temperate forest (from 2000 to 2800 m a.s.l. with common species of *Acer* sp., *Juglans* sp., *Picea smithiana, Pinus wallichiana, Quercus floribunda*, etc.); (2) the subalpine forest (from 2800 to 3800 m a.s.l. with dominated deciduous and evergreen plant species of *Acer acuminatum, Prunus* sp., shrub-like *Ribes glaciale*, *Salix denticulata*, etc. *Abies pindrow*, *Abis spectabilis* and *Taxus baccata,* distributed in Doodh Ganga, Lata Kharak, Sainikhark); (3) the alpine scrublands forest (from 3800 to 4500 m a.s.l. with dominant species of *Rhododendron anthopogon*, *R. lepidotum, R. campanulatum, Juniperus indica)*; (4) the alpine meadows (mainly dominated by herbaceous species including few shrub species such as *J. indica, Lonicera obovata, R. anthopogon, Cassiope fastigiata, Salix hylematica* and *Salix rindleyana)*; and (5) Moraines (the characteristic species of moraines are *Saxifraga pulvinaria, S. hemisphaerica,* and *Androsace globifera*).

METHODOLOGY

Data collection

Intensive vegetation studies were carried out at different surveyed sites in Uttarakhand Himalaya. A total of 405 sampling plots were established at 13 sites. The plots were established systematically at 100 m intervals along forest trails. To avoid sampling the relatively disturbed vegetation along trails, plots were located at least 10 m inside on either side of the trail.

Tree species and their individuals were counted in a 10 m radius circular plot for density, diversity, and species richness estimation. Tree cover was measured using the grided mirror of 25 x 25 cm in four directions around the circular plot. The mirror was kept horizontally at 1.25 m above the ground level and grids which were covered more than 50% by foliage were counted and expressed as percent tree cover. All shrub species and their individuals

Figure 1. Map of the study area showing the surveyed locations in Uttrakhand Himalaya

Table 1. Details of areas surveyed from January 2004 to December 2006

Site code	Site	District	Status	Altitude (m)	GPS location	Dominating vegetation	Sampling plots number
1	Tungnath	Chamoli	KWLS	3200-3500	30°49' 219" E 79°22' 07" N	*Abis pindrow* *R. campanulatum*	15
2	Saukhark	Chamoli	KWLS	3000-3400	30°47' 801" E 79°21' 817" N	Q. semicarpifolis, *R. campanulatum*	43
3	Madhmaheshwer	Chamoli	KWLS	2500-3500	30°63' 171" E 79°22' 187" N	Alpine medows *Q. semicarpifolia*	50
4	Bansinarayan	Chamoli	VP	3200-3800	30°53' 894" E 79°41' 6383 N	Alpine medows *Q. semicarpifolia*	30
5	Mulakhark	Chamoli	VP	2500-2800	30°53' 8443 E 79°44' 073 N	*Q. semicarpifolia*	10
6	Himtoli	Chamoli	NDBR	3000-3600	30°50' 8213 E 79°75' 7793 N	*A. pindrow, T. bacccata,* *B. utilis*	30
7	Latakherk	Chamoli	NDBR	3000-3900	30°29' 8143 E 30°29' 8143 E	*B. utilis, R. campunalatum*	45
8	Belta	Chamoli	NDBR	2900-3200	30°29' 9363 E 79°44' 3973 N	*Pinus wallichiana,* *Q. semicarpifolia*	25
9	Dwali	Bageshwer	NDBR	2599-3000	30°17' 5993 E 79°44' 3973 N	*T. baccata, A. pindrow,* *B. utilis*	30
10	Kafhni	Bageshwer	NDBR	2900-3500	30°18' 2363 E 30°18' 2363 E	*Vibernum* sp, *R. arborium*	25
11	Dungiyadong	Bageshwer	NDBR	2500-2800	30°17' 7373 E 79°02' 4583 N	*Q. semecarpifolia, B. utilis*	30
12	Liwari	Uttarkashi	GPVWLS	3400–3600	31°10' 4733 E 79°02' 4583 N	*Q. floribunda,* *Q. semecarpifolia*	40
13	Her-Ki-Dun	Uttarkashi	GPVNP	3400–3600	31°05' 8473 E 31°05' 8473 E	*Q. semecarpifolia*	32

Abbrevation: KWLS- *Kedarnath Wildlife Sanctuary*, NDBR- *Nanda Devi Biosphere Reserve*, GPVWLS- *Govind Pashu Vihar Wildlife Sanctuary*, GPVNP= *Govind Pahsu Vihar National Park*, VP- *Van Panchayat.*

were counted in a 3 m radius circular plot. Shrub height was measured using a measuring tape. Shrub cover was measured by ocular estimation in 5 equal shrub cover categories of 0-20, 21-40, 41-60, 61-80, and 81-100%. Regenerating tree species and their individuals were also counted in a 3 m radius circular plot at each sampling point

The ground cover composition was quantified by laying four quadrates of 0.50 m x 0.50 m dimension at four locations within a 10 m circular plot. All grass and herb species and their individuals were counted within each plot. Data on various disturbance attributes were also collected at each sampling plot. Several cut and lopped trees and several cattle dung piles were counted within a 10 m radius circular plot. The presence/absence of fire around the sampling point was also recorded.

Data analysis

The density of trees, shrubs, regenerating trees, herbs, grasses, and individual species was calculated for each sampling plot using the formula:

D = No of Individual/Area.

