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A cartographic representation of a timberline, treeline and woody vegetation around a Central Himalayan summit using remote sensing method

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Abstract: Using remote sensing techniques, here we have characterized spatial features of Himalayan treeline ecotone in a watershed (Tungnath, Garhwal in the Indian Central Himalaya), considering timberline, treeline, woody patches, and isolated trees. For the first time, timberline and treeline positions have been drawn and remote-sensing based methodological protocol demonstrated. Satellite image of LISS IV and Digital Globe were used to map Tungnath watershed. Forests occupied 80% of the watershed, leaving a small area (3.7%) for alpine meadows. Total length of timberline in the watershed was 7.91 km with elevation range of 3065–3460 m (average being 3277 m). Timberline length distribution by 50 m elevation band indicated that the highest portion (~41%) of timberline occurred between 3250 m and 3300 m. Timberline elevation decreased from moist to dry slope exposure. In the watershed, elevation of treeline ranged from 3280 to 3510 m which was generally 15 m to 170 m below the upper boundary of watershed but at few locations scattered trees reached at the upper watershed boundary. Beyond timberline in higher areas we recorded 124 woody patches and 50 scattered individuals of *Rhododendron campanulatum* and 47 solitary trees of eight species (*Abies, Betula,* etc.). Distance of woody patches from timberline varied from its edge (zero distance) to above 600 m. These details would help in detecting changes due to climatic warming and other factors, and in developing landscape-level understanding on facilitation/expansion of tree species towards high altitude.

Key words: Himalaya, satellite image, timberline, treeline, watershed, woody patch.

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Introduction

High elevation limit of forests, called as timberline or forest line, represents one of the most conspicuous vegetation boundaries in mountains (Daubenmire 1954; Holtmeier 2009; Körner 1998). Heat deficiency and reduced length of growing season are regarded as the principal causes of timberline and treeline formation (Schickhoff 2005). Considered to be among the most prominent vegetation zones in high mountains, the timberline ecotone is often characterized by a steep environmental gradient, increasing fragmentation of vegetation and stuntedness of trees (Shi & Wu 2013). While timberline is the upper limit of continuous forests, treeline represents the highest elevation trees. In a way, it is an imaginary line that connects the elevations of uppermost trees, often growing as isolated individuals or in small patches (Singh & Rawal 2017). Positions of uppermost outposts of individuals/woody patches are considered an important ecological indicator of climate change (Fissore *et al.* 2015). Beside steering range expansion, these isolated trees provide habitat for several organisms like spider (Frick *et al.* 2007).

Locations of timberline have been documented

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Fig. 1. Location of Tungnath watershed in the Indian Central Himalaya.

by various workers using sources like historical maps and satellite images (Bharti *et al.* 2012; Weisberg *et al.* 2013) and aerial photographs (Danby & Hik 2007). With enhanced resolution it is possible to map individual trees using GPS (Piermattei *et al.* 2012). Such information about timberlines of Himalayas is rather scanty. In recent years mapping of timberline in Himalaya has drawn attention due to its sensitivity to changing climate and its potential use as indicator of climate change in the Himalayas (Bharti *et al.* 2011, 2012; Singh *et al.* 2012) and other mountains (Barry 1994; Kanka *et al.* 2005). To the best of knowledge of authors, high resolution mapping of timberline, treeline and woody vegetation above sub-alpine forests in Himalayas has not been attempted in the past. The spatial distribution patterns of trees in relation to other landscape features of treeline areas are hardly known.

However, some important studies about the factors affecting treeline elevations have been carried out in the European mountains, known to have a long history of treeline studies. For example, a positive relationship has been observed between the elevation of nearest mountain summit and elevation of *Betula* timberline (Odland 2015). There is a need to develop a methodological protocol to understand relationship between timberline and controlling topography of the Himalayan mountains.

