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ALPINE TIMBERLINE RESEARCH GAP IN HIMALAYA: A LITERATURE REVIEW

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ABSTRACT

Alpine timberline, considered to be important ecotone supports rich and highly vulnerable biodiversity and represent one of the most distinct boundaries between forest to tree less alpine areas. It has attracted geographers and ecologist to do research for a long time on the phenomena it encompasses. In recent time, alpine treeline ecotones across most of the world's mountains are being studied because of their potential for monitoring the effects of climate warming on forest ecosystem. Besides, alpine pasture areas in and around timberline zone and commercially important medicinal plants along timberline have also been playing important role as a source of livelihood of mountain communities settled in nearby area. In recent time, with the change in socio-economic aspiration of local mountain communities, there has been a rapid increase in pressure on natural resources in and around timberline area. However, compared to studies of timberline area of European Alps, Andes of South America and mountains of North America, which has reached a very advance stage, very limited studies on timberline of Himalayan mountain range have been carried out. In the present paper, review of timberline research work carried out in the mountain ranges of Europe, North America and Himalaya have been carried out to highlight the gap in alpine timberline research work in Himalaya.

Key words: Alpine, Timberline, Ecotone, Biodiversity, Livelihood, Climate change.

Introduction

Timberline is the most conspicuous vegetation limit in high-mountain areas of all continents, except Antarctic. On account of the greater ecological, physiognomic and taxonomic variety of mountain timberline (Holtmeier, 2003) the standard definition of timberline is far from complete (Kullman, 1990; Holtmeier, 2003). Alpine timberline is broadly defined as the upper limit to tree and forest survival in mountain environment due to various environmental constrains (Wardle 1968). The upper timberline, rather than being abrupt boundary, usually forms an ecotone between the closed continuous forest below and the treeless alpine zone above (Wardle, 1974; Tranquillini, 1979; Holtmeier, 2003).

Alpine treeline ecotones across most of the world's mountains are being studied because of their potential for monitoring the effects of climate warming on forest ecosystems (Holtmeier and Broll, 2005). Past studies of treeline have shown that population structures at treeline ecotones are good indicators of climate change, where trees often respond to climatic warming with increase in recruitment or tree-density, as well as upward advances of the treeline (Camarero and Gutierrez, 2004).

Areas in and around timberline zone, besides supporting rich and diverse flora and fauna in fragile and sensitive ecosystem, are also supporting high altitude wetlands which are acting as reservoir for important rivers of the world. The high altitude lakes found in and around timberline zone of Arunachal Pradesh acts as reservoir of trans-boundary rivers like Brahmaputra. The timberline zone is also very closely linked with the traditional socio-economic activities of local indigenous communities settled in the state which includes grazing and collection of medicinal plants (Farooque *et al.,* 2004).

The timberline zone in the Himalaya is a cradle of high temperate and low alpine biodiversity elements. It is a rich repository of high sensitive elements, which are of considerable biological and economic value. Among others, it includes endemic, endangered, medicinal and edible plant species (Dhar, 1998). The eastern part of the majestic Himalayan mountain range has been identified as a globally important region for biodiversity (Olson and Dinerstein, 1998; Mayers *et al.,* 2000) and support one of the world's richest alpine floras with high level of endemism (WWF, 2001). The extra moisture due to monsoon rains that sweep into the Bay of Bengal in eastern Himalaya supports many more species of plants and animals than the drier western reach of mountains

Globally though the alpine timberline research work is in most advance stage, very limited information regarding this most sensitive ecotone of Himalaya is available.

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(WWF and ICIMOD, 2001).

