Template/Pro forma for Submission

NMHS-Himalayan Institutional Project Grant

NMHS-FINAL TECHNICAL REPORT (FTR)

Demand-Driven Action Research and Demonstrations

NMHS Reference No.:	**NMHS/LG-2016/009**	**Date of Submission:**	**2**	**6**	**0**	**2**	**2**	**0**	**2**	**2**

TIMBERLINE AND ALTITUDINAL GRADIENT ECOLOGY OF HIMALAYAS, AND HUMAN USE SUSTENANCE IN A WARMING CLIMATE

Project Duration: *from* (**01.03.2016**) *to* (**30.09.2021**).

***Submitted to*:**
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GENERAL INSTRUCTIONS:

1. The Final Technical Report (FTR) has to commence from the date of start of the Project (as per the Sanction Order issued at the start of the project) till its completion. Each detail has to comply with the NMHS Sanction Order.
2. The FTR should be neatly typed (in Arial with font size 11 with 1.5 spacing between the lines) with all details as per the enclosed format for direct reproduction by photo-offset process. Colored Photographs (4-5 good action photographs), tables and graphs should be accommodated within the report or should be annexed with captions. Sketches and diagrammatic illustrations may also be given giving step-by-step details about the methodology followed in technology development/modulation, transfer and training. Any correction or rewriting should be avoided. Please give information under each head in serial order.
3. Training/ Capacity Building Manuals (with details contents of training programme technical details and techniques involved) or any such display material related to project activities along with slides, charts, photographs should be brought at the venue of the Annual Monitoring & Evaluation (M&E) Workshop and sent at the NMHS-PMU, GBP NIHE HQs, Kosi-Katarmal, Almora 263643, Uttarakhand. In all Knowledge Products, the Grant/ Fund support of the NMHS should be duly acknowledged.
4. The FTR Format is in sync with many other essential requirements and norms desired by the Govt. of India time to time, so each section of the NMHS-FTR needs to duly filled by the proponent and verified by the Head of the Lead Implementing Organization/ Institution/ University.
5. Five (5) bound hard copies of the Project Final Technical Report (FTR) and a soft copy should be submitted to the **Nodal Officer, NMHS-PMU, GBP NIHE HQs, Kosi-Katarmal, Almora, Uttarakhand**.

The FTR is to be submitted into following two parts:

Part A – Project Summary Report

Part B – Project Detailed Report

Following Financial and other necessary documents/certificates need to be submitted along with Final Technical Report (FTR):

Annexure I	**Consolidated and Audited Utilization Certificate (UC) & Statement of Expenditure (SE)**, including interest earned for the last Fiscal year including the duly filled GFR-19A (with year-wise break-up)
Annexure II	**Consolidated Interest Earned Certificate**
Annexure III	**Consolidated Assets Certificate** showing the cost of the equipment in Foreign and Indian currency, Date of Purchase, etc. (with break-up as per the NMHS Sanction Order and year wise).
Annexure IV	**List of all the equipment, assets and peripherals** purchased through the NMHS grant with current status of use including location of deployment.
Annexure V	Letter of Head of Institution/Department confirming Transfer of Equipment Purchased under the Project to the Institution/Department
Annexure VI	**Details, Declaration and Refund of any Unspent Balance transferred through Real-Time Gross System (RTGS) in favor of NMHS GIA General**

NMHS-Final Technical Report (FTR) *template*

Demand-Driven Action Research Project

DSL: Date of Sanction Letter							
0	1	0	3	**2**	**0**	**1**	**6**
d	d	m	m	y	y	y	y

DPC: Date of Project Completion							
3	0	0	9	**2**	**0**	**2**	**1**
d	d	m	m	y	y	y	y

Part A: Project Summary Report

1. Project Description

i.	Project Reference No.	**NMHS/LG-2016/009**					
ii.	Type of Project	Small Grant		Medium Grant		Large Grant	√
iii.	Project Title	**Timberline and Altitudinal Gradient Ecology of Himalayas, and Human Use Sustenance in a Warming Climate**					
iv.	State under which Project is Sanctioned	**Uttarakhand**					
v.	Project Sites (IHR States covered) (Maps to be attached)	**Kashmir, Uttarakhand and Sikkim**					
vi.	Scale of Project Operation	Local		Regional		Pan-Himalayan	
vii.	Total Budget/ Outlay of the Project	7,91,25,200 (in Cr)					
viii.	Lead Agency	**Central Himalayan Environment Association (CHEA)**					
	Principal Investigator (PI)	**S.P.Singh**					
	Co-Principal Investigator (Co-PI)	**Dr. Subrat Sharma** **Dr. Rajesh Joshi** **Late Dr. R.S.Rawal** **Prof. Zafar Reshi** **Dr. Devendra** **Dr. GCS Negi** **Dr. Ashish Tewari** **Dr. P.S.Ranhotra** **Dr. B.S.Adhikari** **Dr. Pankaj Tewari**					

ix.	Project Implementing Partners	**GBPNIHESD, Almora; GBPNIHE, Sikkim Regional Centre; Wildlife Institute of India; Kumaun University, Kashmir University; Birbal Sahni Institute of Paleobotany**
	Key Persons / Point of Contacts with Contact Details, Ph. No, E-mail	**Dr. Subrat Sharma** (+91-9837294343; subrats63@gmail.com) **Dr. Rajesh Joshi** (+91-7500944111; dr.rajeshjoshi@gmail.com) **Prof. Zafar Reshi** (+91-9419043273; zreshi@gmail.com) **Dr. I. D. Bhatt** (+91-9411703802; id_bhatt@yahoo.com) **Dr. Devendra Kumar** (+91-8001373435; devendrawii@gmail.com) **Dr. GCS Negi** (+91-9084654443; negigcs@gmail.com) **Dr. Ashish Tewari** (+91-9412994110; atewari69@gmail.com) **Dr. P. S. Ranhotra** (+91-6386134724; ranhotra.p@gmail.com) **Dr. B. S. Adhikari** (+91-9412056031; adhikaribs@wii.gov.in) **Dr. Pankaj Tewari** (+91-9412034374; pankutewari@gmail.com)

2. Project Outcomes

2.1. Abstract (not more than 500 words) [it should include background of the study, aim, objectives, methodology, approach, results, conclusion and recommendations).

In a world where most people live far away from mountains and more than half the people (55.7% in 2019) are urban (World Bank 2019), it is not surprising that the terms treelines and timberlines are unfamiliar. Realising the need to develop an understanding of Himalayan treelines, we sent a project proposal to the Ministry of Environment, Forest & Climate Change under the National Mission on Himalayan Studies. A team of investigators from various disciplinary backgrounds conceptualised the study of Indian Himalayan treelines. The investigators had expertise in the following disciplines: ecology, vegetation analysis, plant taxonomy and geography, phenology, tree water relations, meteorology, high altitude biodiversity in relation to environment, dendrochronology and livelihood practices. 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, tree ring width chronology, climatology, ecology, and community livelihoods. The 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 Paleobotany, Lucknow, and Central Himalayan Environment Association, Nainital. Several brain storming workshops along with field visits were conducted to workout methods, time schedule, 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 to interdependence in studies. Currently, treeline research is providing new insights into the study of how biota respond to climate change, the relationships between tree ring growth and climate change in various seasons, the role of growth in relation to stress, seasonal variation in temperature lapse rate and the impact of elevation dependent warming, tree-water relations and water conduits in trees, effects of early snow melt, endemism and future changes. We know very little about several areas related to treeline trees, such as: leaf forms specific to treelines, wood density and bark in various tree forms.

2.2. Objective-wise Major Achievements

S. No.	Objectives	Major achievements (in bullets points)
1.	To characterize and map timberline zone in the IHR using satellite and ground base observations including smart phone applications	• In Himalayas there are of two principal type timberlines, one that is hundreds of km long, and runs parallel to permanent snowline, and the other that occurs in outer ranges like a semi-circular strip around mountain summits, and is generally short, less than 10 km in length. Hereafter, the former has been referred to as continuous timberline (CTL) and the latter as Island timberline (ITL). • The project findings show that only a small fraction mostly below 10% of the length of the timberline has shown upslope shift, giving the impression that the Himalayan timberlines are largely static despite the decades of warming. • The absence of timberlines shift in spite of temperature rises indicate that there are several other factors than temperature change which drive change in timberlines.

2.	To determine the temperature lapse rate (TLR) and pattern of precipitation along altitudinal gradients in different precipitation regimes across the IHR	• Temperature data collected from three elevational transects representing the principal segments of Himalaya, western (Kashmir), central (Uttarakhand), and eastern (Sikkim) indicate marked variabilities in TLR values across regions and seasons with implications for species distribution patterns along the elevation gradient including treeline elevation. • Across the three elevation transects mentioned above, TLR ranged from -0.50°C/100 m in Sikkim to 0.66°C/100 m in Kashmir. It emphasizes that TLR decreases from arid to humid regions.
3.	To study plant diversity, community structure, tree diameter changes and natural recruitment pattern along the three principal sites in the IHR	• The present study demonstrates that the elevational patterns of species richness are not consistent across taxonomic or functional groups of plants. In all, six patterns of species richness in relation to elevation have been observed: Decreasing, Increasing, Low plateau, Low-elevation plateau with a mid-peak, Mid-peak and wavy pattern. The overall species richness displayed a wavy pattern along north facing and south facing slopes at Daksum-Sinthan top site whereas at Drang-Kangdoori top a decreasing and a mid-peak pattern along north facing and south facing slopes was exhibited. Among taxonomic groups, angiosperms including dicots showed decreasing pattern along north facing slope while as a wavy pattern was exhibited along south facing slope at Daksum-Sinthan top. • The number of herb species is more than in Central and Eastern parts of the Himalayas. More herb species than in the Sikkim transect calls for attention, and eastern Himalaya are known for high species diversity.

4.	To understand tree phenological responses, nutrient conservation strategies and tree-water relations in response to warming climate	• The major treeline species of Tungnath respond to increase in atmospheric temperature on earlier onset of bud-break and leafing. Growing period at our study site was recorded greater (4-5 months) than reported (2-3 months) for the timberline in the temperate climates of the world. • The strong baseline data for about 5 yrs. on phenology and leaf characteristics of the major treeline species generated in this study will serve as a bench mark in future to ascertain the impact of CC and plant phenology. • The study shows that in harsh treeline environment characterized by heat deficiency while the length of phenophases is within a limit, functional traits vary widely despite a low species diversity. The maximum value is 166 times of the minimum value for leaf area, 141 times for the leaf mass, and 76 times for stable leaf population and leaf life span.

5.	To study relationship between tree ring growth and past climatic changes in different climate regime across IHR	• The study analyzed the response of tree ring growth to climate change across three principal elevation transects across the IHR (i) Daksum-Sinthan, a non-monsoonal site with low annual precipitation in J&K; (ii) Chopta-Tungnath area, a strongly monsoonal site with moderately high precipitation and dry pre-monsoon in UK; and (iii) Tholung-Kisong transect, a relatively wet monsoonal site in Khangchendzonga Biosphere Reserve in Sikkim. • The warm spring months and less number of snow days at Tungnath could lead to early initiation of wood formation in fir as compared to Kashmir. • At Tungnath site the temperature of November and February months have significant role in growth trend of silver fir during last century (1901 till 2014 AD). The high (low) growth phases correspond with high (low) temperature years. Similar growth trends since last century has also been observed in the Himalayan fir from other studies (Borgaonkar et al. 2011; Chhetri & Cairns 2016; Singh & Yadav 2000) and Tibet (Liang et al. 2011). • The positive relation of growth with soil-moisture of pre-monsoon and summer months suggest the critical role of soil-moisture during early growing period.