Using high resolution satellite images in a watershed in this study we have (i) developed a synoptic view of timberline ecotone, (ii) characterized its various spatial attributes, and (iii) identified locations of individual trees of treeline ecotone in relation to topographical features. The detailed dataset could be bench-marked for long term monitoring of climate change impact and developing relationship between climatic parameters and vegetation. The specific objectives of the study are to (i) prepare a detailed map depicting locations of uppermost edge of forest (timberline), individual trees and woody patches above timberline, and treeline (highest elevation of tree occurrence), (ii) understand relationship between local topographical features (altitude, aspect, watershed boundary, area available above timberline) and timberline and treeline, and (iii) provide a baseline to assess changes for occurring due to climate change.

This mapping of treeline ecotone at a micro-level would provide template for long term monitoring using high resolution satellite images. Spatial attributes of treeline and timberline will provide more synoptic details on treeline expansion than the estimates derived from locations based ground observation. By periodical sampling one could learn about the role and fate of isolated trees and woody patches in driving future development of vegetation and its significance as habitat for wildlife in a warming world.

Study area

Tungnath watershed (between 30.47–30.51° N latitude and 79.15–79.22° E longitude) has an area of 24 km^2 in Mandakini River catchment of Uttarakhand state (Fig. 1). Part of the watershed falls in Kedarnath Wildlife Sanctuary. A Hindu shrine, Tungnath temple, which is visited by pilgrims in thousands during summer, is also located in the alpine area of the watershed. Tungnath is also a destination for trackers, nature lovers, and bird watchers in different seasons. Small seasonal and perennial streams are common. Altitude in the watershed varies between 1630 m and 3625 m asl, however much of the area (82%) falls between 2400 m and 3200 m asl, and little is left above 3200 m (8%) and below 2400 m (9%).

Methods

For a fine resolution mapping of watershed, two different high resolution satellite images were used and the steps given below were followed:

(i) Landuse/landcover mapping of Tungnath watershed was done through multispectral data of LISS IV (spatial resolution of 5.8 m). The acquired snow-free image of year 2015 (21 December) was used to distinguish evergreen and deciduous forests, and to separate treeless alpine areas from the forested areas. For landuse/landcover analysis, layer stacking was done using ERDAS IMAGINE 2016 to develop False Color Composite (Band 2, Band 3, and Band 4). Supervised classification was done to obtain following classes - (1) mixed evergreen and deciduous forests, (2) alpine meadows, (3) low altitude grasslands, (4) woody patches above timberline, (5) forest blanks, (6) cultivated land, (7) rocks and boulders, (8) barren, (9) water bodies, (10) settlement, and (11) road. The validation was carried out using natural colour high resolution image (0.5–2 m) of different seasons from Digital Globe at GoogleEarth™ Pro.

(ii) Timberline and trees were mapped using natural colour and high spatial resolution image (0.5–2 m) of Digital Globe for (a) continuous close canopy towards high altitude limits of forests, i.e., timberline (termination of the continuum of forests extending from lower region to higher region), (b) patches of woody vegetation (*Rhododendron campanulatum* thickets) beyond timberline, i.e., outside forests, and (c) isolated standing individual trees in the alpine meadows, i.e., outside the forests and woody patches.

Visual interpretation technique was employed to separate and map these three features of woody vegetation, and to mark iso-heights as a line in the study area (*timberline* - connecting the highest edge of continuous forest; *treeline*- outposts of individual trees). ArcGIS was used for various analysis and extraction of spatial attributes of vegetation. Treeline, joining top most trees located above timberline, is an imaginary and broken (at several places) line. Distance from watershed boundary was measured as crow fly line between points of maximum elevation of treeline at a location to the nearest point of upper watershed boundary. Distance of individual trees from the nearest timberline point was measured as a positive indicator of advancement in tree establishment beyond timberline. In case of woody patches this distance was measured from lowest elevation at boundary of a patch. Mean elevation of a woody patch was determined by i.e., centroide function.

(iii) Topographical (altitude, slope, aspects) and geographical features (timberline elevation, height of summit, watershed boundary, elevation of individual trees, and others) were obtained from Aster Digital Elevation Model (resolution of 30 m), and relationship was developed between spatial patterns of timberline and topographical features of watershed. DEM of GoogleEarth™ Pro was used to develop relationships of treeline, woody patches and individual trees with topographical features by importing shape files to GoogleEarth™ Pro. Effect of mountain height on the timberline was determined following Odland (2015), and relationship between timberline elevation and mountain heights (summits and watershed boundary) was analyzed by linear regression.