Density values for each layer as well as individual species for each plot were added together to calculate mean densities and standard deviation for different sites. Species diversity and richness of trees, shrubs, herbs, and grasses for each plot were calculated by using Shanon–Weiner Index (*H'*) for species diversity and Margalef's index (*RI*) for species richness using the formula:

$$H' = - \Sigma pi \times \log pi$$

$$RI = S-1/ \ln N$$

where pi is the proportion of i^{th} species in a sample, S is the number of species in sample and N is the number of total individuals. These values were used for the calculation of mean diversity and richness for different sites.

Ordination of habitat variables and sites was performed using Principal Component Analysis (PCA). For ordination, all the sampling plots of 13 sites were pooled together and considered as one sample. The data about habitat variables and vegetation attributes were organized in a sample-variable and sample-species abundance matrix. These matrices were subjected to Natural log and Arcsine transformation to improve normalcy in the data. The transformed data were then standardized by calculating the mean and standard deviation of each column of the data matrix following Zar (1984):

$$S = \frac{a - \text{mean}}{\text{Standard deviation}}$$

Where a is the transformed value of each cell of the matrix.

The main objective of performing PCA was to identify general gradients in the vegetation of Uttarakhand and to ordinate the sites. The first PCA was performed on the data matrix of 37 habitat variables to extract few un-correlated components. *Q*-mode analysis was performed for the ordination of sites. Data were transposed in such a manner that the sites (SU's) were at the variable space and the entire habitat variables were at the site space. All the sites were arranged in two-dimensional space. Gradients (habitat variables) were already identified by *R* mode analysis. The arrangement of sites was explained according to the first two components, which explained the maximum variation in the data set. All factor analyses were performed using the computer program SPSS (Norusis 1990).

Threat scores were calculated by adding up all the threats for each site. The score 1 showing the minimum threat while the score 13 is showing the maximum threats.

RESULTS

Density, diversity, and richness of tree species

Table 2 presents the values of mean tree cover (%), density, diversity, and species richness for each site. The mean tree cover (%) was maximum in Mulakherk (52.12±4.29) followed by Dungiyadong (45.06±3.46) and it was minimum at Tungnath (4.46±2.6). Tree species density (Mean±SD) was maximum in Saukherk (665.5±192.3) followed by Mulakherk (586.2±367.7) and it was minimum at Kafni (24.23±11.68). Mean tree species diversity was maximum at Dungiyadong (0.48±0.02) followed by Mulakherk (0.46±0.06) and it was minimum at kafni (0.06±0.02). The mean tree species richness was found to be maximum at Mulakherk (1.43±0.14) and it was minimum at Tungnath (0.18±0.08). The results were found to be significant for mean tree cover ($F_{12\ 392}=114.3$ $p<.000$) and tree richness ($F_{12\ 391}=5.38$ $p<.000$).

Table 2. Tree species density, diversity, richness and %cover at different sites of Uttrakhand Himalaya

Sites	Cover (%)	Density (individuals/ha)	Diversity (*H'*)	Richness (*RI*)
Tungnath	4.46±2.6	55.2±20.9	0.06±0.02	0.18±0.08
Saukherk	31.57±4.55	665.5±192.3	0.18±0.023	0.31±0.04
Madhmaheshwer	26.3±3.4	276.43±38.1	0.13±0.02	0.27±0.05
Hitoli	35.5±2.9	485.14±33.7	0.31±0.01	0.54±0.04
Bansinarayan	13.56±3.08	107.204±10.6	0.04±0.017	0.07±0.03
Mulakherk	52.12±4.29	586.2±367.7	0.46±0.06	1.43±0.14
Dwali	35.07±3.8	417±99.46	0.33±0.035	0.79±0.08
Kafni	4.0±2.02	24.23±11.68	0.03±0.02	0.09±0.05
Dungiyadong	45.06±3.46	553.48±142.4	0.48±0.02	1.07±0.07
Latakherk	21.22±2.65	448.9±62.13	00.12±0.02	0.33±0.04
Belta	15.6±3.05	114.45±30.35	0.21±0.3	0.33±0.08
Her-Ki-Dun	27.62±3.64	304.92±41.9	0.21±0.03	0.43±0.06
Liwari	20.03±3.26	343.34±42.4	0.26±0.03	0.48±0.07

Density, diversity, and richness of regeneration tree species

Table 3 shows that mean tree seedling density was found to be maximum at Hitoli (4067.9±1566.38) and no seedlings were recorded from Kafni. The results were found to be significant (F12 390=6.026 p<0.000). The mean tree seedling diversity was found to be maximum at Dwali (0.09±0.09) and no seedlings were recorded from Latakherk, Belta, Her-Ki-Dun, and Liwari. The results were not found to be significant (F12 392=.9 p>0.57). The maximum mean tree seedling richness was recorded from Mulakherk (0.21±0.16) and the results were also found to be significant (F12 392=2.718 p<0.01). At most of the surveyed sites, no seedlings were recorded as the area is near the timberline, and vegetation is dominated by shrubby trees. Due to the harsh weather condition, no seedlings and saplings are growing.

