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Plant Community Composition and Structure of Chenab Valley in a Part of Nanda Devi Biosphere Reserve

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Abstract

The present paper deals with the vegetation communities and their diversity patterns in Chenab valley, the buffer zone of Nanda Devi Biosphere Reserve (NDBR) in Chamoli District of Uttarakhand, India. A total of 42 sites were selected randomly based on the landform heterogeneity of the area. Eight forest communities with overlap among vegetation types and also various plant associations were noticed through Principal Component Analysis (PCA) following PAST program and two shrub communities identified separately were, *Berberis* and bamboo. The range of density in various forest communities was from 203-545 trees ha^{-1} and total basal area from 17.5-71.7 m^2 ha^{-1}. The range of species richness of tree layer, shrub layer and herb layer was from 2-14, 1-10 and 4-14 and diversity from 0.693-2.304, 0.514-2.052 and 1.202-2.583, respectively. The distribution pattern of trees, shrubs and herbs shows that the species were evenly distributed in most of the sites and the ß-diversity of the present study area is 7.4. *Rhododendron* and *Taxus*, the undercanopy species facilitated the regeneration of *Chimnobambusa falcata*, while the conversion of lower girth class individuals to higher girth class individuals is steady and progressive. Though, evergreen and deciduous species had good population of seedlings and saplings, but the conversion to next girth class was very poor due to the high anthropogenic pressure. The present study reveals that the forest vegetation in Chenab valley is better than that of other parts of Nanda Devi Biosphere Reserve, for which conservation strategies have been discussed in the paper.

Keywords: ß-diversity, community, grazing, Nanda Devi Biosphere Reserve, total basal area

Introduction

The Himalaya is one of the richest biogeographic zones in India and is well known for its ecological, hydrological, aesthetic and socio-cultural values (Mani, 1974). The location, topography and climate of this complex system have endowed it with rich and diverse life form. The large scale surface removal due to geological instability and cyclic climate change has greatly influenced the floral and faunal communities. The disturbance can alter environmental conditions by changing light availability and soil condition, which are mainly due to heavy anthropogenic pressure (Fredericksen and Mostacedo, 2000). The chronic form of disturbance in these forests often led to inadequate recovery of ecosystems due to continuous exploitation of the forests (Singh, 1998). The recurrent anthropogenic intervention such as fuel wood, fodder, litter and non-timber forest products (NTFP) collection, as well as grazing, browsing and trampling largely by livestock can substantially lead the habitat alteration of the species (Pandey and Shukla, 1999).

Garhwal Himalaya has relatively a mixture of dry and moist temperate climate, which influences the growth and vitality of the forests through the water balance in the watersheds. Chamoli District in Uttarakhand state harbors the rich and varied flora, which has been of great attraction for the professional collectors, ecologists and as well as amateur enthusiast. The occurrence of large number of species in the area and richness of the flora has rendered the district a botanical paradise. The lower Chenab valley, a buffer zone of Nanda Devi Biosphere Reserve forms the most prominent ecological boundary, where sub-alpine forest terminates. In many areas the presence of high altitude oak (kharsu oak, *Quercus semecarpifolia*), maple (*Acer caesium*), conifer (silver fir, *Abies pindrow*) and deciduous species (birch, *Betula utilis*) reach up to timberline. The common montane bamboo (*Thamnocalamus spathiflorus*) is prevalent in the canopy gaps (Puri *et al.*, 1989).

The area above treeline is marked by a zone of stunted trees (krummholz) and shrubs with associate species like *Salix*, *Rosa*, *Cotoneaster* and *Berberis*. The structure and composition of high altitude forests in west Himalaya has been described (Champion and Seth, 1968; Singh and Singh, 1992) and richness and diversity of forest ecosystems by several workers (Adhikari *et al.*, 1991, 1998; Bhandari *et al.*, 1997; Dhar *et al.*, 1997; Hussain *et al.*, 2008; Kumar *et al.*, 1997; Kunwar and Sharma, 2004; Rikhari *et al.*, 1991; Saxena and Singh, 1984) in last few decades. The Garhwal Himalaya is witnessed to a faster place of modernization and development due to various activities, *viz.* coming up large scale dam construction, pilgrimage, widening of roads and eco-tourism. Such signs of

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stretch and strain are now discernible in its inhabitants as also the whole environment (Chadha, 1998).

The Nanda Devi Biosphere Reserve (NDBR) in the western Himalayas is one of the important protected areas in India, has two core zones, namely Nanda Devi NP and Valley of Flowers NP. Both the NPs established in 1982 and designated as World Heritage Sites by UNESCO in 1988 and 2005, respectively in the recognition of their biological and cultural diversity. An assessment of the present status of vegetation in the region is important as it will not only enable us to assess the conservation aspects of this unexplored valley, which have recently been included in Nanda Devi Biosphere Reserve, but also to understand the likely impacts of developmental activities in the area for future management of this very important buffer zone.

Materials

Study area

The study area is located in Chenab valley, the buffer zone of Nanda Devi Biosphere Reserve (NDBR) in Chamoli District of Uttarakhand. The Chenab valley and adjacent areas of village Thang are contiguous with Urgam Reserve Forest in southeast and Badrinath Forest Division in northeast. Joshimath Forest Division of NDBR and the area specified for Vishnuprayag Hydel Project are in the eastern boundary of Thang village (Fig. 1). The village Thang, which is spread over the entire study area (*ca.* 20 km^2) with its six winter hamlets, *viz.* Mulia (2050 m), Malia (2100 m), Kanakot (2200 m), Guar (1700 m), Darun-Ghiwani (2700 m) and Danedar (2500 m) is inhabited by 254 families with 1700 souls. According to Champion and Seth (1968) the present study area harbours forests *viz.,* evergreen broadleaved, deciduous broadleaved, coniferous, mixed broadleaved-coniferous and sub-alpine forests. The valley and adjacent forest area rich in endangered and endemic species *e.g.,* Musk deer (*Moschus Chrysogaster*), Himalayan Tahr (*Hemitragus jemlahicus*), Common leopard (*Panthera pardus*), Asiatic black bear (*Ursus thibetanus*), Serow (*Nemorhaedus crispus*), Royles' Pika (*Ochotona roylei*) among mammals and Monal (*Lophophorus impeyanus*), Koklas (*Pucrasia macrolopha*), Kalij (*Lophura leucomelanos*), Snow Partridge (*Lerwa lerwa*) and Himalayan Snowcock (*Tetraogallus himalayensis*) among birds. Although, agriculture has been primary source of subsistence economy for the local people of the area and enjoy unrestricted access due to traditional rights to use the natural resources, such as fuel wood and fodder collection along with non-timber forest products and use the area for livestock grazing. Exploitation of endangered medicinal plants (*Dactylorhiza hatagirea, Podophyllum hexandrum, Picrorhiza kurooa*) and pastel green (foliose lichen, locally known as *Jhula*) are the major concern of management.

