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Community Structure along Timberline Ecotone in Relation to Micro-topography and Disturbances in Western Himalaya

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Abstract

Four communities, formed as a result of locally varying site conditions, were identified and studied along the timberline ecotone in part of Kedarnath Wildlife Sanctuary (KWS). Communities on the vicinity of pilgrimage site and along gentler slopes were highly disturbed having sharp timberlines, while those located far and in the steep slopes were less affected, forming a little broader transition. The tree density ranged from 340 to 780 trees/ha, while the basal cover of communities varied greatly and ranged from 6.4 to 55.1 m^2/ha. Birch dominated community had lowest basal area among all the communities, while mixed community had the highest. In all the respective communities, from subalpine zone, density and basal area was higher than that of timberline zone. The Importance Value Index (IVI), which used to determine the overall importance of each species in the community structure, of dominant species at timberline was more than 200 in all the communities, except in the mixed community. Influence of the anthropogenic disturbances was apparent on the regeneration performance of all the studied tree species. *Rhododendron campanulatum* was the dominant shrub species of the area and formed krummholz, while distribution of other species varies greatly with forest type. The shrub density decreased from high to low disturbance, while the herbaceous species density increased with prevalence of a few species favoring the high disturbance (grazing). The shrub and herb species richness was higher in the ecotone zone. Some uncommon species like *Balanophora involucrata* and *Aralia cissifolia* were also found at timberline. Three species of Lady's Slipper orchid were reported together from *Betula utilis* community at timberline ecotone.

Keywords: birch, disturbance, Kedarnath Wildlife Sanctuary, regeneration, transition zone, vegetation composition

Introduction

Timberline is the most striking, climatically governed and ecologically important vegetation boundary, which is marked by a change in site conditions and plant communities when crossing the forest limit (Holtmeier, 2003). Timberline not only delineates area of abrupt change in tree morphology (Tranquillini, 1979), but also depicts the effects of abrupt change in climatic conditions. Woody plant species, which subsequently determine many of the ecological conditions, found within forest represented a key biological group for these forest ecosystems (Stapanian *et al*., 1997). At timberline zone structure of plant communities is largely influenced by the frequently occurring disturbances, naturally or due to anthropogenic activities. Apart from disturbances, topography, climate, altitude, aspect and herbivory play a significant role to determine structure of forest communities. All these factors along with forest succession are responsible for spatial heterogeneity of forest structure (Timilsina *et al.,* 2007). The factors acting on plant diversity at fine scale were not the same with those acting at larger spatial scale (Whittaker *et al.,* 2001; Weiher and Howe, 2003). Therefore, understanding towards the dynamics of these forest ecosystems and coupling to other components of the biosphere proved to be important (Shugart *et al.,* 2010).

Any transition zone between the two ecosystems was known to be very sensitive to the biotic and climatic factors, because species are adapted for the microclimatic conditions. These processes were complex and timberline ecotones were not linear climate change indicators, as the response might be a succession of lagged and rapid changes (Alftine and Malanson, 2004; Camarero and Gutiérrez, 2007; MacDonald *et al.,* 1998). Large portion of the past and current literature was dealing with the global distribution of high-altitude forests, with the question of what environmental factors limit tree occurrence at upper limit around the world (Körner and Paulsen, 2004; Tranquillini, 1979; Wardle, 1974). At present, the common thinking is that altitudinal timberlines are currently advancing to higher altitudes such as latitudinal timberlines, which are moving further north in northern hemisphere (Parmesan, 2006; Shugart *et al*., 2001; Weiser and Tuasz, 2007), while this trend have many anomalies, due to its dependency upon local and regional conditions (terrain type, orographic influences, herbivory, disease) and anthropogenic

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influences (Cairns and Moen, 2004; Weiser and Tuasz, 2007). In the current scenario it is interesting to find out the rate at which the timberline may advance in response to global warming (Grace *et al.,* 2002). In case of Western Himalaya it is very difficult to track changes along the timberline, where prevalence of high anthropogenic pressure still remaining for centuries. It is very important to monitor these sensitive areas for future changes due to climate or land use practices, where there is a complete lack of baseline information. The present study deals with small scale heterogeneity in community structure and composition of different forest types along the timberline and their comparison with the respective forests at subalpine zone.

Materials and methods

Study area

The study area is located in Tungnath area (30°29'-30°30'N Lat and 79°12'-79°13'E Long) of Kedarnath Wildlife Sanctuary (hereafter referred as KWS) between 3100-3400 m asl (above sea level) in Uttarakhand, Western Himalaya (Fig. 1). The area forms the upper catchment of the river Alaknanda, a major tributary of Ganga river. The forest of the study area falls under the subalpine one, which gives way to vast alpine meadows beyond the timberline ecotone. Preponderance of shade loving species (*Betula utilis* and *Abies spectabilis*), on north facing slopes and light demanding species (*Q. semecarpifolia* and *R. arboreum*) on south facing slopes with low tree species richness, is the characteristic feature of the subalpine forests along a few other associated species, *viz., Acer caesium, Prunus cornuta, Taxus wallichiana* and *Sorbus foliolosa*. The krummholz formation by *Rhododendron campanulatum* dominates the shrub layer and *Danthonia cachemyriana* is the common grass species, while *Carex* spp. and *Kobresia royleana* represent the major sedges in the region.