(iv) Extensive ground truthing was done for locations of trees (species at timberline and beyond) to map occurrence at highest elevations. Locations were captured using GPS (Garmin Oregon 550) having capability to capture Photo with GPS tagging but comments can not be icorporated. One mobile Application (named HIMA) was developed for Android Phone to use multiple functions (camera, clock, and GPS) in an integrated manner so notes may also be taken in the phone itself. GPS and HIMA app on Android phone (ASUS ZOOLD) were used in ground truthing. On availability of internet connectivity HIMA app automatically uploads the data to the server where it can be visualized on internet (*himalayancitizen.co.in*). This mobile app can be downloaded from Google Play and from the web page of visualization. Above timberline, trees of different species, and individuals of *R. campanulatum* (above 1 m in height) were mapped.

Results

Landuse/landcover

Of the total area of Tungnath Watershed (Fig. 2) about 80% was under forests (Table 1), with 78.5% under mixed evergreen forests, divisible into mixed *kharsu* oak (*Quercus semecarpifolia*) - fir

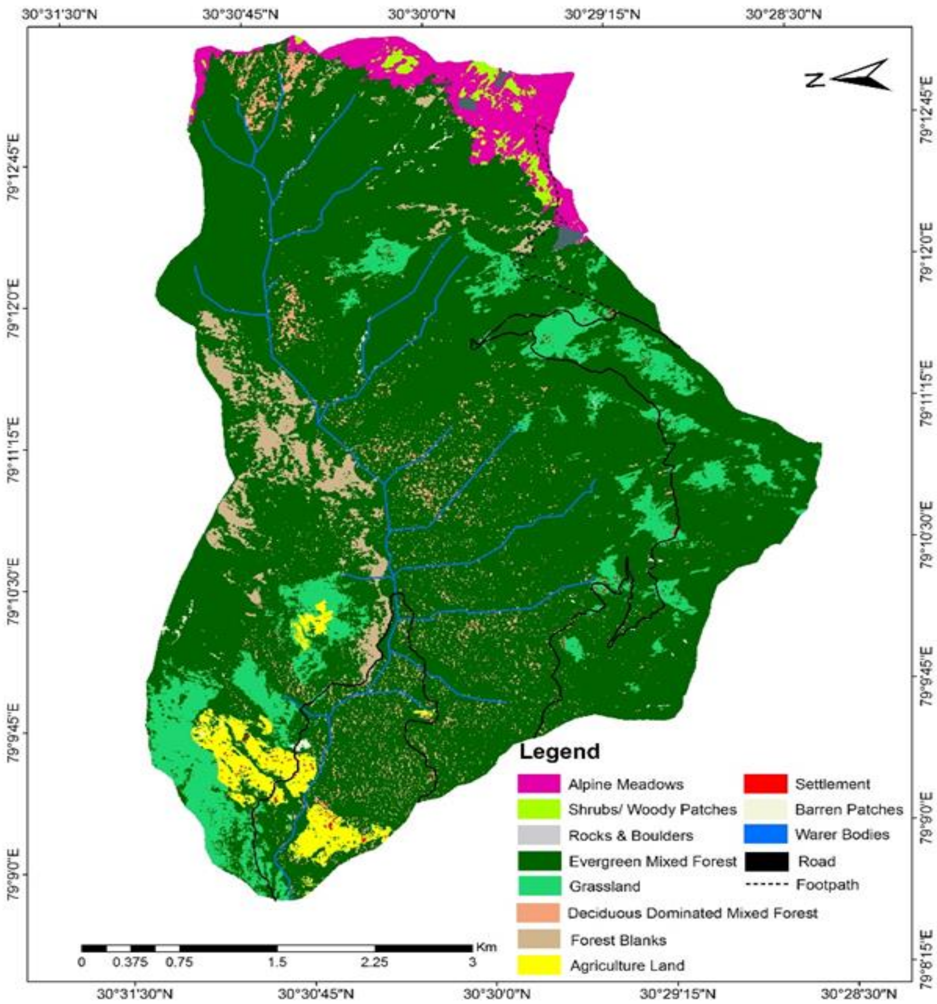

Fig. 2. Landuse/landcover of Tungnath watershed (derived from LISS-IV image).

