2 Capturing Himalayan Timberline Dimension and Ecological Attributes in Warming Climate Through Team Science

S. P. Singh, Ripu Daman Singh, Surabhi Gumber, and Rajesh Joshi

Abstract

We took up a team science approach to carry out a multisite and multidisciplinary study on the 'Indian Himalayan Timberline Ecotones'. Timberlines in the Himalayas reach highest elevation (4900 m) in the Northern Hemisphere, but vary widely in elevation, being 300–600 m lower in moist outer ranges than in dry inner ranges. The zigzag, twisting and curvy timberlines are together more than ~20,000 km long and have a total of 58 tree species. In moist regions, the annual temperature lapse rate is rather low (e.g. 0.53 °C/100 m in Uttarakhand) and varies seasonally (e.g. in December, 0.24 °C/100 m). Along 83–95% of their length, the timberlines are stationary in spite of decades of rapid warming. An analysis of tree ring growth and climate relationship indicates that the intensified pre-monsoon drought could suppress the upward shift of treeline in a warming world. Paradoxically, tree water relations indicate the lack of water stress in treelines. The other changes observed were: upward shift of *Rhododendron campanulatum* and increase in plant species richness because of an early snowmelt. At the end, this chapter discusses the learning from our team science approach.

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S. P. Singh et al. (eds.), *Ecology of Himalayan Treeline Ecotone*,
https://doi.org/10.1007/978-981-19-4476-5_2

Keywords

Snowmelt · Species richness · Team science · Temperature lapse rate · Timberline elevation and length · Tree water relations

2.1 Introduction

A timberline in mountains represents a major ‘physiognomic discontinuum’ along an elevation gradient, in which, because of heat deficiency, forests give way to communities of low stature, consisting of herbs and scrubs. Regardless of growing season length, the treeline is generally formed at an elevation where growing season mean air temperature is 6.7 °C, generally between 5 °C and 7 °C (Körner and Paulsen 2004). Here, reference may be made to two terms that we have used interchangeably in this article: ‘timberline’, which is defined as the upper limit of forests with 30% and more crown cover, and ‘treeline’, which could be considered as an imaginary line connecting the uppermost tree patches (trees are generally considered >2 m tall woody plants with a single stem).

Though the Himalayas are known to have the highest timberline in the Northern Hemisphere (at 4900 m, formed by *Juniperus tibetica*; Miehe et al. 2015), these biotic boundaries and ecotones have remained less investigated, partly because of their remoteness. With regard to the Indian Himalayan region, the terms timberline and treeline have remained missing until recently, when studies on climate change impact on vegetation, particularly on treeline dynamics, began to draw global attention. To develop a meaningful understanding of the Himalayan treelines, we need a team research approach that considers various relevant research components and several representative Himalayan sites. Worldwide, science and social science studies have become increasingly collaborative and team-oriented in approach; that is why about 90% of science and engineering publications have two or more authors (generally six to ten authors, but also in hundreds), and solo publications are becoming rare (Stokols et al. 2008). Multifaceted and complex problems, and complex systems, call for a strong team science effort. Moreover, complex problems involving large areas and varied factors require team science efforts and high technologies. However, in India progress on team-based research has been sluggish. Indian scientists collaborate less frequently nationally as well as internationally. For example, the number of papers based on collaboration between Indian and US scientists is not only very small, but has also declined in the recent years. Neither universities and institutes, nor granting agencies have taken interest in strengthening collaboration and networking, only exception being the interest taken by Department of Science and Technology (DST), Government of India, in recent years (Singh et al. 2018). Overall, researchers in India have remained stuck to their spheres of disciplines and homesteads.

In recent years, the Himalayas have attracted global interest because of the rapid warming (Wester et al. 2019) and resultant shrinkage of the glaciers. Having more snow than any other region outside the two poles, the Himalayas are important source of water for about 1.7 billion people (Bajracharya et al. 2015) living in ten river basins originating from the region (Immerzeel et al. 2010; Bolch et al. 2012). The snowmelt discharges are also connected with several biotic zones namely timberlines, treelines, alpine meadows and subnival and nival species groups occurring above treeline and below permanent snowline. These biotic systems are experiencing marked alterations in their expanse and species composition with long-term consequences for treeline ecology, biodiversity and carbon cycles (Anderson et al. 2020). They are integral parts of larger hydrological systems that snow and ice melts and monsoon rain generate.

Historically, treeline research in different parts of mountains has largely been influenced by plant physiology, and a search for a universal value of air and soil temperatures that limit tree growth has continued to be of general interest for a long time (Körner 2012; Müller et al. 2015). The other question that has been in focus is related to plant carbon reserve and carbon sink as a limiting factor for tree growth at treeline. Recent observations indicate that the postulated 6.4 °C ± 0.7 °C for growing season mean soil temperature at treeline may not hold good universally, as several soil factors, such as decreasing soil nutrient availability with elevation, can affect tree growth in mountain treelines (Müller et al. 2015). Several other factors that are unrelated to temperature but influence treeline formations are: soil moisture, soil erosion, snow avalanches, the height of nearest mountain top, interference and facilitation by other plant species and anthropogenic pressure (Singh 2018). Patterns in treeline elevation and species composition in relation to wider environmental, phytogeographical and historical factors received less importance until recently (Schickhoff 2005; Holtmeier 2009). The global climate change generated interest in treeline dynamics, leading to many studies on change in treeline elevation due to climate warming (Schickhoff et al. 2015; Bhuju et al. 2016; Tewari et al. 2018; Tiwari and Jha 2018). Generally, these studies were based on two to three points along a timberline.

This study is based on a team science approach involving investigations on geographical spread and dimensions of timberline/treelines at Indian Himalayan scale using remote sensing technology. It sheds light on patterns of plant species richness, temperature lapse rate (TLR) through treeline ecotones, tree water relations, tree phenology, tree ring chronology and plant growth in relation to snowmelt under the influence of climate change. The main objectives of this chapter are: (1) to construct a cohesive ecological and phytogeographical picture of Indian Himalayan timberline/treeline ecotone, using relevant findings of our team research, and (2) to share experiences and learning from the application of team research approach in a difficult terrain of a considerable remoteness.

Here, we have emphasized: (1) that the timberline ecotone in the Himalayas is a huge and diverse system with a large structural variability, (2) that the treeline dynamics under the influence of climate change is rather complex because of several factors, particularly related to elevation-dependent warming (EDW) and anthropogenic activities and (3) that there are several new questions that emerge from the team research approach. While shedding light on these issues, we have drawn attention to the fact that the treeline is not only a huge ecological ecosystem, but also it is accompanied by equally important and extensive nival and other biotic components, which are under flux because of climatic changes in a highly sensitive geological settings of the Himalayas.

2.2 Material and Methods

Extending from Afghanistan in the northwest (ca. 26° N and 70° E) to Yunnan in the southeast (ca. 26° N and 100° E), the Himalayas are vast, massive and highly heterogeneous. The region has more snow and ice than any parts of the planet, outside the two poles. That is why it is referred to as the third pole and water tower of Asia. While annual precipitation above 3000 mm is common in the outer ranges receiving direct thrust of monsoon air masses, several areas in the north of the main Himalayan ranges represent some of the largest rain shadows with annual precipitation as low as 300 mm or less. In general, moisture decreases from east to west and from south to north, i.e. from low to high elevations (Singh et al. 2017).