Table 3 shows the mean tree sapling density, diversity, and richness at different surveyed sites of Uttarakhand. Maximum mean tree sapling density was recorded from Hitoli (5176.2±3690.4) and the results were found to be significant (F12 392 =1.81

Table 3. Regenerating tree species seedling and sapling density, diversity and richness at different sites of Uttrakhand Himalaya

Sites	Density (individuals/ha)		Diversity (*H'*)		Richness (*RI*)	
	Seedling	Sapling	Seedling	Sapling	Seedling	Sapling
Tungnath	188.6±145.9	117.9±95.58	0.018±0.018	0	0.037±0.037	0
Saukherk	153.1±77.26	328.4±103.9	0.01±0.01	0.018±0.008	0.026±0.026	0.024±0.017
Madhmaheshwer	431.5±122.65	453.4±106.9	0.016±0.009	0.015±0.009	0.035±0.02	0.09±0.044
Hitoli	4067.9±1566.38	5176.2±3690.4	0.07±0.24	0.045±0.026	0.13±0.045	0.063±0.032
Bansinarayan	35.39±35.39	0	0	0	0	0
Mulakherk	813.6±425.3	0	0.07±0.05	0	0.21±0.16	0
Dwali	243.9±86.18	2265.07±1277.77	0.09±0.09	0.09±0.026	0.03±0.03	0.21±0.06
Kafni	0	56.59±39.17	0	0	0	0
Dungiyadong	670.86±157.35	884.3±152.41	0.07±0.03	0.14±0.06	0.12±0.07	0.37±0.20
Latakherk	222.19±88.95	503±270.85	0	0.011±0.06	0	0.03±0.02
Belta	127.38±81.38	534.4±153.63	0	0.04±0.02	0	0.11±0.06
Her-Ki-Dun	141.49±67.96	71.14±42.37	0	0	0	0
Liwari	183.5±101.37	0	0	0	0	0

p< 0.05). The tree sapling diversity and richness were maximum at Dungiyadong (0.14±0.06 and 0.37±0.20 respectively), but the results were found to be significant only for the sapling richness (F12 392=2.9 p<0.001).

Overall, five tree species were designated as not-regenerating because they were not established in all three categories: tree, seedling and sapling, accounting for 18.6% of all tree species. In Hitoli and Mulkherk, on the other hand, 18.6% of tree species available in tree and seedling stage were deemed good in status followed by Belta and Tungnath with the percent of 11.2 and 7.5%, respectively. Moreover, in Pindari, 14.9% of tree species proved to be good in status. Two sites, Pindari and Sunderdunga, had 14.9% of tree species that were classed as poor regenerating since they were only present in tree and sapling forms instead of seedling (Table 4).

Density, diversity, and richness of shrub species

Table 5 shows the mean shrub cover (%), height (m), density, diversity, and richness at different sites of Uttrakhand. Maximum mean shrub species cover (%) and height was recorded from Bansinarayan (48.3±4.6 and 224.96±35.13, respectively) and the results were found to be significant for cover and height (F12 392=6.61 p<0.000 and F12 392=.66 p<0.000, respectively). Mean shrub species density was maximum at Her-ki- Doon (13256.1±1907.5) while diversity was found to be maximum at Belta (0.24±0.03). The maximum mean richness was recorded at Mulakherk (0.89±0.14) and the results were found to be significant for shrub species density (F12 391=7.46 p<0.000)

Density, diversity, and richness of herb and grass species

Table 6 shows the mean herb species density at different surveyed sites of Uttrakhand. The maximum mean herb density was found at Bansinarayan (320.17±260.76), while it was found minimum at Latakherk (16.08±3.6). Herb diversity was found to be maximum at Dungiyadong (0.69±0.07) and minimum at Latakherk (0.19±0.11). The mean herb richness was found to be maximum at Mulakherk (1.46±0.22) and minimum at Her-Ki-Dun (0.39±0.04). The results for mean herb density, diversity, and richness were not found to be significant (F12 392=1.336 P>0.195, F12 392=1.06 p>0.386, and F12 392= 1.336 p>0.098, respectively).

Table 7 shows the mean grass density, diversity and richness at different surveyed sites of Uttarakhand. The highest mean grass density was recorded at Liwari (102.8±24.73) and minimum at Dwali (2.03±0.76) while maximum grass diversity was recorded at Liwari (2.78±1.5) and no diversity was recorded from Latakherk, Belta, and Hitoli, and results were found to be significant only for grass density (F12 392=9.89 p<0.000). The mean grass richness was recorded maximum at Belta (0.8±0.8) and no richness was recorded from Hitoli, Bansinarayan, Dwali, Kafni, and Latakherk.

Tree species composition

A total of 27 tree species were identified at all the surveyed sites of Uttarakhand Himalaya. Table 8 provides the density values of individual tree species at different sites in Kedarnath Wildlife Sanctuary, Govind Pashu Vihar, and Nanda Devi Biosphere Reserve. A maximum number of tree species were recorded at Sunderdhunga (n= 13) and the lowest at Tungnath and Hitoli (n=3). *Abis pindrow* occurrence was highest at Hitoli (156.15/ha) while *Rhododendron arborium* occurrence was highest at Saukherk (179.28/ha). *Taxus baccata* occurrence was highest at Hitoli (110.95/ha), while *Rhododendron barbetum* and *Rus parviflora* were recorded only from Saukherk (0.65/ha and 2.6/ha, respectively). The maximum tree of *Betula utilis* was recorded from Latakherk (154.28/ha).

Seedlings and saplings of 16 tree species were recorded from all the surveyed sites of Uttarakhand Himalayas (Tables 8 and 9). Table 8 shows the tree species sapling composition from different surveyed sites and the maximum number of saplings were recorded from Sunderdhunga (n=9) while no saplings were recorded from Bansinarayan, Her-Ki-Dun, Liwari and Latakherk areas. *Betula utilis* shows the maximum density of the sapling at Hitoli (1859.95/ha).