Table. 1. Defining rarity and conservation priority classes at different spatial scales (based on Rawal & Dhar 1997). Rarity increases from 1 to 8; conservation priority: I highest and IV lowest. Attributes are coded as: WGR- wide geographical range; RGR- restricted geographical range; BEA-Broad Ecological Amplitude; NEA- Narrow Ecological Amplitude; LA-Locally Abundant; LS-Locally Scarce.

Rarity	Attributes	Level of conservation priority	
		Himalaya	Study Area
1	WGR+BEA+LA	IV	IV
2	WGR+BEA+LS	IV	III
3	WGR+NEA+LA	III	II
4	WGR+NEA+LS	III	I
5	RGR+BEA+LA	II	IV
6	RGR+BEA+LS	II	III
7	RGR+NEA+LA	I	II
8	RGR+NEA+LS	I	I

Table 2. Distribution of woody patches of *R. campanulatum* by different size classes.

Area (ha)	Number	Percent
< 0.05	73	58.9
0.05–0.1	14	11.3
0.1–0.5	26	21.0
0.5–1	7	5.6
>1	4	3.2

(*Abies pindrow* and *Abies spectabilis*) type towards higher altitudes, and (ii) mixed moru oak (*Q. floribunda*) and banj oak (*Q. leucotricophora*) type towards lower altitudes. At few places deciduous mixed forest (2% of the total watershed) occurred, generally along streams. Woody patches above timberline occupied 17.4 ha area.

Of the total watershed area, grasslands below 3000m asl altitude occupied 8.3%, and alpine meadows, above 3000 m asl, 3.7% (80 ha). Before