Generally, the mean annual temperature declines from 22 °C to 24 °C in foothills to 18–20 °C at 1000 m, 10–15 °C at 2000 m, 7–10 °C at 3000 m and less than 7 °C in alpine zone. However, temperature and elevation relationship is not straightforward. For example, the elevated heating surface of the large Tibetan Plateau raises temperature by its mass elevation effect (Zhang and Yao 2016). This is one of reasons for the occurrence of the highest treeline in Tibet. The common treeline genera are: *Abies*, *Betula*, *Juniperus* and *Rhododendron* (Singh 2018). The timberline ecotone is followed by alpine meadows and subnival zone of small-statured plants (Fig. 2.1), which occupy (>4150 m elevation) 5–15 times more area than permanent snow and ice (Anderson et al. 2020). So the biotic layers, though not given as much importance as snow and ice when climate change impact is discussed, are important in the Himalayas in the context of carbon balance in the changing climate.

Sheep and goats have been grazing in alpine areas of Kashmir, Himachal Pradesh and Uttarakhand, since time immemorial, but are rare in Sikkim and Arunachal Pradesh (Singh and Thadani 2015). However, even in western Himalayan states and Nepal, now livestock density is on decline, giving an opportunity for trees to move upslope (Suwal et al. 2016). In all these regions, glaciers are generally shrinking (Singh et al. 2011; Yao et al. 2012; Chudley et al. 2017).

This study sites were located in Kashmir Valley, Uttarakhand and Sikkim, which broadly cover the entire range of variation along the Indian Himalayan Arc. While Kashmir is relatively dry (600 mm annual precipitation) and non-monsoonal, with monsoon months (June–September) accounting for only 28.9% annual precipitation, Sikkim is wet and monsoonal, and Uttarakhand is moderately moist, with average annual precipitation of about 1500 mm (Fig. 2.2).

To conduct the study, first we formed a multidisciplinary team of investigators, with expertise in various relevant areas: vegetation analysis, application of remote sensing techniques to treeline distribution, tree ring width chronology, tree water relations, plant phenology, climatology, ecology and community livelihoods. The

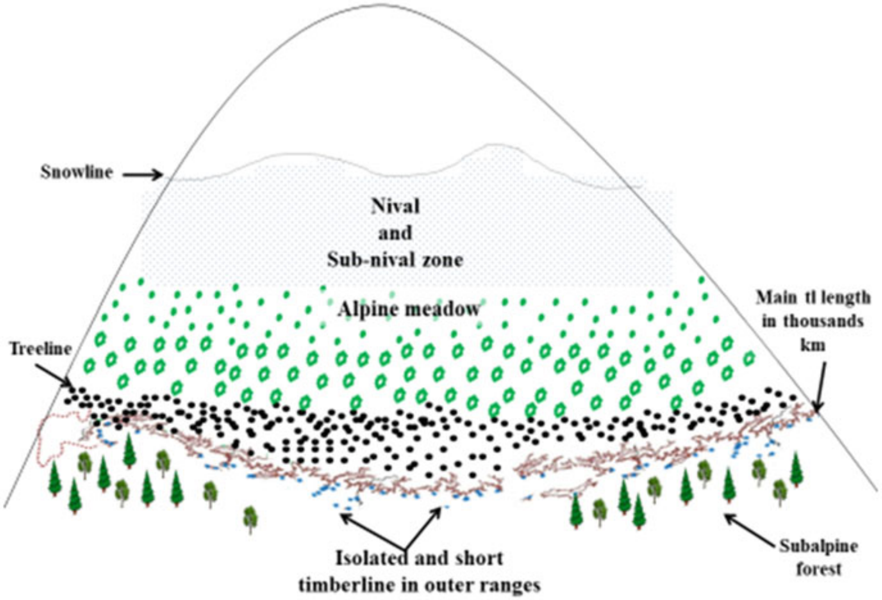
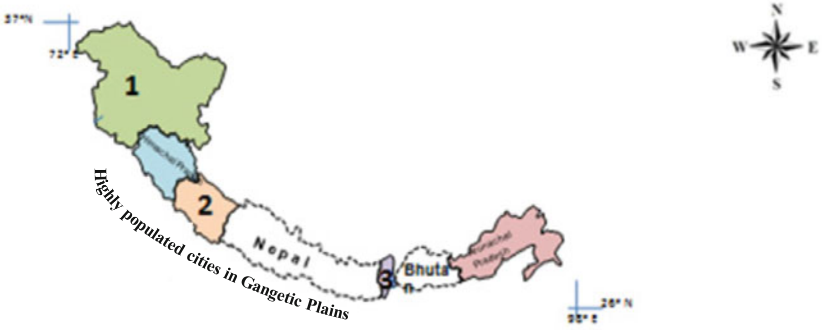


Fig. 2.1 A representation of section of the series of biotic zones below permanent snowline: nival and subnival belt, alpine meadows, treeline, timberline (tl) and forests



1
Daksum-Sinthan Top (DST), Kashmir
Weekly monsoonal with ~600 mm annual precipitation and moist pre-monsoon
State average 900 mm

2
Tungnath, Uttarakhand
Monsoonal with dry pre-monsoon season
State average 1549 mm

3
Yuksam-Dzongri (YD), Sikkim
Moist pre-monsoon and dry winters
State average 2684 mm

Fig. 2.2 The three sites for detailed 'Indian Himalayan Timberline Ecotones' study, which cover much of the range of variation across the Himalayan Arc, and represent three precipitation regimes (Courtesy: Subrat Sharma, GBPNIHESD, Almora) team members represented following organizations: Kashmir University, Srinagar; Kumaun University, Nainital; Wildlife Institute of India, Dehradun; GB Pant National Institute of Himalayan Environment and Sustainable Development, Almora; Birbal Sahni Institute of Palaeobotany, Lucknow; and Central Himalayan Environment Association (CHEA), Nainital. Several brain storming workshops along with field visits were conducted to work out methods, time schedule and study sites for detailed investigation. Field visits in groups helped finalizing sampling design, number of replicates, timing and sample points. Several exercises were carried out confirming interdependence in studies. For example, to find out the impact of pre-monsoon drought on treeline ecosystems we measured and analysed data on soil and tree water status, tree ring width changes, phenological phases and species regeneration. Subsequently, a manual on timberline study methods was developed (Singh and Rawal 2017). The coordinator continuously monitored and influenced the progress on each research component during the entire course of the study. The methods used in various components of the study are listed in Table 2.1.