Geology, soil and climate

The rocks around Tungnath are mainly mylonitized gneisses, augen gneisses, schists and granites constituting Munsiari Formation (Agrawala, 1973). The weathering bedrocks, that provide the bulk of the loose material in these mountains, are crystalline and metamorphic, with sedimentary deposits of Paleozoic age (Gansser, 1964; Gupta, 1964). The soil texture is sandy loam and acidic in nature with a pH ranged between 4 and 5.

The annual climate of the region can be divided into 3 prominent seasons; long winter (October to April), short summer (May to June) and rainy season (July to September). Mean Annual temperature at the timberline ecotone (3300m) ranged between-8.91 (January) and 25.6°C (May) with an average of 6.65 ± 0.68°C. Mean temperature of the warmest month was 12.56 ± 1.23°C, in July (Fig. 2). Annual precipitation was 2410.5 ± 432.2 mm, of

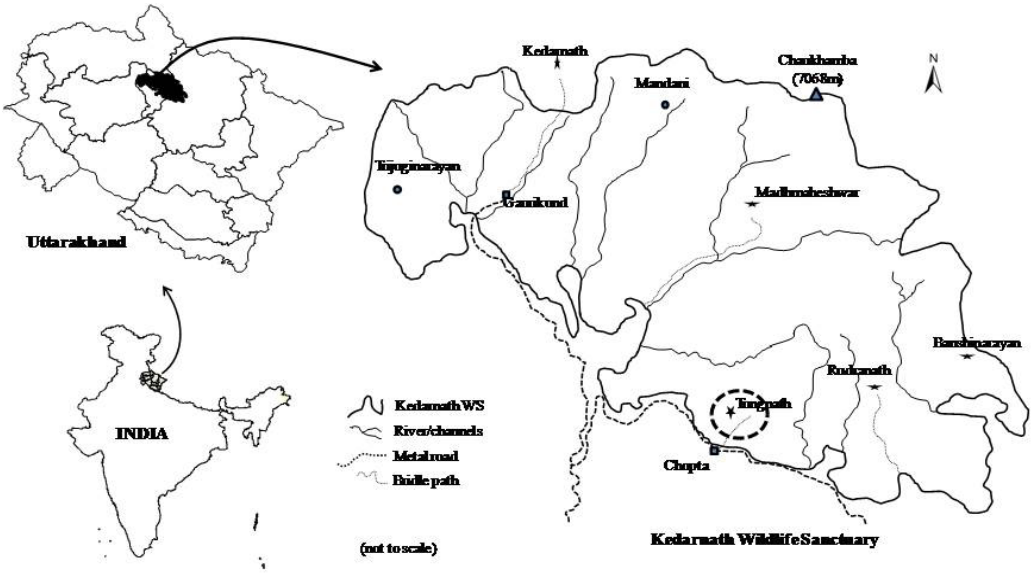

Fig. 1. Map of the study area. Location of Kedarnath WS inside the map of Uttarakhand and Tungnath inside the map of KWS (Kedarnath Wildlife Sanctuary)

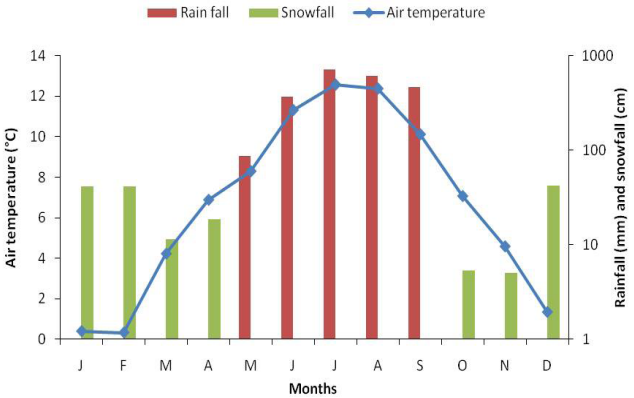

Fig. 2. Mean air temperature, rainfall and snowfall at timberline ecotone in the study area (period 2008-2010)

which 89.5%, recorded during June-September and snow cover lasts for 85 ± 22.7 days/year (Adhikari *et al*., 2011).

Vegetation sampling

Four major communities, *viz., Betula utilis* (birch, Photo 1), *Abies spectabilis* (silver fir, Photo 2), *Quercus semecarpifolia* (kharsu oak, Photo 3) and *Abies-Quercus* (mixed, Photo 4) were identified on physiognomic basis and composition with various levels of disturbance regime at timberline ecotone. Two representative hectare plots (200 m×50 m each) were identified, one at timberline ecotone and the other in subalpine zone (altitudinal 100 m down to timberline ecotone) for each community to find out the difference in species composition and regeneration status. Ten, 10x10 m quadrats were laid within each hectare plot for trees (>20 cm circumference at breast height, cbh) and saplings (<20 cm cbh) and every individual tree and sapling were measured for girth at 1.37 m. Within each 10x10 m quadrat, a smaller quadrat (5x5 m), for shrubs, was laid. Twenty five quadrats (1x1 m) were laid randomly for herbaceous vegetation within the hectare plot. The canopy cover of trees, tree height and canopy depth and canopy width of trees were measured with the help of densitometer, clinometer and measuring tape, respectively. Level of disturbance was assessed qualitatively on the basis of intensity and duration of grazing, livestock, number of sheep and goat, distance from the herder's camp, logging, lopping and fuelwood collection.