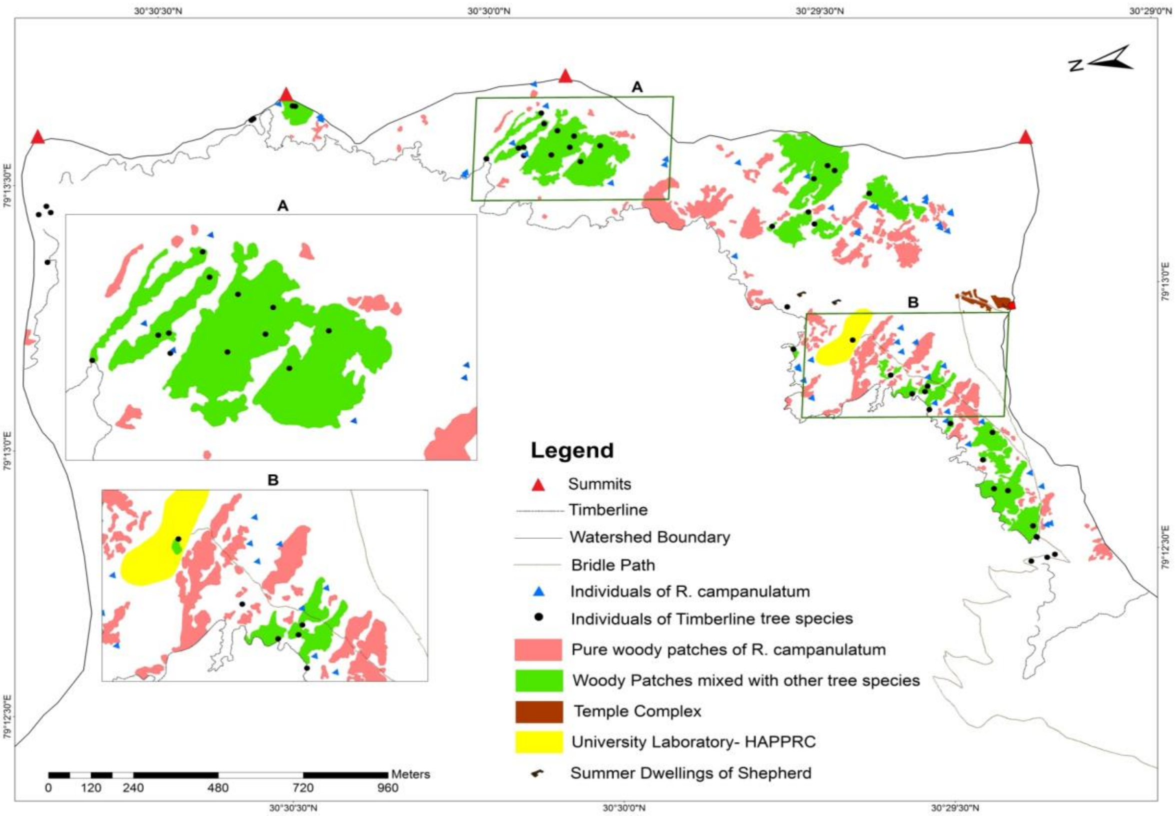

Fig. 3. Details of timberline and woody vegetation (patches and individual trees) above timberline in Tungnath.

inclusion in the Kedarnath Wildlife Sanctuary, this watershed was a grazing ground for sheep and goats, brought from faraway places by nomads, and livestock from nearby villages. Agriculture remains confined to the lower elevation in an area of 56 ha (2.3% of the total watershed).

Spatial features of timberline and treeline

The 7.91 km long timberline took a zig-zag course between 3070 m asl and 3460 m asl (Fig. 3). Of this about 55% was within a hundred meter range between 3200 m and 3300 m asl (Fig. 4A). Field observations from other locations of Uttarakhand also indicate similar altitudinal range for timberlines. Running continuity of timberline in the watershed was broken (7 fragments) by natural (streams, rocks, etc.) and man-made barriers (concrete path made for tourists). The dominant tree species at timberline were *A. spectabilis, B. utilis,* and *Q. semecarpifolia* but their dominance kept in changing along the timberline courses (Fig. 3). The *Betula* timberline was relatively higher, the mean elevations being above 3300 m. The mean timberline elevation dominated by *Abies* was 3250 m and that of *Quercus* was 3200 m.

As for timberline distribution in relation to slope exposure, it was largely divided between NW aspect (~50% of timberline) and W aspect (~31%). The proportion of timberline tended to decrease from moist to dry aspects (Fig. 4B).

Scattered and isolated trees of *A. spectabilis, B. utilis*, *Sorbus foliolosa, Prunus cornota,* and *Acer pictum* were present above timberline. The line connecting uppermost trees (treeline) ranged from 3280 m (minimum) to 3510 m (maximum). Treeline elevation was 15 m to 170 m below the upper boundary of watershed but at few locations scattered saplings of tree species occurred at the upper watershed boundary. Evidently, at these locations trees cannot move up under the influence of climate warming, they could only increase in density.

Among the different tree species forming treelines, the highest advancement (tree-species line) was observed for *Betula utilis* (237 ± 153 m

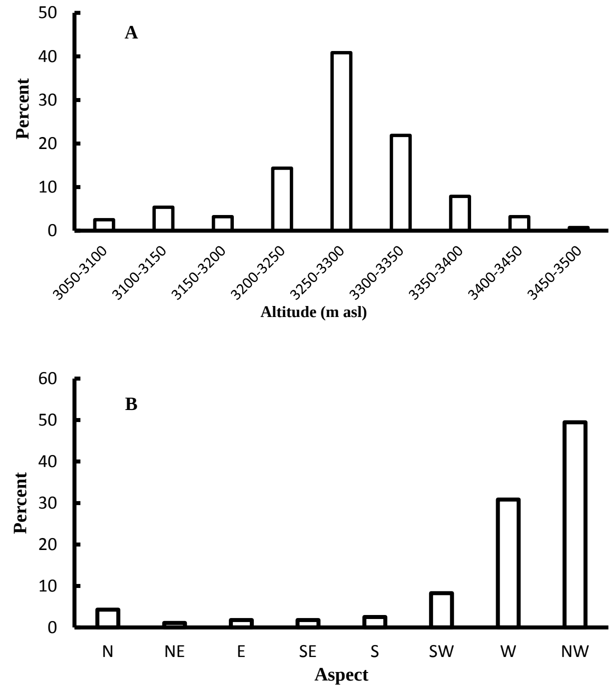

Fig. 4. Timberline distribution (as percentage of the total timberline length) in relation to elevation (A), and aspects (B).

