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The easternmost timberline of the Indian Himalayan region: A socio-ecological assessment

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Abstract: The present study provides a socio-ecological assessment of the timberline zone falling in Tawang and West Kameng districts of Arunachal Pradesh, the easternmost state of India. Satellite imageries were used to stratify land use-cover, slope, and aspects, vegetation types, along with ground-truthing of floristic diversity and forest structure. The region comprised >70% of the total geographical area under forest (82% under dense cover) divisible into eight forest types. The timberline takes a zig-zag course between 3600 and 4600 m. A reconnaissance of vegetation and species richness revealed that the tree and shrub richness peaked in lower one-third of the elevation gradient, whereafter declined sharply with the rise in elevation. In timberline area there were only 5 tree and 11 shrub species. The timberline area, however, comprised 152 plant species, which is significant. A comparison of timberline across Himalayan states reveals that the upper timberline limit increases from northwest to northeast. In Arunachal Pradesh timberlines are dominated by *A. densa*, which is associated with several species of *Rhododendron* and *Sorbus* species. In recent times the timberline ecotone has been subjected to increased developmental activists, such as road construction and fulfilling diverse community needs, viz. timber, firewood, medicinal herbs, grazing grounds. Management of grazing areas, which used to be done by traditional village institutions that maintained the quality of pastures, has been gradually losing its effectiveness. The study emphasized the need for more coordinated researches to develop a better understanding of the timberline area in near future.

Key words: Biotic pressure, eastern Himalaya, implications for management, timberline ecotone, tree structure.

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Introduction

World over the timberline areas, which represent the transition from forest to treeless alpine areas by forming a distinct ecological boundary within the altitudinal vegetation zones, are considered extremely sensitive to climate change and anthropogenic pressure (Holtmeier & Broll 2005; Schickhoff 2005). It is assumed that in the event of warming, treeline will advance to higher elevations (Körner & Paulsen 2004; Singh *et al.* 2012). Himalayan treeline zone is known for widespread pastoralism with varied institutional arrangements and practices across the Himalayan Arc (Dutta 2011; Singh *et al.* 2002; Singh & Sundriyal 2005; Sundriyal 1994, 1995). The lacks of research and data have been the main constraint to take up any remedial measure in such areas. While treelines/ timberlines in Europe have numerous long term studies and data, Himalayan treelines however, have remained unattended. It is argued that in comparison to the Himalayan region the

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timberline researches in other areas are in a much advance stages. Within Himalayas the timberline in the western part of the country is more investigated in comparison to the eastern Himalayan region (Dutta *et al.* 2014). There have been several studies on forest structure and composition from western Himalaya (Bisht *et al.* 2014; Gairola *et al.* 2008; Rai *et al.* 2012; Sundriyal & Bisht 1988), central Himalaya (Gaire *et al.* 2010), and Tibet plateau (Qingshan *et al.* 2007, Shaoliang & Ning 2013; Zhang *et al.* 2009, 2010). However, such information is scanty for the eastern Himalayan region (Chettri *et al.* 2002), and almost no reports are available from Arunachal Pradesh, which makes the easternmost limit of Indian Himalayan region. The state is biologically special as it is situated at the confluence of Indo-Malayan, Afro-tropic, and Indo-Chinese biogeographical realms, and has wide vegetation zones, viz. tropical, sub-tropical, temperate, sub-alpine and alpine that vary in vegetation composition and species richness (Baishya *et al.* 2001; Champion & Seth 1968; Deb & Sundriyal 2007; Hajra *et al.* 1996; Kaul & Haridasan 1987; Rau 1975; Rao & Hajra 1986; Rao & Panigrahi 1961; Sahni 1981).

The eastern Himalayan region is more humid hence supports tree growth up to much higher elevation than western region (Dutta *et al.* 2013). Tawang and West Kameng districts harbor a significantly important part of eastern Himalayan timberline. The forests in the region harbor rich vegetation and species diversity (Roy & Bahera 2005; WWF & ICIMOD 2001). The region is currently subjected to expansion of roads and communication services for both civil and defense needs, which are impacting forest structure, composition and ecological balance of the area (Behera *et al.* 2001). In view of the lack of information on broad physiognomic features, land use-land cover, and vegetation composition it is difficult to devise management and conservation strategies for the timberline area (Dutta 2011). To address the issues of environmental problems at timberline areas, it is important to understand interactions between the social systems and ecological processes (Bennett *et al.* 2009; MEA 2005; Milner-Gulland 2012). Here our aim is to give an introductory report on the timberline area of Arunachal Pradesh based on (i) general land use pattern, (ii) basic features of timberline flora and vegetation, and (iii) anthropogenic factors affecting timberlines in the regions. We used remote sensing techniques to analyse spatial features of this India's most remote forest-rich region. Our paper will provide a baseline for detecting future changes due to global climate change and other anthropogenic factors.

Materials and methods

The study area comprises Tawang and West Kameng districts (26°53´22.11 to 27°51´47.15 N and 91°31´57.37 to 92°50´39.39 E) in Arunachal Pradesh. It is surrounded by Tibet (China) in the north and northeast, Bhutan in the west, Assam state in the south, and East Kameng district on the eastern side (Fig. 1). The study was conducted during 2009–2011 and repeated in 2012–13, and followed a standard research protocol for satellite imagery procurement, analysis, ground truthing, vegetation mapping, floristic diversity assessment, laying forest plot at different sites, and data collection and analysis.

Assessing land use-land cover

To carry out land use land cover mapping remote sensing maps and GIS tools were used at Indira Gandhi Conservation and Monitoring Centre (IGCMC), WWF-India, New Delhi. The investigation covered Tawang and West Kameng districts using IRS P6 LISS III & PAN data acquired from NRSA (Table 1). The data transferred into the computer, geometric rectification was carried out in each image to provide latitude and longitude information into raw satellite scene using raster-based geometric corrections, and finally, the geographical area of Tawang and West Kameng districts was extracted. Further, the extent of timberline was delineated between 3900 and 4200 m altitudes using multiple GPS coordinate. This was the central part of timberline elevation, which roughly ranged from 3600 m to 4600 m. Subsequently, the ground truthing was done at the study sites to finalize the land use-cover and vegetation type maps covering both the districts and the timberline zone. To capture diverse features like drainage, road network, settlements, water bodies, and others, the toposheets of 1:200,000 were acquired and scanned, and geo-referencing technique was used to combine the data. Thereafter the target area was clipped from the toposheets for two districts (Tawang and West Kameng) along with timberline zone. Various thematic layers were digitized to delineate administrative boundaries, contour and spot heights, road network map (associated attributes: type of road), drainage and water bodies map, and location of villages and towns. Different vegetation