Alpine timberline has attracted geographers and ecologists to do research for a long time on the phenomena it encompasses. Pioneers started systematic treeline research in the European Alps in 1900s and by now, profound knowledge of upper treelines in Europe, North America and New Zealand has been accumulated (Schickhoff, 2006). Though, timberline of Himalayas has been identified as most sensitive habitats, thus it deserves high priority for conservation (Dhar, 1998), comparatively very limited studies are available on the alpine timberline area of Himalayan mountain range

1. Global scenario of alpine timberline research

Systematic treeline researches in the European Alps were started in 1900s. From Swiss Alps, there are descriptions by classical scholars of the 18th and even the 16th and 17th centuries (Troll, 1973). Schroter (1926) (Cited in Troll, 1973) in his classic work on plant life of the Alps, used the alpine treeline as the limit between subalpine and alpine stages. Long before him Wahlenberg in his *Flora Laponica* (1812) used the terms, region sub-alpine and region alpine for the vertical graduation of birch woodland and treeless area in the mountains of Scandinavia (Troll, 1973).

Early timberline research was reviewed by Daniker (1923) (Cited in Autio, 2006), who first studied the phenomenon with special regard to ecological conditions and who was the first to use ecological research methods, although some studies on ecological conditions at the timberline were carried out also before Daniker (1923), such as the monograph of Kihlman (1890) (Cited in Autio, 2006) on the northern treeline on the Kola Peninsula. Those studies were based on careful observations and consideration, but not on experimental ecological measurements. Proposals have been appearing in the scientific literature for more than a hundred years concerning the climatic parameters and indices that best denote the location of timberline and treeline (Tuhkanene, 1999).

Troll (1973) reported that the first attempt to study the climatic conditions of the timberlines in a comparative way was made by the Swiss geobotanist Brockmann-Jerosch in 1919. Years before, in the geographical school of E. Bruckner at Berne, a series of investigation on specific vertical limitations in the Swiss Alps was published: the upper treeline by Imhof (1900), the snow line by Jegerlehner (1903), the upper limits of temperature values and the duration of the snow cover by de Quervain (1903), the average elevation by Liez (1903) and the upper limit of human settlement by Fluckiger (1906) were carried out (Troll, 1973).

As the treeline across the world is considered as indicator to monitor the impact of climate change, many studies to analyse the change in the composition (Scott *et al.,* 1987), age structure (Agren *et al.,* 1983) and position (Brink, 1959; Griggs, 1942) of treeline in response to global climate change have been carried out. All these studies suggested that some aspect of climate is important to treeline and that trees must differ from non-trees in their ability either to avoid or to tolerate unfavorable climate. The ecological dynamics of treeline in the Andes have been most investigated at middle latitudes (Villalba *et al.,* 1997; Cuevas, 2000).

Many studies to understand various factors and their role in the formation of treeline around the world have been carried out. Some of the studies which has proposed that multiple factors influence the treeline formation are by Wardle (1974, 1993); Tranquillini (1979); Korner (1998); Holtmeier (2003), etc. Studies to understand the impact of climate stress condition mainly due to frost on the growth of trees in the timberline have been carried out by Tranquillini (1979); Hadley and Smith (1987). Several researchers argued that upper limit of tree growth might be caused by an insufficient carbon balance (Stevens and Fox, 1991; Cairns, 1998). Spatial issues have interested ecologist for longtime and have been receiving increasing attention by the ecologist over last few years (Hao *et al.,* 2007).

Some of the early studies on various aspects of arctic and alpine vegetation were conducted by Bliss (1971); Coe (1967); Wardle (1968); Billings (1973). A large number of authors have described the worldwide positions of treeline areas (Troll, 1973; Wardle, 1974; Arno, 1984). Historical trend have recently been reviewed by Rochefort *et al. (*1994). Troll (1973) conducted studies on upper timberlines in different climatic zones. Habeck (1970) has done vegetation analysis of Glacier National Park. Allen and Peet (1990) conducted gradient analysis of forest of Sagre de Cris to Range, Colorado.