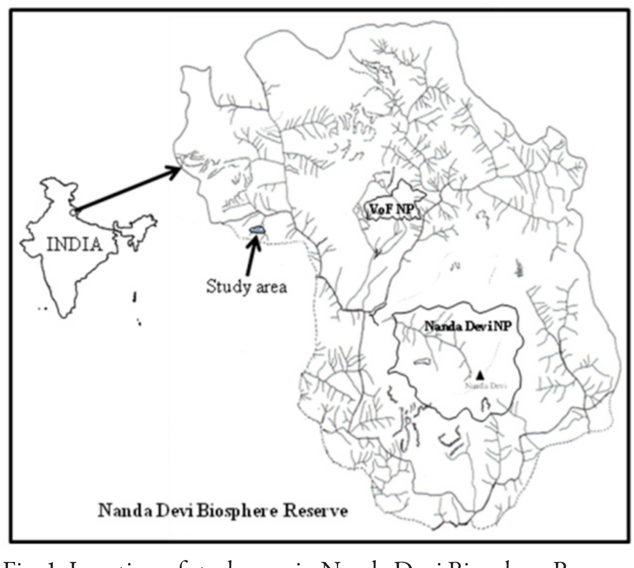

Fig. 1. Location of study area in Nanda Devi Biosphere Reserve, Uttarakhand

The climate of the study area is typically the West Himalayan temperate and alpine type and divided in to five distinctive seasons, *viz.* spring (April), summer (May-June), rainy (July-September), autumn (October-December) and winter (December-March). Precipitation is moderate over most of the year, while concentrated during monsoon and during winters the precipitation was in the form of snow and higher elevation areas experience heavy to moderate snowfall. The rocks in the area fall within the Central Himalayan Zone or Central Crystallines (Heim and Gansser, 1939). With increasing elevation the soil texture becomes finer, especially above 2000 m and a weak podzolization may occur at and around timberline (Singh and Singh, 1992).

Methods

A short reconnaissance trip for 3-4 days was made in the beginning in Chenab Valley and the adjacent forests of Thang village. The characteristic forest types were identified and within each identified forest different sites (1 hectare each) were selected for further data collection based on the extent of forest area. The site specific characters such as altitude, latitude, longitude, aspect, slope, canopy cover and condition of litter and soil were recorded. The data collection was done through systematic random sampling by laying quadrats (Misra, 1968). In each site ten, 10×10 m random quadrats were laid for the enumeration of trees (individuals >31.5 cm circumference at breast height (cbh)). Within each 10×10 m quadrat, 5×5 m quadrat for saplings (10.5-31.4 cm cbh at 1.37 m) and shrubs and four, 1×1 m quadrats for herbs were laid. The density, frequency and total basal area was calculated (Misra, 1968; Muller-Dombois and Ellenberg, 1974), however, Importance Value Index (IVI) was calculated by summing up the relative values of density, frequency and total basal area (Curtis, 1959). The Principal Component Analysis (PCA) was performed to explore the patterns of forest communities and the species distribution following the PAlaeontological STatistics (PAST) program (Hammer, 2002) and the data matrix used for PCA was IVI values of tree species at each site.

The species diversity was determined by using Shannon-Wiener information function (H′, Shannon and Wiener, 1963) and richness (Menhinick's Index) as given in Maguran (1988).

$$H' = -\sum_{i=1}^{s} (pi)\ (\ln pi)$$

Where *s* = the number of species in the sample, *pi* = relative abundance of i^{th} species (ni/N), N = total number of individuals of all kinds, ni = number of individuals of i^{th} species and ln = natural log.

The beta (β) diversity is computed to measure the rate of species change across the stands (Whittaker, 1960).

β diversity = Sc/s

Where, Sc is the total number of species encountered in the entire study area and s is the average number of species per stand.

The data collected for circumference was pooled for deciduous and evergreen species and girth classes were made arbitrarily to know the regeneration status following Ralhan *et al*. (1982) and Rikhari *et al*. (1991).

Results

Community composition

A total of 42 sites were randomly selected in Chenab valley of Nanda Devi Biosphere Reserve. Eight forest communities were identified through Principle Component Analysis (PCA; Fig. 2) and some of them are shown in Photo 1. Although, the overlap among vegetation types and also various plant associations were noticed in the ordination space. The first axis explained 38.82% of the variance and the second axis 11.95%. The first five major forest communities of the study area are shown with 95% ellipses. However, two shrub communities were also recorded from the study area, which were dominated by *Berberis* and *Chimnobambusa*, respectively.

The forest types are separated based on altitudinal gradient and association of tree species (Fig. 2a). It was noticed that eight major forest types occupied the study area *viz.* alder mixed forest, tilonj oak-mixed forest, walnut-mixed forest, mixed forest, kharsu oak forest, kharsu oak-yew forest, kharsu oak-birch forest and kharsu oak-mixed forest. Among these forests the maximum similarity was between kharsu oak dominated forests, while tilonj oak-mixed forest and alder mixed forest similarity was quite low. The species contributing more for tilonj oak-mixed forest were *A. pictum, C. jacquemontii, L. umbrosa, A. indica, C. viminea, L. ovalifolia* and *C. australis*; for alder-mixed forest the species like *R. arboreum, C. deodara, P. pashia, A. pindrow, Q. leucotrichophora and A. caesium* were the major contributor, however, kharsu oak forms the forest with *T. wallichiana* and *B. utilis* separately in subalpine region (Fig. 2b).

Alder-mixed forest

The total tree density of alder-mixed forest was 343 trees ha^{-1}, of which 26% contributed by *Alnus nepalensis* (Tab. 1). The total basal area of the forest was 23.9 $m^2\ ha^{-1}$ and *Q. leucotrichophora* contributed the maximum (37%) followed by *A. nepalensis* (26%; Tab. 1), while the IVI value of *Alnus nepalensis* wasmaximum (79.9). The total snag density of the forest was 33.3±13.3 trees ha^{-1}. The total tree sapling density of the forest was 13.3 individuals ha^{-1} and *Ficus rumphii* was the only species (Tab. 2) and the total tree seedling density was 1047 individuals ha^{-1}, of which *A. pindrow* contributed the maximum (39%) followed by *C. deodara* (33%). The total shrub density was 4760 individuals ha^{-1}, of which *Reinwardtia indica* accounted for 19% followed by *Rubus ellipticus* (18%). The total herb density of the forest was 24 individuals m^{-2} and *Fragaria* and *Galium* contributed the most (Tab. 2).