6.	To understand the impact of depletion of snow-melt water on growth of tree seedlings, grasslands species composition and selected functional processes	• The micro-sites where snow melted earlier (ESM) were richer in species and more productive. This shows that climate warming would lead to an enhanced species richness and plant cover by causing early snow melt and prolonging the growth period. • Warming (OTC experiment) enhanced both plant density and species richness, but the longterm effect cannot be predicted from the experiment. Since species richness and plant densities were similar both in snow-free and snow-added OTCs, we can infer that snow-removal does not affect herbs adversely when conditions are warm. In other words, snow protection is not required when warming is atl east by ~1.5℃. • Snow-free and snow-addition treatments without warming adversely affected both plant density and species richness. The worst affected were snow free plots without warming, possibly because of water scarcity and exposure to cold temperatures without snow cover protection. • A comparison between snow-free and snow addition treatments without warming indicates that the snow addition by protecting plants from cold temperature and by providing subsequently snow-melt water enabled more plant species to grow and in higher densities.

7.	To promote participatory action research (Citizen Science) on innovative interventions to improve livelihoods, women participation in conservation and management of timberline resources	• Unlike the low elevation areas of Uttarakhand and several parts of Nepal, human out migration from Tungnath is not substantial, hence day-to-day pressure on natural ecosystems, including timberline and adjacent ecosystems continues to be unabated. • There is a substantial scope for improving people's livelihoods by initiating economic enterprises which are compatible with the needs of local people and local condition. • Local communities around treelines are highly diverse, needing varied training and skill development streams. Some livelihood interventions were managed in two villages (viz., Makkumath and Sari) of Chopta (Tungnath region) which dealt with off-season vegetable production, mushroom cultivation, floriculture, vermi composting, and rainwater harvesting. Among them, off-season vegetable cultivation in polyhouses was most favoured, followed by mushroom cultivation. • There is an evidence to suggest that several wild mammals have shifted to higher areas including the treeline not because of climate warming but as a response to anthropogenic stresses around tourism sites in lower areas. • Policy interventions are needed to strengthen the conservation of treeline areas by building a healthy relationship between tourism and biodiversity. In biodiversity rich areas, tourism can not be allowed to expand into a "mela form". Alternative options could be to support honey production based on *Apis cerana*, bee which forages many flowering plants during summer.

2.3. Outputs in terms of Quantifiable Deliverables*

S. No.	Quantifiable Deliverables*	Monitoring Indicators*	Quantified Output/ Outcome achieved	Deviations made, if any, & Reason thereof:
•	• Creation of database and knowledge products on vegetation science and tree-soil water relations of timberline in 3 principal sites (J&K, Sikkim and Uttarakhand). • Improved understanding • depicted from thematic maps and database of timberline ecosystem as a special conservation entity and implication to sustainable management and livelihood enhancement. • Improved understanding of future changes in timberline vis-à-vis climate change and human uses • Attempt creation of climate-smart conservation models at the selected sites. • Awareness and Training • material/ knowledge products for sustainable use of resources for improved livelihood. • Promotion of Citizen Science through engagement of community	• Monitoring in comparison to the baseline information to be provided by proponent • No of long-term monitoring sites/plots established in 3 states (Nos.) • Datasets generated (data on taxonomic diversity quantified by species richness, as well as by richness, evenness, diversity, dominance, and rarity at generic and family levels No./ sites). • Publications of knowledge products (No.) • High resolution digital maps depicting changes in timberline (Nos.	**Timberline mapping** • 2 book chapters, other than your records are in press • 10 Maps (1976/77 – 2015) – 2 for each state • 1 Map for entire IHR (2015) • 3 detailed high-resolution maps of permanent sites in three states (J&K, UK, SK) • Mobile base app (1 no) for monitoring inputs by common man **Temperature Lapse Rate** • Established three climate monitoring sites in J&K, Sikkim and Uttarakhand (total 20 loggers installed at different elevation) measuring temperature and relative humidity. • 7 stations for rainfall measurements were installed along Chopta Tungnath transect in Uttarakhand.; Research Paper-1, Book Chapter 2, Article -1; Training Programme organized-1; Established 3 Experimental Forest Hydrological investigation plots at treeline in Uttarakhand	• Could not established raingauge in Sikkim and J&K due to non-availability of safe sites for instrumentation.

	groups •	with time series) • Climate smart conservation models developed (Nos.) • Community groups trained (Nos) • Awareness camps/programs organized (Nos.) • Human use of timberline ecosystems and its contribution to livelihoods (Nos./Area)	**Vegetation and species diversity** **Jammu and Kashmir** • Four plant databases were created based on surveys at two sites (Daksum-Sinthan Top and Drang-Kangdoori) of two aspects (North-facing and South-facing) in Kashmir Himalaya at elevation bands that were 100 m apart. In all 490 species belonging to angiosperms, gymnosperms, pteridophytes, bryophytes and lichens were recorded. At Daksum-Sinthan Top site 405 species were recorded and 267 species were recorded at Drang-Kangdoori site. The species assemblages differed along the north-facing and south-facing aspects with the former contributing more to the species pool than the latter. North facing and south-facing slopes of Daksum-Sinthan top site harboured 286 and 250 species, respectively while at Drang-Kangdoori site 197 and 195 species were recorded at north-facing	

			and south-facing slopes, respectively. • Taxonomic diversity quantified in terms of the number of species belonging to different plant groups at generic and familial levels revealed a predominance of angiosperms with 329 species belonging to 196 genera and 64 families. Among angiosperms, dicotyledons were more numerous (293 species belonging to 172 genera and 53 families) than monocots (36 species belonging to 24 genera and 11 families Gymnosperms, though dominant components of the vegetation and communities, included only 4 species belonging to 4 genera and 2 families. Bryophytes included 111 species belonging to 77 genera 37 families. Forty-six species of pteridophytes belonging to 17 genera and 10 families were also recorded during the present survey (Table 1). Among functional groups herbs predominated with (343	

			species belonging to 188 genera and 63 families) followed by mosses (101 species belonging to 71 genera and 31 families), shrubs (20 species belonging to 18 genera and 12 families), liverworts 10 species belonging to 6 genera and 6 families), trees (8 species belonging to 8 genera and 6 families), subshrubs (5 species belonging to 4 genera and 5 families) and liana (3 species belonging to 2 genera and 1 family). The number of species of each taxonomic and functional plant group across the north-facing and south-facing slopes was different at both sites. • Elevation patterns in species richness were not consistent across taxonomic or functional groups of plants, instead, each group responded differently to elevation gradient i.e., the elevational patterns were taxon-specific. Most of the plant groups exhibited hump-shaped distribution patterns along elevation gradient	

			while some of them showed monotonic increasing and decreasing patterns, others showed inverse hump-shaped, low-elevation plateau with a mid-peak pattern and low plateau distribution pattern. Among taxonomic groups, angiosperms exhibited a monotonic increase and irregular pattern along the north and south-facing slopes of the Daksum-Sinthan site while decreasing and hump-shaped patterns along north and south-facing slopes of the Drang-Kangdoori site. Dicots exhibited patterns similar to that of angiosperms and monocots exhibited inverted hump-shaped patterns along the north and south-facing slopes of the Daksum-Sinthan site while monotonic decrease and low plateau pattern along north and south-facing slopes of Drang-Kangdoori site. Gymnosperms exhibited low plateau and decreasing patterns along the north-facing slope of Daksum-	

			Sinthan and Drang-Kangdoori sites while hump- shaped patterns along the south- facing slope of these two sites. Pteridophytes exhibited irregular and low-elevation plateau with a mid-peak pattern at both sites. Bryophytes exhibited low plateau and monotonic increasing patterns along the north and south-facing slope of the Daksum-Sinthan site while as irregular pattern along these aspects at the Drang-Kangdoori site. • Among functional groups, herbs exhibited a monotonic increase in Daksum-Sinthan and a monotonic decrease in the Drang-Kangdoori site along the north-facing slope while a more or less hump-shaped pattern was exhibited along the south-facing slope of these two sites. Shrubs revealed inverted hump-shaped and decreasing patterns with elevation along the north and south-facing slope of Daksum-Sinthan while as low elevation plateau with a	

			mid-peak pattern and hump-shaped pattern along with these two aspects in Drang-Kangdoori sites. Trees exhibited hump-shaped distribution patterns along altitudinal gradients across north and south-facing slopes at both sites. • Vegetation patterns varied between north-facing and south-facing slopes within a site and were almost similar between the sites. Abies pindrow and Betula utilis dominated the closed forest and treeline ecotone vegetation zone along the north-facing slope in both sites, while as along the south-facing slope of Daksum-Sinthan top site, *Abies pindrow* and *Pinus wallichiana* both dominated the closed forest as well as treeline ecotone. However, at Drang-Kangdoori site, *Abies pindrow* and *Pinus wallichiana* dominated the closed forest while *Pinus wallichiana* dominated the treeline ecotone vegetation zone along the south-facing slope. Species richness patterns also varied across north-facing and south-	

			facing slopes at both study sites with the hump-shaped pattern as the most common type. • The two commonly occurring nurse plant species which are shrubs by their growth habit include *Juniperus squamata* and *Rhododendron campanulatum* dominate the different aspects i.e., south-facing and north-facing slopes of Daksum-Sinthan top and Drang-Kangdoori sites and appear to facilitate the growth and recruitment of tree species. Field observation study revealed that the number of seedlings, saplings and adult trees was more inside than outside the shrub thickets along the north-facing and south-facing slopes at both Daksum-Sinthan and Drang-Kangdoori sites. • The pattern of recruitment/regeneration of tree species was fair at both the sites seedlings > or ≤ saplings ≤ adults or if seedlings ≤ saplings; adults or if seedlings ≥ saplings	

			and the species had no adults) over the entire elevation transect along the north facing and south-facing slopes at both the study sites. • The elevation gradient extended from 2200 to 3800 m.a.s.l along the north-facing and south-facing aspects of Daksum-Sinthan top site while as it extended from 2300 to 3800 m.a.s.l along the north-facing and south-facing aspects of the Drang-Kangdoori site. The elevation extent of closed forest, treeline ecotone and alpine meadow were 2200-3100, 3200-3600 and 3700-3800 m.a.s.l along north-facing and that of the south-facing slope was 2200-3200, 3300-3600 and 3700-3800 m.a.s.l at Daksum-Sinthan top site while as the elevation extent of closed forest, treeline ecotone and alpine meadow across the north-facing slope of Drang-Kangdoori site was 2300-3200, 3300-3600 and 3700- 3800 m.a.s.l while as across south-facing slope,	

			the elevation extent of closed forest, treeline ecotone and alpine meadow was 2300-3200, 3300-3400 and 3500-3800 m.a.s.l. • Sharing of research findings with the scientific community **Uttarakhand** • 105 long-term monitoring plots were established in 3 different aspects (NW, SW and NE) in Uttarakhand site. • A total of 474 species of vascular plants (Angiosperms and Gymnosperms) belonging to 274 genera and 82 families, 108 macrolichen species (41 genera, 15 families), 205 bryophytes species belonging to 54 families and 58 species of pteridophytes were recorded in Uttarakhand site along with this the ecological and soil characteristics of each studied plot were assessed and datasets were generated for the timberline zone the representative site (Uttarakhand).	