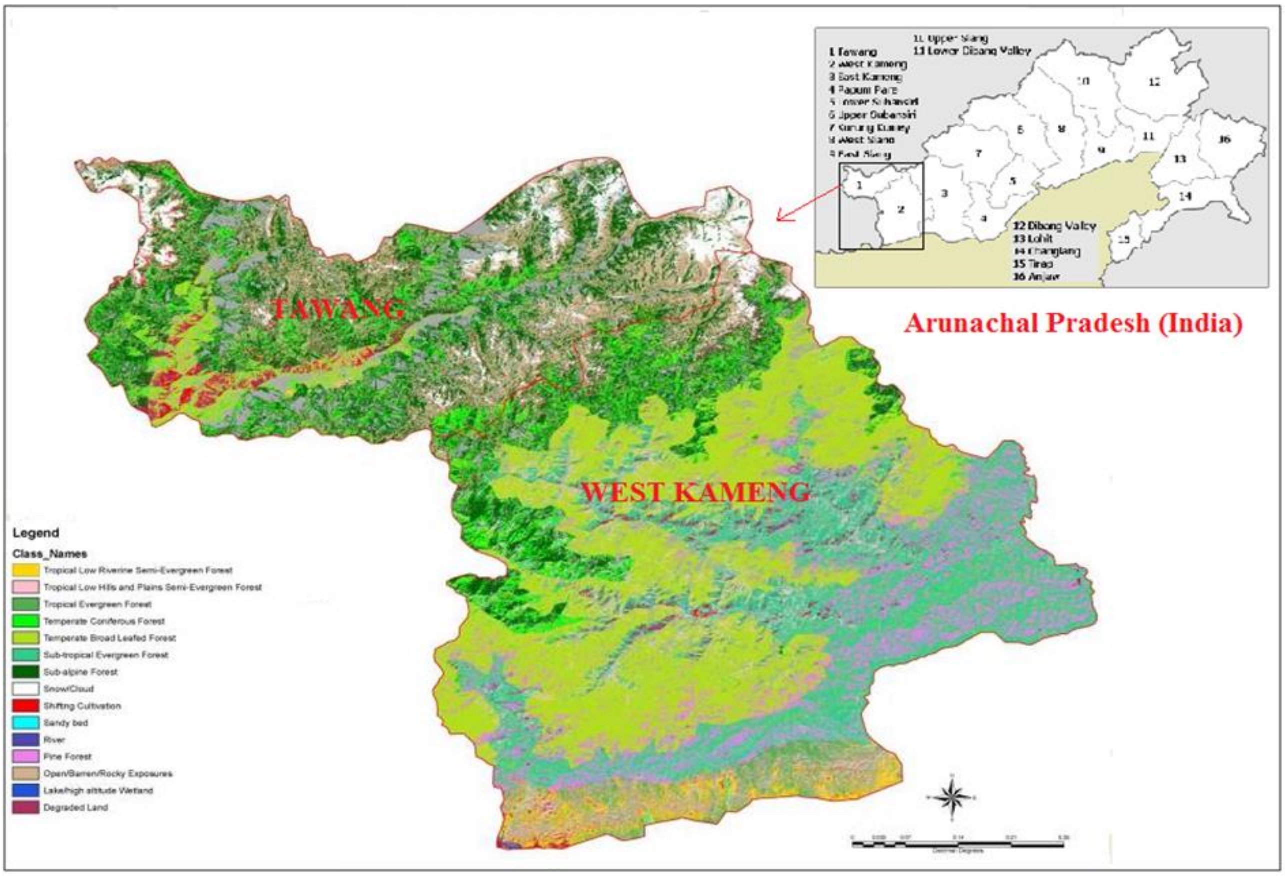

Fig. 1. Land use - land cover map of Tawang and West Kameng districts, Arunachal Pradesh, India

Table 1. Details of the imageries, their spatial resolution and date of procurement.

Sensor	Path-Row	Spatial Reso-lution	Swath	Month & Year
LISS III	110 – 52 111 – 52	23.5 m	141 km	7th Jan 2008 19th Dec 2007
PAN	110 – 52 A 111 – 52 A	5.8 m	70.3 km	14th Dec 2007 19th Dec 2007

layers, non-forest layers and water layers which were classified by above techniques, merged together to get the one classified image. Finally, based on spectral signatures, GPS location, and ground truthing details, information (images) on different land use-land cover classes and vegetation composition were extracted. Thus for two districts, the major outputs were derived, in the form of land use-cover, vegetation type, and distribution of vegetation along slopes and aspects maps. In this the focus was on timberline ecotone. More details regarding satellite imageries, RS-GIS tools and processing of data, and its analysis are available (Dutta 2011).

Assessing floristic diversity

Repeated surveys were made to different parts of Tawang and West Kameng districts, particularly the timberline areas. Based on elevation and dominant vegetation types, the study area was broadly classified into tropical evergreen forests (< 900 m elevation), subtropical-broadleaved forests and sub-tropical pine forests (900–1800 m), temperate broadleaved forests (1800–3000 m), sub-alpine forests and forest limit and alpine vegetation (> 3000 m) (Bahera *et al.* 2001; Kaul & Haridasan 1987; Roy & Bahera 2005). The composition of dominant vegetation types at all elevations was noted. For tropical and subtropical zones only important trees species were enumerated. However, for temperate broadleaved forest and the upper forest limit, a detailed list of species at the top- and mid-canopy levels along with the small trees and shrubs, climbers and epiphytes were recorded. Field notes were prepared on plant distribution range, habit, and time of flowering. The plant specimens were collected and made into herbarium. Each plant was identified to species level with the help of subject experts and existing flora at State Forest Research Institute, Itanagar and Botanical Survey of India, Itanagar.

Sampling for forest structure

Based on the field observations and physiognomic features of forests, three forest stands located at Sela-Nuranag (Stand-1), Pangila (Stand-2), and Sela Pass-Baisakhi (Stand-3) were investigated for detailed information on the tree structure and species composition. For the structural analysis of forest stands a representative plot of 100 × 500 m (5 ha) was earmarked using grid map at each forest stand; the plot was further sub-divided into five 100 × 100 m sub-plots. Tree structure was analyzed using 10 × 10 m quadrats, randomly placing six quadrats in each sub-plot. Each stand was sampled with 50 quadrats. To study tree species regeneration and shrub species density, 5 × 5 m quadrats were randomly placed, two quadrats in each 10 × 10 m quadrats that were used for tree sampling. Thus, a total of 100 quadrats were laid and analyzed at each forest stand. Tree individuals having DBH > 10 cm were categorized as adult trees, DBH < 10 cm but height > 30 cm as saplings, and height < 30 cm as seedlings (Sundriyal & Sharma 1996). Data were pooled separately for each forest stand and calculated for measuring frequency, density, total basal area, relative density and dominance of each species.

Local community dependence on resources

Information on timber and firewood, medicinal plant collections, and grazing were collected. For data on timber and firewood collection, three investigated forest stands (Stand 1 to 3) were targeted. All trees cut and lopped at each site were counted and extrapolated for per hectare values. Accordingly, the forest stands were identified as least, moderately, and highly disturbed stands. For collecting data on medicinal plant extraction, information from local villagers involved in this trade was gathered through personal interviews and semi-structured questionnaires. A total of 34 villagers representing 6 villages were interviewed. Besides, records of the Forest Department were gathered in relation to number of permits issued for medicinal plant collection, sites visited, and the name of the permit holders and quantity collected. The plants were categorized as medicinal, aromatic, resin, dye and spices along with their market rates. Based on the information collected, the analysis was done to have an idea of change in the trend in terms of availability of different plants at various sites.