average distance from timberline), followed by *S. foliolosa* (218 ± 157 m). Average advancement of tree-species line from timberline for other species (*A. spectabilis, A. pictum, Q. semecarpifolia*, *R. arboreum*, *P. cornota*, *Viburnum grandiflorum*) ranged from < 10 to 94 m.

Spatial characteristics of Rhododendron campanulatum *above timberline*

Above timberline, *R. campanulatum* extended into alpine meadows. This species forms extensive patches of woody vegetation as well as occurred as solitary individuals. The advancement of *R. campanulatum* krummholz seems to be a common feature of treeline ecotone in this part of Himalayas.

Woody patches

Above timberline, 124 woody patches of different sizes were formed by *Rhododendron campanulatum* (Fig. 3). These patches were either exclusively of *R. campanulatum* (85% of the total woody patches) or *R. campanulatum* mixed with a few individuals of *Abies, Betula*, and *Sorbus* (15% of the total patches of *R. campanulatum*). Among timberline species, *Sorbus foliolosa* (a small tree)

Table 3. Distribution of woody patches and individual trees of *R. campanulatum* by 50 m elevation bands ranging from 3200 m to 3550 m asl.

Altitude	Woody Patches		Individual Trees	
(m asl)	Number	Percent	Number	Percent
3200–3250	2	1.6	-	-
3250–3300	16	12.9	8	16.0
3300–3350	56	45.1	15	30.0
3350–3400	19	15.3	11	22.0
3400–3450	13	10.5	2	4.0
3450–3500	13	10.5	6	12.0
3500–3550	5	4.0	8	16.0

was most commonly occurring tree species in these woody patches.

The total area under woody patches of *R. campanulatum* was 22.6 ha, which accounted for about 17% of the total area above timberline. The area of individual woody patches ranged widely from 72 m^2 to 36,704 m^2, and with increasing patch size, the number of patches decreased, almost 59% of patches being smaller than 500 m^2 (Table 2). Woody patches having the other tree species were bigger in size (7000 $\pm$ 9500 m^2 average size) than the pure patches of *R. campanulatum* (900 ± 1600 m^2).

Distribution of woody patches (elevation at central point of the patch) by 50 m elevation bands along altitudinal gradient indicates that the highest number of woody patches (56) occurred between 3300 m and 3350 m asl (Table 3). In general, individual patches had a narrow range of elevational width (lowest and highest point of a patch). In few patches such a spread was observed for 75 m or more. Further investigations are required for micro-habitat characterization of such patches.

Some woody patches occurred next to timberline, but there were many several hundred meters upslope (up to 750 m). More than half of patches (59%) occurred within the 100 m distance from timberline, thereafter the number kept on decreasing leaving only 3 patches above 500 m distance from timberline (Fig. 5).

Like timberline, a few woody patches (6 in number) occurred at the locations on the watershed boundary, while farthest was located at a distance of 925 m from the watershed boundary. 43.5% of the woody patches were located at a distance of < 200 m from nearest watershed boundary.