GIS techniques are now being also used to analyse vegetation cover of timberline area. Kral (2009) studied the vegetation cover of alpine timberline ecotone of Czech Republic in which a new method of automated alpine tree line ecotone identification from Remote Sensing data was proposed and tested successfully. Shift in timberline position is being also studied using GIS and remote sensing technique to understand the impact of climate change (Kufer and Cairns, 1996; Theurillat and Guisan, 2001). Detailed observations on vegetation ingression in alpine regions of Europe are being carried out under the Global Research Initiatives on Alpine (GLORIA) project (Pauli *et al.,* 2006). In this project, 867

vegetation samples above tree line from 60 summit sites from Europe have been studied and found that there is a decline in cold-adapted species and increase in warm-adapted species, a process described as thermophilization (Gottfried *et al.,* 2012)

Many detailed studies of forest structure, dynamics, and its significance in ecosystems on the Alps (Guisan *et al.,* 1995) were conducted. Similarly floristic analysis of high Andes of Ecuador by Joergensen *et al. (*1995) and timberline habits in Bolivian Andes by Kessler (2002) are also available. Kok *et al. (*1995) studied the effect of cutting and grazing on Andean treeline vegetation. Wiser and Tausz (2007) have described the correlation of forest types and structure of vegetation with various environmental factors. There have been studies on regeneration of tree species in Andes timberline by several researchers (Joergensen *et al.,* 1995; Kessler, 2002; Kok *et al.,* 1995). According to some of the studies, regeneration success determines whether the treeline shifts or remains static in response to environmental changes (Cuevas, 2000; Holtmeier, 2003). In Italian Central Alps maximum density of saplings have been recorded 9015 per ha and minimum 980 per ha (Emanuele *et al.,* 2008).

Mankind and domestic animals have caused extensive, often severe, damage to upper timberline environments throughout most of the world, sometimes with catastrophic consequences for human life (Arno and Hammerly, 1984). Lowdermilk (1953) described the degradation of high mountain forests and upper timberlines in the southern French Alps, where population pressure pushed cultivation and development far up the steep slopes. Many researchers have described the negative impact of human activities in timberline of mountains of North America, Andes of South America and European Alps (Webster, 1982). There were also studies to understand the impact of climate change and anthropogenic disturbances on high altitude vegetation (Theurillat and Gusan, 2001).

2. Alpine timberline research in Himalaya

There have been very limited studies on the timberline of Himalaya and some of the general description of timberline of Himalaya have been described by Schickhoff (2006); Dhar (1998); Arno and Hammerly (1984); Troll (1973). Troll (1973) described the global treeline elevation range, as in 4700m in Tibet and 5000m in the Andes of Bolivia and Chile. Dhar (1998) documented endemic and endangered medicinal plants found in and around treeline of Himalaya. Most of the studies of timberline area of Himalaya have been from Tibet Plateau of China and Nepal.

Though there are several studies on dependence of mountain communities of Himalayan region on forest resources from time immemorial to meet the demand of food, fuel, feed for livestock, construction materials, medicines viz; Chettri *et al.,* 2002; Mahat *et al.,* 1987 and contributions of the traditional culture of indigenous communities in conservation of biodiversity viz; Rao *et al.,* 2003; Liu *et al.,* 2002; Ramakrishnan, 2003. And, there is no study primarily focusing on dependence of mountain communities of Himalaya on resources available in timberline zone.

2.1. Alpine timberline research in Indian Himalaya :

Though from Indian Himalaya, number of studies focusing various aspects of subalpine forest area are available, very few studies specific on timberline from Indian Himalaya, mainly from the western Himalaya (Dhar, 2000) and central Himalaya (Rawal and Dhar, 1997; Rawal *et al.,* 1991; Rawal and Pangtey, 1993) have been carried out. In the Western Himalaya of India, in the area above 3200m, Gairola *et al.* (2008) has reported *Betula utilis* to be most dominant in some part with *Rhododendron campanulatum* as associate species and in some area *Abies pindrow* is most dominant with *Quercus samecarpofolia* as associate species. While Kharkwal *et al. (*2005) reported that in Central Himalaya part of India (Kumaun region) at an altitude of 4000 m to 4600 m *Alnus nepalensis* and *Betula utilis* form the last tree limit. In Kumaun Himalaya shrub species richness at elevation of 3800m to 4000m has been 31 and 14 have been reported by Kharkwal *et al. (*2005). In Eastern Himalaya, India, some studies from western Arunachal Pradesh documenting the rich faunal diversity in the high altitude areas are only available (Srivastava and Dutta, 2010a, 2010b; Mishra *et al.,* 2004). Dutta *et al. (*2013) documented 122 plant species from timberline area of Arunachal Pradesh out of which 11 species are of high conservation value.