The timberline and alpine areas are visited by nomadic graziers for summer grazing. For the study, a total of 23 herders from 10 villages were interviewed with regard to the changes in livestock population in past ten years, grazing routes, movement, and period of camping at different stations in the pastures. Considering that some pastures were owned by the community, the villagers were enquired about traditional rules and regulations for pasture management and change in such practices, if any. They were also questioned the challenges of pastures and animal management. Finally, after field verification of the information, a map was prepared to understand the movement patterns during grazing.

Data analysis

Statistical analysis of the data and differences in mean values of the studied parameters was done by determining the analysis of variance (ANOVA) using SPSS statistical programme. The graphical representation of data is done using MS Office Excel.

Results

Land use-cover of the region and delineation of timberline area

Tawang and West Kameng districts comprised a total geographical area of 2470 km^2 and 4883 km^2, respectively, divisible into 15 land use-cover classes (Fig. 1, Table 2). Of the total geographical area of two districts, 73% was under forest (with 82% was under dense-category) (Fig. 2). We identified eight forest types: the temperate broad-leaved forest exhibited the highest forest area (32.6%), followed by sub-alpine forest (20.9%), sub-tropical evergreen forest (19.1%), pine forest (9.1%), temperate coniferous forest (6.9%) and tropical semi-evergreen forest (6.3%). A reconnaissance of the timberline area revealed that the minimum and maximum altitudinal limit of timberline was 3600 to 4600 m above sea level (Fig. 3). An analysis of the broad vegetation types within this elevation belt revealed that the largest area was under sub-alpine forest. Within the timberline area the temperate conifer

Table 2. Land use - land cover of Tawang & West Kameng districts, and timberline area in Arunachal Pradesh, Northeast India.

Land use - land cover type	Tawang district		West Kameng district		Timberline zone (3900–4200 m)		Total of two districts	
	Area (sq km)	% of total district area	Area (sq km)	% of total district area	Timber-line area (sq km)	% area within this zone	Area (sq km)	% of total area
A. Broad Vegetation Classes:								
Tropical Evergreen Forest	0.40	0.02	155.47	3.18	0	0	155.87	2.12
Tropical Low Hills and Plains Semi-Evergreen Forest	2.29	0.09	332.63	6.81	0	0	334.92	4.56
Tropical Low Riverine Semi-Evergreen Forest	1.25	0.05	111.65	2.29	0	0	112.91	1.54
Sub-tropical Evergreen Forest	0.02	0	1022.35	20.94	0.21	0.03	1022.37	13.91
Pine Forest	2.34	0.09	486.70	9.97	0	0	489.04	6.65
Temperate Broad Leaved Forest	142.40	5.77	1602.45	32.82	11.90	1.91	1744.84	23.73
Temperate Coniferous Forest	180.16	7.29	193.99	3.97	33.90	5.45	374.14	5.09
Sub-alpine Forest	771.13	31.22	345.68	7.08	194	31.20	1116.81	15.19
Total forest	1099.99	44.53	4250.92	87.06	240.01	38.59	5350.90	72.78
B. Other Categories:								
Agriculture and human settlement	35.10	1.42	12.34	0.25	6.31	1.01	47.43	0.65
Sandy bed	2.66	0.11	9.52	0.20	0.50	0.08	12.18	0.17
River	0.37	0.01	3.38	0.07	0.40	0.06	3.75	0.05
Snow/Cloud	217.37	8.80	39	0.80	28.92	4.65	256.37	3.49
Open/Barren/Rocky Exposures	727.21	29.44	168.73	3.46	170.79	27.47	895.95	12.19
Degraded Land	44.74	1.81	104.62	2.14	6.29	1.01	149.37	2.03
Lake/high altitude Wetland	5.52	0.22	1	0.02	0.42	0.07	6.52	0.09
Hill Shadow	336.85	13.64	293.20	6	168.17	27.05	630.04	8.57
Total Non-forest	1369.82	55.45	631.79	12.94	381.80	61.40	2001.61	27.22

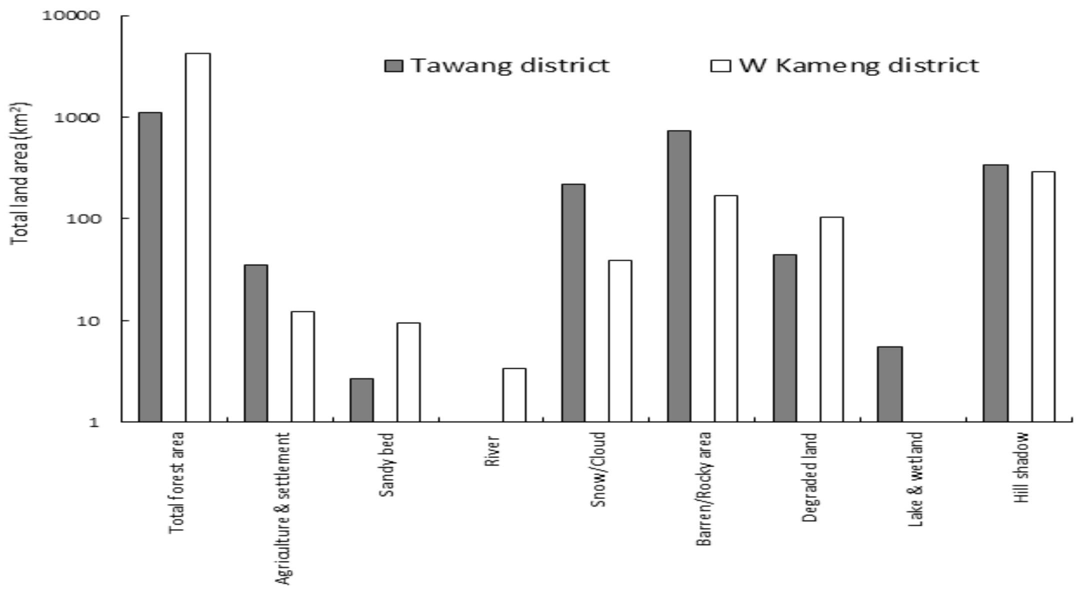

Fig. 2. Land use-cover statistics of Tawang and West Kameng districts, Arunachal Pradesh.