Tilonj oak-Mixed forest

The total tree density of tilonj oak-mixed forest was 490 trees ha^{-1}, of which *Q. floribunda* contributed 22% and the total basal area was 53.0 $m^2\ ha^{-1}$, of which 39% contributed by *Q. floribunda* (Tab. 1). The dominant tree species was *Q. floribunda* with maximum IVI (82) followed by *Aesculus indica* (43). The total tree sapling density of the forest

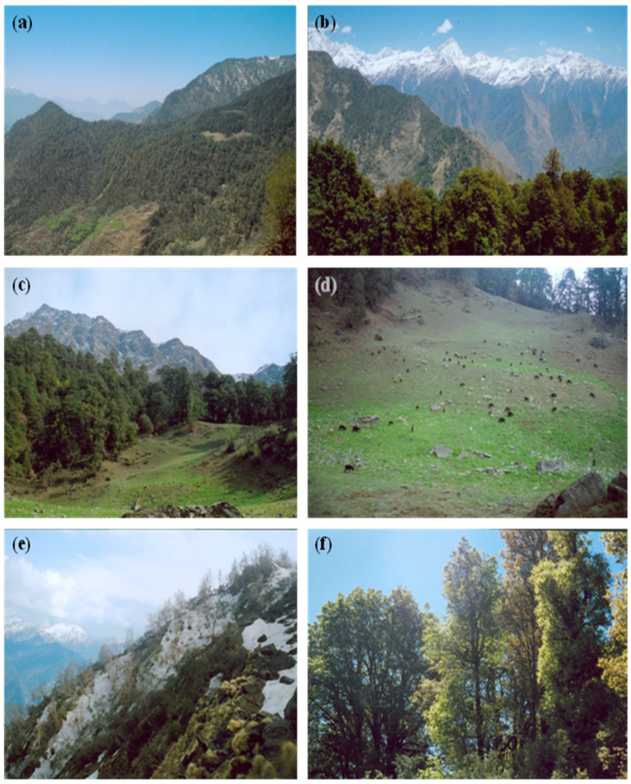

Photo 1. View of Chenab valley with agricultural fields along with evergreen broadleaved forest (a), *Quercus semecarpifolia* forest in the foreground and snow clad peaks on opposite slopes (b), a view of Dhor meadow along with *Quercus semecarpifolia* forest on the edge (c), grazing pressure in Selamghetta meadow (d), timberline forming *Betula utilis* forest in steep slopes (e), and deciduous (*Acer* spp.) forest (f)

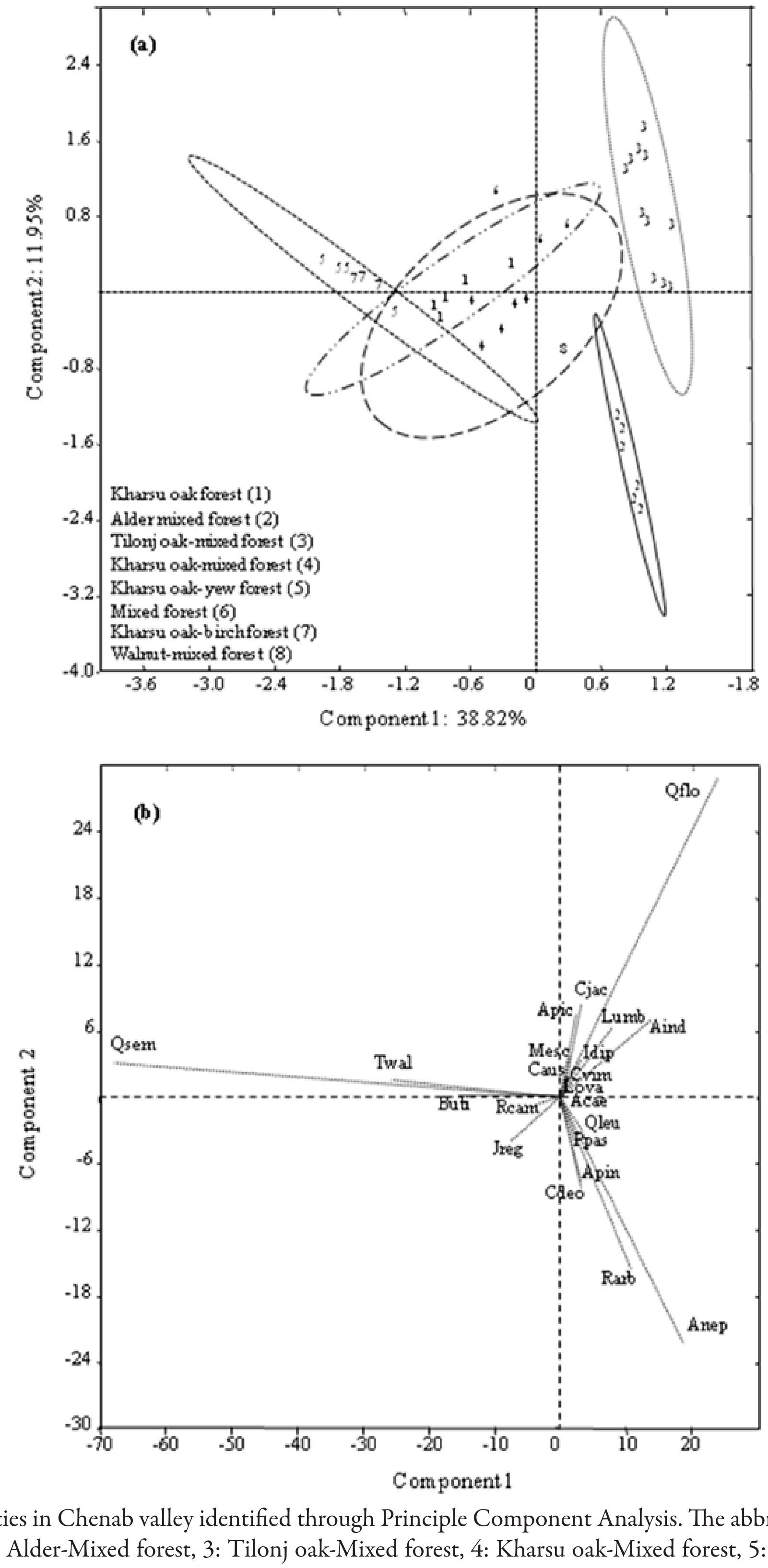

Fig. 2. Forest communities in Chenab valley identified through Principle Component Analysis. The abbreviations used in Fig. (2a) 1: Kharsu oak forest, 2: Alder-Mixed forest, 3: Tilonj oak-Mixed forest, 4: Kharsu oak-Mixed forest, 5: Kharsu oak-Yew forest, 6: Mixed forest, 7: Kharsu oak-Birch forest and 8: Walnut-Mixed forest, in Fig. (2b) Qsem: *Quercus semecarpifolia*, Qflo: *Q. floribunda*, Qleu: *Q. leucotrichophora*, Lumb: *L. umbrosa*, Idip: *I. dipyrena*, Mesc: *Myrica esculenta*, Caus: *Celtis australis*, Rarb: *Rhododendron arboreum*, Rcam: *R. campanulatum*, Twal: *Taxus wallichiana*, Buti: *Betula utilis*, Jreg: *Juglans regia*, Cdeo: *Cedrus deodara*, Apin: *Abies pindrow*, Anep: *Alnus nepalensis*, Ppas: *Pyrus pashia*, Cvim: *Carpinus viminea*, Lova: *Lyonia ovalifolia*, Acae: *Acer caesium*, Apic: *A. pictum* and Aind: *Aesculus indica*

Tab. 1. Density, Total Basal Area (TBA) and Importance Value Index (IVI) of different species in different forest communities