Table 9 shows the maximum number of seedlings at Hitoli, Mulakherk, and Sunderdhunga (n=6). No seedlings were recorded from Kafni, Her-Ki-Dun and Liwari. The maximum number of seedlings were recorded for *Betula utilis* from Hitoli (5910.75/ha)

Table 4. Density (numbers of individuals/ha) of different tree species at all the sites of Uttrakhand Himalaya

Tree species	Tungnath	Saukherk	Madhaheshwer	Hitoli	Bansin-arayan	Mulakherk	Pindari (Dwali)	Kafni	Sunder dunga	Herki doon	Liwari	Latakherk	Belta
Vibernum	4.26^{F}	6.5^{P}	0^{P}	0^{NR}	0 ^{NR}	0 ^{NR}	44.58^{P}	16.56^{P}	3.18 ^{P}	0 ^{NR}	0^{NR}	0^{NR}	7.64^{P}
Sorbaris tomentosa	25.47^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0N^{R}	0^{NR}	0^{NR}	0^{NR}	0^{NR}
Abis pindrow	25.47^{G}	0 ^{NR}	0 ^{NR}	156.15^{G}	0 ^{NR}	0 ^{G}	20.17^{NR}	0 ^{NR}	5.96^{F}	61.31^{NR}	0^{NR}	50.25^{NR}	11.46^{G}
R. arborium	0^{NR}	196.28^{F}	66.01^{F}	0^{NR}	0 ^{NR}	18.57^{G}	41.4^{F}	1.27^{NR}	163.48^{G}	0^{NR}	0^{NR}	8.49^{NR}	0^{NR}
Q.semicarpifolia	0^{NR}	179.28^{G}	167.34^{G}	0^{NR}	32.78^{G}	47.77^{G}	0 ^{NR}	0 ^{NR}	29.72^{P}	0^{NR}	47.79^{NR}	0^{NR}	0^{NR}
Taxus baccata	0^{NR}	7.15^{F}	0 ^{NR}	110.95^{G}	0 ^{NR}	42.46^{G}	40.3^{F}	2.55^{NR}	2.12^{G}	0^{NR}	0.99^{NR}	4.24^{NR}	1.27^{NR}
R. barbatum	0^{NR}	0.65 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}
Rus parviflora	0^{NR}	2.6 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}
Cuprosus torulosa	0^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}	11.46^{F}
Acer sp.	0^{NR}	0 ^{NR}	2.32^{F}	73.96^{F}	0 ^{NR}	29.19 ^{NR}	134.82^{F}	2.55^{NR}	63.69^{F}	0^{NR}	0.99^{NR}	0^{NR}	1.27^{NR}
Viburnum veruosum	0^{NR}	0 ^{NR}	4.6 ^{NR}	0^{NR}	0 ^{NR}	2.65 ^{NR}	0^{P}	0 ^{NR}	0^{NR}	0^{NR}	0^{NR}	0.707^{NR}	0^{NR}
Betula utilis	0^{NR}	0 ^{NR}	8.68	93.48^{G}	80.55 ^{NR}	0 ^{NR}	5.31^{P}	0 ^{NR}	3.18^{NR}	85.99^{NR}	85.59^{NR}	154.28^{F}	11.46^{P}
Prunus cornuta	0^{NR}	0 ^{NR}	0 ^{NR}	7.19^{G}	5.6 ^{NR}	5.31^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}
P. wallichiana	0^{NR}	0 ^{NR}	0 ^{NR}	26.7^{G}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0^{NR}	0^{NR}	2.83^{NR}	84.1^{G}
Populus sp.	0^{NR}	0 ^{NR}	0 ^{NR}	1.02^{P}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}	1.27^{P}
Lyonia sp.	0^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	2.65^{NR}	0 ^{NR}	0 ^{NR}	15.9 ^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}
Ribes alpestris	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	2.65^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}
Q. floribunda	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	13.27^{G}	0 ^{NR}	0 ^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}
Syzium sp.	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	0 ^{NR}	23.35^{F}	1.27^{NR}	9.55^{G}	7.96^{NR}	133.35^{NR}	0^{NR}	1.27^{NR}
Salix sp.	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	0 ^{NR}	2.12^{P}	0 ^{NR}	0^{NR}	0^{NR}	0^{NR}	259.02^{F}	0^{NR}
Alnus sp.	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	0 ^{NR}	1.06^{NR}	0 ^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}
Juglans regia	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	4.25^{NR}	0^{NR}	0^{NR}	0^{NR}	0^{NR}
Aesculus sp.	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	15.9^{P}	0^{NR}	0^{NR}	0^{NR}	0^{NR}
Carpinus sp.	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	39.27^{P}	0^{NR}	0^{NR}	0^{NR}	0^{NR}
Toona siliata	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	0 ^{NR}	1.06 ^{NR}	0 ^{NR}	3.18^{P}	0^{NR}	0^{NR}	0^{NR}	0^{NR}
Maneer*	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	54.95^{NR}	0^{NR}	0^{NR}	0^{NR}
*Jaritha**	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0 ^{NR}	0^{NR}	11.94^{NR}	72.65^{NR}	0^{NR}	0^{NR}

*= *Unidentified Species*; NR= *Not regenerating*, G= *Good*, P= *Poor*, F= *Fair.*

Table 5. Shrub species density (individuals/ha), diversity, richness, cover and height at different sites of Uttrakhand Himalaya