Plate 1. Timberline at Thembang

Plate 2. Scattered Abies near Sela

Plate 3. Rhododendron above timberline

Plate 4. Road construction in alpine areas

Plate 5. Timber & firewood collection at timberline

Plate 6. Sheep grazing in alpine area

Plates 1–6: Pictorial view of the timberline at Tawang and West Kameng districts of Arunachal Pradesh

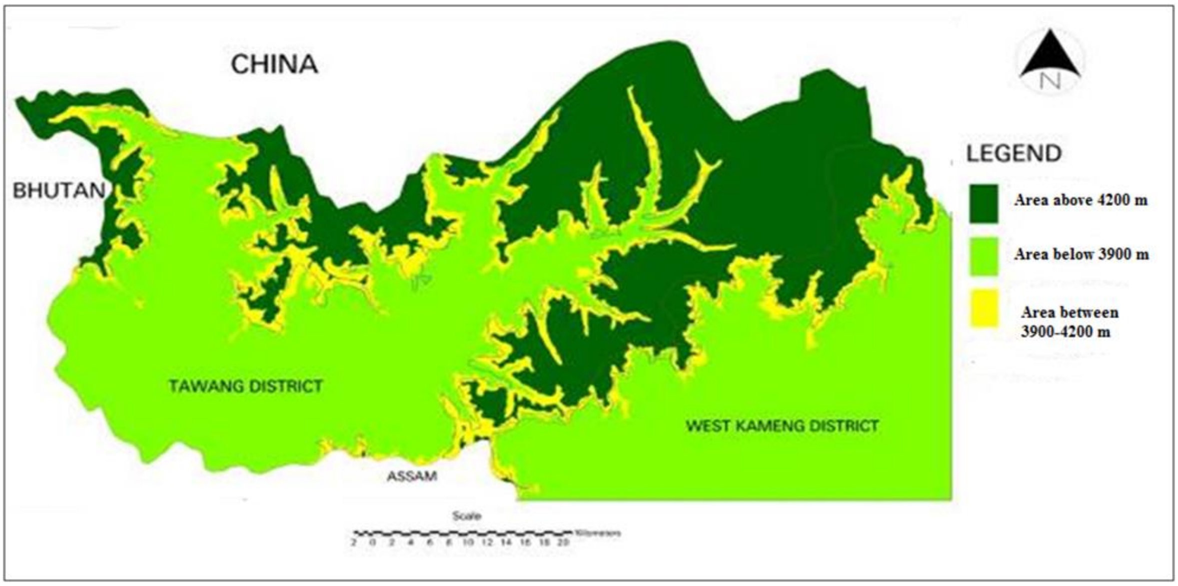

Fig. 3. Distribution of timberline area (between 3900 to 4200 m elevations) in Tawang and West Kameng districts.

forest comprised more area than temperate broad-leaved forest (Fig. 4). A pictorial view of timberline and diverse biotic pressure at high altitude areas is provided (Plate 1 to 6).

Elevation pattern of species richness and floristic composition

Tree species number increased somewhat from tropical evergreen forests (< 900 m) to subtropical broadleaved forests (900–1800 m), thereafter declined sharply in temperate broadleaved forests (1800–3000 m) (Fig. 5). The shrub species number peaked in the temperate broadleaved forest. Although a complete inventory of the herbaceous species was not made, an increasing trend in species number was observed with increasing altitude. For climbers, a decreasing trend in species richness with altitude was observed, while epiphytes showed an inconsistent trend.

The important tree species of tropical evergreen forests were *Terminalia myriocarpa* (hollock), *Altingia excelsa* (jutuli), *Ailanthus grandis* (borpat), *Amoora wallichii* (amari), *Canarium strictum* (dhuna), *Duabanga gradiflora* (khokhan), *Mesua ferrea* (nahar), *Morus laevigata* (bola), *Albizia arunachalensis* (siris), *Kydia glabrescence* (pichola), etc. Above this zone, forest was evergreen broadleaved with the dominance of *Quercus lamellosa*, *Quercus pachyphylla*, *Q. griffithii, Q. serrata, Michelia* sp., *Magnolia* sp., etc. There were also patches of *Pinus roxburghii* and *P. wallichiana*. In temperate broad-leaved forest areas *Quercus griffithii* and *Q. lanata* grew in association with *Rhododendron arboreum*, *Magnolia campbellii, Michelia doltsopa,* etc. There was usually dense undergrowth, mostly of bamboo-like *Chimonobambusa callosa*. Patches of deciduous species like *Acer oblongum, A. pectinatum, A. campbellii,* and *Betula alnoides,* along with *Alnus nepalensis,* could be seen along water courses. The mid-story was predominated by small trees and shrubs like *Pyrus polycarpa, Pyrus pashia, Sorbus foliolosa, Prunus cerasoides, Illicium griffithii, Rhododendron falconeri, R. grande, R. edgworthii, Spiraea micrantha, Symplocos racemosus*, *Lyonia ovalifolia, Cotoneaster frigidus, Corylopsis himalayana,* etc. Though the climbers showed low density in these forests, a few climber species recorded from the forests comprised *Clematis buchananiana, C. connata, C. barbellata* and *C. cadmia*. Among the epiphytic elements orchids like *Cymbidium grandiflorum, C. giganteum, Eria coronaria* and *Pleione praecox* were common along with some ferns like *Arthromeris himalayense, Clenopteris subfulcata,* and *Asplenium ensiforme* etc.

Timberline physiognomy and floristic

The Temperate coniferous stands consisted of several conifers and rhododendrons; *Rhododendron falconeri, R. cinnabarinum* and *R. barbatum* at lower limits, and mixed coniferous vegetation of *Abies densa, A. delavayi, Cupressus corneyana, Taxus walli-*

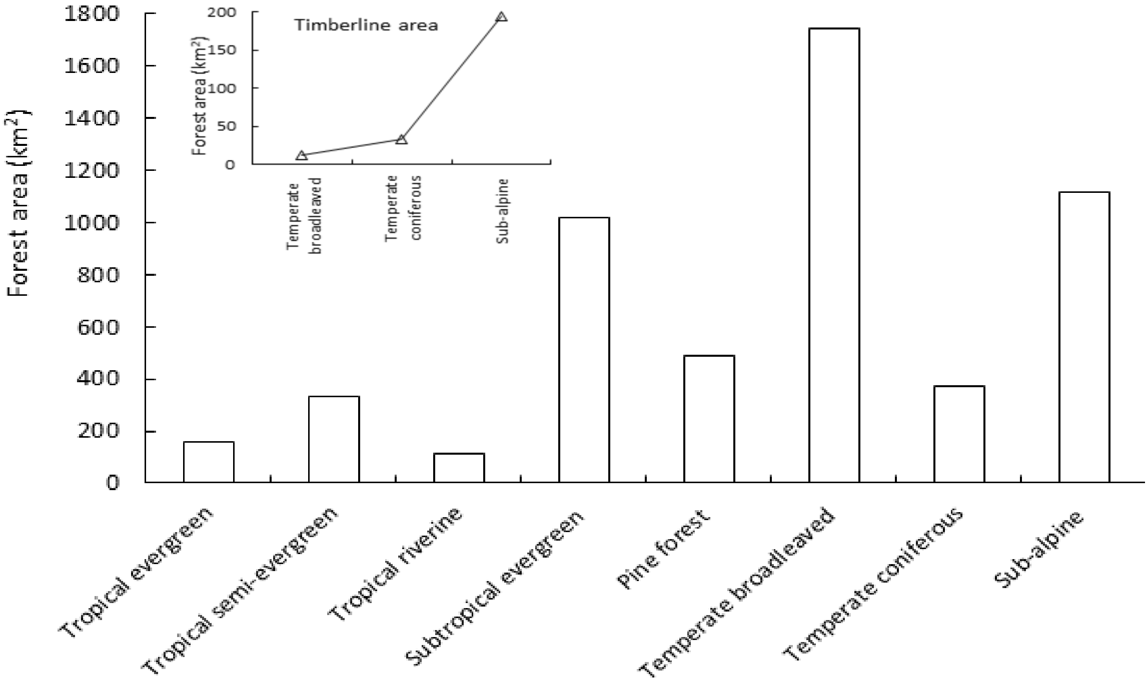

Fig. 4. Broad vegetation types and respective forest land in Tawang and West Kameng districts (bar diagram) and timberline area (subset line graph).