			• 3 research papers, 2 newsletters and 2 abstracts were published. • One field-based workshop was organized in Uttarakhand field site for young researchers to build their skill/capacity in field-based research: identification, sampling and data collection techniques used in vegetation assessment (lower and higher taxa). In this workshop 23 researchers from different organizations (Institutes, Universities etc.) were participated. **Sikkim** • 1 No.: Yuksam-Dzongri, West Sikkim (1700-400m) • Distribution data of plant species including lichen (communicated in FTR) • Publication: 8 Nos. Research Papers (IF:15.215); 1 No. Book Chapter (list provided and details of publication attached in FTR) **Phenology** • The strong baseline data for about 5 yrs. on phenology and leaf	

			characteristics of the major treeline species generated in this study will serve as a bench mark in future to ascertain the impact of climate change on leafing and flowering responses of plants. • Pioneering database for 5 years on phenology of 5 major treeline species (Uttarakhand) was established that will serve as a bench mark for future studies to decipher the impact of climate change on plant growth responses. • 03 publications • Organization of one (01) field workshop on “Vegetation assessment, collection and documentation of floristic elements” (20-25 Sept. 2020) in which over two dozen researchers from regional Institutes/Universities and resource persons participated. **Tree water relations** **Soil water potential** • Soil water potential was measured at two different	

			elevation one at 3500m (A) and another at 3300m (B). The soil water potential was estimated by Psypro water potential system at depths of 10cm, 30cm and 60cm. • Across all seasons and years the soils were mostly moist. Moderate stress was observed in winter season. • At site A the most negative water potential was in the top layer during summer season (-3.05±0.25Mpa and - 2.8±0.08MPa) whereas at site B it was in winter (-3.40±0.15MPa) and summer seasons (- 2.5±0.02MPa). • At 60cm depth soil water potential was between - 0.58±0.02MPa (Rainy season) and - 2.59±0.15MPa (Winter season) **Tree water potential** • Twig water potential was measured using a pressure chamber (PMS Instrument Co. model 1000, range 70 bars) at predawn (Ψ PD) (5.30- 6.30 A.M.) and in the midday (1.30- 2.30 pm) (Ψ MD). • The timberline species	

			were never severely stressed during the study period and the Ψ PD were generally above -1.0 MPa. In *Q. semecarpifolia* (-0.99±0.05 MPa), *A. spectabilis* (-0.89±0.03MPa) and *B. utilis* (-0.76±0.02MPa) minimum Ψ PD was during the summer season in *R. arboreum* (-0.86±0.03MPa) and *R. campanulatum* (-0.80±0.03MPa) during the winter season. • The lowest Ψ MD values in all species except *B. utilis* were encountered during winter season and varied between -1.24±0.02MPa and -1.50±0.06MPa, *B. utilis* had the most negative water potential n autumn (-1.06±0.03MPa) just before the commencement of leaf fall (mid-September). • The magnitude of daily change (ΔΨ= Ψ MD – Ψ PD) across all species was maximum during the rainy season except in *Q. semecarpifolia*. In *Q. semecarpifolia* the maximum daily change was during the spring season 0.81MPa.	

			• At Chitkul (H.P.) treeline during summer season the Ψ PD of trees ranged between -0.94±0.05MPa and -1.1±0.02 MPa and of seedlings between -0.80±0.04MPa and -1.4±0.01MPa. The Ψ PD of trees at this site during summers were relatively more negative than Tungnath treeline. During autumn season the Ψ PD of trees ranged between -0.15±0.01MPa and -0.26±0.02 MPa and of seedlings between -0.13±0.01MPa and -0.21±0.01MPa. During autumn the Ψ PD was more negative in Tungnath treeline than Chitkul treeline. **Components of water potential** • Pressure-Volume Curves (P-V curves) were prepared following the bench drying method from overnight saturated twigs. Osmotic potential at full turgor (OP f), the osmotic potential at zero turgor (OP z) and RWC% at turgor loss point (RWC z) were calculated	

			from P-V curves. • All treeline species showed a small osmotic adjustment between the rainy and autumn season and a larger adjustment between winter to spring season. • The magnitude of adjustment in *B. utilis* at zero turgor was -0.17MPa and -0.57at full turgor. • In all other species the osmotic adjustments between rainy and autumn season both at zero and full turgor was above -0.72MPa. • A large decline in osmotic potential was evident during winter to spring being maximum in *B. utilis* (-1.24MPa) followed by *A. spectabilis* (-1.22MPa), *R. arboretum* (-0.82MPa) and *Q. semecarpifolia* (0.7MPa) at zero turgor. *R. campanulatum* was the only species which showed minimal capacity to adjust both at zero and full turgor. • The RWC% across all studied seasons was generally high and ranged between 54.63±1.46% during the summer season in *Q. semecarpifolia* and	

			93.26±0.74% in *R. arboreum* during the autumn season. • It was only in *Q. semecarpifolia,* where RWC at zero turgor had declined to 54.63±1.46% during summer and 58.89±5.99% during the autumn season. **Leaf conductance** • Leaf conductance measurements were made seasonally, using AP 4 porometer (Delta-T Devices). • In *Q. semecarpifolia*, *R. arboreum* and *B. utilis* the morning conductance was maximum during the rainy season and ranged between 204.2±14.3 and 319.6±15.46 m mol m^{-2} sec^{-1}. However, in *R. campanulatum* it was in the summer season (175.9±3.9 m mol m^{-2} sec^{-1}). • In *Q. semecarpifolia* the maximum afternoon conductance was in autumn season (268.6±15.1 m mol m^{-2} sec^{-1}), in *R. arboreum* in rainy season (268.0±24.7 m mol m^{-2} sec^{-1}) and in *R.*	

			campanulatum (243.5±6.4 m mol m^{-2} sec^{-1}) and *B. utilis* (314.8±15.2 m mol m^{-2} sec^{-1}) during summer season. • At Chitkul treeline the morning leaf conductance values during the summer season in *R. campanulatum* and *B. utilis* trees were 165.0±5.4 and 215.0±23.1 m mol m^{-2} sec^{-1} and afternoon conductance was 96.0±4.2 and 132.3±10.4 m mol m^{-2} sec^{-1} which were similar to Tungnath site. The morning leaf conductance of trees for autumn season were exceptionally high at Chitkul site in comparison to Tungnath site. During autumn season the morning conductance of *R. campanulatum* was 783.8±105.4 m mol m^{-2} sec^{-1} and of *B. utilis* was 667.1±123.1 m mol m^{-2} sec^{-1}. The seedling leaf conductance for these species was also exceptionally high 1147.7±59.0 and 1323.3±100.4 m mol m^{-2} sec^{-1}.	

			Seed maturation: • The seed size in *Q. semecarpifolia* increase with altitude however no clear trend existed in germination across two years between low and high elevation sites. Maximum germination occurred when seed moisture content ranged between 41 and 48% and germination ranged from 58 to 68%. • In *R. arboreum* germination was low and was below 40%. In *R. campanulatum* the germination was relatively higher and ranged between 50 and 54%. **Tree ring-width chronology** • Generated the annual Tree- ring growth database by collecting tree core samples from the trees of tree-line ecotone and temperate altitudes from Uttarakhand, Himachal and J&K Indian states. • Developed the Tree-ring width Chronologies (TRWC) of *Abies* (fir), *Pinus* (pine) and *Cedrus* (cedar) trees from the three	

			Indian Himalayan sites. • Established the sensitivity index of tree-growth with various climatic variables such as temperature, precipitation, soil moisture, glacier mass balance and normalized differential vegetation index (NDVI). • Reconstructed the soil-moisture and NDVI for the past 3 century for the J&K and Uttarakhand. • Generated the girth and age class distribution of the fir trees at the tree-line ecotone zones. • Developed an understanding on the forest stand structure at tree-line by establishment of relationships between age, girth and altitudes of trees. • Formulated the age-girth relationship models of tree-line trees for the forest management application. • Reconstructed the Tree-line shift for the sites and assessed the climatic and other factors controlling the tree-line dynamics. • Three publications (one in press) and one manuscript communicated.	

			Snow removal experiment • The present study is a pioneer study conducted in the Himalayan region to understand the influence of snowmelt water on herbaceous vegetation at timberline ecotone. • Two approaches, a) Natural Snowmelt Experiment (NSE, 2016-2019) and b) Snow Manipulation Experiment (SME, 2020-2021), were adopted to generate baseline information to understand the changes in species behaviour (composition, structure and phenology) in relation to snowmelt regime (timing of snowmelt and snow cover). • For NSE, 14 (50x50m) permanent plots were established in the study area along elevation gradient covering Timberline (4 sites between 3200-3300m), Treeline (4 sites between 3300-3400m) and alpine (6 sites between 3400-3600m). Early snowmelt (ESM) and Late snowmelt (LSM) micro-sites were identified on basis of	

			snowmelt timing within each plot, and 3 (1x1m) quadrats were permanent established at each microsite. For SME, two major herbaceous communities (Potentilla-mixed and Fragaria-mixed communities) were selected. For each community, a plot (20x20m) was permanently marked. In each plot, 5 (1x1m) permanent quadrats at 3m distance with various treatments (Control, Open Top Chamber (OTC) with snow addition, OTC without snow, Snow addition in a plot and Snow free plot) were established. • For NSE, across months' data was generated fortnightly for species richness, dominance and diversity. The phenological data was recorded for 107 species encountered in permanent plots. Whereas, the above-mentioned parameters were obtained for SME, except phenological records. **Livelihood Interventions** • 80 training programmes	• The data could not be taken due to COVID pandemic and lockdown during early and mid-growing season for the year 2020 and 2021 for snow manipulation experiment.

			and refreshers on mushroom cultivation, bird watching, carbon sequestration measurement, ringal weaving, polyhouse construction, nursery preparation were organized in the three study villages (Makkumath, Sari, Huddu, Tala-Ushara). • More than 1500 villagers got benefitted by these training programmes and are successfully sustaining the livelihood generating interventions for their upliftment. • 20 awareness campaigns with regard to biodiversity conservation and solid waste management were organized in the study villages and Chopta Tungnath. • 50 Rural Resource Persons developed in various disciplines • Research Article 1; Abstracts presented 5; and Knowledge products 10	

(*) As stated in the Sanction Letter issued by the NMHS-PMU.