Three vegetation layers, *i.e.* tree, shrub and herb were analysed for species richness, density, diversity and regeneration of tree species following Curtis and McIntosh (1950) and Phillips (1959). Total basal area of tree species was used to determine the relative dominance of a species. Importance value index (IVI) was calculated by sum of relative frequency, relative density and relative dominance following Phillips (1959). The Shannon-Weiner diversity Index (Shannon and Wiever, 1963) and Sorensen's similarity Index (Sorenson, 1948) was computed following Magurran (1988), while evenness (equability) was calculated after Pielou (1966). Species richness was determined as the number of species per unit area (Whittaker, 1975).

Results

Variance in disturbance level among communities

High altitude ecosystems are extremely sensitive to anthropogenic and climatic disturbance (extreme events). At the timberline zone tree species struggle for survival, growth and regeneration due to harsh climatic conditions. Disturbance in the form of grazing, especially by cattle (buffalo and cow), horse and mule, has negative effect on tree regeneration and growth of under canopy species. In silver fir community disturbance falls at its maximum level. Maximum herder's camps and seasonal shops, situated nearby, were largely made by fresh logs, in which the consumption of fuel wood was very high. This community

Photo 1. *Betula utilis* community at Timberline

Photo 2. *Abies spectabilis* community at Timberline

Photo 3. *Quercus semecarpifolia* community at Timberline

Photo 4. Mixed community at Timberline

was heavily grazed by sheep, goats and cattle in the entire growing season. Fuelwood consumption, logging and soil erosion was frequent in this community. Kharsu oak community was less affected as compared to the silver fir community, where unproductive domestic cattle were left by

villagers for several months, but camps were away and less fuel wood consumption was noticed. Due to natural barrier (deep gorge) and remoteness, mixed and birch communities were less affected, while occasional grazing by sheep, goats and fuelwood collection was observed in later community. The growth of herbs starts off late due to shady aspect and ends early; hence grazing duration was less. The subalpine zone of the respective timberline communities were less affected, except the silver fir community.

Species richness and diversity

Along the timberline ecotone species richness was highest in birch community followed by kharsu oak and mixed communities. Tree species richness was highest in mixed community and lowest in birch community. In low disturbed birch community, tree species richness was lowest among all communities, but shrub and herb species richness was highest. The species richness of shrub and herb was recorded lowest in the highly disturbed community formed by silver fir. The tree species richness ranged from 3-5 and there was not much variance in terms of species richness, while distribution of species highly depends on the site specific microclimate and reflects through evenness and diversity values.

In the subalpine zone, overall species richness was lower than that of timberline ecotone for any community, while tree species were more in number. Shrub and herb species richness was equal or lower than that of timberline ecotone, except in the highly disturbed silver fir community (Tab. 1). Tree, shrub and herb species evenness and Shannon-Wiener index values were minimum in less disturbed communities and maximum in highly disturbed forests (Tab. 1).

Tab. 1. Species richness, Shannon's diversity index and evenness in different forest communities

Parameters	Taxa	Birch		Silver fir		Kharsu oak		Mixed	
		TL	SF	TL	SF	TL	SF	TL	SF
Species richness	Tree	3	4	4	4	4	5	5	7
	Shrub	12	11	5	8	9	10	9	9
	Herb	60	47	44	53	59	34	54	42
Total		75	62	53	63	72	49	68	58
Diversity	Tree	0.47	0.86	0.76	0.28	0.68	0.99	1.42	1.52
	Shrub	1.57	1.46	0.85	1.61	1.54	1.93	1.69	1.69
	Herb	3.23	2.65	2.52	3.17	3.25	2.85	3.06	2.78
Evenness	Tree	0.43	0.62	0.55	0.20	0.49	0.61	0.88	0.78
	Shrub	0.63	0.61	0.53	0.77	0.70	0.84	0.77	0.77
	Herb	0.78	0.69	0.67	0.79	0.79	0.81	0.77	0.74

Similarity among communities

More than 50% similarity was observed in terms of tree species composition among the communities at timberline. Similarity between kharsu oak and mixed timberlines was the highest (89%), whereas timberline communities, formed by silver fir and kharsu oak, were least similar (50%). Similarity of tree species had broader range (25-83%) along the subalpine forest than in timberline zone due to high species richness. Similarity was found the highest between kharsu oak and mixed communities (100%), whereas similarity of birch forest with all other forests was comparatively low (25-54.5%). Composition of shrub layer in the silver fir community was different from all other communities and similarity with other communities was between 47-61%, because only a few species survived and dominated.

Along the subalpine zone mixed community had maximum similarity (54.5-83%) with other communities, whereas birch and silver fir community had minimum similarity in terms of species composition (25%). The similarity among shrub species was higher (>80%) in most of the communities. Herbaceous species composition was more or less similar among the communities and only a few species were restricted to a particular community and the difference was in the dominant species' density.