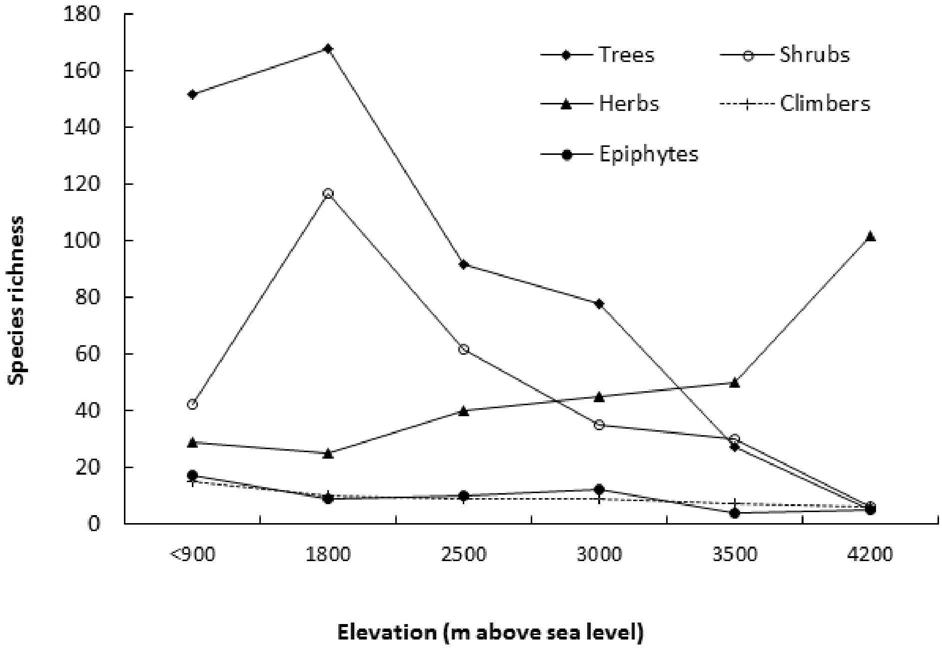

Fig. 5. Species richness and life forms at different elevations at Western Arunachal Pradesh.

chiana var. *baccata*, *Tsuga dumosa*, *Larix griffithiana,* etc. towards upper limits. Besides, patches of *Rhododenron grande* and *R. hodgsonii* were also found within this belt. The shrub layer of such forest type comprised *Berberis* spp., *Mahonia nepalensis, Leycesteria formosa, Rhododendron camelliiflorum, R. dalhousiae, Gaultheria fragrantissima, Satyrium nepalense, Calanthe manii, Bergenia purpurascens, Nellia thyrsiflora, Rosa sericea, Rubus paniculatus* and *R. biflorus*. There were many climber, epiphytes, and herbaceous species.

A detailed survey of Baisakhi-Sela, Pangila and above in West Kameng district and Sela-Nurunang, Bhagajang, Nagula and Lumpo area of Tawang district revealed that the upper timberline elevation limit was 4600 m. The timberline physiognomy varied from place to place. At many places it was abrupt type with alpine meadows above it (Plate 1), while at other places the timberline was fringed by rhododendron bushes and/or patchy and scattered trees (Plate 2). The timberline was made up of *Abies densa* with short tree and/or dwarf bushes of *Rhododendron hogdsonii, R. thomsonii, R. lapidotum, R. bhutanense, R. anthopogon, R. campanulatum x barbaratum, R. cinnabarium* and other rhododendron species (Plate 3). *Abies densa* formed a mono-dominant stands on north slope, however with moderate biotic pressure it occurred with other tree species on south slope. East slope was relatively more disturbed. *Sorbus* species was also found on south and east facing slopes. *R. campanulatum* and *Juniperous indica* were recorded only on south slope (Table 3). Among shrubs *Berberis* sp. was most dominant.

Altogether the timberline area comprised a total of 5 tree species and 11 shrub species (Table 3, 4). The tree density was the highest at moderately-disturbed site (Stand 2), followed by least-disturbed site (Stand 1) and minimum at highly-disturbed site (Stand 3). Among the tree species, *Abies densa* was present in all the stands, and *Sorbus microphylla* in two stands. Among the shrub species, only *Berberis* sp. was recorded from all the stands (Table 3). A conspicuous feature of the timberline was the dominance of *Abies densa* under all levels of biotic pressure (Table 3). The biotic pressure at north, south, and east was recorded least, moderate and high and *Abies* recorded a height of 5.00 ± 0.12 m, 16.04 ± 0.27 m, and 5.06 ± 0.32 m at north, south and east slopes, respectively, which exhibits that south slopes support better growth condition may be due to higher solar radiation. The density of saplings and seedlings of all the tree species also differed in the three timberline forest stands. *R. lapidotum, R. barbaratum* and *Rhododendron thomsonii* were other important shrub species at timberline. And among all, the highest relative density was of *Berberis* sp. at timberline (Table 4).

The vegetation above 4000 m composed of herbaceous and deep-rooted cushioned plants, such as *Aconitum fletcherianum, Meconopsis paniculata, Potentilla peduncularis, Rhodiola himalensis, R. wallichiana, R. quadrifida, Sedum multicaule, Saxifraga hispidula, Epilobium tetragonum, Geranium lamberti, Primula denticulata, P. elongata, Swertia hookeri, Polygonum macrophyllum, P. vaccinifolium, Bistorta affinis, Rumex nepalensis*, etc. Some common grass and sedge species of the alpine meadows were *Kyllinga odorata, Chrysopogon aciculatus, Carex haematostoma* and *Agrostis zenkeri*. The timberline flora comprised a total of 152 plant species, 52 of them were recorded within timberline and below (about 100 m below), 28 species along timberline and above (about 100 m above), and 76 species distributed both below and above timberline zone (Fig. 6). The dominant shrub at timberline and below was *Berberis* (5 species), although it was totally absent above timberline. Genus *Senecio* (with 3 species) was recorded growing along timberline and below. *Saxifraga* (3 spp.) was a dominant genus at timberline and above. Other prominent genus recorded growing both below and above timberline zone were *Primula, Rhododendron, Potentila*, and *Cyananthus*. The study also reveals that some species have high conservation significance, viz. *Rhododendron nevium, R. sikkimense, Aconitum ferox, Nardostachys grandiflora, Picrorhiza kurrooa, Nardostachys grandiflora, Saussurea yakla, Saussurea globossa* and *Primula poluninii* because of their endemic and restricted distribution as well as due to their high demand mainly for medicinal purpose.