2.4. Strategic Steps with respect to Outcomes (in bullets)

S. No.	Particulars	Number/ Brief Details	Remarks/ Attachment
1.	New Methodology developed	1	Annexure-II

S. No.	Particulars	Number/ Brief Details	Remarks/ Attachment
2.	New Models/ Process/ Strategy developed		NA
3.	New Species identified		NA
4.	New Database established		NA
5.	New Patent, if any		NA
	I. Filed (Indian/ International)		NA
	II. Granted (Indian/ International)		NA
	III. Technology Transfer (if any)		NA
6.	Others (if any)		NA

3. Technological Intervention

S. No.	Type of Intervention	Brief Narration on the interventions	Unit Details (No. of villagers benefited / Area Developed)
1.	Development and deployment of indigenous technology	NA	
2.	Diffusion of High-end Technology in the region	NA	
3.	Induction of New Technology in the region	NA	
4.	Publication of Technological / Process Manuals	NA	
	Others (if any)	NA	

4. New Data Generated over the Baseline Data

S. No.	New Data Details	Status of Existing Baseline	Additionality and Utilisation New data
	NA		

5. Demonstrative Skill Development and Capacity Building/ Manpower Trained

S. No.	Type of Activities	Details with number	Activity Intended for	Participants/Trained			
				SC	**ST**	**Woman**	**Total**
1.	Workshops	20	Statistical workshop and knowledge dissemination with regard to timberline				400

2.	On Field Trainings	05	Carbon sequestration measurement, and identification of lower plant groups			70	100
3.	Skill Development	50 (including refreshers)	Mushroom cultivation, nursery preparation, polyhouse establishment, ringal weaving, carbon sequestration measurement, and bird watching			450	750
4.	Academic Supports	05	Statistical on-hand trainings, identification of lower plant groups, carbon sequestration measurement				60
	Others (if any)						

6. Linkages with Regional & National Priorities (SDGs, INDC, etc)/ Collaborations

S. No.	Linkages /collaborations	Details	No. of Publications/ Events Held	Beneficiaries
1.	Sustainable Development Goal (SDG)			
2.	Climate Change/INDC targets			
3.	International Commitments			
4.	Bilateral engagements			
5.	National Policies			
6.	Others collaborations			

7. Project Stakeholders/ Beneficiaries and Impacts

S. No.	Stakeholders	Support Activities	Impacts
1.	Gram Panchayats		
2.	Govt Departments (Agriculture/ Forest)		
3.	Villagers	Mushroom cultivation, nursery preparation, polyhouse	• Direct involvement of **73% women** in

		establishment, ringal weaving, carbon sequestration measurement, and bird watching	the study area in on and off farm activities such as off-season vegetable cultivation, ringal weaving and mushroom cultivation, resulting in **increased income and decision making towards livelihood options and marketing**. • **Marked change** in relationships and attitudes in project areas were noticed over the period 2016 to 2021 (study period) in context to several social issues such as **biodiversity conservation, waste management, women involvement in decision making** etc. • Willingness to join new livelihood generating activities • Local communities along treelines are highly diverse demanding varied trainings and skill development streams.
4.	SC Community		As mentioned above
5.	ST Community		-
6.	Women Group		As mentioned above

	Others (if any)		

8. Financial Summary (Cumulative)

S. No.	Financial Position/Budget Head	Funds Received	Expenditure/ Utilized	% of Total cost
I.	Salaries/Manpower cost			
II.	Travel			
III.	Expendables &Consumables			
IV.	Contingencies			
V.	Activities & Other Project cost			
VI.	Institutional Charges			
VII.	Equipments			
	Total			
	Interest earned			
	Grand Total			

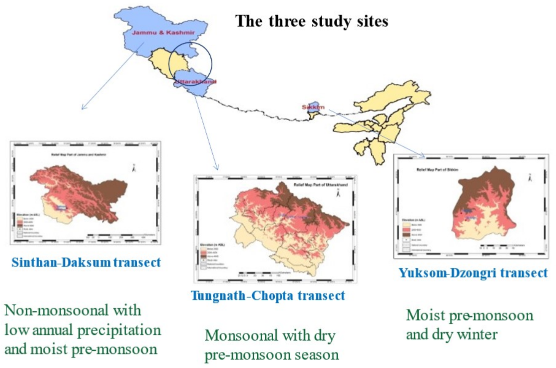
* Please attach the consolidated and audited Utilization Certificate (UC) and Year wise Statement of Expenditure (SE) separately, *ref*. **Annexure I.**

9. Major Equipment/ Peripherals Procured under the Project** (if any)

S. No.	Name of Equipments	Cost (INR)	Utilisation of the Equipment after project
1.			
2.			
3.			
4.			
5.			

Details should be provided in details **(*ref*** Annexure III &IV).**

10. Quantification of Overall Project Progress

S. No.	Parameters	Total (Numeric)	Remarks/ Attachments/ Soft copies of documents
1.	IHR States Covered	03	
2.	Project Site/ Field Stations Developed	03	
3.	New Methods/ Modeling Developed	01	Annexure-II
4.	No. of Trainings arranged	05	
5.	No of beneficiaries attended trainings	750	
6.	Scientific Manpower Developed (Phd/M.Sc./JRF/SRF/ RA):	*30*	02 students rewarded with PhD
7.	SC stakeholders benefited		
8.	ST stakeholders benefited		
9.	Women Empowered	530 (including female staff)	
10.	No of Workshops Arranged along with level of participation	05 (organized and participated)	
11.	On field Demonstration Models initiated	03 (attach maps about location & photos)	
12.	Livelihood Options promoted	04	
13.	Technical/ Training Manuals prepared	01	
14.	Processing Units established	.... (attach photos)	
15.	No of Species Collected		
16.	New Species identified		
17.	New Database generated (Types):		
	Others (if any)		

11. Knowledge Products and Publications:

S. No.	Publication/ Knowledge Products	*Number*		*Total Impact Factor*	*Remarks/* Enclosures
		National	International		
1.	Journal Research Articles/ Special Issue:	5	28		Annexure III and IV
2.	Book Chapter(s)/ Books:	25 (including 23 under submission)			Annexure II, III and V
3.	Technical Reports				
4.	Training Manual (Skill Development/ Capacity Building)	01			
5.	Papers presented in Conferences/Seminars				
6.	Policy Drafts/Papers				
7.	Others:				

* Please append the list of KPs/ publications (with impact factor and further details) with due Acknowledgement to NMHS.

12. Recommendation on Utility of Project Findings, Replicability and Exit Strategy

Particulars	Recommendations
Utility of the Project Findings	The research findings emphasize that there is a need to treat **treelines as a separate entity of study, management and conservation with emphasis on trans-boundary cooperation**. Given the special status of ICIMOD for the Himalayan countries, it is in position to take initiatives to strengthen collaboration among countries for long term data collection, monitoring of changing anthropogenic activities in conjunction with climate change, and development of management practices. Both plants and animals are to shift not only from lower to higher elevations, but also along the Himalayan West to East Arc across different states and countries.
Replicability of Project	(i) ***Building upon the infrastructure that IHTRP has created:*** A policy provision is required to build upon the research infrastructure that a project like IHTRP has created**.** Here research infrastructure is a broad term, which includes data collection which can be continued following the methods already in place with some

	adjustments, instruments placed in the field, and a research scholar familiar with the sites and research methods. From our present project, long term data collection can be managed with about Rs. 50 to 60 lakhs per year. The services of the project coordinator could also be availed. (ii) ***Temperature lapse rate:*** Long-term data from several representative sites would be required to understand how climate change is affecting elevation-dependent warming and temperature lapse rate (TLR). The other related questions for both basic understanding and management are: How are seasonal differences in TLR likely to affect biotic components? How is TLR itself modified by climate change? The other question relates to how widespread pollution in the big cities of adjacent plains are affecting these processes. A macro-ecological approach which gives a coherent picture of various interconnected systems might serve the purpose of managing high landscapes in the Himalaya. (iii) ***Two types of Himalayan timberlines:*** Following our IHTRP study, there is a need to recognize two distinct types of treelines in the Himalaya: the island type treelines (ITL) in the outer ranges, and the continuous treelines (CTL) in the inner /main Himalayan ranges. They differ in length, climatic conditions and responses to climate change, and are exposed to different forms of disturbances. Both livestock grazing and tourist activities are more in the ITL than CTL. Further, ITL is more vulnerable to climate change than CTL, so would require closer monitoring and regulation. (iv) ***Plant species dynamics around mountain summits:*** Treelines and mountain summits are likely to experience changes in species composition, species accumulation, migration and extinction due to climate change impacts. We need to mark and maintain

	permanent plots to monitor species flux around summits on a long-term basis. While doing so, sites should be chosen to appropriately represent outer ranges as well as inner valleys, which differ in treeline elevation, climatic conditions, and treeline dimensions. As our remote sensed data indicates, mountain summits in the outer ranges are expected to be more vulnerable to climate change. Treelines go higher in a dry climate, hence they are higher on south-facing slopes than on north-facing slopes. The difference is related to the warmer temperatures of south-facing slopes when sky is clear; temperatures are higher because of more solar radiation. An annual precipitation of 250 mm is enough for treeline formation (Miehe et al. 2008). Trees also grow on mountain slopes with lower precipitation when trees get upslope runoff. Scree-type loose surfaces keep evaporation losses low. Sites with such surfaces and underlying sand or volcanic ash store moisture, as there is no capillary connection to the surface. (v) ***Transboundary cooperation and expanded team science:*** Greater research networking is required to capture Himalaya-level variability in treeline dynamics and climate change impacts. This would require greater research cooperation and alignment of research purposes and approaches across borders. Team research should be expanded to include research for several Himalayan countries and shared transboundary landscapes and measures should be taken to build team science culture. A few research scholars/field assistants could be trained to collect comparable data in the different countries. (vi) ***Resolving difficult questions about tree-water relations in Himalayan treelines:*** Globally, tree-water relation studies in treelines are scanty partly because

	treelines are not considered to be water stressed (Körner 2012b). Evaporation at low temperatures is low. However, this needs to be analysed more deeply as treelines vary a lot, with inner valleys being far drier than outer ranges. **High leaf water conductance, particularly in inner dry treelines, and high daily change in tree water potential during monsoon are some observations which are difficult to explain based on existing data.** Studies on more sites and over a longer period are required to ascertain the water status of treeline species. Studies on tree ring growth in relation to precipitation and drought, particularly pre-monsoon drought, indicate that the upward shift of treelines is partly restricted because of the intensification of pre-monsoon droughts. In the inner valleys of Sikkim, for example, rainfall rapidly declines with elevation. So, at least at higher elevations, water stress could be a limiting factor in relative terms. Several studies on the relationship between tree-ring width and climate indicate that pre-monsoon temperature and tree-ring growth are negatively correlated and pre-monsoon precipitation and annual tree-ring width are positively correlated. Evidently, water stress is a factor in treeline ecology, which we are not able to capture adequately through our tree-water relations investigations. It is clear that we need to better understand tree-water relations of treeline species in the Himalaya and consider treelines of both moist outer ranges and dry inner valleys. Methodologically, the research should consider both water potential and selected parameters as well as dendrochronological studies with focus on climate relationships.
Exit Strategy	This study was a small initiative to understand treeline dynamics and draw the attention of policy makers, decision

	making bodies, academia, and other stakeholders and to establish Himalayan treelines as a separate and principal unit of conservation and management in a changing world. There is a need to develop **training material** on treeline management and conservation for stakeholders at different levels, such as forest department personnel, biodiversity management committees, NGOs, and army and para-military personnel. Develop short courses on treelines and climate change for schools and college level students. Treeline-based tourism should be carefully developed and monitored. **In a nutshell,** treelines should be declared a separate unit of conservation and management. Research should be carried out to monitor changes that are occurring in the treeline continuum consisting of forests, alpine meadows and nival communities, apart from studies of treelines to capture inter-community exchanges, and responses across communities to climate change impacts. Transboundary cooperation and research collaboration will be crucial for developing a Himalayan perspective on treelines in a changing world.