Sites	Cover (%)	Height(cm)	Density (individuals/ha)	Diversity (*H'*)	Richness (*RI*)
Tungnath	22.2±5.8	88.52±9.85	2421.16±491.66	0.05±0.06	0.09±0.05
Saukherk	27.5±4.11	117.28±14.3	5237.8±1590.39	0.30±0.03	0.58±0.07
Madhmaheshwer	27.1±3.26	122.95±13.65	3354.75±792.68	0.29±0.05	0.55±0.06
Hitoli	20.73±2.3	73.09±12.41	7586.8±1233.19	0.19±0.03	0.34±0.06
Bansinarayan	48.3±4.6	224.96±35.13	5577.16±833.58	0.09±0.02	0.23±0.02
Mulakherk	11.5±2.4	89.18±9.37	3183.56±982.27	0.34±0.05	0.89±0.14
Dwali	9.7±1.6	70.23±10.43	2459.1±543.8	0.16±0.03	0.33±0.07
Kafni	12.28±4.08	73.95±18.07	976.2±266.4	0.05±0.02	0.11±0.05
Dungiyadong	26.0±3.5	81.63±8.73	5749.13±1071.4	0.35±0.0.36	0.66±0.07
Latakherk	19.6±3.14	100.86±13.8	3201.8±561.56	0.067±0.02	0.11±0.03
Belta	22.1±4.3	63.34±7.98	5588.9±895.8	0.24±0.03	0.47±0.07
Her-Ki-Doon	34.25±3.03	106.6±13.04	13256.1±1907.5	0.22±0.02	0.37±0.04
Liwari	25.78±3.77	78.38±10.43	4886.9±1124.28	0.14±0.02	0.21±0.04

Table 6. Herb species density, diversity and richness at different sites of Uttrakhand Himalaya

Sites	Density (individuals/m^2)	Diversity (*H'*)	Richness (*RI*)
Tungnath	48.2±3.2 7	0.62±0.04	1.21±.14
Saukherk	26.73±2.86	0.47±0.03	1.05±0.06
Madhmaheshwer	37.28±3.89	0.54±0.061	0.99±0.08
Hitoli	67.26±13.55	0.226±0.032	0.39±0.05
Bansinarayan	320.17±260.76	0.46±0.04	0.98±0.09
Mulakherk	126.3±34.37	0.51±0.068	1.46±0.22
Dwali	65.26±9.9	0.45±0.04	0.82±0.07
Kafni	36.7±2.8	0.38±0.038	0.58±0.07
Dungiyadong	58.9±6.9	0.69±0.07	1.35±3.55
Latakherk	16.08±3.6	0.19±0.11	0.177±0.04
Belta	21.88±3.24	0.39±0.039	0.82±0.09
Her-Ki-Dun	105.6±26.5	0.25±0.02	0.39±0.04
Liwari	148.43±14.89	0.51±0.03	1.02±0.06

Table 7. Grass species density, diversity and richness, at different sites of Uttrakhand Himalaya

Sites	Density (individuals/m^2)	Diversity (*H'*)	Richness (*RI*)
Tungnath	13.46±2.6	0.05±.02	0.11±0.04
Saukherk	4.8±1.01	0.04±.02	0.11±0.04
Madhmaheshwer	13.4±2.95	0.04±.04	0.05±0.02
Hitoli	16.9±3.4	0	0
Bansinarayan	6.97±2.02	0.07±.04	0
Mulakherk	32.1±11.31	0.09±.04	0.15±0.07
Dwali	2.03±0.76	0	0
Kafni	6.56±1.18	0.012±0.012	0
Dungiyadong	9.13±4.2	0.019±0.013	0.06±0.05
Latakherk	6.04±1.56	0	0
Belta	10.84±5.12	0	0.8±0.8
Her-Ki-Dun	60.35±16.4	0.12±0.026	0.16±0.03
Liwari	102.8±24.73	2.78±1.5	0.029±

General ordination

The principal component analysis of habitat variables extracted nine components, which explained a maximum variance of 96.2% in the data matrix. The first PC accounted for 20.24% of the variance while the second and third PC accounted for 17.05% and 16.6% of the variance. The list of the variables along with the loading on the first three components is given in Table 10. The first component was related to the gradient of the tree as it had the highest loading on PC I. PC I was significantly correlated with tree cover, tree density, tree diversity, and tree richness. The PC II represented gradients of grass and disturbance factors. The grass diversity, grass richness, grazing, and tree lopping had high loadings on PC II.

Ordination of sites

Ordination of 13 sites was done by transposing the data matrix of 37 habitat variables. Gradients for the first and second PC were already identified while doing *R*-mode analysis. PC I accounted for about 22.1% variation while PC II accounted for about 17.42 % of the variation. Both components together

Table 8. Density (numbers of individuals/ha) of different tree species sapling at all the sites of Uttrakhand Himalaya

Species	Tungnath	Saukherk	Madhaheshwer	Hitoli	Bansinarayan	Mulakherk	Pindari	Kafni	Sunderdunga	Her-Ki-Dun	Liwari	Latakherk	Belta
Abis pindrow	23.58	0	0	171.16	0	0	0	0	94.36	0	0	0	28.29
Vibernum sp.	94.33	36.09	70.75	0	0	0	58.97	14.15	23.59	0	0	0	226.3
R. arborium	0	187.69	135.06	0	0	29.47	200.52	0	224.11	0	0	0	0
Q. semicarpifolia	0	36.09	218.67	0	0	0	0	0	141.54	0	0	0	0
Acer sp.	0	0	25.72	45.65	0	0	460.09	0	283.08	0	0	0	0
Taxus baccata	0	28.87	0	22.82	0	0	47.18	0	23.59	0	0	0	0
Populas sp.	0	0	0	34.23	0	0	0	0	0	0	0	0	99.04
Betula utilis	0	0	0	1859.95	0	0	23.59	0	0	0	0	0	70.75
Syzizium cumenii	0	0	0	0	0	0	94.36	0	0	0	0	0	0
Salix sp.	0	0	0	0	0	0	70.77	0	0	0	0	0	0
Toona ciliate	0	0	0	0	0	0	0	0	11.79	0	0	0	0
Carpinus sp.	0	0	0	0	0	0	0	0	58.97	0	0	0	0
Aesculus sp.	0	0	0	0	0	0	0	0	70.77	0	0	0	0
Juglans regia	0	0	0	0	0	0	0	0	0	0	0	0	14.14
P. wallichiana	0	0	0	0	0	0	0	0	0	0	0	0	14.14
Excelsa	0	0	0	0	0	0	0	0	0	0	0	0	14.14