Community structure

Tree layer

Micro-habitat specific dominance of tree species was evident in the timberline zone. The result revealed that dominant species had IVI value >200, except in mixed timberline community, formed by silver fir and kharsu oak, while in the subalpine zone IVI was low for dominant species. *R. arboreum* and *S. foliolosa* were present in all communities, while *T. wallichiana* only in kharsu oak community. Trees were sparsely distributed along the timberline ecotone with low density; hence total basal area (TBA) was also low as compared to subalpine forest. Abrupt termination of forest due to high anthropogenic pressure, in silver fir community at timberline, lead to the stand structure with large number of trees in higher girth classes and natural regeneration was absent, hence highest TBA among all communities. Along the timberline ecotone the highest TBA was recorded in the silver fir community (55.1 $m^2 ha^{-1}$) followed by mixed (42.0 $m^2 ha^{-1}$), kharsu oak (30.0 $m^2 ha^{-1}$) and birch (6.4 $m^2 ha^{-1}$) communities, where tree density was 580, 420, 340 and 780 trees/ha, respectively. In the subalpine zone of these communities, TBA was ranged between 28.5 m^2/ ha (birch) to 65.2 m^2/ ha (kharsu oak), while density ranged between 420 trees/ha (birch) and 810 trees/ha (kharsu oak) in these communities (Tab. 2). Due to uneven terrain most of the species had either random distribution and some species had contiguous distribution along the communities. Except birch community, tree density was low along the timberline ecotone as compared to subalpine zone, for silver fir and kharsu oak community, and more or less the same in mixed community.

Tab. 2. Comparative account of density (trees/ha), TBA (m^2/ha) and IVI of tree species in different communities along timberline and subalpine forest

Tree species	Parameters	Communities							
		Birch		Silver fir		Kharsu oak		Mixed	
		TL	SF	TL	SF	TL	SF	TL	SF
Betula utilis	Density	540	310	-	-	10	-	110	70
	TBA	5.7	15.4	-	-	0.1	-	5.5	4.7
	IVI	261.8	175.4	-	-	10.6	-	46.9	25.7
Abies spectabilis	Density	-	-	300	490	10	50	230	250
	TBA	-	-	43.5	59.3	2.7	6.1	20.8	20.9
	IVI	-	-	208.6	268.1	19.0	29.9	110.6	96.0
Q. semecarpifolia	Density	-	-	-	-	280	430	170	230
	TBA	-	-	-	-	26.9	46.5	11.6	24.0
	IVI	-	-	-	-	243.4	167.2	67.2	89.5
Sorbus foliolosa	Density	20	-	100	10	40	-	250	110
	TBA	0.1	-	6.8	0.4	0.3	-	2.4	1.7
	IVI	12.2		62.2	10.2	26.9		64.8	29.0
R. arboreum	Density	20	30	10	10	-	310	20	80
	TBA	0.5	3.5	0.04	0.4	-	11.9	1.8	9.1
	IVI	26.0	43.1	11.4	10.2	-	89.8	10.5	40.1
Prunus cornuta	Density	-	-	10	10	-	10	-	10
	TBA	-	-	4.8	1.1	-	0.2	-	1.1
	IVI	-	-	17.7	11.5	-	6.3	-	6.2
Acer caesium	Density	-	40	-	-	-	10	-	30
	TBA	-	1.4	-	-	-	0.5	-	0.4
	IVI	-	24.1	-	-	-	6.8	-	13.5
Taxus wallichiana	Density	-	40	-	-	-	-	-	-
	TBA	-	8.2	-	-	-	-	-	-
	IVI	-	57.4	-	-	-	-	-	-

Tab. 3. Shrub species density along Timberline ecotone and subalpine forest zones (individuals/ha)

Shrub species	Birch		Silver fir		Kharsu oak		Mixed	
	*TL	*SF	TL	SF	TL	SF	TL	SF
Rubus niveus	720	9080	240	3280	80	40	2360	5480
Thamnocalamus spathiflorus	-	10680	-	-	-	960	-	2920
Spiraea bella	8280	40	-	400	2240	800	160	1160
Rosa sericea	600	1240	40	1560	2480	1360	960	1040
R. campanulatum	400	360	2840	920	520	360	1760	840
Salix denticulata	5720	160	-	-	80	-	40	-
Viburnum grandiflorum	560	880	920	1320	360	200	640	440
Cotoneaster acuminatus	280	800	-	200	440	840	280	880
Rhododendron lepidotum	1880	-	-	-	-	-	-	-
Lonicera myrtillus	-	640	40	240	-	120	240	320
Ribes glaciale	40	1280	-	40	120	-	-	-
Berberis jaeschkeana	40	-	-	-	120	280	160	-
Rosa macrophylla	480	-	-	-	-	-	-	-
Rhododendron barbatum	-	40	-	-	-	80	-	40
Spiraea canascens	80	-	-	-	-	-	-	-

*TL: Timberline and *SF: subalpine forest

Shrub layer

In most of the communities shrub density was lower along the timberline ecotone as compared to the subalpine zone. Lowest shrub density along timberline was recorded in silver fir community (4080 individuals/ha), where *R. campanulatum* was the only species and shrub density reached highest in birch community (19080 individuals/ha). Shrub density along the subalpine zone was the highest in birch community (25200 individuals/ha) and the lowest in kharsu oak community (5040 individuals/ha). *R. campanulatum* was distributed most consistently along the timberline as well as in the subalpine zone. *Rubus niveus* forms dense shrub layer in the shady and moist areas. A large number of regenerating individuals of hill bamboo (*Thamnocalamus spathiflorus*) were found in many localities, however, *Spiraea canescens* and *Skimmia laureola* were found restricted to some pockets only and a rare shrub species *Aralia cissifolia* was found only in birch dominated community (Tab. 3).