(**PROJECT PROPONENT/ COORDINATOR**)

(Signed and Stamped)

(**HEAD OF THE INSTITUTION**)

(Signed and Stamped)

Place: Nainital
Date: 26/Feb/2022

PART B: PROJECT DETAILED REPORT

1 EXECUTIVE SUMMARY

With regard to the geographical coverage and research elements investigated (Figure 1), this Indian Himalayan Timberline project of NMHS is an outstanding effort in the realm of macroecology. It considered: patterns of vegetation changes along elevation gradients leading to treelines, gauging and mapping timberline dimensions and shifts using remote sensing techniques and dendrochronological methods, characterizing tree water relations and tree phenology, temperature lapse rate, effect of early snow melt and livelihood linkages (Figure 2). To deal with such research dimensions, a team of 11 principal investigators from six organizations was developed. Methods were developed through two workshops, and research activities were continuously coordinated. In this summary we have the terms timberline and treelines interchangeably, unless they have been used for the specific purpose.

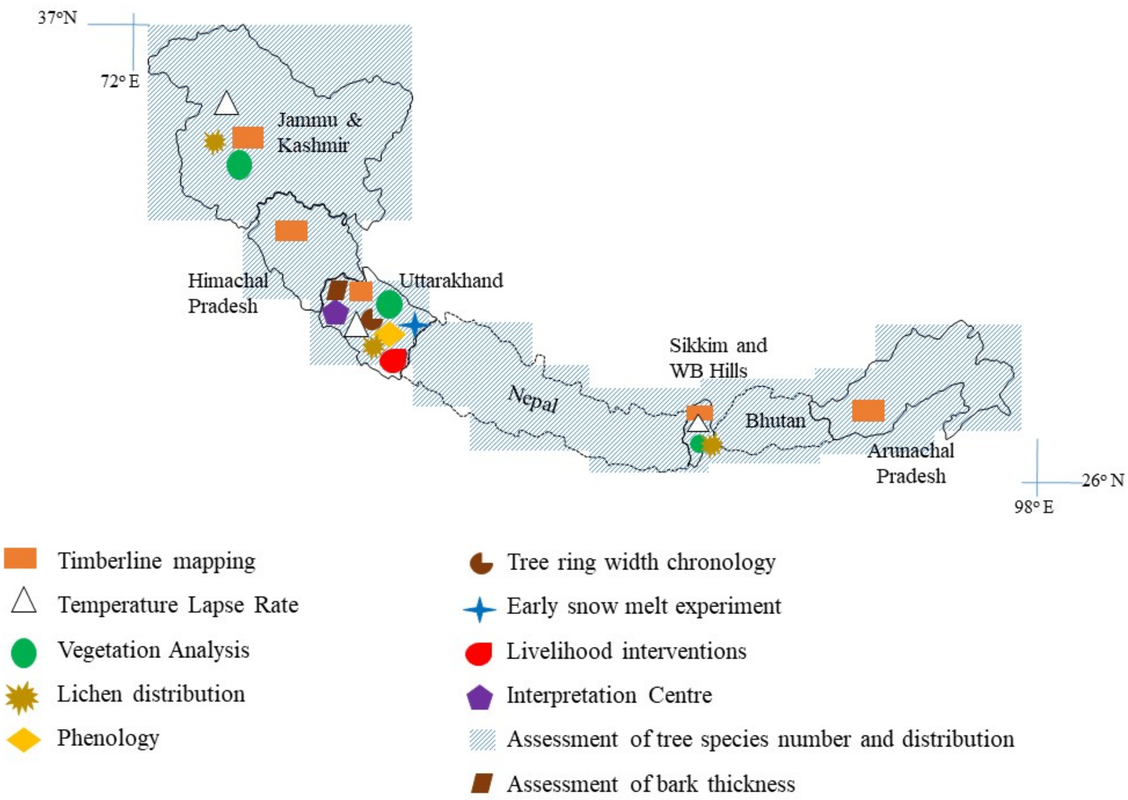


Figure 1 Map of study components of timberline project (NMHS)- Coordinator team.

A brief report by study components is as following:

Timberline Mapping

Using satellite-based mapping, timberlines of five states/regions of Indian Himalaya were analyzed: Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh. The scale that this study covered far exceeds of those carried out before in the Himalaya. It broadly represents all parts the Himalayan West-to-East Arc, other than Nepal, and considers the geographical spread if timbelrines. The main features of the research findings are as following:

- Traversing high ranges, the Himalayan timberlines are several thousands of kilometres in total length, and they are an important biotic entity from management and conservation viewpoints. Twisting and turning in a zigzag fashion, they seem to be roughly 6-8 km long per km crow flight distance. They are of two principal types, one that is hundreds of km long, and runs parallel to permanent snowline, and the other that occurs in outer ranges like a semi-circular strip around mountain summits, and is generally short, less than 10 km in length. Hereafter, the former has been referred to as continuous timberline (CTL) and the latter as Island timberline (ITL). While ITLs receive direct thrust of monsoon, CTLs are generally shielded from its direct thrust with high ranges.
- The elevational range of timberline in a region is 1600-1800 km. For example, in Kashmir it is 1600 km, between 2600-2800 m and 4000-4200 m elevations. ITLs are located below CTLs type. For example, in Kashmir 87.7% of total length of ITL fragments (951 km total) occurred between 3000-3600 m, while 40% of the total length of CTL type occurred between 3400-3800 m elevations.
- The presence of woody patches and solitary individuals above timberline is a common feature. In Kashmir such patches (generally of less than 1 ha area) were of *Rhododendron campanulatum* (on north slope aspect) and *Juniperus indica* (south slope aspect), and occurred from about 3250 to 4039 m elevation. The isolated individuals of *R. campanulatum* could be seen up to 3750 m. The patches facilitated tree growth by giving shelter to their seedlings and saplings against wind and livestock grazing (also see the vegetation component).
- An analysis of change in timberline elevation for last 38 years, between 1976/1977 and 2015 shows that across the study regions timberlines have remained stationary along their length from 83% in Sikkim to 95% in Arunachal Pradesh. These figures give the impression that the Himalayan timberlines are stationary even after the decades of warming, however, the portions showing upward shift amounted to about 120 km in Sikkim to 319 km in Arunachal Pradesh. Among the CTL, the variations are wider, as the percentage remaining stationary has been 11.1% in Kashmir to 94.5% in Himachal

Pradesh. The reasons for timberline remaining stationary, despite the decades of warming can be several, both natural and anthropogenic. This emphasizes that the climate is not the sole driver of timberline elevation.

- The upward shift of timberlines (within the shifted portion) between 1976-2015 ranged from 100-189 m, with decadal rate varying from **26 m in Sikkim to 50 m in Kashmir**.
- In Kashmir as an example, only 7.8% (256 km) of total timberline length of 3297 km (CTL) showed an upward shift between 1975 and 2015. The average rate of upslope shift of timberline portion which shifted was 50 m per decade during last four decades (Table. 1).
- The ITL type of timberline was more liable to shift upward in Kashmir. Of the 9 pieces of timberline only one was stationary and 8 showed partial upslope movement. It involved 82 km of ITL timberline or 32% of the total length. Pattern in the other states varied in details, but were broadly similar to those of Kashmir.
- The study meticulously analysed the extent of change in rainfall and temperature of stationary and shifting timberlines/parts of timberlines. There was no consistent response. In some the MAT (Mean Annual Temperature) increased more in the shifted position and in the others then it increased more in the stationary portion of the timberlines. The effect of rain (total precipitation was not available) alone and in continuation with MAT was also not uniform.

Table 1. Elevational change in timberline from 1976-2015. The Himalayan timberline are generally stationary after several decades of global warming.

	Kashmir	Himachal Pradesh	Uttarakhand	Sikkim	Arunachal Pradesh
Continuous type timberline (CTL)					
Total timberline length (km) in 1976	3297	3253.6	2839.0	707.3	6372
Percent timberline length remaining stationary- by 2015	92.2%	94.6%	89%	97%	95%
The timberline length (km) showing shift	265	177.4	314	121.9	224
Upward shift in elevation (in m) over timberline length and decadal rate	201 m (50 m/decade)	145 m (37 m/decade)	189 m (48 m/decade)	56m downward; 100 m upward (15m/decade; 26 m/decade)	145 m (37 m/decade)
Mean elevation of timberline- 1976-1978	3331 m	3248 m	3555 m	3528 m	3620 m
Mean elevation of timberline- 2015, and change (in m)	3336 m (5 m)	3442 m (194 m)	3571 m (16 m)	3620 m (92 m)	3662 m (42 m)
MAT of the shifted part in 1976	5.1±2.2°C	9.1±3.3°C	12±2.6°C	8±3.2°C	10.9±2.4℃
MAT of the shifted part in 2015	5.3±2.2°C	10±3.2°C	12.1±2.2°C	8.8±3.2°C	10.8±2.4℃
Decadal rate of change in MAT for the shifted timberline	0.04°C	0.23°C	0.04°C	0.2°C	-0.002 ºC

Decadal change in MAT for stationary part over a period of 37 years	0.1°C	0.22°C	0.03°C	0.24°C	0.001°C
Mean annual precipitation for shifted part- 1976	694±195 mm	1219±351 mm	1248±228 mm	1112±341 mm	862±310 mm
Mean annual precipitation for shifted part- 2015	1309±427 mm	1299±218 mm	1147±148 mm	1429±476 mm	1059±245 mm
Decadal rate of change in precipitation for upward shifted part	162 mm	21 mm	-27 mm	86 mm	52 mm
Decadal change in mean annual precipitation for stationary part over a period of 37 years	151 mm	-13 mm	-18 mm	98 mm	67 mm
Island type Timberlines (ITL)					
Total number	9	65	32	1	13
Number remaining stationary (no.)	1 (11.1%)	60 (94.5%)	22 (70.6%)	0	7 (53.8%)
Number showing upward shift	8 partially	3 partially and 2 entirely	4 partially and 6 entirely	1 entirely	6 partially
Shifted timberline length	82 km	11.5 km	92.3 km	21.8 km	76 km
MAT for shifted part in 1976	8.85±1.5°C	13.4±2.4°C	14.6±1.1°C	13.1±0.7°C	15.4 ± 1.1℃
MAT for shifted part in 2015	9.4±1.4°C	14.6±2.3°C	15.2±1.1°C	13.9±0.7°C	15.3 ± 1.1℃
Decadal rate of change in upward shifted part	0.15°C	0.33°C	0.16°C	0.21°C	-0.02 ºC

Decadal change in MAT for stationary part over a period of 37 years	0.07°C	0.15°C	0.08°C	-	0.001°C
Mean annual precipitation of the shifted part- 1976	1033±86 mm	1636±442 mm	1219±51 mm	1543±63 mm	989 ± 175mm
Mean annual precipitation of the shifted part- 2015	1611±199 mm	1492±222 mm	1165±43 mm	2253±90 mm	1622± 202mm
Decadal rate of change for upward shift from 2015	152 mm	-38 mm	-14 mm	192 mm	164 mm
Decadal change in mean annual precipitation for stationary part over a period of 37 years	212 mm	-19 mm	-18 mm	-	166 mm

Temperature and precipitation

In Kashmir, CTL sites are warming at a higher rate than ITL sites, possibly because of mass elevation effect (MEE). ITL sites get more rain (965±135 mm in 1976) than CTL sites (751±184 mm), and there rainfall from 1976 to 2015 increased more (225 mm decade^{-1}) than at CTL sites (136 mm decade^{-1}).