Table 2.1 A list of study components along with purpose with regard to Indian Himalayan Timberline Research Project (IHTRP)

Study components	Purpose and remarks
Mapping the timberline in the Indian Himalayan region (IHR) using satellite imageries, and comparing with past records	To compare changes in elevation of timberline at the regional level, and over time, and provide region-level dimensions of timberline
Temperature lapse rate (TLR) based on observed temperature data along an elevation transect	To develop the first observed data-based TLR; examining how it differs from the West to East along the Arc, seasonally, and because of the climate change
Phenology of trees, namely *Abies spectabilis*, *Quercus semecarpifolia* and *Rhododendron campanulatum*	To find out the timing of various phenophases such as leaf expansion, leaf nutrient resorption and upslope advancement of krummholz species
Tree and soil water relations	To find out the severity of water stress in treeline, and species response to various seasons in comparison to lower elevation trees
Tree ring width chronology; changes in soil water status in time due to climate change	To find out longer climate and tree growth relationships and to predict future changes
Patterns of community and ecosystem changes along altitudinal gradient centred around treeline	To establish the patterns in species richness in relation to elevation in different taxonomical groups and growth forms; how non-tree species populations are distributed in relation to the physiognomic discontinuum of treeline?
Species richness and plant density in relation to snow	To find out how early snowmelt is likely to affect species growth and species richness in meadows

Note: The study sites were Kashmir, Uttarakhand and Sikkim

2.3 Results and Discussion

2.3.1 Length of Timberlines

The Himalayan timberline is long, high and yet depressed. It moves back and forth and sideways, varying in elevation and across the breadth of the Himalayas from south to north. In the Indian Himalayan state of Uttarakhand, the timberline length, as an example, is estimated to be 2839 km within the horizontal distance of 455.1 km (Table 2.2), giving an average length of 6.24 km/km horizontal distance (Latwal et al. 2018). Similar patterns are being observed in other Indian Himalayan regions (Indian Himalayan Timberline Research Project [IHTRP] Annual Report 2019–2020, Dr. Subrat Sharma and his associates, Govind Ballabh Pant National Institute of Himalayan Environment and Sustainable Development [GBPNIHESD]). At this scale the total timberline length of the Himalayan Arc from Pakistan to Yunnan (72° E to 97°30′ E) is likely to be approximately 24,000 km. In addition to this long principal timberline, there also occur timberline strips of a few kilometres length around mountain summits generally in the outer ranges (Table 2.2). For example, in Uttarakhand, the combined length of timberline strips of this type is <50 km, compared to 2839 km length of the principal timberline (Latwal et al. 2018).

2.3.2 Timberline Elevation and Shift

The timberline elevations are lower in outer ranges than in inner areas around the main Himalayan ranges, their mean values being 3687.88 m and 4272 m, respectively (Fig. 2.3). In the main Himalayan ranges, timberline elevations are higher because of drier conditions and greater mass elevation effect. The mountains with large masses are able to separate their atmosphere from free atmosphere more than mountains with small masses. According to Zhang and Yao (2016), timberlines in the Himalayas could not have been higher than 3500–3700 m elevation without the

Table 2.2 The extent of timberline length where no elevation change occurred from 1976 to 2015 in Uttarakhand

	Uttarakhand
Total timberline (continuous long timberline) length (km) in 1976	2839.0
Percentage of above timberline length remaining stationary	89%[a]
The upper extent of upward shift (m) in above timberline	189 m
Island type/short strip timberlines (no.)	32
Remaining stationary (no.)	22 (70.6%)
Upward shift	4 partially and 6 fully

Note: Data from IHTRP- Annual Report 2019–2020, Dr. Subrat Sharma and his associates from GBPNIHESD

[a] Values similar to this have been recorded for several other regions of the Himalayas (Dr. Subrat Sharma and his associates from GBPNIHESD)

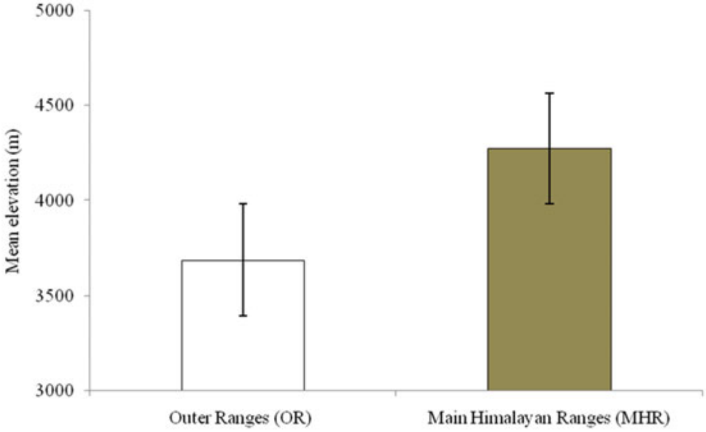


Fig. 2.3 Mean timberline elevation in Hindu Kush Himalaya in Outer Ranges ($n = 73$), and Main Himalayan Ranges ($n = 80$) (in each case, n is the number of sample site)

mass elevation effect. The mass elevation effect is the highest (above 11 °C) with middle part of the Tibetan Plateau and declines towards peripheral areas (Han et al. 2018).

The Himalayan timberlines have remained stationary in most parts (89%) for last four decades (Latwal et al. 2018; Dr. Subrat Sharma and and his associates) (Table 2.2) in spite of decades of global warming. Several factors unrelated to direct temperature impact are known to check the upward shift of treelines, of which soil nutrients, soil moisture (Müller et al. 2015), intensified pre-monsoon drought, nature of tree species and biotic interferences (Holtmeier 2009; Gaire et al. 2014; Singh et al. 2018) are quite common. Increase in growth and density of existing plants are shown to restrict the upward shift of treeline species.

The spread of krummholz may facilitate the establishment of *Betula utilis*, and thus promote the upward shift of treeline (Prof. Zafar Reshi and his associates). However, when densified, a species may also restrict tree establishment and advancement (Liang et al. 2016). Such a tree species-to-species interaction helps to explain why treelines have generally not advanced in response to climatic warming in the Himalayas. So the decline in grazing pressure may not necessarily lead to the upslope progress, as the let-up in grazing pressure may help some other species to spread and thicken and form a barrier to treeline advancement. Furthermore, it could reduce the cover of meadow particularly around mountain summits, and may deplete meadow species richness.