Herb layer

Herb density was recorded low along the timberline ecotone. In birch, silver fir, kharsu oak and mixed communities herb density was122.5, 238.6, 179.6 and 193 individuals/m^2, respectively along timberline ecotone. Along the subalpine forest herb density was 152.5, 245.8, 107 and 126.6 individuals/m^2 in birch, silver fir, kharsu oak and mixed communities, respectively. The highest herb density was found in silver fir community in both timberline and subalpine zones. *Trachydium roylei* and *Oxygraphis polypetala* were abundant mainly in grazed and open canopy areas along timberline. Birch community had the lowest herb density due to dense shrub layer and low disturbance (Tab. 4). *Fragaria nubicola* was most frequent and dominant component of the herb layer at timberline compared to subalpine forests. In the area of high grazing pressures and near to herders camp *Polygonum polystachyum*, *Rumex nepalensis* and *Haeckelia uncinata* were the dominant species, while *Senecio alatus, Ainsliaea aptera* and *Polygonum amplexicaule* were the dominant species in moist areas. A rare, parasitic herb, *Balanophora involucrata* was also recorded in birch and kharsu oak communities.

Tab. 4. The dominant herb species along the Timberline ecotone and subalpine forest in different communities. The density (individuals/m^2) values are in parenthesis

Communities	Timberline	Subalpine forest
Birch	*Fragaria nubicola* (16.8) *Viola biflora* (14.8) *Smilacina purpurea* (11.1) *Trachydium roylei* (8.5) *Senecio alatus* (7.1)	*Viola biflora* (37.1) *Fragaria nubicola* (27) *Polygonum amplexicaule* (22.9) *Strobilanthes atropurpureus* (7.1) *Impatiens sulcata* (6.6)
Silver fir	*Circaea alpina* (80.4) *Fragaria nubicola* (28.8) *Galium rotundifolium* (22.5) *Polygonum amplexicaule* (15.5) *Polygonum chinense* (12.4)	*Fragaria nubicola* (36.3) *Circaea alpina* (27.1) *Triplostigea glandulifera* (17.5) *Polygonum amplexicaule* (16.5) *Viola biflora* (13.7)
Kharsu oak	*Fragaria nubicola* (25.3) *Polygonum amplexicaule* (18) *Selinum vegenatum.* (15) *Viola biflora* (14.6) *Primula sessilis* (10.9)	*Fragaria nubicola* (18.3) *Triplostigea glandulifera* (17.4) *Polygonum amplexicaule* (13.5) *Polygonum chinense* (6.15) *Circaea alpina* (5.5)
Mixed	*Fragaria nubicola* (21.6) *Polygonum amplexicaule* (21.0) *Polygonum chinense* (20.7) *Viola biflora* (19.15) *Circaea alpina* (13.4)	*Circaea alpina* (22.5) *Polygonum amplexicule* (17) *Triplostigea glandulifera* (16.6) *Fragaria nubicola* (12.5) *Viola biflora* (9.1)

Population structure

Along the timberline ecotone regeneration status of all tree species was quite good as compared to subalpine forest, except the silver fir community. The conversion rate from seedling to sapling was negligible in disturbed area, while the highest number of seedlings and saplings were observed in birch community (Fig. 3A) followed by kharsu oak. In birch community higher girth class trees were less in number and attained maximum girth up to 101-120 cms. About 70% of the total population was represented by seedlings and saplings. The density presented to be the highest (72%) in 21-40 cm girth class followed by 41-60 cm class (22%) in the community and *Betula utilis* contributed the most in all classes (seedling to tree). In silver fir community at timberline, regenerating individuals had 40% contribution and higher girth class trees were more in number (Fig. 3A). About 68% of the individuals in kharsu oak community were represented by the seedlings and saplings (Fig. 3A). About 23% of the tree individuals were represented in 41-60 cm girth class, while other classes were almost similar in occurrence. Mixed community had the highest percentage of regenerating individuals (84%) and individuals were mostly distributed in 21-80 cm girth classes, whereas representation of the higher girth class trees was very poor (Fig. 3A).

With respect to timberline forest community, the regeneration was very poor in subalpine forest. The seedlings were found only in the areas of the tree fall/small forest gaps and along the edges due to rock or forest gap. Most of the individuals were distributed in higher girth classes. As compared to the timberline ecotone, the subalpine zone was represented by the trees of diverse girth classes in birch community (Fig. 3B). In silver fir community girth class distribution was similar to that of the timberline, where middle as well as higher girth class trees were represented by a greater number of individuals (Fig. 3B). Regeneration within the kharsu oak community was almost negligible as compared to the timberline ecotone and *Rhododendron arboreum* had the highest number of seedlings and samplings representing 72% of the community regeneration (Fig. 3B). The regenerating individuals (seedlings and saplings), in mixed community, represented 37% of the total density and the highest number of individuals in the community was distributed between 21-80 cm girth classes (Fig. 3B).