During the study period both temperature and rainfall have changed, and the extent of changes differed between stationary and shifted portions of timberlines, but not uniformly. Changes varied across the study regions. The portions which moved upslope could be warmer as well as cooler than portions which were stationary. Similarly, patterns were uncertain with regard to rainfall. Unfortunately, there was no access to total precipitation. Such uncertainties applied to both types of timberline. Furthermore, the CTL (average rainfall 1268±407 mm) sites were drier than ITL sites (average rainfall 1821±575 mm).

Pin pointed observations on some of the changes are given in Appendix I.

Temperature Lapse Rate

Temperature data collected from representative sites of three parts of Himalaya, western (Kashmir), central (Uttarakhand), and eastern (Sikkim) indicate marked differences in TLR values across regions and seasons with implications for species distribution patterns along the elevation gradient and treeline elevations. Across the three elevation transects mentioned above, **TLR ranged from -0.50°C/100 m in Sikkim to 0.66°C/100 m for Kashmir**. It emphasizes that TLR decreases from arid to humid regions. TLR values in Bhutan and Arunachal, the other parts of the humid eastern Himalaya are similar (0.46-0.51°C/100 m) to that of Sikkim. If temperatures were the only determinant of vegetation, it should change more rapidly with elevation in relatively arid Kashmir than moist Sikkim.

The seasonal changes in TLR can be profound, however, its relationships with species distribution and their adaptational attributes are hardly analyzed. Generally, In UK and Sikkim **TLR drops from autumn to December, and is the highest during pre-monsoon**, the latter being about twice as much as the former. Not much is known about the cause of low December TLR, and its effect on organism distribution. Evidently, winters in high elevation areas of the Himalaya are milder than generally perceived. **Because of the mass elevation effect (MEE)**, large mountain regions like Himalayas are warmer than small mountains (Sakai and Malla 1981). The phenomenon of Elevation Dependent Warming (EDW) in relation to global climate change may also contribute to decreasing the TLR. During winters pollution and reduction in solar radiation in lower areas has also emerged as a modifier of TLR. Because of snow depletion in treeline and alpine areas in the warming climate **albedo has decreased**, which is expected to further increase the warming rate in high elevation. This differential warming between high and low elevation areas is likely to be another cause of decline in winter TLR.

The TLR decline from autumn to December in UK and Sikkim, and the decline could be recent and connected with the global warming, particularly elevation dependent warming. In Kashmir where monsoon is weak, TLR keeps increasing until August, then drops as autumn sets in, and here too the lowest is during winters. These changes and their relationships need to be analyzed by comparing data from different mountainous regions. TLR is likely to further change because of the greening of the higher areas due to upslope shift of treelines, expansion of subnival plants with the retreat of glaciers and thawing of permafrosts.

In a brief, more sites representing different climatic conditions are required to be investigated on a long term basis to understand TLR patterns and their influences on high elevation vegetation, ecosystem processes and ecosystem services. A study located in the Ladakh has shown that the cold desert TLR can be relatively very higher, 0.86°C/100 m (Thayyen 2014). The value of TLR varies with aspect and is not the same for maximum and minimum temperature. The annual TLR is more on cooler aspect than the warmer aspect.

Climate and ecological modelling using climatic prediction are subject to several problems in treelines and other high mountain areas of Himalayas largely because of data scarcity (Bobrowski et al. 2021). That is why Himalayan treeline areas are under-represented in climate change species range shifts. Since species occurrence and dynamics are driven by heat deficiency and local precipitation, climate data are necessary for defining species richness.

Note: *Our objective was to cover one site for the TLR study (Tungnath site), however, we extended to three sites to give a composite picture of the Indian Himalayan Arc. Thus, our TLR estimates for Himalayas are most convincing as it is based on several sites and years. However, since climate change is occurring rapidly, and it impacts TLR and its interaction with vegetation, long term studies are required.*

Patterns along elevational transects in vegetation

Vegetation analysis was based on the three elevation transects leading to treelines in Kashmir, Uttarakhand and Sikkim (overall 1700-4000 m). The vegetation parameters measured included species richness, diversity, stand density, total basal cover, regeneration, and some functional feature. The present study is significant since it simultaneously studied pattern of taxonomic and functional diversity in different groups of plants unlike most previous studies that have studied only taxonomic diversity mostly of one or the other plant group.

Kashmir

A total of 490 species belonging to 294 genera and 113 families were documented from the Kashmir Himalaya of which 405 species (266 genera and 108 families) were present in Daksum-Sinthan Top (DST) transect and 267 species belonging to 186 genera and 86 families were present in Drang-Kangdoori Transect (DKT) (Table 2). Among functional groups herbs predominated with (343 species belonging to 188 genera and 63 families), shrubs (20 species belonging to 18 genera and 12 families), trees (8 species belonging to 8 genera and 6 families), subshrubs (5 species belonging to 4 genera and 5 families) and liana (3 species belonging to 2 genera and 1 families). The number of herb species is more than in Central and Eastern parts of the Himalayas. More herb species than in the Sikkim transect calls for interpretation as the eastern Himalaya are known for high species diversity.

Table 2. Species richness across the Himalayan Arc. DST- Daksum Sinthon Transect; DKT- Drang-Kangdoori transect; YDT- Yuksam-Dzongri transect. Values in parenthesis are of elevational range in meter.

	Kashmir transects				**Uttarakhand transects**			**Sikkim transects**
	DST		**DKT**		**South west aspect (3000-3300)**	**North east aspect (2900-3200)**	**North west aspect (3000-3300)**	**YDT (1700-4000)**
	North aspect (3200-3600)	**South aspect (3300-3600)**	**North aspect (3200-3600)**	**South aspect (3300-3600)**				
Tree (nos.)	8	6	6	5	25	24	26	77
Shrub (nos.)	20	12	15	14	40	30	23	56
Herb (nos.)	218	178	153	144	145	129	128	134
Lichen (nos.)	88		-	-	108			114
Peak elevation (m)- trees	2500, 2700, 2800	2400	3100	3100, 3200	2400-2500	2100-2200	2100-2200	3200
Peak elevation (m)-shrubs	2300	2300	2900	3200	2400-2500	2100-2200	2100-2200	3800
Peak elevation (m)- herbs	3700	2600	2300	3100	3200-3300	2600-2700	3200-3500	2600
Dominant tree species	*Abies pindrow, Betula utilis, Rhododendro*	*A. pindrow, Juniperus squamata, Pinus*	*A. pindrow, Salix denticulata, B. utilis, J.*	*A. pindrow, J. squamata*	*Quercus semecarpifolia, R. arboreum, Acer*	*Q. semecarpifolia, R. arboreum, R.*	*A. spectabilis, Q. semecarpifolia, R.*	*A. densa, Rhododendron spp.*

	n campanulatum	*wallichiana*	*squamata, R. campanulatum, R. anthopogon*		*acuminata*	*barbatum, Taxus wallichiana*	*arboreum, Sorbus cuspidata, Prunus cornuta*	

Species richness patterns along elevation gradient: Present study revealed that the patterns of species richness varied across taxonomic or functional groups of plants. In all the four elevational transects were studied, each taxonomic and functional plant groups produced an elevation pattern characteristic to the group. Such a taxon-specific patterns reflect the ecology of the taxonomic groups, their requirements and their response and relationship with the factors of temperature, precipitation, day length that co-vary with altitude (McCain 2009, 2010) and such observations are supported from similar findings of Grytnes et al. (2006) and Zhang et al. (2016).

Difference in opposite slopes: In Daksum-Sinthan top (DST), the closed canopy forest on the **north facing (cooler) slope** stretched from 2200 to 3200 m a.s.l. was formed largely by *Abies pindrow*, along with interspersion of *Picea smithiana, Pinus wallichiana, Prunus cornuta, Acer caesium, Euonymus fimbriatus* and *Aesculus indica*. The dominant tree and shrub species that formed the closed canopy timberline along this slope were *Abies pindrow* and *Viburnum foetans*, respectively. Treeline ecotone stretched from 3200 to 3700 m a.s.l. with *Betula utilis* and *Abies pindrow* as the dominant tree species and *Rhododendron campanulatum* as a major krummholz species. Treeline on this slope was represented by *Betula utilis*. Alpine meadow stretched from 3700 to 3800 m a.s.l., and in it *Rhododendron anthopogon* and *Cotoneaster spp*. were the dominant shrub species. On the **south slope aspect** treeline ecotone stretched from 3300 to 3600 m a.s.l. and the dominant species were *Pinus wallichiana* and *Abies pindrow* (Table 2). Alpine meadow stretched from 3700 to 3800 m a.s.l., and in this *Juniperus wallichiana* mats were common and *Polygonum affine* along with *Cotoneaster spp*. occur at an elevation of 3800 m a.s.l.

At Drang-Kangdoori transect (DKT), the treeline ecotone extended from 3200 to 3600 m a.s.l. *Betula utilis* was in association with *Abies pindrow* in north aspect. Further upwards *Betula utilis* was the only tree species that grew upto an altitude of 3600 m a.s.l. and was associated with *Rhododendron* under-storey shrub. Treeline ecotone stretched from 3300-3400 m a.s.l. and the dominant tree species in this zone was *Pinus wallichiana* followed by *Prunus cornuta*.

At all sites and slope aspects, *A. pindrow* had a large number of seedlings but few saplings, indicating a low survival of seedlings. *P. wallichiana* produced seedlings in large numbers on only in the south slope aspect, but second was poor.

Across the sites and aspects, the elevation at which species attained the highest average tree diameter was 3300-3400 m for *B. utilis* the species which frequently formed the treeline. It was followed by *Prunus cornuta* (3000-3300 m) and *A. pindrow* (3100 m), which occur either with *B. utilis* or occur just below. The other two conifers *P. wallichiana* (2600 m), and *Picea smithiana* (2600-2900 m) realize their highest average tree diameter at relatively lower elevation.

The present study demonstrates that the elevational patterns of species richness are not consistent across taxonomic and functional groups of plants. In all, six patterns of species richness in relation to elevation have been observed: Decreasing, Increasing, Low plateau, Low-elevation plateau with a mid-peak, Mid-peak and wavy pattern. The overall species richness displayed a wavy pattern along north facing and south facing slopes at Daksum-Sinthan top site whereas at Drang-Kangdoori top a decreasing and a mid-peak pattern along north facing and south facing slopes was exhibited. Among taxonomic groups, angiosperms including dicots showed decreasing pattern along north facing slope while as a wavy pattern was exhibited along south facing slope at Daksum-Sinthan top.

Uttarakhand

A total of 474 species of vascular plants (Angiosperms and Gymnosperms) belonging to 274 genera and 82 families were recorded in extensive survey within the investigated altitude zone 2000-3500 m al. in Chopta-Tungnath region of Uttarakhand, West Himalaya. Of the total species, 44 (9%) species were trees, 57 (12%) shrubs, 321 herbs (68%), 6 (1%) climbers, 32 (7%) grasses and 14 (3%) sedges. Among the families, Asteraceae, Rosaceae, Poaceae, Orchidaceae, Lamiaceae etc. were the species rich dominant families in entire high altitude zone (including all life forms). Asteraceae (29 genus, 50 species) was recorded dominant family in terms of genera and species number, followed by Rosaceae (16 genus, 38 species) and Poaceae (24 genus, 34 species). **Of the 82 families, 32 families were monotypic**. Of the 274 genera, *Carex* (10 spp.) and *Potentilla* (10 spp.) were the species rich genera; and **192 genera were monotypic**. Of the total 474 recorded species, **141 were Himalayan endemic** (including endemic and near endemic) and 325 native species have been recorded from the high altitude zone. The remaining species were non-native representing various biogeographic provenances of the globe.