2.3.3 Arrested Timberlines and Associated Plant Communities

Treelines in the Himalayas are generally depressed, largely because of historical anthropogenic activities, such as pastoralism, cutting of trees and burning (Schickhoff 2005). In other words, the existing treeline temperatures are warmer

Table 2.3 Growing season mean temperature of three treeline sites (located in Kashmir Valley, Uttarakhand and Sikkim; they are the main study sites of National Mission on Himalayan Studies [NMHS] project; Singh 2018), and estimates of treeline depression (in m) compared to climatic treelines (elevation at which growing season mean temperature is 6.7 °C; Körner 2012)

Study site: elevation (m) and latitude/longitude	Growing season (May–September) mean temperature (GST) (°C)	Difference between TT and GST of the site (°C)	Treeline depression (m)
Kashmir: 3900 m elevation; 33°32′–33°41′ N/75°25′–75°31′ E	8.6	1.9	292.3
Uttarakhand: 3300 m elevation; 30°47′–30°51′ N/79°15′–79°22′ E	10.3	3.6	679.2
Sikkim: 4000 m elevation; 27°30′ N/88°30′ E	7.5	0.8	158.8

Note: The mean temperature lapse rate (TLR, per 100 m elevation) is 0.53 °C for Sikkim, 0.51 °C for Uttarakhand and 0.65 °C for Kashmir (Joshi et al. 2018), referred to as climatic treeline temperatures. Difference between climatic treeline elevation and existing treeline elevation was calculated as: existing growing season temperature = climatic treeline temperature (6.7 °C)/ temperature lapse rate (TLR) × 100 m. This difference is referred to as treeline depression

than that ascribed to climatic treelines. Considering that globally mean growing season temperature at climatic treeline is 6.7 ± 0.85 °C (Körner 2012), we can calculate how much depressed treelines are in comparison to climatic treeline by using mean annual temperature lapse rate. Accordingly, the three treeline sites being studied in detail (located in Kashmir, Uttarakhand and Sikkim) by us (Singh 2018) are lower than climatic treelines by 292 m, 680 m and 159 m, respectively (Table 2.3). Treeline sites of Uttarakhand and Kashmir are affected by heavy summer time grazing, while in Sikkim pastoralism at present is low. Possibly, because of this, Sikkim treeline is close to that of climatic treeline. Currently, grazing pressure is on decline in the Himalayas as a whole because of declining livestock, and this is considered one of the reasons of upslope movement of treeline apart from climatic warming (Gaire et al. 2014). However, increase in tourism can affect treelines in opposite direction.

The general validity of certain soil and air threshold temperature for all treeline location without a clearly broader error (6.4 ± 0.7 °C) is questionable (Müller et al. 2015). In the Himalayas the timberline/treeline turns and twists to track a threshold temperature, but the range of temperature along their length is very wide, particularly on a higher side (up to 12 °C mean growing season temperature), because of extraordinarily wide elevation range (~2000 m). The lack of upward timberline shifts in spite of the decades of warming shows that the timberlines now are warmer than in the past. It may lead to densification of trees and enhanced tree growth as long as snowmelt water is available, but subsequently as snowmelt water depletes, the sites would become too dry for tree survival. Such 'arrested treelines' need to be monitored and the tipping point of treeline degradation identified. In a warmer timberline, litter decomposition and nutrient cycling are likely to be higher and vulnerable to change.

Though considerable amounts of data have been generated on the effect of climate change and snow and ice in the Himalayas (Gautam et al. 2009; Gardner et al. 2013; Bajracharya et al. 2015) and its consequences on snowmelt hydrology and water availability (Immerzeel et al. 2012), how they are being impacted by changes in various vegetation zones in the Himalayas is hardly investigated (Gaire et al. 2014; Anderson et al. 2020). Generally, when the Himalayan timberlines are not moving up they are arrested, but marked changes could occur in timberline ecotones and species and communities that make them (Singh et al. 2018), alpine meadows (Adhikari et al. 2018) and subnival zone, which, according to an estimate, cover 5–15 times area of permanent glaciers and snow cover (Anderson et al. 2020). The upward advancement of *Rhododendron campanulatum* into meadows above treeline has been found at the rate of 3.4 m/year during last two to three decades at Tungnath in Uttarakhand (Singh et al. 2018). The upslope advancement of *R. campanulatum* has also been reported from Nepal (Prabinarana et al. 2017). The advancement of woody plants into vegetation of small-statured plants may lead to changes in the carbon storage in biomass and soil pools and lead to a rapid vegetation dynamic.

Changes in the plant growth form can result in marked changes in snow and ice cover and storage, and hydrological parameters (Anderson et al. 2020). The development of plant cover on bare soil surfaces in the subnival zone results in reduced albedo and more warming, outstripping the cooling effect caused by increase in evapo-transpiration (Shen et al. 2015). The expansion of subnival zone due to the decrease in temperature-limited areas in the warming climate (Gonzalez et al. 2010) needs to be studied for its impact on snow- and ice-driven high-altitude hydrology. It may be pointed out that the area above 4150 m, which was used to estimate changes in subnival plant cover in the Himalayas by Anderson et al. (2020), is being affected by the spread of krummholz and shrubs in several areas, particularly below 5000 m. The occurrence of the treeline above 4000 m is quite common in the eastern part of the Himalayan Arc. There, under-canopy woody layer (several rhododendrons, and junipers) is getting denser and spreading, thus restricting canopy tree species like fir to be sparser (<100 trees/ha). These structural factors are known to influence forest hydrology (Mestre et al. 2017). In brief, the climate-change-driven impacts on the high Himalayas would not limit to cryosphere, and to understand species and growth form dynamics and the issues of water management, studies are needed to consider large-scale changes occurring in vegetation layers right from subnival communities to alpine meadows adjacent to treelines and timberline, and their dynamic hydrological connections.

2.3.4 Relationship Between Global Warming, Air Pollution and Temperature Lapse Rate

The temperature lapse rate (TLR) estimated from observed data at Tungnath site (Uttarakhand) was relatively low (mean annual rate 0.53 °C/100 m; Joshi et al. 2018). This low TLR could be partly because of the elevation-dependent warming

(EDW), which emphasizes that the higher and cooler parts of an elevation transect is warming at a higher rate than warmer lower areas (Palazzi et al. 2019). Warming is observed to be high in elevations where snow mass loss and albedo reduction are high, suggesting the snow-albedo feedback as the main cause of elevation-dependent warming (EDW) (Minder et al. 2018; Palazzi et al. 2019). At the Uttarakhand site, the TLR was lowest in December (0.24 °C/100 m) when air pollution in lower elevation areas has been high for last several years, resulting in solar radiation dimming and cooler temperatures. This in combination with EDW seems to change the seasonal pattern, as the decline in temperature from autumn months to December (the first winter month) is less in higher elevation areas than in lower elevation areas. The solar dimming effect of aerosol particles is particularly high in low-elevation areas near the big cities of Gangetic plains (Wester et al. 2019). The pollutants can spread to snow-clad mountain areas resulting in an albedo reduction. In Tungnath, because of delay in snowfall, the dark cover of senescent and decayed plants was made visible, resulting in a reduced albedo (Joshi et al. 2018) than following winter months when snowfall occurred. There is a need to observe these temperature change patterns at more representative sites and over a longer period to understand the TLR effect in relation to elevation-dependent warming. It may be pointed out that plant cover changes considerably affect regional carbon balance, species composition and community development. The EDW-linked snow depletion partly explains the greening of subnival zones in the Himalayas, as observed recently (Anderson et al. 2020). The reduced TLR and change in its timing are expected to cause not only more climate change, but also profound changes in vegetation cover and species composition.