Table 9. Density (numbers of individuals/ha) of different tree species seedling at all the sites of Uttrakhand Himalaya

Seedling	Tungnath	Saukherk	Madhmaheshwer	Hitoli	Bansinarayan	Mulakherk	Pindari	Kafni	Sunderdunga	Her-Ki-Doon	Liwari	Latakherk	Belta
Abis pindrow	141.4	0	0	410.78	0	29.48	0	0	23.59	0	0	0	70.75
Vibernum sp.	47.16	0	0	0	0	0	0	0	0	0	0	0	0
Rhododendron arborium	0	86.63	96.47	0	0	29.48	47.18	0	306.6	0	0	0	0
Q. semicarpifolia	0	86.63	295.8	0	31.2	206.3	0	0	0	0	0	0	0
Acer sp.	0	0	12.86	34.23	0	0	212.3	0	82.57	0	0	0	0
Taxus baccata	0	7.21	0	239.63	0	58.95	11.79	0	23.59	0	0	0	0
Betula utilis	0	0	0	5910.7	0	0	0	0	0	0	0	0	0
Pinus wallichiana	0	0	0	57.05	0	0	0	0	0	0	0	0	99.04
Prunus cornuta	0	0	0	22.82	0	0	0	0	0	0	0	0	0
Q. floribunda	0	0	0	0	0	353.7	0	0	0	0	0	0	0
Aager sp.	0	0	0	0	0	29.47	0	0	0	0	0	0	0
Syzizium sp.	0	0	0	0	0	0	35.38	0	70.77	0	0	0	0
Walla regia	0	0	0	0	0	0	0	0	47.18	0	0	0	0
Salix sp.	0	0	0	0	0	0	0	0	0	0	0	188.66	0
Betula utilis	0	0	0	0	0	0	0	0	0	0	0	97.16	0
Cuprosus torulosa	0	0	0	0	0	0	0	0	0	0	0	0	14.14

explained about 35.59% of the variation (Table 11). Figure 2 shows the arrangement of sites in ordination space defined by PC I and II. Four broad clusters are clearly recognizable. Kafni, Saukherk and Madhmaheshwer are present at the lower end of PC I and middle end of PC II, these sites show the low tree cover, tree density, tree diversity, and tree richness with medium to high grass density, richness, and has medium to high grazing as well as tree lopping pressure. The Mulakherk, Latkherk, Belta, and Liwari are present at the middle of PC I but the lower end of PCII, these sites are showing the medium tree cover, tree density, diversity, and richness with low grass density and richness as well as low grazing and lopping pressure. Dungiyadong and Her-Ki-Dun are present in the middle of PC I and PC II, these sites are also having medium tree cover, density, diversity, and richness with medium grass diversity, richness, medium grazing, and lopping pressure. The Hitoli, Tungnath, Bansinarayan, and Dwali are present at the higher end of PC I and the higher end of PC II and having the habitat characteristics of high tree cover, density, diversity, and richness with high grass diversity, richness, and high grazing and lopping pressure.

Anthropogenic pressure

Mean tree cutting, lopping, cattle dung, grazing, and impact of the fire were assessed and Table 12 shows that the maximum number of tree cutting was recorded from Kafni (3.8±3.79) followed by Dwali (2.8±2.3). The maximum mean tree lopping was recorded from Mulakherk (1.9±0.82) followed by Latakherk (1.02±0.24). Since Tungnath is dominated by *Rhododendron companulatum* and no large trees are available, hence no signs of tree cutting and lopping were recorded. The maximum number of cattle dung were recorded from Liwari (6.09±1.08) Followed by Belta (2.88±0.74), grazing pressure was also recorded maximum from Liwari (36.87±6.09) followed by Mulakherk (28.0±11.13). The impact of the fire was recorded only from three sites i.e. Hitoli (26.5±4.2), Mulakherk (4.0±1.4), and Belta (5.2±3.11). Based on different threats, the threat scores were calculated and it was found that Saukhark, Dhungiyadong, and Bansinarayan are the least threatened sites, while the Hitoli, Mulakherh, and Liwari were found to be the most threatened site (Table 12).

Table 10. Principal Component Analysis of the habitat variable showing component loading on three principal components

Variable	PCI	PCII	PCIII
Altitude	-0.722	-0.027	-0.518
Slope	-0.07	-0.07	0.529
Tree cover	0.947	0.149	-0.03
Tree density	0.811	0.116	-0.127
Tree diversity	0.943	0.139	-0.183
Tree richness	0.94	0.112	-0.230
Tree sapling density	0.612	-0.639	0.222
Tree sapling diversity	0.172	0.05	-0.74
Tree sapling richness	0.632	-0.435	0.50
Tree seedling density	0.797	0.112	0.237
Tree seedling diversity	0.550	0.614	0.256
Tree seedling richness	0.558	0.563	0.284
Shrub cover	-0.34	-0.05	0.06
Shrub density	-0.12	0.036	-0.323
Shrub diversity	0.234	0.262	0.039
Shrub richness	0.364	0.317	-0.04
Shrub height	-0.056	-0.016	0.02
Herb density	-0.068	0.365	0.796
Herb diversity	0.217	0.218	0.902
Herb richness	0.179	0.391	0.660
Grass cover	-0.442	0.136	0.605
Grass density	-0.06	0.433	0.398
Grass diversity	-0.007	0.920	0.238
Grass richness	-0.129	0.844	0.251
% Grass	-0.022	-0.013	0.116
% Herb	-0.099	-0.022	0.838
%Litter	0.546	-0.099	-0.295
% Rock	0.136	-0.259	-0.845
% Bare ground	0.118	0.289	-0.09
% Moss	-0.40	0.08	0.227
%Lichen	-0.155	-0.325	-0.093
Tree lopping	0.355	0.845	0.09
Tree cut	-0.249	0.078	-0.01
Cattle dung	0.191	0.362	-0.399
Grazing	0.140	0.889	0.204
Fire	0.218	0.083	-0.033
Distance from nearest human habitation	-0.251	-0.864	0.065
% variation	20.24	17.05	16.6
% cumulative variation	20.05	37.1	53.7