In Western and Central Himalaya of India, some of the studies on the change in vegetation types along the altitude gradient (Bharti *et al.,* 2012; Dhar, 2002; Kharkwal *et al.,* 2005; Sharma *et al.,* 2009) have been carried out. Assessment of vegetation changes in timberline ecotone of Nanda Deve National Park of Uttarakhand was carried out by Bharti *et al. (*2012) and community structure along timberline ecotone in relation to micro-topography and disturbances in Western Himalaya was carried out by Rai *et al. (*2012). Roy and Behra (2005), analysed the biological richness in different altitudinal zones which cover timberline zone in Arunachal Pradesh. There are some studies in western and central Himalaya of India analyzing vegetation types in timberline zone and high altitude area viz; Panigrahy *et*

*al. (*2010) and Bharti *et al. (*2011). In the Western Himalaya of India, in the area above 3200 m, *Betula utilis* has been reported to be most dominant in some part with *Rhododendron campanulatum* as associate species and in some area *Abies pindrow* is most dominant with *Quercus samecarpofolia* as associate species (Gairola *et al.,* 2008). While Kharkwal *et al. (*2005) reported that in Central Himalaya part of India (Kumaun region) at an altitude of 4000 m to 4600 m *Alnus nepalensis* and *Betula utilis* form the last tree limit. In sub-alpine zone of west Himalaya above 3200 m altitude density of saplings and seedlings have been reported 2200 to 6667 per ha and 1867 to 9866 per ha (Gairola *et al.,* 2008). Gaire *et al. (*2010) also reported high density of shrub species from the site with high tree density from western Himalaya.

At higher altitudes of the Indian part of western Himalaya, Ram *et al. (*1989), Sundriyal and Joshi (1990), have done extensive work on grassland ecology and Dhar and Kachroo (1983) conducted a study on alpine flora of Kashmir Himalaya which are in close proximity to timberline. Studies on traditional pastoralism practiced by mountain communities mostly in and around timberline zone of India (Tambe and Rawat, 2009; Bhasin, 2011; Dev *et al.,* 2003) are available. In Arunachal Pradesh, there are very few studies (Singh and Brokpa community, 2009; Farooque, 1992) to document and understand the traditional Yak and sheep grazing system of the local Monpa communities, where they use pasture land in and around timberline zone.

2.2. Alpine timberline research in China and Nepal Himalaya : Position of the treeline in Tibet has been described by Zhang *et al.* (2009); Miehe *et al. (*2007) and reported that tree line in Tibet is among the highest in the world. In China, some studies on vegetation composition and structure along timberline from Tibet part of Himalaya is available. Quingshan *et al. (*2007) studied the population structure of Smith fir in the timberline ectone of Sejila Mountain and reported that *Abies georgei* var. *smithii* as most common tree species. Qiaoying *et al. (*2006) studied the ecological characteristics of *Abies georgei*, Zhang *et al. (*2009) studied the spatial structure of alpine trees in Mountain Baima Xueshan and Zhang *et al. (*2010) described the altitudinal variation in seedling and sapling density in the Sergyemla Mountains of Tibet. From the treeline ecotone of Baima Xueshan Mountain of south east Tibet 3 tree species have been reported (Zhang *et al.,* 2009). Other important studies on the structure, composition and diversity of timberline available in Tibet, are viz;Wang *et al. (*2004); Liu *et al. (*2003); Cui *et al. (*2005) and Zhang *et al. (*2007). Zhang *et al. (*2007) reported that in the sunny slope, i.e. south facing slope *Juniperous saltuaria* is most common. Tree density within timberline zone of Mountain Baima Xueshan has been recorded to be 844 per ha to 522 per ha which is more than Mountain Sejila (400 per ha) of south east Tibet (Zhang *et al.,* 2009 and Qingshan *et al.,* 2007) and maximum DBH of tree species has been reported 32.9 cm and minimum 6.8 cm (Quingshan *et al.,* 2007) and 23.6 cm to 25.2 cm (Zhang *et al.,* 2009).