Based on the **rarity analysis nine species (3.05%) were recorded as locally scarce and with narrow ecological amplitude** (rarity class 4, 8), hence are at high risk of becoming endangered locally. Species (excluding trees, rarity class 4 and 8) were: *Mahonia napaulensis*, *Arisaema concinnum*, *Buplerium dalhausianum*, *Anaphalis royleana*, *Anemone raui*, *Bupleurum hamiltonii*, *Juncus concinnus*, *Plantago depressa* and *Salvia hians*.

Bryophytic flora was represented by 205 species belonging to 54 families. Out of which, 17 were thalloid, 29 leafy liverworts and 155 mosses (58 Acrocarps and 97 Pleurocarps) in the study site (Tungnath). The leafy liverworts and acrocarpous mosses were found dominant in areas above timberline and thalloid liverworts and pleurocarpous mosses were found conspicuous in below timberline areas.

As many as **10 species were reported new to western Himalaya**: *Delavayella serrata* Steph. (a rare Indian liverwort of family Delavayellaceae was rediscovered from Western Himalaya after more than four decades as an epiphyte in association with other foliose liverworts). *Symphyodon echinatus* (Mitt.) Jaeg. belonging to Family Symphyodontaceae (characterized by the multicellular filamentous brownish colored gemmae) turned out to be the new addition to western Himalayan moss flora; and *Aptychella planula* (Mitt.) Fleisch. a gemmiferous pleurocarpous moss, belonging to the family Sematophyllacae is as new addition for Western Himalaya, earlier known to be restricted in the eastern Himalayan region.

The tree density tended to decrease with increasing altitude, significantly (R^2=0.11, $p<0.01$). It peaked around 2400-2600 m and thereafter decreased monotonically. Interestingly the peaks and patterns of the tree density varied in different studied transects, highlighting the influence of anthropogenic impacts or microclimatic conditions in the forests, as the patterns are not uniform for all three transects. The sapling and seedling density declined with altitude (for saplings R^2=0.36, $p<0.01$; and for seedlings R^2=0.35, $p<0.01$). Tree species regeneration was poor because seedlings fail to reach sapling stage. The tree density ranged from 215 at 3200 m to 464 ind./ha at 2300 m altitude belt. These values are lower than in Sikkim. In Sikkim, small tree species predominate.

The Total tree basal area showed a hump shaped curve with peak at 2800 m (68.7 m^2 ha^{-1}). The tree species richness decreased with increasing altitude, the shrub species richness did not follow any uniform pattern; the herb species richness increased with increasing altitude.

The physical properties of soil for both upper and deeper soil depths along altitude gradient for overall representative site (including all three transects) showed that, the soil moisture content increased with increasing altitude. Soil porosity for first soil depth showed significant increasing trend with altitude (R^2=0.06; $p<0.01$). Soil water holding capacity for the first soil depth showed increasing trend with altitude, significant positive relation (R^2=0.06; $p<0.05$) and second soil depth did not have significant relation with altitude (R^2=0.03; $p>0.05$). In the entire altitude zone soil texture was dominated by sand content, which showed significant positive relation with altitude. The organic carbon content in soil showed an increasing pattern with altitude (6.24% at 2200 m to 9.4% at 3000 m). The available nitrogen content in soil did not show significant relation with altitude, with the available phosphorous content in soil increased with altitude.

Note: *A field based workshop titled "Vegetation assessment, collection and documentation of floristic elements- Higher and lower flora" was organized by CBCM of GBP-NIHE during 20-25 September, 2020 at the project site Chopta-Tungnath treeline ecotone falling in Chamoli and Rudraprayag Districts of Uttarakhand. Over twenty researchers were selected from the regional universities/institutions and a couple of resource persons from Botanical Survey of India, northern regional circle, Dehradun, Wild Life Institute of India, Dehradun, Kumaun University, Nainital, GBP-NIHE and IHTP project PIs participated in this workshop involving both lectures and field work. Survey and assessment of lower group of plants (Pteridophyte, Bryophyte, and Lichens) was carried out by a group of 20 researchers from four regional organizations guided by experts (please see detail in Workshop Proceedings) using a belt transect method (50m long and 10m wide) in the representative locations across six sites covering altitudinal interval (200 m each), aspect (SE and NW) and forest vegetation type in Chopta-Tungnath timberline zone. In each location species richness, density and habitat specific details of Pteridophytes, Bryophytes, and Lichens were recorded, plant specimen were collected and preserved. The*

Bryophytes and Lichens were identified on the basis of morphological characters of thallus, reproductive structure, color, size and shape under the supervision of experts.

Sikkim

The Sikkim timberline/treeline ecotone was studied in two ways. In one, following the elevational gradient analysis, 2300 m transect was sampled in Yaksum-Dzongri (YD) and various vegetational attributes were described in relation to elevation. In the other, the focus was on treeline ecotone communities. For this nine horizontal sites within an area of 20 km were investigated in Khangchendzonga National Park (KNP). In spite of many efforts, elevational change in species richness and species composition in vegetation is still not adequately understood.

YK elevational transect

Our sampling of vegetation in every 100 m band from **1700 to 4000 m** (2300 m range) in Sikkim (Yuksam-Dzongri, transect) revealed the following: the transect included 267 plant species of 174 genera and 81 families, of which 77 were tree species, 56 shrub species and 134 herb species. The percentage of woody species was about 50%, which is significantly higher than in similar elevation transects in the Western Himalayan region. However, this eastern Himalayan transect is relatively poor in herbs. The **dominant families in terms of species richness** were **Ericaceae, Fagaceae, and Lauraceae for trees**; **Ericaceae, Rosaceae and Berberidaceae and Rubiaceae for shrubs** and **Compositeae, Polygonaceae, Rosaceae and Primulaceae for herbs**. The elevation pattern of species richness and density varied from one growth form to another. Peaking at 3000 m, tree density (mean 1324 trees ha^{-1}) was markedly higher than the other two regions of Himalaya. The elevation for peak shrub density was 3800 m and that for herbs 2600 m.

The treeline was largely of *Abies densa* and several *Rhododendron* species. Up to considerably high elevation, 3200 m, the **total tree basal area** was high, peaking at **52.5 m^2ha^{-1}**, whereafter it declines rapidly to less than a meter square at treeline (4000 m). Within Indian Himalayan Region (IHR) tree species richness and tree density are the highest in the eastern part and herb species richness in the western part. These observations have not drawn enough ecological interest, however, warrants more data to generalize. The high tree density in the eastern Himalaya might restrict herbs. It is possible that tree densification is a contribution of climate warming.

Box I

Sikkim elevation gradient-a few points of interest

- In it plant species richness (trees, shrubs and herbs) showed monotonic decline along the elevation gradient in Sikkim
- Tree density and tree basal area in Sikkim transect were high up to considerable elevations and peaked as following: trees at 3300 m, shrubs at 3800 m, and herbs at 2600 m
- Woody species accounted for about 50% of the Sikkim transect species, which is much higher than in Uttarakhand transect (21%) and Kashmir transect (7.4%).
- Despite being basically stress tolerant lichen species richness decreased from Sikkim to Kashmir, along which stress increased

KNP timberline- Characterizing the vegetation of treeline ecotone of KNP, Sikkim

The KNP terrain is characterized by 70% area above 4000 m elevation, annual precipitation of 765 mm, snow covered for about 6 months, with maximum temperature of 14.16°C and minimum of -12.16°C.

The study focused on treeline ecotone, sampled at 9 contiguous sites within 20 km horizontal extent of Dzongri landscape (each of the 9 sites was sampled within 3, 20x50 m plots, and each plot was sampled with 5, 10x10 m quadrats for trees and 15, 5x5 m for shrubs, and tree saplings). For analyzing regeneration and possible densification in 3 vertical transects each 2 m wide for each site was sampled up to the elevations where seedlings and saplings occur.

Across the 9 timberline sites 11 tree and 9 shrub species of 10 genera and 6 families occurred. Of the 20 species, 13 were of Ericaceae (Pandey et al. 2018). As in other timberlines of Sikkim and adjoining areas of Eastern Himalaya, *Abies densa* was the sole canopy (up to 40 m height) species. It formed a sparse canopy, while small trees (8-12 m tall) which together had 180-250 IVI (out of 300) formed dense layer of undercanopy. It included *Sorbus microphylla*, *Rhododendron lanatum*, *R. wightii*, *Prunus cerasoides* and more (Table 3). The treeline was divisible into five communities with Dumcan's multiple range test and their separation was largely related to elevation and humus. The absence of birch, *Betula utilis* was a conspicuous feature, though a few trees of it were seen away from the timberline. *Rosa sericea* dominated the shrub layer.

Treeline (3804-3989 m, generally) was diffuse type, and extended up to 187.7 m above timberline (the uppermost forest with 30% crown density). However, the highest elevation (3989 m) timberline and treeline were fused. Between timberline and treeline, *A. densa* regenerated well, indicating an anticipated densification of treeline ecotone, however, the absence of seedlings and saplings beyond 187.7 m above timberline indicates that the treeline has not advanced in response to climatic warming.

Because of small populations, *Pieris villosa, R. thomsonii, Viburnum cordifoilum,* and *R, arboreum* were rare and locally threatened. The tree density in KNP was much lower (< 374 tree ha^{-1}) than in DK transect (mean 1324 trees ha^{-1}) indicates that it was severely disturbed before the biosphere was declared.

Though the elevational range of timberline communities was only of about 200 m (3787-3987 m) five communities were separable, largely in relation to elevation and humus content. In all 9 sites *A. densa* was the canopy species, and in one even it was absent. The presence of a few standing trees (snags) of *A. densa* above the current timberline emphasized that in the past treeline was higher, and could have been damaged by anthropogenic pressure before the KNP was created.

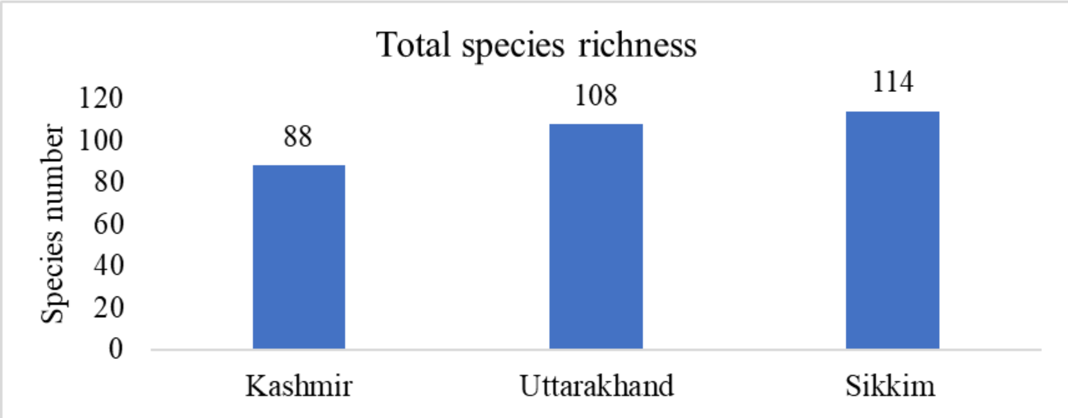
Table 3. Woody species (20 species) of KNP timberline from 9 sites (within 20 km) by IVI percentage class (IVI= Importance Value Index) (derived from Pandey et al. 2018).