Species	Density (trees ha^{-1})	TBA (m^2 ha^{-1})	IVI
Alder mixed forest			
A. pindrow	30.0 ± 5.8	1.2 ± 0.3	21.6 ± 2.0
A. nepalensis	90.0 ± 13.6	6.2 ± 0.7	79.9 ± 5.5
C. deodara	35.0 ± 14.4	1.4 ± 1.4	23.4 ± 9.6
Q. leucotrichophora	80.0 ± 4.7	8.8 ± 0.4	17.6 ± 6.7
R. arboreum	56.7 ± 11.8	2.2 ± 0.3	49.2 ± 10.2
Others	51.7 ± 9.9	4.2 ± 1.9	108.3 ± 27.7
Total	343.3	23.9	
Tilonj oak - mixed forest			
A. caesium	5.5	0.6	3.1
A. pictum	23.6 ± 9.2	3.1 ± 1.1	12.8 ± 4.9
A. indica	53.6 ± 6.5	10.2 ± 1.5	42.5 ± 5.6
A. nepalensis	32.7 ± 3.5	3.1 ± 0.5	21.7 ± 2.3
C. viminea	8.2	0.5	3.2
C. australis	21.8 ± 0.2	1.5 ± 0.4	11.1 ± 0.7
C. jacquemontii	42.7 ± 9.3	3.2 ± 0.6	20.7 ± 0.8
I. dipyrena	6.4	0.6	4.1
L. umbrosa	69.1 ± 6.8	1.1 ± 0.2	28.1 ± 3.1
L. ovalifolia	9.1	1.5	5.6
M. esculenta	12.7 ± 0.1	1.0 ± 0.1	7.4 ± 2.3
Q. floribunda	107.3 ± 8.0	20.9 ± 1.9	81.9 ± 5.9
Q. leucotrichophora	5.5	0.5	3.8
R. arboreum	49.1 ± 3.3	1.7 ± 0.1	22.9 ± 4.3
S. chinensis	8.2	0.7	3.6
Others	34.5 ± 11.4	2.7 ± 0.5	27.7± 6.7
Total	490.0	53.0	
Mixed oak forest			
A. pictum	70.0 ± 4.1	11.8 ± 3.6	41.8 ± 22.4
Aesculus indica	23.3	6.0	16.4
Juglans regia	33.3	2.7	12.8
Q. floribunda	83.3 ± 8.8	19.4 ± 3.2	63.3 ± 6.3
Q. semecarpifolia	90.0 ± 10.0	22.8 ± 2.8	71.7 ± 9.6
R. arboreum	66.7 ± 0.1	2.0 ± 1.6	29.6 ± 11.1
Taxus wallichiana	60.0 ± 16.3	5.2 ± 1.0	36.7 ± 4.9
Others	56.7 ± 12.2	3.3 ± 0.4	27.4 ± 8.6
Total	483.3	73.2	
Kharsu oak mixed forest			
Acer pictum	20.0	4.2	16.2
A. indica	20.0	3.6	14.4
Betula utilis	12.0	0.5	5.4
C. jacquemontii	62.0 ± 7.6	5.2 ± 0.4	36.8 ± 5.1
Juglans regia	94.0 ± 25.7	11.1 ± 6.6	46.9 ± 10.7
Q. semecarpifolia	112.0 ± 9.7	29.6 ± 4.9	90.5 ± 5.5
R. arboreum	106.0 ± 14.7	3.7 ± 1.5	47.2 ± 3.7
Taxus wallichiana	44.0 ± 0.1	2.6 ± 0.7	22.3 ± 4.8
Others	38.0 ± 9.5	2.6 ± 0.6	20.2 ± 6.9
Total	508.0	63.0	

was 432 individuals ha^{-1}, of which *Litsea umbrosa* contributed 43% and the total tree seedling density was 582 individuals ha^{-1}, of which *A. pictum* contributed 31% and followed by *Q. floribunda* (21%; Tab. 2). The total shrub

Tab. 1. Density, Total Basal Area (TBA) and Importance Value Index (IVI) of different species in different forest communities (cont.)

Species	Density (trees ha^{-1})	TBA (m^2 ha^{-1})	IVI
Kharsu oak forest			
C. jacquemontii	10.0	0.8	7.5
J. regia	94.0 ± 18.6	5.8 ± 0.9	47.2 ± 2.8
L. umbrosa	24.0	0.2	10.8
Q. floribunda	10.0	2.4	13.8
Q. semecarpifolia	122.0 ± 26.2	35.4 ± 7.0	116.9 ± 7.8
R. arboreum	16.0	0.6	15.7
R. campanulatum	62.0 ± 9.5	3.1 ± 0.5	28.4 ± 5.9
T. wallichiana	52.0 ± 18.1	4.7 ± 0.7	39.6 ± 6.3
Others	74.0 ± 22.1	5.7 ± 2.3	20.2 ± 14.5
Total	464.0	58.7	
Walnut - mixed forest			
R. arboreum	100.0	3.0	59.4
J. regia	110.0	13.2	104.8
T. wallichiana	100.0	7.0	77.8
L. umbrosa	100.0	2.0	57.9
Total	410.0	25.2	
Kharsu oak - yew forest			
Q. semecarpifolia	100.0 ± 6.3	32.9 ± 0.5	173.7 ± 5.0
R. arboreum	12.5	0.4	11.1
T. wallichiana	97.5 ± 6.3	8.2 ± 0.5	115.2 ± 5.0
Total	210.0	41.4	
Kharsu oak - birch forest			
B. utilis	103.3 ± 3.3	14.0 ± 4.5	132.2 ± 6.6
Q. semecarpifolia	100.0 ± 0.1	28.7 ± 0.3	167.8 ± 6.5
Total	203.3	42.6	

density was 9604 individuals ha^{-1} and the total herb density was 36 individuals m^{-2}.

Mixed oak forest

The total tree density of the forest was 483 trees ha^{-1}, of which 19, 17 and 14% contributed by *Q. semecarpifolia, Q. floribunda* and *A. pictum,* respectively (Tab. 1). The total basal area was 73.2 m^2 ha^{-1}, of which 31% and 27% contributed by *Q. semecarpifolia* and *Q. floribunda*, respectively. The dominant tree species of the forest were *Q. semecarpifolia* and *Q. floribunda* with IVI values 72 and 63, respectively. The snag density of the forest was 27±13.5 trees ha^{-1}. The total tree sapling density was 395 individuals ha^{-1} and *T. wallichiana* contributed the maximum (42%). The total tree seedling density was 2053 individuals ha^{-1}, of which *T. wallichiana* contributed 44%. The total shrub density was 4307 individuals ha^{-1} and *Indigofera* and *Cotoneaster* contributed the maximum (25% each; Tab. 2). The total herb density was 44 individuals m^{-2}, of which *Bergenia* contributed 14%.