2.3.5 Change in Growth Periodicity

In monsoon climate, grasses and other herbs begin growth with the onset of monsoon rain, generally in June (Zobel and Singh 1997). However, in treeline communities and alpine meadows, most herb species start growing well before the arrival of monsoon, as now melt water supply begins in April and May. Because of the synchronization of plant growth with snowmelt, these herbs have a long growth period, generally 150–200 days. The advancement in snowmelt is expected to further prolong growth period of such species. However, we do not know the fate of such early growing species when snow depletion renders meadows dry. The site might be taken over by late growth initiating species, which wait for monsoon to arrive to start growth (23 species at Tungnath) (Adhikari et al. 2018; Dr. B. S. Adhikari and his associates). The shift from the species that depend on snowmelt for growth initiation to those that depended on monsoon rain is expected to change the community structure and species diversity in meadows. Fast-growing species of lower elevations may arrive and outcompete some of the species.

2.3.6 Treeline Water Relations

Global warming, if not accompanied by increased precipitation, can adversely affect plant growth, plant cover and growth form (Hatfield and Prueger 2015). In monsoonal regions of the Himalayas, pre-monsoon (March, April and May) is the driest and warmest time of the year (Singh et al. 2017), yet trees and shrubs put forth new shoots and expand leaves during that period so that canopy is fully developed to take the advantage of monsoon (June–September), for fixing carbon and increasing carbon stock (Singh and Singh 1992; Zobel and Singh 1997). Studies on tree ring growth generally indicate that in certain cases growth has been constantly high during last two to three decades of climate warming. However, growth suppression and the lack of upward treeline shifts due to water stress have also been recorded (Gaire et al. 2014).

Tree water relation studies at Tungnath, a site located in outer ranges receiving over 2000 mm annual rainfall, indicate that water stress at treeline is not severe (pre-dawn tree water potential mostly being above −1 MPa; Tewari et al. 2018). But this may not apply to dry inner ranges where pre-dawn water potential is frequently below −1 MPa. Tree water relations at the Tungnath treelines differ in some important aspects from those of low-elevation forest trees of the region (Fig. 2.4). First, at treelines, species undergo a high daily change (measured as difference between pre-dawn and mid-day water potential) in tree water potential during monsoon months (1.1 MPa, compared to 0.16 MPa in low-elevation forests). This conspicuous difference is difficult to explain, and needs to be further investigated. The high daily change in tree water potential in monsoon at treeline corresponds with high leaf conductance values. Second, species exhibit very high leaf water conductance values (>1000 m mol m^2/s) in treelines in dry inner areas. What enables a species to realize much higher leaf conductance at a drier site than a moist site? What enables them to keep stomata open at a dry high-elevation site? What is the role of low humidity combined with low atmospheric pressure in it? We need to do more research to understand these patterns. To predict forest hydrological changes in a warming climate, detailed studies on tree ring growth and tree water relations encompassing various Himalayan habitats might be required. Our present study on tree water relations and tree ring width chronology has enabled us to raise more questions. More studies are required to understand basic processes and controlling environmental factors related to plant water status in treeline areas. Increase in dry season stomatal conductance with elevation (1700–2700 m) has been reported for tropical forests in dry season (Mujawamariya et al. 2018). In China, Wang et al. (2016) found that among trees, shrubs and leaves, trees have the highest stomatal density but the lowest stomata length, and the latter increased with elevation. Actual measured photosynthetic rates are usually as high as or even higher than those at lower elevations (Körner and Diemer 1987; Shi et al. 2006).

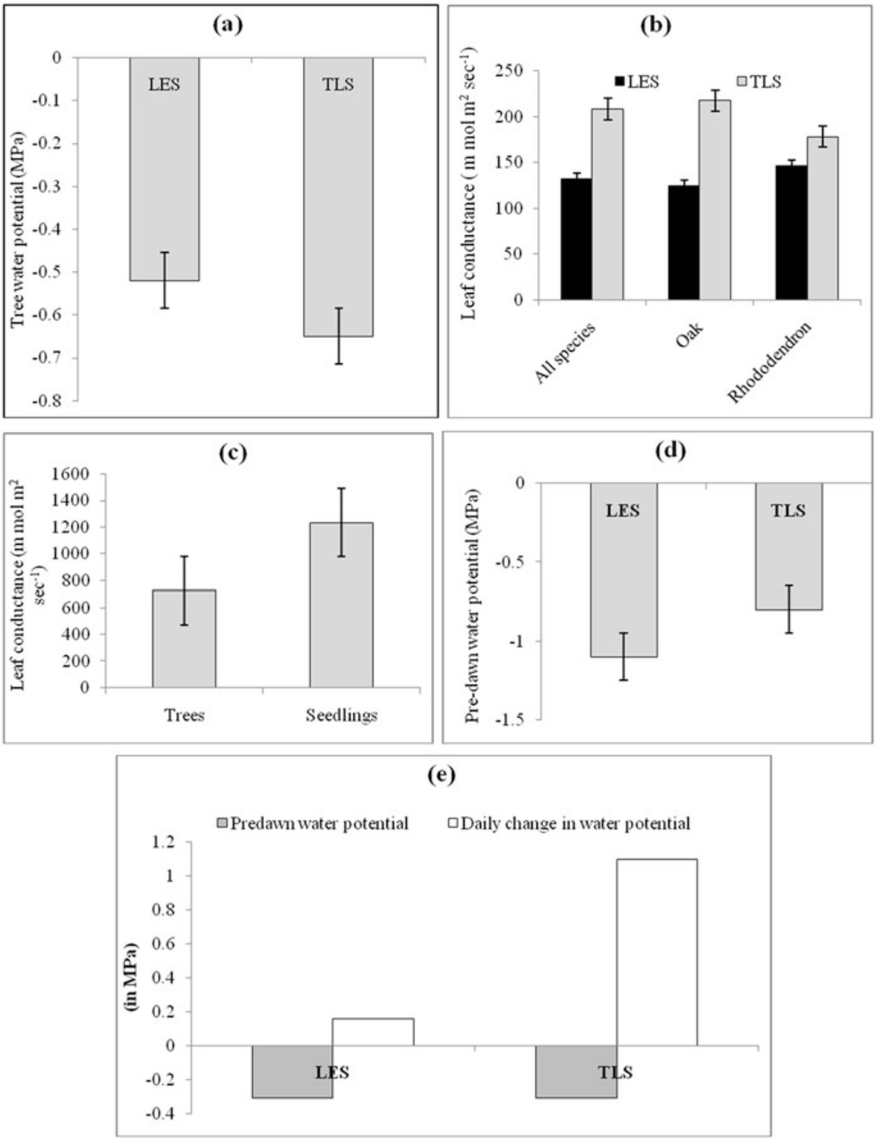


Fig. 2.4 (**a**) A comparison of mean daily change in tree water potential in low-elevation species (LES; <2400 m) and treeline species (TLS; >3000 m). (**b**) A comparison of tree leaf conductance between LES and TLS. For LES, the mean values are based on 11 species measured in 6 seasons (fall, from mid-September to mid-November; winter, from mid-November to mid-January; spring, from mid-January to mid-February; early summer, from March to April; summer, from May to mid-June; and rainy, from June to mid-September) and for TLS the mean is of the values of 5 species measured in 4 seasons (pre-monsoon, from March to June; monsoon, from July to September; autumn, from October to November; and winter, from December to February). (**c**) Leaf conductance values of *Betula utilis* in TLS at Chitkul (dry inner valleys): a comparison between trees and seedlings. (**d**) A comparison of pre-dawn water potential in pre-monsoon season