Socio-economic dependence on and around timberline area

i) Collection of timber and firewood

In the three timberline stands, the number of trees cut and lopped (branches) was 23, 54, and 121 per ha in stand 1, 2, and 3, respectively, which exhibited high pressure on forests. The area has been subjected to road construction for civil and defense need that also led to huge quantity of timber and firewood collection (Plate 4 and 5).

ii) Collection of medicinal plants

Local dwellers visit as many as 37 sites for collection of medicinal plants in a season. In total 16 plant species were collected for commercial use, of which kutki (*Picrorhiza kurrooa),* nying (*Aconitum ferox*), and yartsa-gambu (*Cordyceps sinensis*) were collected at and above timberline and lishi *(Illicium griffithii),* chirata *(Swertia chirata*), langyeru (Indian Madder) *(Rubia cordifolia*), taxus (Himalayan Yew) *(Taxus baccata*), boch *(Acorus calamus*), pangpos *(Valeriana jatamansi*), dalchini *(Cinnamomum verum*), ginseng *(Panax pseudo*

Table 3. General characterisitics of three study sites at timberline zone of western Arunachal Pradesh.

Name of the species	Stand 1	Stand 2	Stand 3
Location	Sela - Nurunang	Pangila	Sela Pass - Baisakhi
Elevation range	4000 m to 4100 m	3900 m to 4100 m	3900 m to 4100 m
Aspect	North facing	South facing	East facing
Slope	25° to 30°	15° to 60°	35° to 55°
Distance from settlement area	25 km*	4 days trek	12 km
Biotic pressure	Low	Medium	High
Forest Type	Temperate Conifer	Temperate Conifer	Temperate Conifer
Tree Species richness	1	5	2
Shrub Species richness	6	7	5
Tree Density (ha^{-1})	627.27	671.29	205.26
Basal area (m^2 ha^{-1})	13.60	42.36	4.86
Sapling density (individuals ha^{-1})	160.00	1803.14	115.79
Seedling density (individuals ha^{-1})	333.30	19142.86	94.74
Shrub density (individuals ha^{-1})	1933.33	2074.29	2515.79

Table 4. Relative density (%) of tree and shrub species at different forest stands at timberline zone of western Arunachal Pradesh.

	Species	Stand-1	Stand-2	Stand-3
Trees	*Abies densa*	100	54.46	76.92
	Rhododendron hogdsonii		18.30	
	Rhododendron sp. 3		14.05	
	Sorbus microphylla		5.53	23.08
	Sorbus sp.		7.66	
Shrubs	*Berberis* sp.	30.72	8.26	79.5
	Rhododendron thomsonii		66.12	4.6
	Rhododendron lapidotum	22.88		10.04
	Rhododendron bhutanense	12.23		3.35
	Rhododendron anthopogon	7.52		
	Rhododendron campanulatum x barbaratum	17.55	8.82	
	Rhododendron cinnabarium		5.79	
	Rhododendron campanulatum		0.83	
	Rhododendron sp. 2		3.31	2.51
	Juniperous indica		6.89	
	Unidentified 1	9.09		

ginseng), s-panja *(Gymnadaenia orchidis*), lham *(Pinus wallichiana),* and kaifal, poonpo, pilla-zari (unidentified) were gathered from temperate forests. All the species were collected in large quantities.

A discussion with community revealed that in recent years there had been a net decline (by about 37%) in the availability of medicinal plants. Therefore, the collectors were moving to new sites which occur in more remote areas than before. Although the prices of most of the medicinal plants have increased over the years, the people prefer to collect them from remote sites because they fetch high prices. There was a set procedure for collection and selling medicinal plants from the region, which has been in place for many decades.

iii) Grazing pressure

Brokpa, the nomadic pastoral community of the Monpa tribe, is known to rear sheep, yak (pure

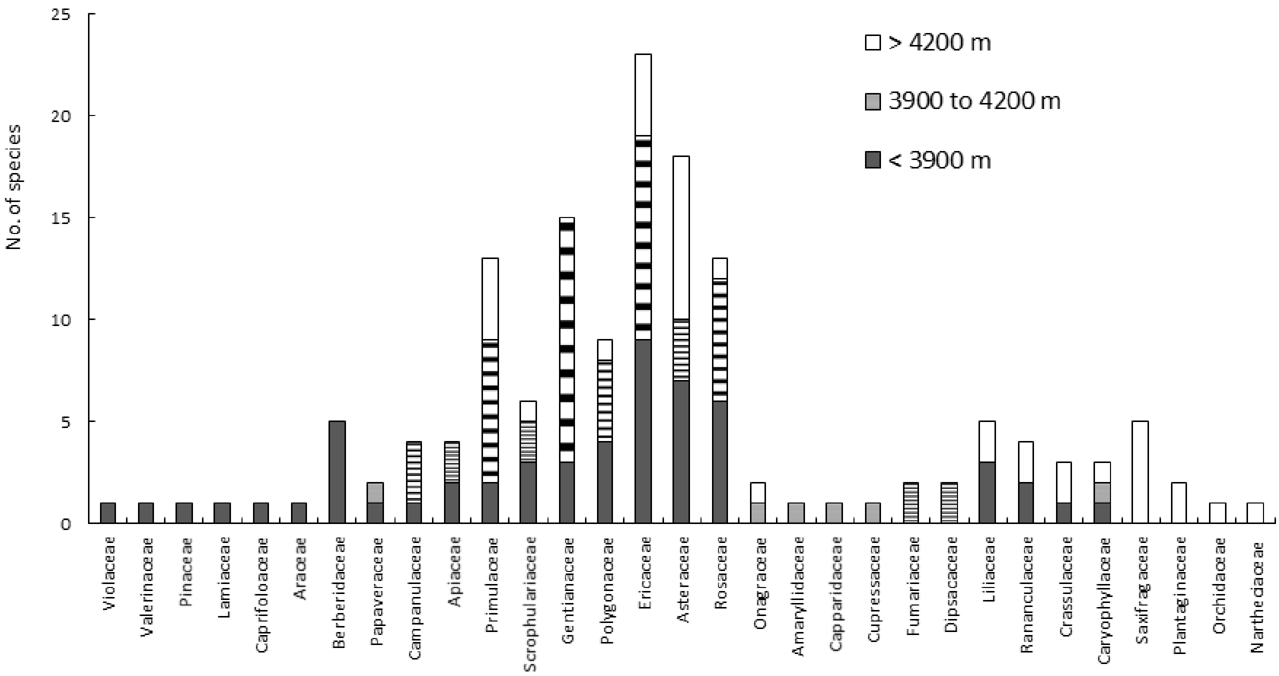

Fig. 6. Plant families recorded at timberline area at the eastern Himalaya, Arunachal Pradesh.

male), bree (pure female), dzo (male crossbred), dzomo (female crossbred), galang (male crossbred) and kot (female crossbred), and for that they visit alpine meadows (4000 to 4500 m) during May to October (Plate 6). Because of a preference for selected pasture, local graziers follow certain routes. Interestingly some villagers (e.g. Thembang village of West Kameng district) hold traditional rights on alpine pastures and they impose a tax on the herders for grazing in areas under their jurisdiction. Meat, milk, butter, cheese, and wool were most common animal-products which were either self consumed or sold in market to earn cash. For stay at high altitude areas graziers build temporary sheds using considerable quantity of timber. Besides, a significant quantity of firewood is also used by them. Some graziers also collect wild plants for food and medicinal purposes. During winter months all domestic animals move to lower elevations between 2000–2500 m.