Kharsu oak-mixed forest

The total tree density of the forest was 508 trees ha^{-1}, of which 22% contributed by *Q. semecarpifolia* and fol-

Tab. 2. Density of sapling and seedling of tree (individuals ha^{-1}), shrubs (individuals ha^{-1}) and herbs (individuals m^{-2})

Forest/Community	Density				
	Seedling	Sapling	Tree	Shrub	Herb
Alder mixed forest	1047.0	13.3	343.0	4760.0	24.2
Tilonj oak - mixed forest	581.8	432.0	490.0	9603.6	35.8
Mixed oak forest	2053.0	646.7	483.0	4306.7	44.1
Kharsu oak mixed forest	832.0	314.0	508.0	6024.0	25.0
Kharsu oak forest	2584.0	550.0	464.0	8344.0	39.5
Walnut - mixed forest	2080.0	1360.0	410.0	7240.0	65.0
Kharsu oak - Yew forest	1870.0	660.0	210.0	7450.0	42.6
Kharsu oak - Birch forest	333.3	470.0	203.0	10240.0	31.1
Berberis community	-	-	-	2680.0	31.3
Bamboo community	-	-	-	5900.0	42.6

lowed by *R. arboreum* (21%; Tab. 1). The total basal area was 63.0 m^2 ha^{-1}, of which *Q. semecarpifolia* contributed 47%. The dominant tree species was *Q. semecarpifolia* and had maximum IVI (91). The snag density of the forest was 42±18 trees ha^{-1}. The total tree sapling density was 328 individuals ha^{-1}, of which 46% contributed by *Q. semecarpifolia*. The total tree seedling density was 832 individuals ha^{-1}, of which 30% contributed by *J. regia* and 28% by *Q. semecarpifolia* (Tab. 2). The total shrub density was 6024 individuals ha^{-1}, of which *Chimnobambusa falcata* contributed 36%. The total herb density was 25 individuals m^{-2} and maximum contribution was 20% by *Thymus serpyllum*.

Kharsu oak forest

The total tree density of the forest was 464 trees ha^{-1}, of which 26% contributed by *Q. semecarpifolia*. The total basal area was 58.7 m^2 ha^{-1} and *Q. semecarpifolia* contributed 60% (Tab. 1). The dominant tree species was *Q. semecarpifolia* with maximum IVI (117). The snag density of the forest was 30±21 trees ha^{-1}. The total tree sapling density was 513 individuals ha^{-1}, of which 47% contributed by *Q. semecarpifolia* and followed by *J. regia* (39%). The total tree seedling density was 2584 individuals ha^{-1}, of which *J. regia* contributed 40% followed by *Q. semecarpifolia* (31%) and *T. wallichiana* (29%). The total shrub density was 3906 individuals ha^{-1}, of which *Chimnobambusa falcata* contributed 83% (Tab. 2). The total herb density was 39 individuals m^{-2} and dominated by *Potentilla* and *Iris* (10% each).

Walnut-mixed forest

The total tree density of the forest was 410 trees ha^{-1} and all the species contributed equally to the density. The total basal area was 25.2 m^2 ha^{-1}, of which 52% contributed by *J. regia* (Tab. 1). The dominant tree species was *Juglans regia* with maximum IVI (105). The snags were totally absent in the forest. The total tree sapling density was 1360 individuals ha^{-1}, of which *Litsea umbrosa* occupied 60% (Tab. 2). The total tree seedling density was 2080 individuals ha^{-1} and *Juglans regia* contributed 77%. The total shrub density was 7240 individuals ha^{-1}, of which *Cannabis sativa* contributed 36% followed by *Chimnobambusa falcata* (29%). The total herb density was 59 individuals m^{-2} and dominated by *Potentilla fulgens* (24%; Tab. 2).

Kharsu oak-Yew forest

The total tree density of the forest was 210 trees ha^{-1}, of which 48% contributed by *Q. semecarpifolia* and followed by *Taxus wallichiana* (46%). The total basal area was 41.4 m^2 ha^{-1} and *Q. semecarpifolia* contributed 79%. The dominant tree species was *Q. semecarpifolia* with maximum IVI (174; Tab. 1). The snag density of the forest was 93±11 trees ha^{-1}. The total tree sapling density was 752 individuals ha^{-1}, of which 40% and 32% contributed by *Taxus wallichiana* and *Q. semecarpifolia*, respectively. The total tree seedling density of the forest was 1870 individuals ha^{-1}, of which *Taxus wallichiana* contributed 75%. The total shrub density was 7450 individuals ha^{-1} and dominated by *Cotoneaster* (28%; Tab. 2). The total herb density of the forest was 43 individuals m^{-2} and dominanted by *Iris kumaonensis* (32%).

Kharsu oak-Birch forest

The tree density of kharsu oak-birch forest was 203 trees ha^{-1}, of which *Betula utilis* contributed 51% followed by *Q.*

Tab. 3. Species richness (SR), diversity (H') and evenness (E) of tree, shrub and herb layers in different forests/communities

Forest/Community	Tree			Shrub			Herb		
	SR	H'	E	SR	H'	E	SR	H'	E
Alder mixed forest	9	1.909	0.75	11	2.035	0.696	15	2.953	1.278
Tilonj oak - mixed forest	7	1.826	0.887	18	2.683	0.813	20	3.53	1.705
Mixed oak forest	7	1.875	0.931	6	1.712	0.924	14	2.768	1.138
Kharsu oak mixed forest	7	1.841	0.901	9	1.921	0.758	11	2.47	1.075
Kharsu oak forest	5	1.544	0.936	11	2.252	0.865	16	3.005	1.261
Walnut - mixed forest	4	1.385	0.999	4	1.336	0.951	10	2.165	0.871
Kharsu oak - Yew forest	3	0.877	0.801	6	1.699	0.911	8	2.04	0.961
Kharsu oak - Birch forest	2	0.693	0.999	4	1.292	0.91	6	1.745	0.955
Berberis community	-	-	-	4	0.834	0.576	4	1.239	0.863
Bamboo community	-	-	-	1	-	-	6	1.715	0.926

semecarpifolia (49%) and the total basal area was 42.6 m^2 ha^{-1}, of which 67% contributed by *Q. semecarpifolia* (Tab. 1). The dominant tree species was *Q. semecarpifolia* with maximum IVI (168). The snag density of the forest was 63±35 trees ha^{-1}. The total tree sapling density was 313 individuals ha^{-1} and the contribution of *Q. semecarpifolia* was maximum (65%). The total seedling density was 333 individuals ha^{-1} and dominated only by *Q. semecarpifolia* (Tab. 2). The total shrub density was 10240 individuals ha^{-1} and dominated by *Juniper macropoda* and *Skimmia laureola* (39 and 30%, respectively). The total herb density of the forest was 31 individuals m^{-2} and *Morina* and *Iris* contributed the maximum (26% each).

Berberis community

The total shrub density of the community was 2440 individuals ha^{-1}, of which *Berberis chitria* contributed 79% (Tab. 2). The total herb density of the community was 20 individuals m^{-2} and *Oxalis corniculata* was the dominant species (44%).

Bamboo community

The total shrub density of bamboo community was 5900 individuals ha^{-1} (Tab. 2) and *Chimnobambusa falcata* is the only species.

Among different forest communities the highest density of trees recorded for kharsu oak-mixed forest, tilonj oak-mixed forest and mixed oak forest (483-508 trees ha^{-1}), sapling density for Walnut-mixed forest (1360 sapling ha^{-1}), seedling density for kharsu oak forest (2584 seedling ha^{-1}), shrub density for kharsu oak-birch forest and Tilonj oak-mixed forest (9604-10240 shrubs ha^{-1}) and herb density for Walnut-mixed forest (65 individuals m^{-2}; Tab. 2).