2.3.7 Learning by Doing Team Research

Our study on the Himalayan timberlines involved about over 30 researchers, dispersed across six institutions, which included national institutes and state universities and non-government organizations. The team originated from team members, not from any authority or institutional setup. The leading researchers of the timberline team had diverse expertise and institutional background, involving disciplines as varied as tree ring chronology and local level livelihoods (Table 2.4). The coordinator of the team conceptualized a research project on the Himalayan timberline keeping in view the fact that even basic information on the subject was not available. Then, he shared the first project draft with identified experts in relevant fields. Needless to say, he made some efforts to make them interested to work together on a common framework. The first draft of research proposal received the inputs of members, resulting in a polished draft of research proposal for the National Mission on Himalayan Studies (NMHS) of the Ministry of Environment, Forest and Climate Change (MoEF & CC). The mission's research part was managed by a small team of scientists from Govind Ballabh Pant National Institute of Himalayan Environment and Sustainable Development (GBPNIHESD), Kosi-Katarmal, Almora, whose director and nodal person had requisite capacity and sensitivity to appreciate the significance of such a team approach to investigate an important research area of the Himalayas. That perhaps played a role in making the MoEF & CC Ministry convinced in providing a large grant to the Himalayan timberline research. Even before the project was approved, the researchers had begun to exchange their ideas, identifying study sites and developing field sampling designs. The research team assembled at Tungnath, Uttarakhand, one of the study sites, soon after the grant was approved, to fine-tune the methodological details keeping in view the difficulties that the remote and high Himalayan timberlines generally pose. For example, to reach a timberline suitable for research in Sikkim one required to walk a full day. Timberline was easily accessible in Kashmir, but there the insurgency was a serious obstacle. In Uttarakhand, getting to timberline was not a problem, but tourism was a serious threat to timberline environment and data collection, and the maintenance of permanent plots. Since the Himalayan sites are generally affected by human disturbance, one cannot be sure that devices installed to measure temperature and other parameters would be safe over a sufficiently long period for data collection. The solidarity of the team individuals encouraged us to install equipment. That some of the leading researchers belonged to study regions, helped a lot in terms of site selection, conducting research and understanding the meaning of data generated. The team members used to meet periodically, share data, brainstorm, improve methods and add new studies and sites, and plan strategies to further improve the

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Fig. 2.4 (continued) between LES and TLS. (**e**) Monsoon season (July–September) pattern in pre-dawn water potential and daily change in tree water potential of LES and TLS (Source: Singh et al. 2006; Tewari et al. 2018; and Dr. Ashish Tewari and his associates)

Table 2.4 Team composition and study designs

Science team composition and study designs	Features/remarks
Size and composition of research team: One coordinator, 11 principal investigators (PIs)/ researchers and 17 research scholars from various disciplines (students with master degree)	A team of >10 researchers is considered a large team; generally, research teams consist of <10 researchers (including both PIs and students) but in exceptional cases the number could be in hundreds and thousands; attempts were made to include other Himalayan countries, but it could not materialize
Age structure and gender ratio of the team: 60+ = 2, 45–60 = 7, 30–45 = 3, <30 =17 (research scholars); of the 29 members, 6 were female	The team was uneven-aged; women were represented in research scholar category
Extent of inter-disciplinarity, and trans-disciplinarity in the team: PIs had research expertise in general ecology, biodiversity and plant taxonomy, vegetation science, remote sensing, tree water relations, sustainable development, phenology, meteorology and physics, paleoecology and dendrochronology, and local livelihoods	Researchers from different disciplines co-developed research questions and designed sampling to answer them
Geographical distribution of scientists was wide, and included scientists from institutions located in western, central and eastern parts of the Himalayas, plains and foothills of mountains within India	Efforts were made to include scientists of other Himalayan countries, but could not materialize
Proximity of team members	Not co-located
Study sites: 3 timberline (>3000 m) sites within 75°26′6″ E–88°08′58.69″ E longitude and 27°29′04.79″ N–33°36′43″ N latitude; in addition, secondary data were collected from the entire West-to-East Arc (~3000 km length) of the Himalayas (extending from Afghanistan in the northwest [ca. 70°E] to Yunnan in the southeast [ca. 100°E]; the latitudinal range of the arc is of about 10°, from 36° N [Afghanistan] to 26° N [Yunnan])	It helped to identify various drivers of change of biodiversity, tree species composition and timberline elevations across the Himalayan Arc, which is very heterogeneous
Task interdependence	High among biodiversity experts, phenology and water relations; in others, it was moderate or low
Goal alignment	Strong

project. The research findings were shared with decision makers including the Chief Minister of Uttarakhand, various scientists and officials, both at national and state levels. In this regard the meetings at Dehradun, Indian National Science Academy (INSA), Delhi, Gangtok and Srinagar were notable. A short film was made and shared widely. Research training was another area that was used frequently to develop human resource.

The group realized soon that historically timberline studies generally had a strong physiological leaning, and ecological and geographical dimensions were peripheral. So, while working out the details of methods, the group had to work together to apply ecological concepts, and develop terminologies and sampling designs.

The capacity of the coordinator to make the team members interested in timberline research contributed significantly to the progress of the research. However, the team science did not develop in a formal way, as there was no separate provision for it under the NMHS programme, and the members lacked academic familiarity with the nuances of mechanisms required for its structuring and making it operative. That is why weaknesses pertaining to the lack of trans-disciplinarity and synthesis of data were left unattended. The team could not do enough to strengthen collaboration among young researchers; most of joint efforts were limited to individual level. Academic discussions and exchange of ideas could not be mainstreamed. A serious drawback at this system level is that there is no well thought-out scheme to build on the platform this project has created. The average age of investigation was a bit higher; perhaps a younger team could have sustained research enthusiasm longer.

2.4 Conclusion

The study carried out by the research team has contributed substantially to the basic understanding of the Himalayan timberline ecotone from the standpoints of macroecology. It emphasizes that the presence of the Himalayan timberline ecotones should be considered at a regional scale; their role in the functioning of the high Himalayan systems is far more than generally perceived. The lack of upward shift of timberline ecotone in spite of decades of warming shows that there are several more factors that influence timberline dynamics in the Himalayas. It also sheds light on why the Himalayan treelines are not only very high but also vary widely in elevation. Evidently, treeline species can survive a wide range of temperature and other environmental conditions. A given treeline species could be a part of treeline with temperatures ascribed to it as well as warmer temperatures. Temperature lapse rate (TLR), which is linked to treeline elevation and climate change pattern, deserves far more attention than generally given; knowledge about tree water relations of treeline ecotone remains scanty in spite of our present efforts. It has raised several difficult questions, rather than giving solutions. Several research approaches in the Himalayas have largely focussed on glaciers, which would be of only a limited use; it should expand to include hydrological implications of melt water flow, and community and ecosystem level changes that occur in and around treeline and timberline areas under the influence of climate change. Our findings shed light on changes in phenology of treeline species and those occurring in alpine meadows due to warming and early snowmelt, but the data collected are too scarce to bring about a major advancement in our understanding.