Studies on position of the treeline in Nepal was also carried out by Gaire *et al. (*2010) at Langtang National Park, Central Nepal. In timberline areas of Nepal, some of the studies that have been carried out on vegetation structure and dynamics are by Gaire *et al. (*2010) and Shrestha *et al. (*2007). From the treeline ecotone of Langtang National Park of Nepal, 6 to 4 tree species from altitude in between 3700 m to 4000 m have been reported by Gaire *et al. (*2010). Also from Chaurikharka from Langtang National Park of central Nepal tree density has been reported to be 697 per ha and DBH of *Abies spectabalis* in between 26.25 cm to 17.2 cm (Gaire *et.al.,* 2010). Gairola *et al. (*2008). In Bhutan part of Himalaya, there has been no specific study so far on the vegetation structure along the timberline zone, however, there are few studies on the structure and composition of conifer forest (Darabant *et al.,* 2002; Rosset, 1999) and conifer tree species like *Abies densa* (Gratzer *et al.,* 2002) and other tree species like *Rhododencron hogdsonii* (Gratzer and Rai, 2004) which are the most dominant tree species in the timberline area.

In the timberline area of Tibet Plateau of Himalaya studies of tree species regeneration have been carried out by some researchers and some of them are by Quingshan *et al. (*2007); Qiaoying *et al. (*2006); Zhang *et al. (*2009); Zhang *et al. (*2010); Wang *et al. (*2004); Liu *et al. (*2003); Cui *et al. (*2005) and Zhang *et al. (*2007). Similar studies from timberline area of Nepal have been also carried out by some researchers (Gaire *et al.,* 2010; Shrestha *et al.,* 2007). In mountain Baima Xueshan of south east Tibet however, maximum density of saplings have been reported to be 400 per ha and minimum 111 per ha (Zhang *et al.,* 2009). In treeline ecotone of Langtang National Park of central Nepal, density of saplings have been reported in between 595 per ha to 3045 per ha and density of seedlings have been reported 614 per ha to 1261 per ha (Gaire *et al.,* 2010)

Studies on traditional pastoralism practiced by mountain communities mostly in and around timberline zone of China (Ning, 1999); Nepal (Pandey and Chetri, 2005); Bhutan (Mokten *et al.,* 2008) are available. According to Ning (1999) lack of mobility as an impact of establishing private exclusion through fencing of grazing areas which earlier were managed jointly by group of

herders in China has been identified as a key factor leading to the degradation of rangelands. From Bhutan, Moktan *et al.* (2008) reported that the spatial and temporal pattern of grazing practiced by herdsmen provides a reasonable time interval for forage regeneration. However, Sathyakumar and Adhikari (2005) reported that in Merak and Sakteng, degradation of overgrazed grasslands was due to a large livestock population.

Conclusion

Alpine timberline being one of the most vulnerable and biologically rich ecotones in the globe, there is a need for extensive research to understand the likely impact of different kinds of pressure and threats including climate change on the phenomenon encompassing timberline. It has been found that since 16th century scholars had started collecting information about timberline of Swiss Alps and systematic scientific research on timberline of Europe, North America and New Zealand started in 1900s. Though, general descriptions of timberline of Himalaya are available since mid 1900s along with the studies to describe global status of timberline. Additionally, studies primarily focusing on various timberline phenomenon of Himalaya started only after 1980. Most of the eco-physiological analyses of timberline were carried out in European Alps and Andes of South America which are being followed to describe and understand timberline globally including Himalaya.