Species richness and diversity

The tree species richness was highest in alder mixed forest (9) followed by tilonj oak-mixed forest, mixed oak forest and kharsu oak mixed forest (7 in each), while lowest species richness was in kharsu oak-birch forest (2; Tab. 3). The tree diversity ranged from 0.693 (kharsu oak-birch forest) to 1.909 (alder mixed forest, Tab. 3). The shrub species richness was highest in tilonj oak-mixed forest (18) and lowest in bamboo community (1). The shrub diversity was highest in tilonj oak-mixed forest (2.683) followed by alder mixed forest (2.035) and lowest in *Berberis* community (0.834, Tab. 3). The herb species richness was highest in tilonj oak-mixed forest (20) followed by kharsu oak forest (16) and alder-mixed forest (15) and lowest in *Berberis* community (4). The distribution pattern of trees, shrubs and herbs shows that species were evenly distributed in most of the sites (Tab. 3).

The β diversity, a measure of rate of species change was observed and it was in following order: tilonj oak-mixed forest (3.9) > kharsu oak forest (2.8) > alder mixed forest (2.5) > kharsu oak mixed forest (1.8) > mixed forest (1.7) > kharsu oak-yew forest (1.3) > walnut-mixed forest, kharsu oak forest and birch forest (1.0). However, the zonal β diversity was highest in upper temperate (5.9) followed by sub-alpine (4.0) and lower temperate (1.9). The β diversity for the entire Chenab valley (1750-3060 m) was 7.4.

Discussion

The alder forest seems to be an early seral stage along riverine areas (Mohan and Puri, 1954), however, silver fir with some broadleaved species seems to be a late seral stage in one of the forest of the present study area in the higher altitudes, appearing as the climax and similar association is also suggested (Parker, 1942). This is mainly due to the fact that these areas become nitrogen depleted and alder is the only species to grow along riverine areas and establish themselves due to their ability to fix nitrogen (Sharma and Ambasht, 1988). In the present study, the density of alder forest is 4-5 times lower than the values reported for Pindari region, Kumaun (Adhikari *et al.*, 1991). The density values of tilonj oak-mixed forests of present study area ranged from 350-720 trees ha^{-1}, which are on the higher side of the values reported for Dharamganga, Asiganga, Bhatwari and Dogadda watersheds (240-370 trees ha^{-1}) by Adhikari and Rawat (2004), however, the values (760-1107 trees ha^{-1}) reported for Kumaun region by Singh *et al.* (1994) are higher than the reported values of present study. The density values of kharsu oak dominated forest in present study ranged from 264-545 trees ha^{-1}, which is higher than that of reported for kharsu oak by Adhikari and Rawat (2004) in Bhatwari and Asiganga watersheds (223 and 230 trees ha^{-1}, respectively). The density values reported for Dharamganga (362 trees ha^{-1}) and Dogadda (372 trees ha^{-1}) catchments by Adhikari and Rawat (2004), timberline kharsu oak forest (340 trees ha^{-1}) in Tungnath by Rai *et al.* (2012),) and for Pindar catchment (480 trees ha^{-1}) by Adhikari *et al.* (1995) are comparable with the present study forests and lower than that of the values reported for Tungnath by Rai *et al.* (2012) at subalpine region (810 trees ha^{-1}).

The density values of mixed broadleaved forest in Pindari region of Kumaun (360-640 trees ha^{-1}) reported by Adhikari *et al.* (1991) are higher than that of the present study and comparable with conifer-broadleaved forest (413 trees ha^{-1}) of Sakteng WS (Adhikari, 2005). The density values of kharsu oak-birch forest (203 trees ha^{-1}) of present study is comparable with the values (205 trees ha^{-1} and 238-250 trees ha^{-1}, respectively) reported for Gangotri region by Adhikari and Rawat (2004) and Nanda Devi National Park by Adhikari (2004). However, the density value of birch forest (700 trees ha^{-1}) in Pindar catchment, Kumaun by Garkoti and Singh (1994) and in Sakteng WS, Bhutan (573 trees ha^{-1}) by Adhikari (2005) are on the higher side of the range reported for present study. The density values reported by Adhikari (2005) in Sakteng Wildlife Sanctuary for oak-conifer forest (144 trees ha^{-1}) and oak forest (270 trees ha^{-1}) are on the lower side of the

Tab. 4. Comparative account of tree density (tree ha^{-1}) and total basal area (m^2 ha^{-1}) from different study sites in west Himalayan region

Forest type	Tree density	Total basal area	Reference
P. roxburghii	540-1630	25.0-47.2	Singh *et al.* (1994)
	335	46.3	Adhikari and Rawat (2004)
	616	43.9	Dhar *et al.* (1997)
Q. leucotrichophora	570	36.8	Singh *et al.* (1994)
	295.0	23.5	Adhikari and Rawat (2004)
	1100	35.3	Dhar *et al.* (1997)
Quercus floribunda	760-1107	33.9-71.0	Singh *et al.* (1994)
	298	56.2	Adhikari and Rawat (2004)
Aesculus indica	280	59.7	Singh *et al.* (1994)
	330	74.5	Adhikari and Rawat (2004)
Cupressus torulosa	270-510	26.6-51.5	Adhikari *et al.* (1998)
Cedrus deodara	370	24.8	Adhikari and Rawat (2004)
P. wallichiana-C. deodara	865	59.9	Kumar *et al.* (1997)
Quercus lanuginosa	660-993	35.8-60.0	Singh *et al.* (1994)
	832	67.7	Dhar *et al.* (1997)
Abies pindrow	350	105.6	Singh *et al.* (1994)
	260	30.4	Adhikari and Rawat (2004)
	258-322	28.9-48.7	Adhikari (2004)
	660	78.9	Dhar *et al.* (1997)
Abies densa	298	27.1	Adhikari (2005)
Quercus semecarpifolia	480	73.0	Singh *et al.* (1994)
	304	38.8	Adhikari and Rawat (2004)
	550	50.8	Dhar *et al.* (1997)
	340-810	30-65.2	Rai *et al.* (2012)
Acer cappadocicum	505	56.3	Garkoti and Singh (1994)
Abies pindrow-B. utilis	230	36.9	Adhikari (2004)
B. utilis-R. campanulatum	700	28.3	Garkoti and Singh (1994)
	205	5.2	Adhikari and Rawat (2004)
	573	28.4	Adhikari (2005)
	238-250	12.7-16.2	Adhikari (2004)
	470	21.4	Dhar *et al.* (1997)
	420-780	6.4-28.5	Rai *et al.* (2012)
R. campanulatum	196	8.6	Adhikari (2005)
	1180	11.7	Garkoti and Singh (1994)

range reported for the present study. The density values reported for *P. wallichiana - C. deodara* and *A. spectabilis-Q. semecarpifolia* forests (2100 trees ha^{-1} and 2090 tree ha^{-1}, respectively) by Kunwar and Sharma (2004) are quite higher than the values reported for present study.