2.4.1 Way Forward: Research Questions and Future Strategies

The present NMHS-sponsored research enterprise enabled us to establish a research base, which could be used to build a long-term and elaborated research programme on the Himalayan treelines. In this regard, following observations may be of help:

1. With regard to research and management, treelines should not be considered in isolation of connected biotic zones, namely alpine meadow and nival species, and abiotic systems such as permanent snow area that provide water to biotic systems should also be included. Though physiognomically these biotic components are divided functionally, they can be considered as interconnected components of a continuum consisting of forests, timberline, treeline and short-statured plants and barren snow and ice area, all under state of flux due to climate change. In this continuum, wild and domestic animals should also be included.
2. The question how climate change is affecting elevation-dependent warming and temperature lapse rate (TLR) calls for long-term data from several representative sites.
3. How seasonal changes in TLR are likely to affect biotic components, and how TLR is influenced by widespread pollution in the big cities of adjacent plains are the related important questions for both basic understanding and management. A macro-ecological approach that gives a coherent picture of various interconnected systems might serve the purpose of managing the high-landscape Himalayas.
4. Among the seasons, the research focus should be on the pre-monsoon period (April–June), which is of critical importance because while water stress during this period is the highest, most species shed leaves as well as begin growth. This is also important culturally as it is the time of peak tourism and water demand, and forest fires. There are evidences to suggest that tree ring width is severely affected by pre-monsoon droughts.

Treeline and mountain summits are likely to experience changes in species composition, species accumulation, migration and extinction as climate change impact increases. We need to mark and maintain permanent plots to monitor species flux on a long-term basis. While doing so, sites should be chosen to appropriately represent outer ranges as well as inner and main ranges, which differ in treeline elevations, climatic conditions, and treeline dimensions and scales. To capture the Himalaya-level variability, research networking among the Himalayan countries is necessary. Efforts would be required to enhance interdependence and alignment in research purposes and approaches. Team research should be expanded to include researches for several Himalayan countries and measures should be taken to hone up team science culture.

Acknowledgements This study was carried out as part of the Indian Himalayan Timberline Research Project (IHTRP). The financial support received under the National Mission on Himalayan Studies (NMHS), Ministry of Environment, Forest & Climate Change, Government of India, is duly acknowledged. We thank the Coordinator, IHTRP project, and Director, GBPNIHE, Almora, for providing the necessary facilities to conduct this study. We give great importance to the research contributions of all the Principal Investigators, and the research scholars of IHTRP who worked in difficult terrains of the treeline areas of the Himalayas. We extend our special thanks to Indian National Science Academy (INSA) and Central Himalayan Environment Association (CHEA) for providing facilities for this study.

References

Adhikari BS, Kumar R, Singh SP (2018) Early snowmelt impact on herb species composition, diversity and phenology in a western Himalayan treeline ecotone. Trop Ecol 59(2):365–382

Anderson K, Fawcett D, Cugulliere A, Benford S, Jones D, Leng R (2020) Vegetation expansion in the subnival Hindu Kush Himalaya. Glob Chang Biol 26(3):1608–1625

Bajracharya SR, Maharjan SB, Shrestha F, Guo W, Liu S, Immerzeel W, Shrestha B (2015) The glaciers of the Hindu Kush Himalayas: current status and observed changes from the 1980s to 2010. Int J Water Resour Dev 31(2):161–173. https://doi.org/10.1080/07900627.2015.1005731

Bhuju DR, Shah SK, Gaire NP (2016) Environmental reconstruction and impact of climate change on vegetation at treelines of Nepal Himalaya. Annu Rep Pro Nat Foundation Jpn 24:169–180

Bolch T, Kutusov S, Li X (2012) Updated GLIMS Glacier Database for the Tian Shan. National Snow and Ice Data Center, Boulder

Chudley TR, Miles ES, Willis IC (2017) Glacier characteristics and retreat between 1991 and 2014 in the Ladakh Range, Jammu and Kashmir. Remote Sens Lett 8(6):518–527. https://doi.org/10.1080/2150704X.2017.1295480

Gaire NP, Koirala M, Bhuju DR, Borgaonkar HP (2014) Treeline dynamics with climate change at the central Nepal Himalaya. Clim Past 10:1277–1290. https://doi.org/10.5194/cp-10-1277-2014

Gardner AS, Moholdt G, Cogley JG, Wouters B, Arendt AA, Wahr J, Berthier E, Hock R, Pfeffer WT, Kaser G, Ligtenberg SRM, Bolch T, Sharp MJ, Hagen JO, Van den Broeke MR, Paul F (2013) A reconciled estimate of glacier contributions to sea level rise: 2003 to 2009. Science 340:852–857

Gautam R, Hsu NC, Lau KM, Tsay SC, Kafatos M (2009) Enhanced pre-monsoon warming over the Himalayan-Gangetic region from 1979 to 2007. Geophys Res Lett 36(7). https://doi.org/10.1029/2009GL037641

Gonzalez P, Neilson RP, Lenihan JM, Drapek RJ (2010) Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. Glob Ecol Biogeogr 19(6):755–768. https://doi.org/10.1111/j.1466-8238.2010.00558.x

Han F, Zhang BP, Zhao F, Wan L, Tan J, Liang T (2018) Characterizing the mass elevation effect across the Tibetan Plateau. J Mt Sci 15:2651–2665. https://doi.org/10.1007/s11629-018-4978-2

Hatfield J, Prueger JH (2015) Temperature extremes: Effect on plant growth and development. Weather Clim Extremes 10(PA):WACED140046. https://doi.org/10.1016/j.wace.2015.08.001

Holtmeier FK (2009) Mountain timberlines. Ecology, patchiness, and dynamics. In: Advances in global change research. Springer, Dordrecht, p 36

Immerzeel WW, Van Beek LPH, Bierkens MFP (2010) Climate change will affect the Asian water towers. Science 328(5984):1382–1385. https://doi.org/10.1126/science.1183188

Immerzeel WW, Van Beek LPH, Konz M, Shrestha AB, Bierkens MFP (2012) Hydrological response to climate change in a glacierized catchment in the Himalayas. Clim Chang 110:721–736. https://doi.org/10.1007/s10584-011-0143-4

Joshi R, Sambhav K, Singh SP (2018) Near surface Temperature Lapse Rate for Treeline environment in Western Himalaya and possible impacts on ecotone vegetation. Trop Ecol 59(2):197–209

Körner C (2012) Treelines will be understood once the functional difference between a tree and a shrub is. Ambio 41:197–206

Körner C, Diemer M (1987) In situ photosynthetic responses to light, temperature and carbon dioxide in herbaceous plants from low and high altitude. Funct Ecol 1:179–194. https://doi.org/10.2307/2389420

Körner C, Paulsen J (2004) A world-wide study of high altitude treeline temperatures. J Biogeogr 31:713–732