Comparative account of timberline in the Himalayan region

A comparative analysis of timberline across Himalayan states reveals that upper timberline elevation increased from northwest to northeast and attained maximum in Arunachal Pradesh as recorded in this study (Table 5). The general floristic and physiognomic pattern of upper timberline in the western Himalayan region comprised birch (*Betula utilis*) and several conifers (*Abies pindrow*, *Pinus wallichiana*, *Picea smithiana*). *Rhododendron campanulatum* and *Juniperus* spp. occurring both inside and outside timberline forests. The krummholz formation is common, particularly in areas with heavy snowfall. In the eastern part of Nepal and towards Sikkim the dominance of birch drops sharply. Many rhododendron species express their predominance at upper timberline from Sikkim to Arunachal Pradesh (Table 5). In this study, the uppermost timberline is dominated by *Abies densa* either as single conifer species or interspersed with *Rhododendron* spp. and *Sorbus* sp. Some other species, viz. *Picea* spp., *Larix griffithiana* are also reported from other timberline areas but relatively at lower elevations.

Discussion

Timberlines in Tawang and West Kameng districts of Arunachal Pradesh, the easternmost Himalayan state of India occurred between 3600 and 4600 m above sea level. It consisted of the eastern Himalayan fir, *Abies densa,* with *Rhododendron hodgsonii* and *Sorbus* spp. as its associates. The shrub in timberline forests mostly comprised *Berberis* sp. (dominated in two stands)

Table 5. Timberline location, physiognomy and floristic pattern in the Himalayan region.

Region	Locations	Lat./ Long.	Timberline elevation	Species	Authors
Jammu–Kashmir	Wardwan, Chenab valley, Bhadarwah Hills	32°–33°48–55'N/ 75°40'–50'E	3500–3600 m	*Betula utilis, Abies pindrow, Pinus wallichiana, Salix* sp., *Juniperus* spp., *Rhododendron campanulatum*	Kaul & Sarin 1974; Gupta & Kachroo 1983; Singh & Kachroo 1983
Himachal Pradesh	Chamba, Sutlej valley, Ladhakh	32°–34°23–58'N/ 77°02'–40'E	3500–4200 m	*Quercus semecarpifolia, Pinus wallichiana, Betula utilis, Sorbus aucuparia, Salix* spp., *Rhododendron campanulatum, Juniperus excelsa*	Rau 1974; Seybold & Kull 1985; Gupta 1994
Uttarakhand	Nanda Devi, Pindari, Sarju Valley, Tungnath, Valley of Flowers, Gangotri, Tons & Bhagirathi valley	30°–31°07–55'–N/ 78°–79°4'–50'E	3300–4100 m	*Betula utilis, B. alnoides, Abies pindrow, Quercus semecarpifolia, Juniperus recurva, Sorbus* sp., *Rhododendron arboreum, R. barbatum, R. campanulatum*	Gupta 1983; Sundriyal & Bisht 1988; Singh & Singh 1992; Rawal & Pangtey 1994; Garkoti & Singh 1994; Rawal & Dhar 1997; Maikhuri *et al.* 1998; Kala *et al.* 2002; Schickhoff 2005; Gairola *et al.* 2008; Rai *et al.* 2012; Bisht *et al.* 2014
Nepal	Buri Gandaki, Barbung Khola, Ghasa, Helambu, Langtang, Marpha, Chulungche	27°–28°36–56'N/ 83°–86°49' E	3600–4400 m	*Betula utilis, Abies spectabilis, Rhododendron campanulatum, R. barbatum, Juniperus* sp., *Pinus wallichiana, Larix griffithiana, Sorbus microphylla*	Metz 1998; Miehe *et al.* 2000; Schickhoff 2005; Gaire *et al.* 2010
Sikkim	Singalila National Park, Jelep La, Zemu valley, Kangchendzonga Biosphere Reserve	26°–27°27–47'N/ 87°–88°21–59'E	3600–4200 m	*Abies densa, Betula utilis, Quercus lineata, Betula* sp., *Rhododendron arboreum, R. campanulatum, R. hodgsonii, R. falconeri, R. grande, Arundinaria aristata, Juniperus* sp.	Pradhan *et al.* 2001; Chettri *et al.* 2002; Singh *et al.* 2003

Contd…

Table 5. Continued.

Region	Locations	Lat./ Long.	Timberline elevation	*Species*	Authors
Bhutan	Black Mountains, Sankosh Valley, Tremo La, Bumthang V.; Pologong Chu, Narimthang	27°17–55'N/ 89°–91°13'-42'E	3700–4100 m	*Abies densa, Juniperus* sp., *Rhododendron hodgsonii*, *R. campylocarpum*, *R. campanulatum*, *R.lanatum, Picea* sp., *Arundinaria* sp.	Schickhoff 2005
Arunachal Pradesh	Sela, Nurunang, Pangila, Baisakhi, Lohit valley, Walong, Mishmi Hills, Lepa	26°–29°03–53´N/ 91°–97°05–3´E	3600–4600 m	*Abies densa, Sorbus* spp., *Rhododendron* spp., *Juniperus* spp., *Larix griffithiana*	Rao & Panigrahi 1961, Present study

and *Rhododendron thomsonii* (dominated in one stand). Apart from these, many *Rhododendron* species *(R. lapidotum, R. bhutanense, R. anthopogon, R. campanulatum x barbaratum, R. cinnabarium, R. campanulatum)* and *Juniperous indica* occurred in the timberline ecotone. Overall, the timberline ecotone was species rich (152 species in total occurred). From timberlines of other parts of the Arunachal Pradesh state other than *Abies* sp., *Picea* sp., *Larix griffithiana* are also reported, but generally below upper timberline (Rao & Panigrahi 1961). Considering that the vegetation of the area has been least investigated (Dutta *et al.* 2014; Schickhoff *et al.* 2015), we made an effort to delineate major land use-cover categories. Eight forest types that included almost all forest types of northeast Himalaya (FSI 2015) occurred in the state. Tree species richness was high up to 1800 m, then declined sharply with increasing elevation, while shrubs increased in number from < 900 m to 1800 m, whereafter it declined with elevation. In contrast, herb species richness increased with elevation, the rise being particularly sharp from 3500 m to 4200 m, possibly because forest trees become sparser. Species richness peak in the lower one-third of elevation gradient, as found for trees and shrubs in our study, is a common feature of the relationship between species richness and elevation (Trigas *et al.* 2013). A taxonomic exploration of West Kameng district has shown the presence of 1428 plant species belonging to 690 genera and 163 families (Paul *et al.* 2010; Sarmah 2005). Species, in general have affinities with Indo-Malayan, Afrotropic, and Indo-Chinese region (Hajra *et al.* 1996, Paul *et al.* 2010). The altitudinal variation in species can also be attributed to different environmental (climatic) variables, spatial features (area, size, and geometric constraints), evolutionary history, and biotic processes at different altitudes (McCain & Grytnes 2010; Roy & Behra 2005).