Individual trees

Outside the woody patches, a total 50 solitary individuals of *R. campanulatum* were also identified

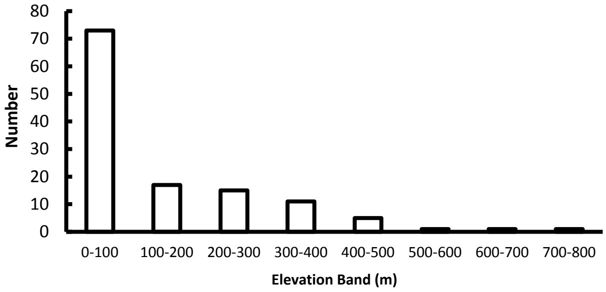

Fig. 5. Frequency distribution of woody patches above timberline in relation to distances (100 m band) from timberline.

above timberline between 3250 m and 3550 m asl on the image, and were mapped (Fig. 3). The highest number of individuals (30% of total) occurred in the same altitudinal range (3300–3350 m) where woody patches occurred most (Table 3). About 66% of the individuals were located within 200 m from the timberline (Table 4). With increase in distance number of individuals was decreasing.

Spatial characteristics of individual trees above Timberline - Timberline tree species

A total 47 solitary individuals of 8 species were identified at treeline (presence of a tree at the highest elevation); 62% of such treeline individuals were of *Abies* (32% of the total individuals at treeline) and *Sorbus* (30%). *B. utilis* and *R. arboreum* contributed equally (13% each). Four species (*Acer, Viburnum, Prunus* and *Quercus*) were represented by one or two individuals at different locations of treeline.

Timberline is not a straight line; hence distance of individual tree to nearest timberline point (crow fly distance) was measured to realize advancement in tree establishment. Some trees were just adjacent to timberline <10 m, whereas the farthest was at 470 m (*Sorbus*) from timberline (~3510 m asl, Fig. 6). Among these eight species, *Q. semecarpifolia* was slow moving species (all individuals were <10 m from timberline) which could be due to viviparous nature of seeds. In contrast, *Betula,* having wind dispersed seeds, was growing from 50 m (3320 m asl) to 460 m (3500 m asl) above timberline. This range for *Abies* was from <10 m (3320 m asl) to 230 m (3360 m asl).

More than half of the individual trees of all species were located within 100 m from the timberline (57%, Table 4). A greater scatter of tree individuals within 100 m distance band indicates

Table 4. Distribution of scttered solitary individual trees by distance band of 100 m from the nearest edge of timberline.

Distance Range	Scattered Individual			
	R. campanulatum		Timberline Tree Species	
(m)	Number	Percent	Number	Percent
0–100	23	46.0	27	57.4
100–200	10	20.0	4	8.5
200–300	1	2.0	9	19.1
300–400	7	14.0	4	8.5
400–500	2	4.0	3	6.4
500–600	3	6.0	-	-
600–700	4	8.0	-	-

that individuals can establish as high as up to 3400 m and more, if the distance is below 100 m from timberline (Fig. 6). It shows that distance is more limiting than elevation under a certain limit.

Space above timberline/treeline and summit syndrome

Due to local topographical variations, elevation ranges of treeline and timberline coincided at a few points in the watershed. Elevations of timberline (n = 23) and treeline (n = 14) were positively related with mountain heights (in this case, summits and nearest point of watershed boundary) of the Tungnath watershed. It was observed that an increase in mountain height will lead to an increase in timberline (P = 0.01) and treeline (P = 0.04) elevation. Between the two, the upper elevation of timberline was more influenced by availability of space towards higher elevation. It shows that the presence of low height mountains may lower the local timberline elevation in the Himalayas.

Discussion

This study has shows that the use of remote sensing techniques can give several useful cartographic information about treeline ecotone which are not possible by manual sampling (Fig. 3). The remote sensing techniques enabled us to give a detailed spatial distribution of timberline, treeline, woody patches, and isolated individual trees above timberline. Treeline and timberline elevations are known to be affected by several factors, apart from heat deficiency. Grazing pressure (Piermattei *et al.* 2012), the lack of substrate or habitat for seedling establishment (Germino *et al.* 2002), and abiotic