The total density of shrubs in present study forests ranged from 1960 (alder mixed forest) - 23120 shrubs ha^{-1} (kharsu oak forest). The shrub density of all the forests of present study is more or less similar, except tilonj oak-mixed forest, kharsu oak forest and kharsu oak-birch forest, where upper limit of density is too high. These values are comparable with the range reported for mixed-broadleaved forest and silver fir-tilonj oak mixed broadleaved forest (1880-6090 shrubs ha^{-1} and 6630 shrubs ha^{-1}, respectively) by Adhikari *et al.* (1991) and cypress forest (1280-4170 shrubs ha^{-1}) by Adhikari *et al.* (1998). The shrub density values reported by Adhikari (2005) for oak-conifer forest and conifer-broadleaved forest (6497 and 6661 shrubs ha^{-1}, respectively) of Sakteng WS, Bhutan are also comparable with the present study forests, while the values of oak forest (1496 shrubs ha^{-1}) are on the lower side of the range reported for present study forests. A comparative account of density is given in Tab. 4.

The total basal area in alder mixed forest of present study area ranged from 14-34 m^2 ha^{-1}, which is quite lower than the basal area reported for alder forest in Pindar catchment, Kumaun Himalaya (Adhikari *et al.*, 1991). The total basal area of tilonj oak-mixed forest in the present study ranged from 40-70 m^2 ha^{-1}, which is comparable with the total basal area reported for tilonj oak forest in Dharamganga, Bhatwari and Dogadda watersheds (49-65 m^2 ha^{-1}) by Adhikari and Rawat (2004) and also comparable with the range reported for Kumaun Himalaya (34-71 m^2 ha^{-1}) by Singh *et al.* (1994). However, the total basal area values for tilonj oak-mixed forest reported by Adhikari and Rawat (2004) in Dharamganga and Asiganga watersheds (34-36 m^2 ha^{-1}) are lower than that of present study forest.

The total basal area of kharsu oak forest in the present study ranged from 42-78 m^2 ha^{-1}, which is higher than that reported by Adhikari and Rawat (2004) for Dharnmaganga, Bhatwari, Asiganga and Dogadda watersheds (40, 41, 36 and 36 m^2 ha^{-1}, respectively), however, comparable with the values reported by Adhikari *et al.* (1995) for kharsu oak forest in Pindar catchment, Kumaun Himalaya (76 m^2 ha^{-1}) and subalpine kharsu oak forest by Rai *et al.* (2012) in Tungnath (65.2 m^2 ha^{-1}). The total basal area of kharsu oak-birch forest is on the higher side of the range reported for present study forest than that of birch forest by Adhikari (2004) in Nanda Devi NP (13-16 m^2 ha^{-1}), Adhikari and Rawat (2004) in Gangotri watershed (5 m^2 ha^{-1}) and Singh *et al.* (1994) in Pindar catchment, Kumaun Himalaya (23 m^2 ha^{-1}), as these are pure birch forests. The total basal area values of present study forests ranged from 18-72 m^2 ha^{-1} are comparable with the values reported for the forests of Kumaun Himalaya (23-61 m^2 ha^{-1}) by Rikhari *et al.* (1991) and 21-84 m^2 ha^{-1} for tropical and temperate forests of the world by several workers (Dabel and Day, 1977; Duvugneaud and Denaeyer De-Smet, 1970; Franklin *et al.*, 1979; Reiners, 1972; Rochow, 1972). Similarily, the total basal area reported by Bhandari *et al.* (1997) for temperate forests of Garhwal Himalaya (15-60 m^2 ha^{-1}) is comparable with the present study forests, while the density (320-2080 trees ha^{-1}) is quite higher than that reported for present study (203-545 tees ha^{-1}). The total basal area values for *P. wallichiana-C. deodara* and *A. spectabilis-Q. semecarpifolia* forests (90 m^2 ha^{-1} and 152 m^2 ha^{-1}, respectively) reported by Kunwar and Sharma (2004) are quite higher than that reported for present study. A comparative account of total basal area of different forests is given in Tab. 4.

The polynomial regression shows that the density of trees decline ($r^2 = 0.52$, $p<0.001$) along an altitudinal gradient (Fig. 3a), while there is no correlation between altitude with density of shrubs and herbs. No correlation was observed between the density of trees, shrubs and herbs. The polynomial regression shows that the total basal area of trees decline ($r^2 = 0.24$, $p<0.01$) along an altitudinal gradient (Fig. 3b). A significant positive correlation ($r^2 = 0.46$, $p<0.001$) was observed between the total basal area and density (Fig. 3c). Similar observations were also made for the forests of Kumaun Himalaya (Adhikari *et al.*, 1991; Rikhari *et al.*, 1997; Singh *et al.*, 1994).

The tree species diversity values (0.69-1.91) of present study forests lie on the lower side of the range reported by several workers (Monk, 1967; Ralhan *et al.*, 1982; Risser and Rice, 1971; Saxena and Singh, 1982) for temperate forests (0.8-3.4) and are less than those reported for moist tropical forests (3.5-5.4) by Knight (1975) and Singh *et al.* (1981). The diversity values are compared with the values reported for high altitude forests by Adhikari *et al.* (1991) and Dhar *et al.* (1997) in Pindar catchment (0.81-3.55) and Askot WS (0.68-2.39), respectively in Kumaun Himalaya and Adhikari (2005) for various forest communities in Sakteng WS, Bhutan (0.19-1.78).

As it is reflected by the β diversity values that these forests form the lower and upper transition zones in the present study area, are comparable with the values reported