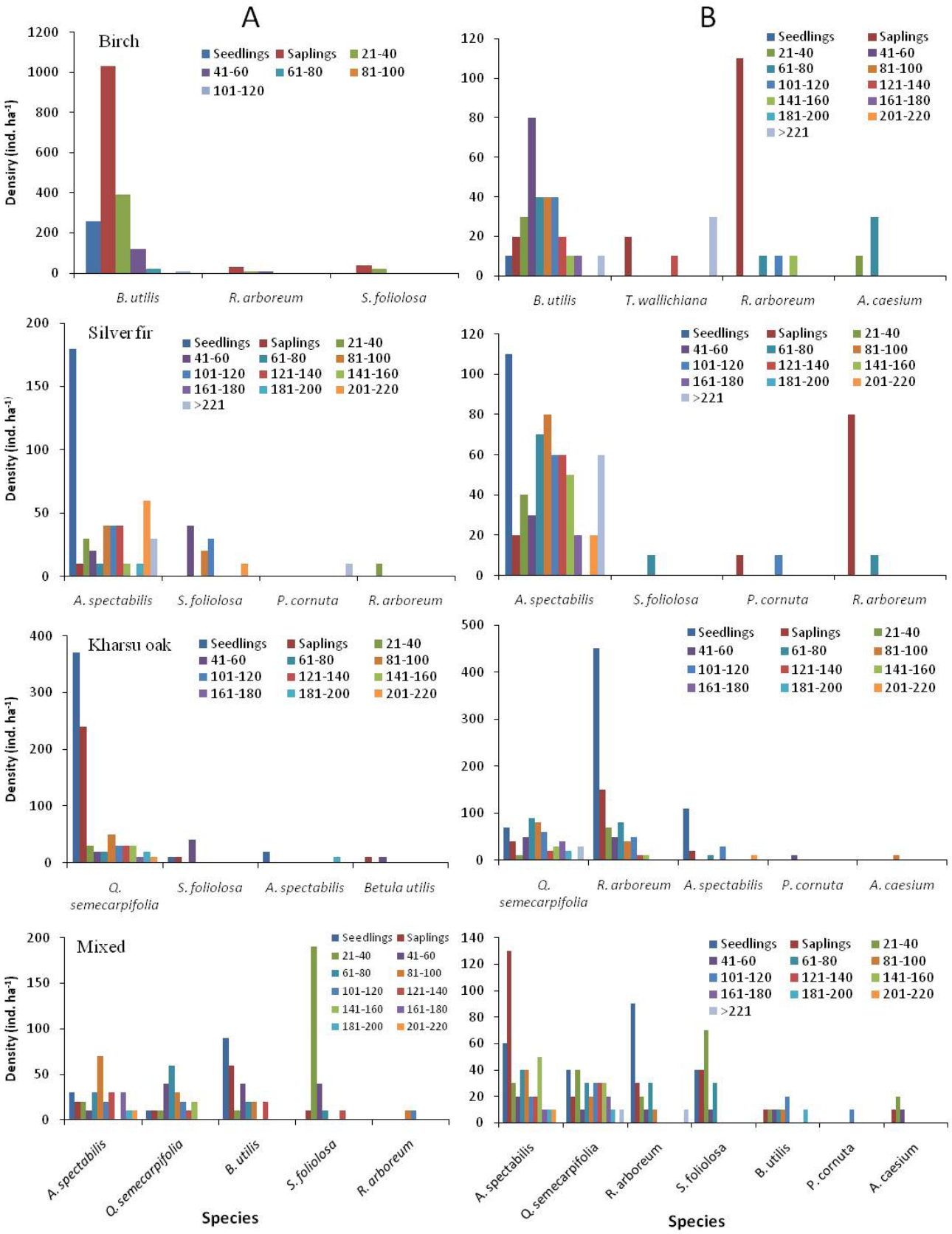

Fig. 3. Population structure of different communities along timberline ecotone (A) and subalpine forest (B)

Canopy architecture

While crossing the subalpine forest, tree height, canopy cover and canopy width decrease, towards timberline zone, and physiognomy of community, at timberline ecotone, become sparse with open canopy. All these structural attributes were at the lowest in birch community. In the timberline zone tree height was the greatest in the silver fir community due to presence of old growth trees, whereas kharsu oak community had significant tree height in subalpine zone among all communities. More canopy cover and canopy depth in subalpine kharsu oak community was due to the presence of dense undercanopy, formed by *R. arboreum*, a major co-dominant species of the community. Due to less harsh climate and disturbance, ratio of canopy depth/tree height was higher along the subalpine zone (0.77±0.03) than at timberline zone (0.73±0.1). At timberline zone the highest ratio was observed in birch community (0.84), while silver fir community along the subalpine zone had the maximum ratio (0.81). Extreme climatic conditions (snow deposition, longer snowpack duration, aspect) and low disturbance in birch community, along timberline zone, leads to more canopy depth/height ratio along the edges, whereas high disturbance level to less canopy depth/height ratio (0.6) in the silver fir community (Fig. 4).