The timberline ecotones of the present study has 5 tree species, which is higher than that of the western Himalayan region (Gairola *et al.* 2015; Kharkwal *et al.* 2005), and similar to the tree species richness of timberlines in Nepal and Tibet (Gaire *et al.* 2010; Zhang *et al.* 2009). Interestingly, *Rhododendron campanulatum*, which is a common timberline species in the western and central Himalayan regions, was inconspicuous in Arunachal Pradesh. Birch (*Betula utilis*), the flagship timberline species in much of the Himalayas was absent here; possibly, conditions are too moist for birch to compete with evergreen tree species. An analysis of birch distribution in Arunachal reveals that it is found 200–300 m lower than that of the fir. However, more investigations are required to ascertain the relative position of birch in Arunachal. In western Himalaya, birch (*B. utilis*) exceeds the upper limit of all other tree species.

The upper timberlines in western Himalayan region generally have birch (*B. utilis*) and conifers (like *Abies pindrow*, *Pinus wallichiana*, *Picea smithiana*). There *Rhododendron campanulatum* and *Juniperous* spp. are also common. *Quercus semecarpifolia* an evergreen oak forms abrupt type of timberline, particularly in Himachal Pradesh and Uttarakhand (Bisht *et al.* 2014; Gairola *et al.* 2008; Rai *et al.* 2012; Rau 1974; Rawal & Pangtey 1994; Seybold & Kull 1985; Sundriyal & Bisht 1988). In Nepal timberline forest comprised *Abies* *spectabilis* with birch and rhododendron species (Gaire *et al.* 2010; Metz 1998; Miehe & Miehe 2000). Timberlines in Sikkim and Bhutan also have a dominance of conifers and rhododendrons (Chettri *et al.* 2002; Schickhoff 2005). Interestingly, *Quercus* and *Betula* species that form an important part of Western and Central Himalayan timberlines were absent at upper timberline in Arunachal Pradesh. This exhibits a gradual shift in floristic composition from deciduous birch in northwest to evergreen fir and rhododendron in northeast. From eastern Nepal to Sikkim, birch drops in importance while conifers and rhododendrons increase. Many rhododendron species express their predominance in upper timberline from Sikkim to Arunachal Pradesh. Perhaps decreasing winter cold and increasing humidity in the northeast favour rhododendrons (Schickhoff *et al.* 2015). In Tibet timberlines are dominated by *Abies forestii* var. *georgei, Abies georgei* var. *smithii, Juniperus saltuaria, Lonicera* spp., *Rhododendron* spp., *Sabina saltuaria,* and *Spiraea* sp. (Qingshan *et al.* 2007; Shaoliang & Ning 2013; Zhang *et al.* 2009, 2010). In this study the timberline forest comprised *Abies densa, Rhododendron hodgsonii* and *Sorbus microphylla* and in comparison to other areas krummholz formation was least evident.

The upper limit of timberline elevation increases from western to eastern Himalayan region and reaches upto 4600 m in Arunachal Pradesh, as recorded in this investigation. The upper timberline in Arunachal is higher than those reported for many western and central Himalayan sites, though generally timberlines are higher in drier climates (Körner 2012). Because of the use of remote sensing method, this study captured a larger view of timberline distribution. Manual sampling is limited to a few spots of timberline, so fails to assess its entire elevation range. In moist sites snow may stay longer, and thus, suppress tree growth. However, in Arunachal Pradesh early arrival of rains (May-end) would result in early snow melt. Arunachal is close to Tibetan Plateau where occurs the most elevated timberline of the Northern Hemisphere (at 4700 m elevation, Shi & Wu 2013).

Changing anthropogenic activities

Biotic pressure has high impacts on the Himalayan timberline. In Arunachal Pradesh, the timberline areas along with the alpine regions are under intense anthropogenic pressures, leading to a widespread degradation. A large number of migratory graziers visit the area during summer months, practice seasonal agriculture, and build temporary shelters. They also harvest NTFPs, particularly medicinal plants. Herder take sheep and yaks to graze pastures between 4000 and 4500 m. Notably, at many places pastures were under local jurisdiction and community control. In recent years, however, the number of households involved in pastoral activities has declined in view of changed perception and more education which is leading to adopt new livelihood opportunities and living style. Change in the socioeconomic condition of local communities is also responsible for such a shift. This is also true for many other regions including Arunachal Pradesh and Nepal where traditional societies are registering a decrease in the number of families involved in grazing due to change in lifestyle (Farooquee & Rao 2001; Pandey & Chetri 2005). The traditional pasture management system has been useful in avoiding overgrazing; however, no effort was made to conserve such practices. Tibet and Bhutan have made some efforts in this direction and that has contributed to sustainable grazing (Derville & Bonnemarie 2010). To obtain higher economic benefits herders also collect high-value medicinal plants (such as aconitum, kutki, and cordyceps), despite a ban imposed on their collection (Singh & Sundriyal 2005). The medicinal plant collection has increased in recent years and newer sites are being visited for this purpose. In view of the rapid change of values, the management of natural resources is weakening, thus threatening timberline areas. However, moderate grazing contributes to maintaining several species and to species diversity.

Implications for management and conclusion

The present study highlights that integration of RS-GIS can contribute to better understanding of vegetation cover and floristic diversity of the region, which could be utilized in management planning for the region. In recent times the timberline zone has been under increased developmental activists, such as road construction and infrastructure development, which have led to significant increase in extraction of timber, firewood, and medicinal herbs. Besides, the traditional management of high altitude pastures, which used to be done by traditional village institutions, was gradually declining in view of the change of socio-economic fabric of communities. Such an increase in biotic pressure poses a considerable threat to species diversity and landscape. It may affect land cover, species composition, and structure in near future. Climate change may also add to such changes, however, it needs further authentication. There is a need to promote conservation education among graziers and medicinal plant collectors, and adoption of alternate means of energy at such high altitude areas as it may lead to improving the species status at highly degraded stands. Besides, promoting new economic opportunities, such as ecotourism, can bring better livelihood option to local communities for which their capacity needs to be built. Developing community skills on sustainable harvest of medicinal plants and making them aware of the ill effects of overgrazing along with the involvement of government and village level institutions in management activities would greatly help to improvise situation of timberline area. There is also a need to take up more coordinated researches for developing a better understanding of the timberline area and its management, which can contribute to the sustainable conservation of the region.

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