DISCUSSION

The vegetation studies carried out under the present investigations differ considerably from the previous studies on vegetation in Uttarakhand Himalaya. The previous studies on vegetation have focused largely on describing the structure, composition, and

Table 11. Principal Component Analysis of all the surveyed sites in habitat variable space showing component loading

	PCI	PCII
Bansinarayan	0.862	-0.176
Belta	-0.239	-0.535
Dungiyadong	0.268	0.417
Dwali	0.603	-0.163
Her-Ki-Dun	0.128	0.140
Hitoli	0.634	0.241
Kafni	-0.140	0.563
Latakherk	-0.274	-0.375
Liwari	-0.418	-0.616
Madhmaheshwer	-0.610	0.341
Mulakherk	-0.334	-0.301
Saukherk	-0.518	0.571
Tunganath	0.703	-0.055
% Variations	22.1	17.42
% Cumulative variations	22.1	35.59

diversity of a particular forest type (e.g. oak, chir pine, etc.). The present study has looked at high-altitude forests (alpine meadows, subalpine, etc) at different sites with the objectives of assessing the present status of vegetation, and therefore data on various aspects have been presented site-wise. In analyzing data, no distinction has been made between various types of high-altitude forests.

The tree species density was maximum at Bansinarayan while diversity and richness were maximum at Dungiyadong and Mulakherk area. Though Bansinarayan is not a part of Kedarnath Wildlife Sanctuary it still shows the high density of trees and the area is dominated by *Q. semicarpifolia* forest. The upper reaches of the Bansinarayan, dominated by pasture land (alpine meadows) below which the area is dominated by thick bushes of *Rhododendron companulatum*. Mulakherk and Bansinarayan are continuous patch and Mulakherk fall under Nanda Devi Biosphere Reserve. The tree density, diversity, and richness were minimum at Kafni, due to proximity to the glacier it is covered,

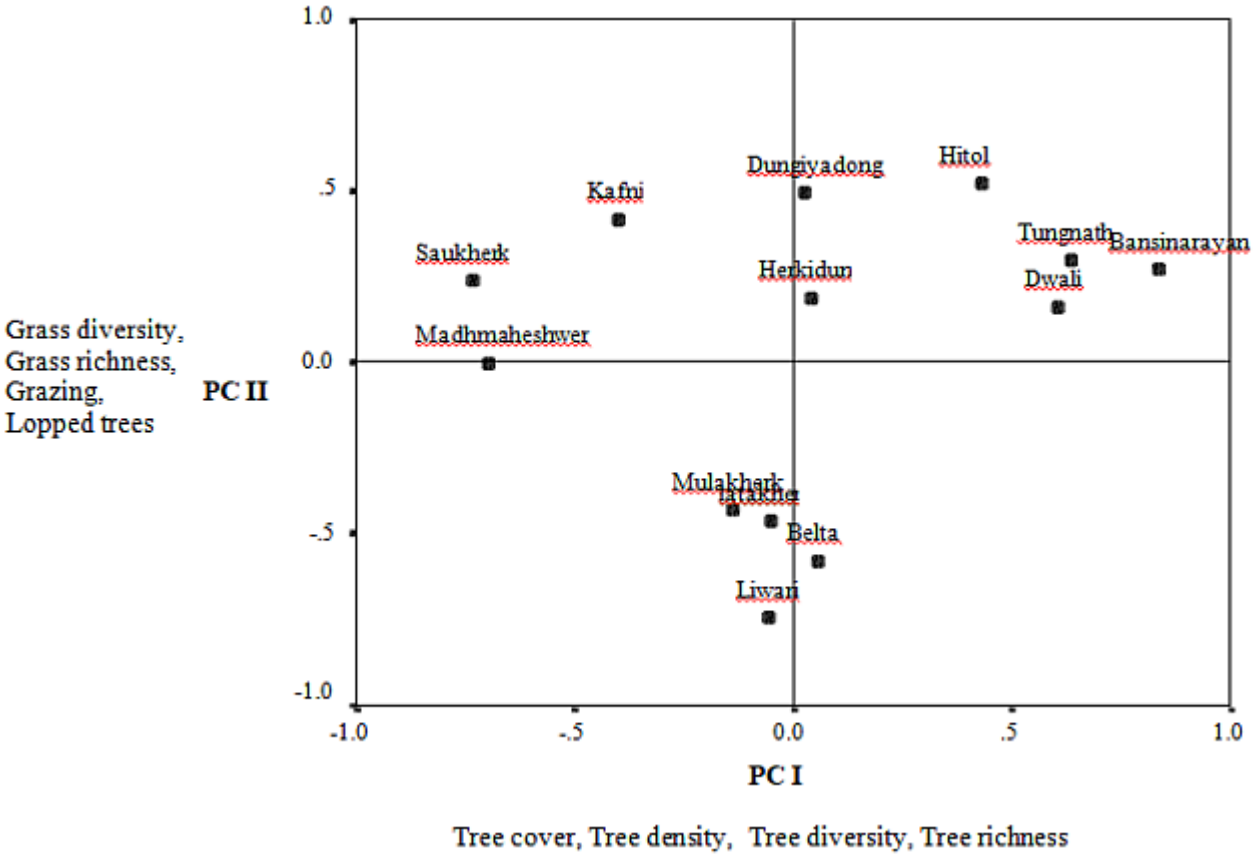

Figure 2. Ordination of sites in habitat variable space

Table 12. Number of cut trees, lopped trees, cattle dung piles per plot, percent grazing, percent of the fire, and threat scores at all the sites of Uttrakhand Himalaya