Globally, timberline research is in a very advance stage where studies to understand the relationship between position of timberline with various biotic and abiotic factors are being carried out. Research work to understand the impact of climate change on position and composition of timberline is in progress as treeline across the world is considered as an indicator to monitor the impact of climate change. In Himalaya, despite a significant number of research work on various aspects of Alpine and Sub-Alpine forest areas, research work primarily focusing on timberline of Himalaya are very limited.

Studies on vegetation structure, composition and regeneration of plant species of timberline are available from Tibet plateau of China, Nepal and Central and Western part of Indian Himalaya. Though there are some studies from eastern part of Himalaya covering India and Bhutan on the tree species found in timberline area like *Abies* and *Rhododendron*, but there is no study focusing on timberline of the area. Similarly, though studies on human activities like collection of medicinal plants and grazing in high altitude areas of Himalaya are available, no analysis of impacts of these anthropogenic activities directly on timberline has been carried out so far.

Himalayan mountain range, which cover nearly 750,000 km.^{2} area support highly diverse and fragile ecosystems and act as water tower of Asia, is also crucial for livelihood of about 1.3 billion people of the continent. Position and composition of timberline is one of the important indicators to understand the impact of climate change and pressure due to various anthropogenic activities on Himalayan range as whole. Thus for clear mechanistic understanding, long term coordinated research work on timberline of Himalaya to predict the potential impacts and changes by human activities and related global changes in this fragile and sensitive region is urgently required. For understanding the impact of climate change on timberline areas of Eastern Himalaya, setting up permanent plots to study the phenology and composition of timberline species is urgently required. Time series analysis of vegetation status and position of timberline with help of GIS should be taken up. It is very much important to set up dedicated Research Centre in research and academic institutions located in North East India to work in coordination with national and international experts for generating baseline, carry out long term research and initiate necessary steps to ensure conservation and management of timberline areas of Eastern Himalaya.

हिमालय में तुंगीय वृक्षावली अनुसंधान की आवश्यकता : साहित्य समीक्षा

पीयूष कुमार दत्ता, बी.के दत्ता, ए.के. दास तथा आर.सी. सुन्द्रियाल

सारांश

तुंगीय वृक्ष सीमा महत्वपूर्ण पारिसमन्वय का कारक है। जो अति संवेदनशील उच्च तुंगीय जैवविविधता के मापदण्ड निश्चित करता है और तुंगीय क्षेत्रों में वनों और वृक्षविहीन क्षेत्रों का विभाजन करता है। वन पारिपद्धति पर जलवायु के गर्म होने के प्रभावों को मॉनीटर करने के लिए विश्व के अधिकांश पर्वतों की तुंगीय वृक्षावली पारिसमन्वय का अध्ययन किया जा रहा है। इसके साथ-साथ तुंगीय वृक्षावली के आसपास रहने वाले पर्वतीय समुदायों की आजीविका में वाणिज्यिक दृष्टि से महत्वपूर्ण औषधीय पादप भी मुख्य भूमिका निभाते है। हाल के वर्षों में स्थानीय पर्वतीय समुदायों की सामाजिक-आर्थिक आकांक्षाओं के वृद्धि के कारण वृक्षावली क्षेत्र में प्राकृतिक संसाधनों पर भारी दवाब पड़ा है। किन्तु यूरोपीय पर्वत श्रेणियों, दक्षिणी अमेरिका की एन्डीज तथा उत्तरी अमेरिका की पहाड़ियों पर अध्ययन अपने चरम पर पहुंच चुका है जबकि हिमालयी पर्वतीय वृक्ष सीमा पर सीमित अध्ययन ही हो पाया है। इस प्रलेख में यूरोप, उत्तरी अमेरिका और हिमालय की वृक्ष सीमा पर किये गये अध्ययनों की समीक्षा की गई है और हिमालये वृक्ष सीमा पर अनुसंधान की कमी को पूरा करने पर जोर दिया गया है।

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