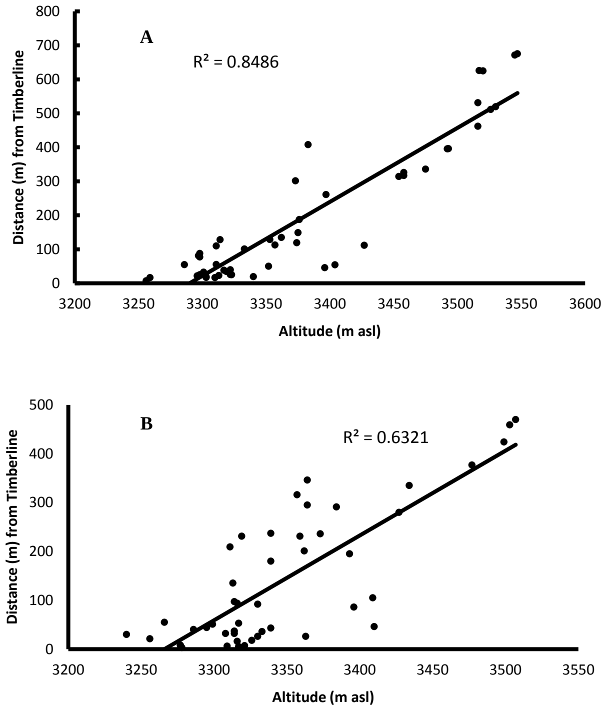

Fig. 6. Distribution of solitary individual trees along altitude (above timberline) and distance from timberline - (A) *R. campanulatum*, and (B) Tree species of timberline.

factors (solar irradiance and nighttime temperature) in photosynthetic carbon acquisition by seedlings, (Johnson *et al.* 2004), and soil moisture (Hughes *et al.* 2009) are some of factors often suggested to limit the upslope shift of trees. Using remotely sensed data we found that there is significant positive correlation between timberline/ treeline elevations and height of nearest mountain ranges or summits in the watershed.

The scattered individual trees and woody patches are not only structural features of treeline ecotone, but also facilitators of further growth of vegetation in a warming world. In other words, the isolated individual trees and woody patches may provide nuclei- for the growth of vegetation. Facilitative effects of woody patches are known for tree species recruitment in harsh alpine environment. For example, *Rhodeodendron* thickets provide microsite habitat for seedling establishment of *Betula* species in Europe (Akhalkatsi *et al.* 2006). In Andes, above-timberline small forest patches had similar patterns of seed dispersal as the timberline but minimal (< 1%) seeds were dispersed up to 10m into the grasslands of high altitudes (locally known as *Puna*). At edge of a patch/forest timberline, seedling abundances were lower in the grasslands relative to the adjacent forest and forest–*puna* ecotone (Rehm & Feeley 2013). This indicates that patches above the timberline may act as source for further forest expansion into the higher reaches, however competition with alpine communities and with *Rhododendron* patches may also limit it. In Australia, it has been observed that tussock grasses may physically protect as well as compete with the tree seedlings of *Eucalyptus pauciflora* growing near treeline (Noble 1980).

In addition to biological attributes of a tree species and impacts of climate change, cultural influences are critical for understanding the response of timberline. Alpine zone of the Tungnath watershed is affected by livestock grazing and tourism. Such activities may influence perceived shifts of timberline (upward movement) due to climate change. The presence of large herbivores and their activities in alpine landscape may either strengthen or nullify the impacts of a changed climate (Cairns & Moen 2004; Hofgaard *et al.* 2009). The recent expansion of black pine (*Pinus nigra*) trees in the central Apennines of Italy was attributed to reduced livestock grazing as well as to climate change (Piermattei *et al.* 2012). At Tungnath site, while grazing pressure is on decline, tourism and hiking activities have increased. Improved road network has increased human pressure and disturbances.

Conclusion and future research

Remote sensing techniques can help in capturing several spatial characters of treeline ecotone at micro-watershed level by providing spatial distribution of timberline, treeline, woody patches, and isolated trees above timberline. This study for the first time shows the precise position of treeline and timberline in a Himalayan watershed. This is the first remote sensing based attempt which contributes to methodological protocol to develop insight into the characteristics of Himalayan treeline ecotone. Such details are required to detect changes due to climate change and other factors. Further research is required (i) to know and quantify species association/vegetation assemblages of woody patches, and (ii) in association with present data set to develop landscape level understanding on facilitation/ expansion of tree species towards high altitude.

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