Latwal A, Sah P, Sharma S (2018) A cartographic representation of a timberline, treeline and woody vegetation around a central Himalayan summit using remote sensing method. Trop Ecol 59(2): 177–186

Liang E, Wang Y, Piao S, Lu X, Camarero JJ, Zhu H, Zhu L, Ellison AM, Ciais P, Peñuelas J (2016) Species interactions slow warming-induced upward shifts of treelines on the Tibetan Plateau. Proc Natl Acad Sci U S A 113:4380–4385

Mestre L, Toro-Manríquez M, Soler R, Huertas-Herrera A, Martínez-Pastur G, Lencinas MV (2017) The influence of canopy-layer composition on understory plant diversity in southern temperate forests. For Ecosyst. 4:6. https://doi.org/10.1186/s40663-017-0093-z

Miehe G, Pendry CA, Chaudhary RP (eds) (2015) Nepal: An Introduction to the Natural History, Ecology and Human Environment of the Himalayas. Edinburgh: Royal Botanic Garden, Edinburgh

Minder JR, Letcher TW, Liu C (2018) The character and causes of elevation-dependent warming in High-resolution simulations of rocky mountain climate change. J Clim 31:2093–2113. https://doi.org/10.1175/JCLI-D-17-0321.1

Mujawamariya M, Manishimwe A, Nitrugulirwa B, Zibera E, Ganszky D, Bahati EN, Nyirambangutse B, Nsabimana D, Wallin G, Uddling J (2018) Climate sensitivity of tropical trees along elevation gradient in Rwanda. Forests 9:647. https://doi.org/10.3390/f9100647

Müller M, Schickhoff U, Scholten T, Drollinger S, Böhner J, Chaudhary RP (2015) How do soil properties affect alpine treelines? General principles in a global perspective and novel findings from RolwalingHimal, Nepal. Prog Phys Geogr 40:135–160. https://doi.org/10.1177/0309133315615802

Palazzi E, Mortarini L, Terzago S, Hardenberg JV (2019) Elevation-dependent warming in global climate model simulations at high spatial resolution. Clim Dyn 52:2685–2702. https://doi.org/10.1007/s00382-018-4287-z

Prabinarana A, Bhuju D, Koirala M, Boonchird C (2017) Dendroecological studies of *Rhododendron campanulatum* D. Don along the elevational gradient of Manaslu Conservation area, Nepal Himalaya. Pak J Bot 49(5):1749–1755

Schickhoff U (2005) The upper timberline in the Himalayas, Hindu Kush and Karakorum: A review of geographical and ecological aspects. In: Broll G, Keplin B (eds) Mountain ecosystems: studies in treeline ecology. Springer, Berlin, pp 275–354

Schickhoff U, Bobrowski M, Böhner J, Bürzle B, Chaudhary RP, Gerlitz L, Heyken H, Lange J, Müller M, Scholten T, Schwab N, Wedegärtner R (2015) Do Himalayan treelines respond to recent climate change? An evaluation of sensitivity indicators. Earth Syst Dynam 6:245–265

Shen M, Piao S, Jeong S-J et al (2015) Evaporative cooling over the Tibetan Plateau induced by vegetation growth. Proc Natl Acad Sci U S A. 112:9299–9304. https://doi.org/10.1073/pnas.1504418112

Shi P, Körner C, Hoch G (2006) End of season carbon supply status of woody species near the treeline in western China. Basic Appl Ecol 7:370–377. https://doi.org/10.1016/j.baae.2005.06.005

Singh SP (2018) Research on Indian Himalayan Treeline Ecotone: an overview. Trop Ecol 59(2): 163–176

Singh SP, Rawal RS (2017) Manuals of field methods. Central Himalayan Environment Association, Nainital

Singh SP, Singh JS (1992) Forests of the Himalayas: structure, function and impact of man. Gyanodaya Prakashan, Nainital, p 294

Singh SP, Thadani R (2015) Complexities and controversies in Himalayan research: a call for collaboration and rigor for better data. Mt Res Dev 35(4):401–409. https://doi.org/10.1659/MRD-JOURNAL-D-15-00045

Singh SP, Zobel DB, Garkoti S, Tewari A, Negi CMS (2006) Patterns in water relations of central Himalayan trees. Trop Ecol 47(2):159–182

Singh CP, Panigrahy S, Parihar JS (2011) Alpine vegetation ecotone dynamics in Gangotri catchment using remote sensing techniques. International Archives of the Photogrammetry, Remote Sensing and spatial information Sciences, Volume XXXVIII-8/W20, workshop of ISPRS Bhopal, India

Singh SP, Singh RP, Gumber S, Bhatt S (2017) Two principal precipitation regimes in Himalayas and their influence on tree distribution. Trop Ecol 58(4):679–691

Singh SP, Sanwal M, Dimri VP, Dubey SK (2018) The climate change programme of the Department of Science and Technology. Curr Sci 115(1):22–24

Stokols D, Misra S, Moser RP, Hall KL, Taylor BK (2008) The ecology of team science: understanding contextual influences on transdisciplinary collaboration. Am J Prev Med 35(2): 96–115. https://doi.org/10.1016/j.amepre.2008.05.003

Suwal MK, Shrestha KB, Guragain L, Shakya R, Shrestha K, Bhuju DR, Vetaas OR (2016) Land-use change under a warming climate facilitated upslope expansion of Himalayan silver fir (*Abiesspectabilis* (D. Don) Spach). Plant Ecol 217:993–1002. https://doi.org/10.1007/s11258-016-0624-7

Tewari A, Shah S, Singh N, Mittal A (2018) Treeline species in Western Himalaya are not water stressed: a comparison with low elevation species. Trop Ecol 59(2):313–325

Tiwari A, Jha PK (2018) An Overview of Treeline response to environmental changes in Nepal Himalaya. Trop Ecol 59(2):273–285

Wang JS, Feng JG, Chen BX, Shi PL, Zhang JL, Fang JP, Wang ZK, Yao SC, Ding LB (2016) Controls of seed quantity and quality on seedling recruitment of Smith fir along altitudinal gradient in southwestern Tibetan Plateau. J Mt Sci 13(5):81–821

Wester P, Mishra A, Mukherji A, Shrestha AB (eds) (2019) The Hindu Kush Himalaya assessment—mountains, climate change, sustainability and people. Springer, Cham

Yao T, Thompson L, Yang W, Yu W, Gao Y, Guo X, Yang X, Duan K, Zhao H, Xu B, Pu J, Lu A, Xiang Y, Kattel DB, Joswiak D (2012) Different glacier status with atmospheric circulations in Tibetan Plateau and surroundings. Nat Clim Chang 2:663–667. https://doi.org/10.1038/nclimate1580

Zhang B, Yao Y (2016) Implications of mass elevation effect for the altitudinal patterns of global ecology. J Geogr Sci 26(7):871–877. https://doi.org/10.1007/s11442-016-1303-2

Zobel DB, Singh SP (1997) Himalayan forests and ecological generalizations. Bio Sci 47(11): 735–745. https://doi.org/10.2307/1313096