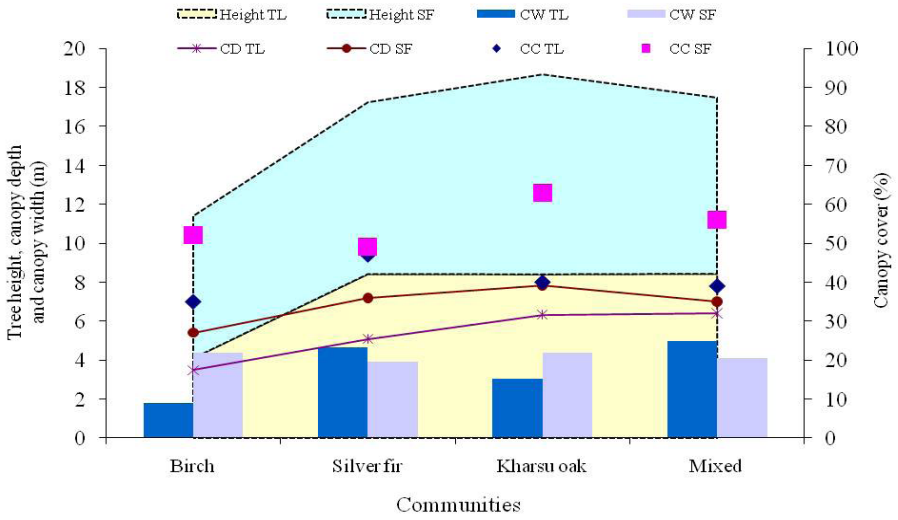

Fig. 4. Comparative representation of tree canopy depth, canopy height, canopy width and canopy cover of communities along the timberline and subalpine forests (TL: timberline, SF: subalpine forest; CD: canopy depth; CW: canopy width; CC: canopy cover)

Discussion

The aim of this study is to provide a detailed view of the locally varying timberline communities in KWS with reference to variations in the site conditions and disturbances. The structural and functional traits of any forest ecosystem are directly governed by the regional climate and topography. Spatial heterogeneity in structure and composition is more pronounced in the ecotones, which may vary with topography of the landscape and anthropogenic disturbance. Tewari and Singh (1985) reported that forests having >60% crown cover as good, 30-60% as medium and 10-30% as poor forests, while crown cover in highly disturbed forests was 40%. But, in case of timberline ecotone thinning of canopy is a natural process to optimize photosynthesis by receiving more sunlight during short growing period, but a broad ecotone and regenerating individuals is the primary condition at timberline (Tranquillini, 1979) in natural condition (absence of disturbance). The most consistent thing, which for centuries never stopped, in the high altitudes of Himalaya, was the anthropogenic disturbance in the form of lopping, logging, fuelwood consumption and grazing. From extensive forest clearing before independence and by revenue department just after independence to the current scenario high altitude forests were always under pressure in its different forms. From the extensive survey along the timberline in this region, it was obvious that timberlines always depressed and never attained their natural elevation of occurrence, except few localities, which were unapproachable. In many areas of KWS, remnant of the old trees in the higher altitude than the present timberlines were observed, which strongly support the present inference about the depression in the position of timberline. The areas approached by the seasonal shop holders and local herders were highly depressed and formed a timberline with sharp boundary. Ecotones resulting from the change in environmental gradients are hypothesized to be sensitive indicators of climate change (Rochefort *et al*., 1994), although the use of disturbance-regulated timberline ecotones to monitor climate change was questioned (Noble, 1993). The position of the timberline is affected by the complex interactions with past and

current climates and various disturbances (Körner, 1998) and its position has been suggested as a sensitive indicator of climate change (Kullman, 1998), because an improved climate would be expected to rapidly influence growth of established individuals, but land use change (protection) in Western Himalaya would be prerequisite for it.

Uniform terrain along the climatic limit of survival led to the dominance of a single species in the entire landscape and to the formation of a more or less monoculture. Undulating topography (ridges or depressions) within the large slope sometimes provided opportunity to establish a small population of few other species within the habitat of major dominant species hence, maximum number of species had either random or contiguous distribution in the communities. Such conditions were found better for the forest health, which reflects increase in species richness. More tree species richness in mixed community at subalpine zone was due to the small scale topographic changes and aspects which supported species other than the dominant ones, while uniform condition in case of birch community resulted in the form of low species richness. Subalpine forest of the same community, at timberline, had ameliorated climatic conditions due to canopy trees, where microclimate was not much restricted to micro level and more species occupying the habitat. Birch community had higher shrub and herbaceous species richness, which might be due to low canopy cover of the community. Similar condition was also observed by Moral (1972), Whittaker and Niering (1975), Zobel *et al*. (1976) and Kumar and Ram (2005). Distribution of species along the timberline was uneven and Shannon's diversity index was low due restricted distribution of co-dominant species in certain pockets. It was also reported that the regional patterns of species richness were the consequences of many interacting factors, such as plant productivity, competition and geographical area, historical or evolutionary development, regional species dynamics, environmental variables and human activity (Woodward, 1988; Zobel, 1997).

Forest degradation increases vulnerability of forest communities and lead to micro-climatic changes in turn strongly influences the composition of forest undercanopy (Chen *et al.,* 1992; Kapos *et al.,* 1995). A small change in the habitat affects negatively the species distribution. More shrub species similarity, among the communities in the subalpine zone as compared to timberline, indicated the altitudinal change of 100 m become habitat specific and restricted the distribution of species, which were more sensitive to the external disturbances at timberline zone. Highly disturbed timberline was least similar in term of species composition with other communities because well adapted species could survive under harsh conditions.