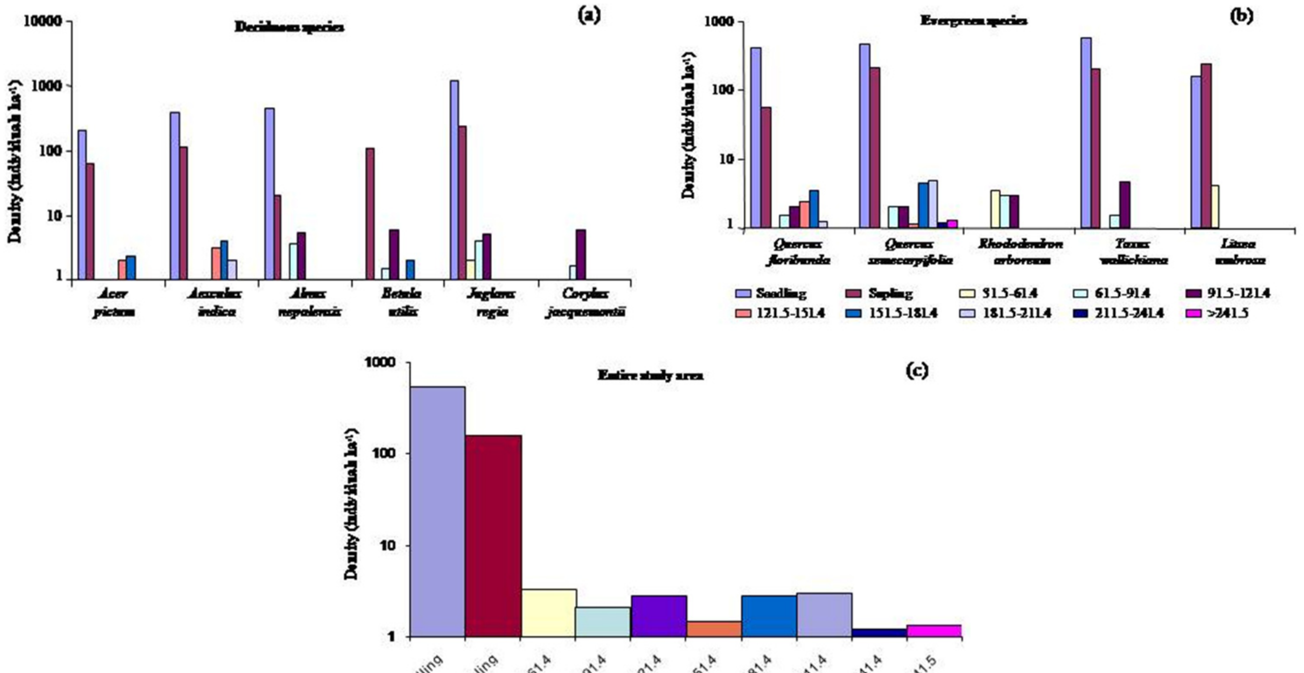

Fig. 3. Population structure of different deciduous (a) and evergreen (b) species and pattern of regeneration in the entire study area

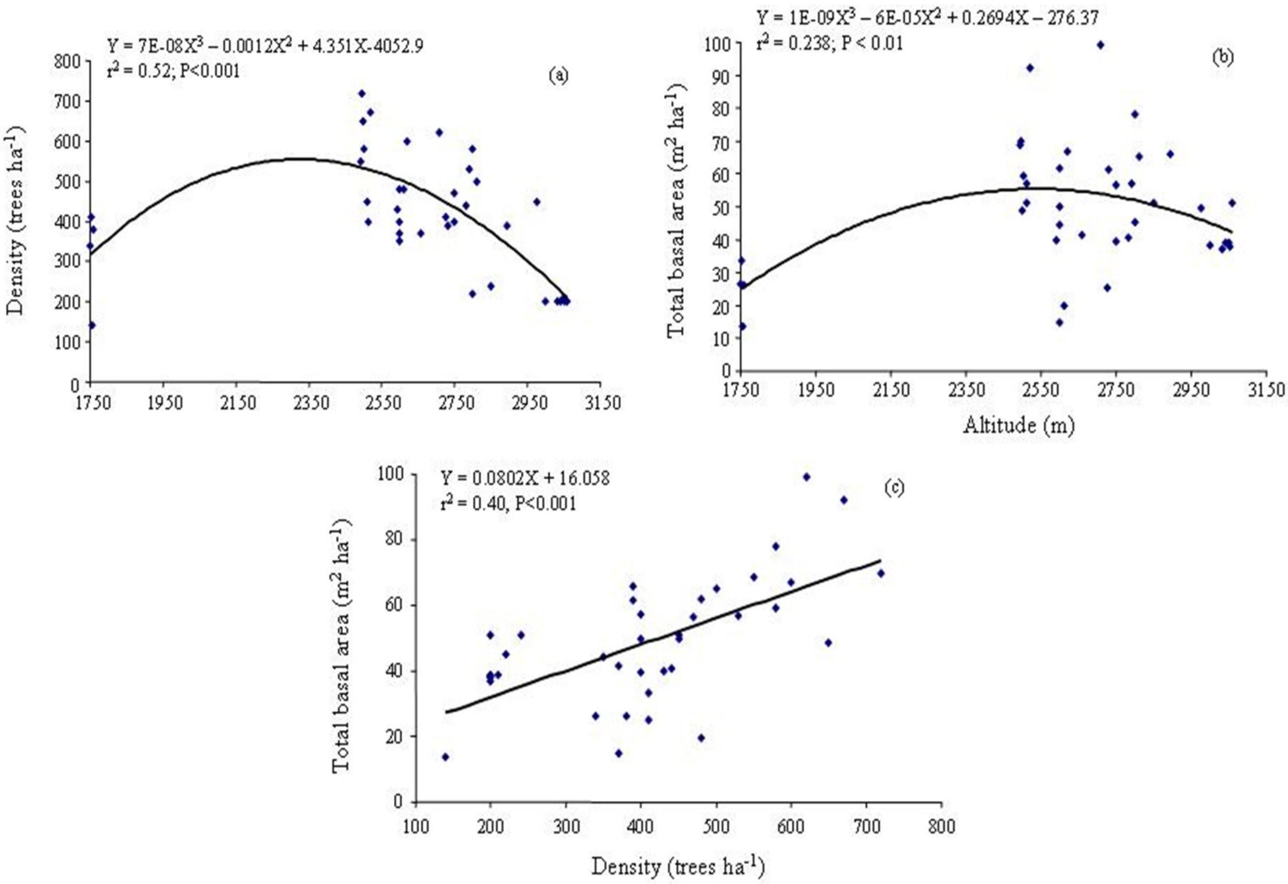

Fig. 4. Relationships between density, total basal area with altitude and total basal area with density in the study area

for Bhagirathi catchment (upper temperate: 4.1 and sub-alpine: 4.5), while too low for warm temperate zone: 3.9 (Adhikari 1997). The β diversity values of present study forests are also well within the range (<2000: 2.6, between 2000-2500: 3.1 and between 2500-3000: 5.5; except >3000m: 10.0) reported along an altitudinal gradient in Sakteng WS (Adhikari, 2005). The high β-diversity value in the sub-alpine zone is mainly due to different communities of kharsu oak and also reported for the Sakeng WS in sub-alpine zone that the topography supports the growth of various forest communities. The β diversity values of present study forests are comparable with the values (1.2-2.1) reported for the forests along an altitudinal gradient at and around Nainital by Rikhari *et al.* (1991), and across the gradient of disturbance in oak forests (undisturbed forests: 0.5 and disturbed forests: 2.9) by Upreti *et al.* (1985). The overall β-diversity of the study area is 7.3, which is within the range reported for Nepal (4.8-20.6) by several workers (Kanai *et al.*, 1975; Ohsawa *et al.*, 1975; Schmidt-Vogt, 1990; Yoda, 1967) and lower than that of Kumaun Himalaya (14.5) reported by Singh *et al.* (1994).

Conclusions

In nutshell, the seedlings and saplings of *Betula utilis* and *Q. semecarpifolia* in their own forest have shown good regeneration, while *Abies pindrow* and *Cedrus deodara* proliferated in the area. The broken branches of *Taxus* due to heavy snowfall have led the formation of canopy gaps, which has supported bamboo growth. The alpine meadows above timberline are reservoir of many ecologically and economically (medicinal) important species, which needs adequate research and management. The impact of climatic variability can be seen by the invasion of *Betula utilis* and *Juniperus macropoda* in the meadows. The meadows like Selamghetta, Darkharak and Pilpar have added aesthetic value to the valley and showed a drastic change in plant communities and their composition. Due to heavy anthropogenic pressure in these meadows and nearby forests, which has led the habitat destruction, imposed a threat to the endangered plant species as well as the wildlife of the area. Therefore, it is felt that the livestock grazing can be controlled through the regulatory mechanism i.e. rotational grazing, as it has been a major pressure in the past, to conserve the biodiversity and sustainability of the area with the help of State Forest Department.

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