Sites	Mean density (numbers/ha)					
	Tree cutting	Tree lopping	Cattle dung	% Grazing	% fire	Threat score
Tungnath	0±0	0±0	1.3±0.45	23.33±6.22	0±0	10
Saukherk	0.006±0.005	0±0	0±0	0±0	0±0	1
Madhmaheshwer	0.22±0.007	0.16±0.008	0.36±0.12	11.9±2.4	0±0	8
Hitoli	1.0±0.19	0±0	0±0	0±0	26.5±4.2	11
Bansinarayan	0.3±0.15	0.003±0.003	0.13±0.13	1.16±0.74	0±0	3
Mulakherk	1.0±0.25	1.9±0.82	1.2±0.41	28.0±11.13	4.0±1.4	12
Dwali	2.8±2.3	0.003±0.003	0±0	0.33±0.33	0±0	4
Kafni	3.8±3.79	0±0	0±0	0±0	0±0	5
Dungiyadong	0.006±0.004	0.33±0.33	0.003±0.003	0±0	0±0	2
Lata	0.6±0.23	1.02±0.24	2.2±0.55	0.55±0.28	0±0	6
Belta	0.8±0.30	0.008±0.005	2.88±0.74	10.4±4.56	5.2±3.11	9
Her ki doon	0.25±0.13	0.12±0.005	0.92±0.34	7.5±3.11	0±0	7
Liwari	0.75±0.15	0.59±0.17	6.09±1.08	36.87±6.09	0±0	13

with snow most of the time and lies above the tree line. Due to the fire in past, the sapling density was maximum at Hitoli (Ilyas and Khan 2005), while diversity and richness were maximum at Dungiyadong.

The density, diversity, species richness, and cover of grass and herb layer generally showed inverse relationships with some of the negative correlations being significant such as between grass density and herb diversity, species richness, and cover. While the herb layer density, diversity, and richness increased, grass density, diversity, and richness increased with altitude as at the higher altitude the area is dominated by alpine meadows. Therefore high altitude sites had higher grass diversity. Saxena and Singh (1982) found higher herb diversity in the open-canopy forest than the closed-canopy forests. The negative correlation between tree cover and altitude suggest that generally forest at higher altitude had more open canopy thereby favoring higher growth of herbs than the forest at low and middle altitude sites. The tree species composition and abundance of dominant and co-dominant species at various sites recorded under this study are similar to species composition and abundance pattern for individual species reported by Saxena and Singh (1982).

The maximum density of regenerating species was found at Diwali and Hitoli while the minimum was at Kafni, Bansinarayan, Mulakherk, and Liwari as these regions are dominated by shrubby vegetation such as *Rhododendron companulatum* and alpine meadows (pasture land). Regenerating tree species diversity and richness were again found to be maximum at Dwali, Dungiyadong and minimum at Bansinarayan, Kafni, Latakherk Belta, Herki doon, and Liwari, while sapling diversity and richness was found to be minimum at Tungnath, Kafni, Bansinarayan, Her ki doon Liwari and Mulakherk.

Again for the same region as these sites are near and above figures in the tree line. Hitoli is dominated by *Betula utilis* forest suffered from an incident of forest fire during 2002. The intensity of the fire was so high that its height reached up to 5m. This may be the reason for the high seedling and sapling density in Hitoli as post-fire the regeneration is very high. Maximum shrub cover and shrub height at Bansinarayan while density at Herkidoon. Maximum shrub diversity was at Dungiyadong and richness was high in Mulakherk because these areas are situated at very high altitudes, near the tree line and very few trees are there and whatever trees are available they are present at the lower reaches. Being on the higher side of the alpine meadows forest the Bansinaran, Dungiyadong, and Mulakherk have very high herb density, diversity, and richness, while grass density, diversity, and richness were found to be maximum at Her-Ki-Doon, Liwari, and Belta. Grazing pressure was also found to be maximum at these sites as well.

The ordination carried out under the present investigation is one of the most comprehensive attempts at understanding the patterns of relationship among various surveyed sites at the landscape level.

The tree cover, density, diversity, and richness plays a powerful role in discriminating the sites at PC I while the second PC is a gradient related to attributes of grass diversity, richness, grazing pressure, and tree lopping, near alpine pasture the grazing pressure is high because during the rainy season cattle owners, take their cattle in alpine pastures and stays there throughout the monsoon, and only after the monsoon they leave.

The threat was correlating with the tree species density, diversity, and richness. The regeneration is slow with high anthropogenic pressure. Hence for the management of the different surveyed sites, having higher threats should be given the conservation priorities, by providing the alternative of fuel, fodder, timber and employment to the locals so that the dependency of locals on the natural resources can be reduced. And that is how there should be a balance between the different ecosystems to sustain the maximum biodiversity.

Ethical Approval: No Ethical approval was required to carry out this study. Although permission to work in Uttrakhand Himalayas was already taken from Uttrakhand forest department.

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