Tree density, in mixed community, was the greatest due to higher species richness than that of other communities, which were covering different layers of the canopy. Higher density in the birch community was due to the prevalence of lower girth class trees, which were negligible in other communities and old growth stands due to disturbance, led to the low tree density in other two communities. Higher total basal area of a community along the timberline indicates lack of low girth class trees, such as

Tab. 5. Comparative account for tree density and total basal area of similar communities across the Himalayan landscape

Communities	Location	Tree density (Trees/ha)	TBA (m^2/ha)	Author
Betula utilis	Nyishang, Nepal*	1233-1284	10.1-23.0	Shreshtha *et al*. (2007)
	Pakistan	688	34.0	Ahmed *et al*. (2006)
	Pindari	560	26.0	Kalakoti *et al*. (1986)
	Askot WS	470	21.4	Dhar *et al*. (1997)
	Sarju catchments	450	31.3	Rawal and Pangtey (1994)
	Kumaun	700	23.2	Singh *et al*. (1994)
	NDBR	747-1206	17.9-35.9	Rawal (1999)
	Nanda Devi NP	160-380	4.4-23.6	Adhikari (2004)
	KWS	580-420	6.4-28.5	Present study
Abies spectabilis	Melmjan, Nepal	360-840	43.1-118.2	Nakasuga (197)2
	Langtang NP, Nepal	734	20.6	Gaire *et al*. (2010)
	NDBR (Lata)	620	34.3	Joshi and Samant (2004)
	Nanda Devi NP	160-760	19.4-69.6	Adhikari (2004)
	KWS	420-520	55.1-61.1	Present study
Abies-Quercus	KWS	780-780	42.0-62.0	Present study
Q. semecarpifolia	Askot WS	550	50.8	Dhar *et al*. (1997)
	Sarju catchments	450	63.3	Rawal and Pangtey (1994)
	Kumaun	250-2070	5.0-114.0	Singh *et al*. (1994)
	Pindari	480	73.4	Adhikari *et al*. (1995)
	Binsar-Mahadev, Pauri	310-520	31.5-57.3	Baduni and Sharma (1996)
	KWS	340-810	30.1-62.2	Present study

*Included >10 cm girth classes

in silver fir community, which is higher along timberline as compared to other studies in the Himalayan region. A comparative account of density and total basal area of the subalpine forests was given in Tab. 5.

In the present study area disturbance had influenced shrub layer composition and distribution of species along the ecotone. The shrub density was found decreasing with increase in disturbance level, while herb density increased. In birch community shrub density presented the highest among all the communities and lowest in silver fir community. While herb density was lowest in birch community but presence of many rare species such as Lady's slipper orchid (*Cypripedium* spp., Rai *et al*., 2010), and *Balanophora involucrata* along the edge of forest indicated the importance of this transition for the rare species. Herb density was highest in silver fir community due to abundant growth of the species favoring the disturbance, and compact and damp soil condition. The species were unable to attain sufficient growth due to high grazing pressure, while found in large number. The dominance of one layer might affect diversity of another stratum (Whittaker, 1972) and vice-versa. The shrub density was higher along the subalpine forests of these communities, where disturbance was comparatively lower than that of timberline ecotone.

Throughout the Western Himalaya, very poor regeneration along the timberline ecotone and poor conversion rate from seedlings to saplings was observed. Canopy openness due to natural as well as anthropogenic disturbances always provided opportunity to seedlings establishment along the edges of forests. In the areas of low grazing pressure, good sapling numbers were observed such as in birch community, but negligible in the disturbed sites. In the highly disturbed areas seedlings were survived only in certain pockets, such as under the krummholz vegetation and unable to survive up to sapling stage. Unsuccessful regeneration along the disturbed timberlines of Western Himalaya might lead to the severe ecosystem instability in the events of predicted climate change, if species will shift upward in the altitudes in future. These species might have no space to migrate upwards due to disturbance or other species may replace these species. The high density of *Betula utilis* seedlings along the timberline of its own community indicated favorable climatic conditions in recent decades, which allowed growth and survival of seedlings beyond the canopy shelter.

The present study revealed that the area was one of the richest areas in terms of community heterogeneity, but it was under high anthropogenic pressure. Most of the areas lacking natural condition (broad transition zone with krummholz vegetation) and sharp timberlines were formed which terminated abruptly. The small scale heterogeneity in the structure and composition was due to topographic variation. High heterogeneous conditions reflect restricted distribution of the communities across the timberline, which may lead to more vulnerability in the present state of disturbances. Many species present only along the edges of forest might be facing severe threat in the form of population decline, which might lead to local extinction of species from that region. The narrow range species (altitudinal range) might be more under pressure under changing climatic conditions with high anthropogenic pressure. In the naturally protected area timberline species showing high regeneration towards the alpine area beyond the canopy shelter, this indicated some ameliorated conditions for growth and survival of seedlings in the recent decades. A good number of seedlings and saplings beyond 10-15 m from the edge of forest were observed in this area. If present climatic conditions would prevail in the Himalayan region; these timberlines (especially *B. utilis* which grow in tough terrains) would be showing shift in the altitude unless anthropogenic pressure not influences the establishment of seedlings up to maturity, which would strongly influence the biodiversity, species distribution and ecosystem balance in the Himalayan region. Long term monitoring is necessary to find out impacts of anthropogenic disturbances and climate change on timberline vegetation, which is of prime importance in biodiversity conservation.

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