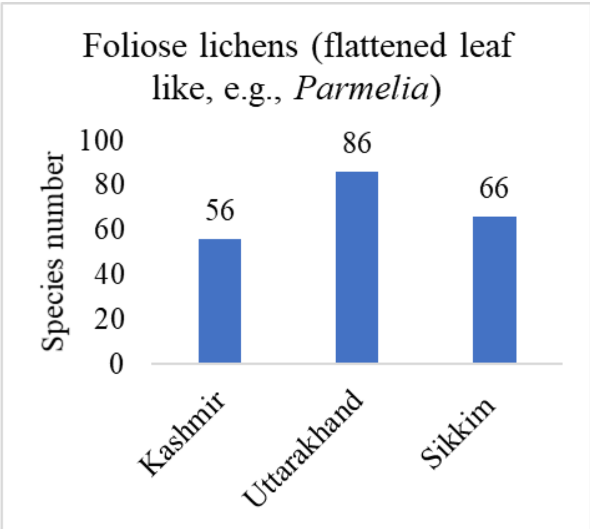
IVI Class	Species
15-20%	*Abies densa*, *Sorbus microphylla*, and *Rhododendron lanatum*
10-20%	*Rosa sericee*, *Rhododendron wightii*
5-10%	*Prunus cerasoides*, *Ribes glaciale*, *Rhododendron hodgsonii*
<5%	*Rhododendron campanulatum*, *Juniperus recurva*, *Rhododendron thomsonii,* and nine more

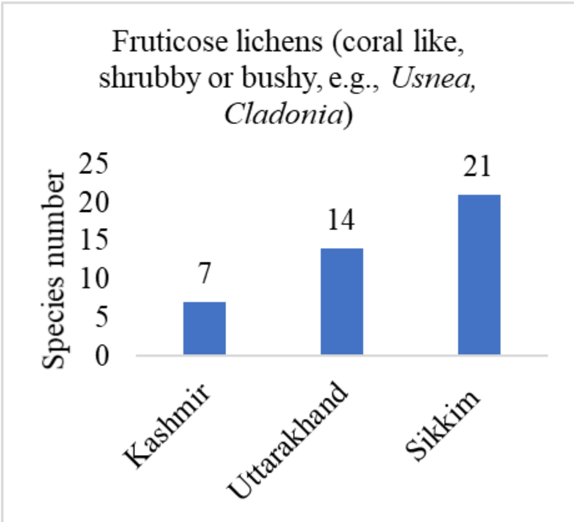
Elevational distribution of Macrolichen along the Himalayan Arc

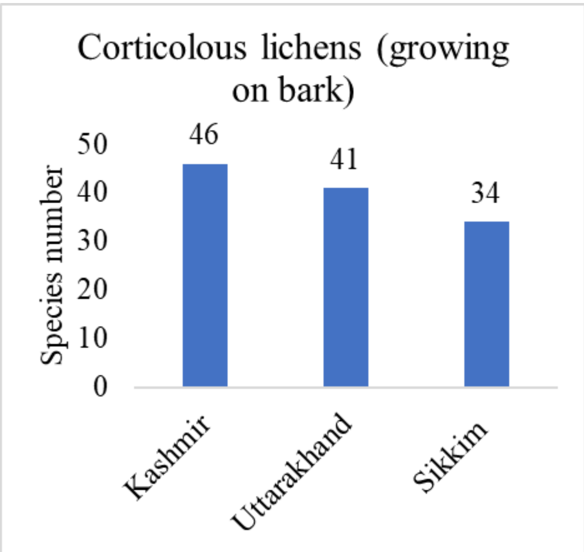
Across the three transects of Kashmir, Uttarakhand (UK) and Sikkim, there occurred 245 species belonging to 77 genera and 26 families. Though lichens are known for their stress tolerance as a basic life history strategy, their species number increased from Kashmir (88) to Sikkim (114) (Figure 2). Though UK is often considered a part of the western Himalaya of which Kashmir is a typical representative, only 4.5% species (11 species) were common among the three regions. The three regions shared 26% genera (20 of 77 genera) and 42.3% families (11 out of 26 families). These percentages are much lower than the common genera the three regions share for trees. In all the three parts of the Himalayas *Abies, Betula, Rhododendron, Sorbus, Picea* and *Juniperus*, as an example occur. Evidently, lichens are sluggish in dispersal and spread along the Himalayan Arc, the beta diversity is likely to be high.

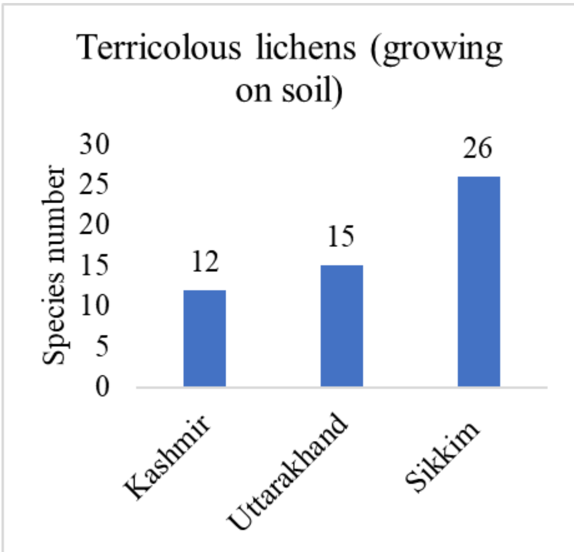
The foliose lichens were most important groups, followed by fruticose lichens. The latter increases in species number with increasing moisture from Kashmir to Sikkim, while foliose forms peaked in UK, which is intermediate. As for substrate categories, corticolous lichens decreased with increasing moisture, from Kashmir to Sikkim, and terricolous species increased with increasing moisture. The species number of Parmeliaceae, the most important family increased sharply from Kashmir (24 species) to Uttarakhand (46 species), and then moderately to Sikkim (51 species).











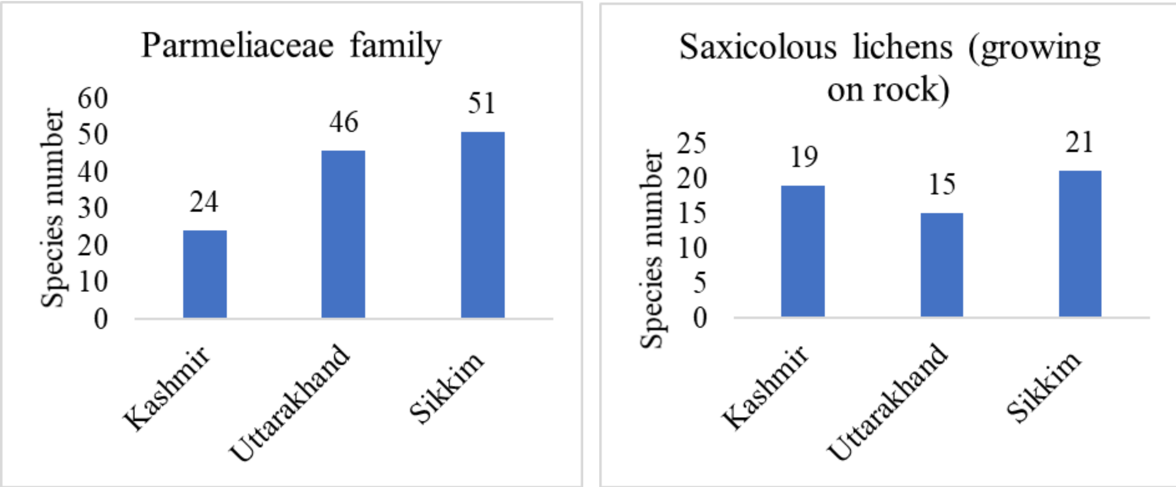


Figure 2 Distribution of macrolichens and their groups across the Himalayan Arc (Kashmir, Uttarakhand, and Sikkim) (derived from Nanda et al. 2021).

The elevational distribution of the lichen species richness showed a hump-shaped pattern; in Uttarakhand it showed rather a low plateau type pattern, not the typical hump.

The mean β-diversity calculated in pairs of elevation bands was in the range of 0.48-0.58 in Kashmir, 0.03-0.63 in Uttarakhand, and 0.46-0.77 in Sikkim. So, it was similar across the pairs of elevation bands in Kashmir, varied widely from one pair to another in UK, and was relatively higher in Sikkim indicating generally high species turnover along the elevational transect. β-diversity tended to rise with elevation (Nanda et al. 2021).

Phenology

Phenological events and leaf and shoot growth dynamics was studied in five treeline species (viz., *Abies spectabilis, Betula utilis, Quercus semecarpifolia, Rhododendron arboreum* and *R. campanulatum*) distributed between 2955 and 3334 m asl in timberline of Tungnath (Uttarakhand), West Himalaya between May 2016 and April 2021 (~5 years). Also, leaf nutrient (Nitrogen) dynamics and soil nutrients (organic carbon and N) were studied at periodical intervals to determine the nutrient conservation strategies of the treeline species.

- The Himalayan tree species have all those physiognomic forms which occur in lower elevation areas: deciduous broadleaf evergreen with one leaf life span and multi-year evergreens. All these tree species showed inter-year variations both in initiation and culmination of the five phenophases (i.e., bud-break and leafing, leafdrop, flowering and fruiting) across the study years which was significantly correlated ($P < 0.001$) with mean annual temperature (MAT). Vegetative bud-break was recorded as early as in early-April in *A. spectabilis* and *B. utilis,* and in mid-May in the remaining species. Interestingly, the two early bud breaking species differ most in leaf longevity, the birch being deciduous and fir multi-year evergreen. In the slightly warmer spring

(April-June 2017, mean= 8.33°C) bud-break and flowering occurred earlier by about 2-3 weeks in all the species than in the 2020, which was cooler by 1.8 °C (April-June 2020, mean= 6.59°C).

- Leaf drop was an extended activity in *A. spectabilis*, *R. arboreum* and *R. campanulatum* (5-7 months), and in *B. utilis* (deciduous) it was a rapid activity (2 months).
- The duration of stable leaf population in the mature shoots of these species varied from 2-3 months in *B. utilis* (leaf life span= 30 weeks) and *A. spectabilis* (leaf life-span= 193 weeks), respectively. Leaf number per shoot at mature stage ranged from 4 in *B. utilis* and 133 in *A. spectabilis*. Mature leaf area (range= 0.33 - 54.9 cm^2, the maximum being 166 times more of the minimum) and mature leaf mass (range= 0.0083 - 1.17 g/leaf, the maximum being 141 times of the minimum) across the species was found for *A. spectabilis* and *R. campanulatum*, respectively.
- The mature shoot length varied from 4.5 cm in *R. campanulatum* to 13.3 in *B. utilis* and shoot diameter from 2.9 mm in *B. utilis* to 6.9 mm in *A. spectabilis*. Thus, the birch had thin and long shoots with sparse leaves, while the fir had thick shoot with densely packed leaves. Leaf mass loss was found ranging from 27.8 - 42.5% in *A. spectabilis* and *B. utilis*, respectively.
- All these species bear flowers before the onset of monsoon so that fruiting and fruit maturation coincides warm and wet rainy season. However, the fruit maturation and seed dispersal varied considerably across these species.
- Inter-annual variation was also observed in nitrogen resorption of the trees. In the warmer year (2017; mean annual temperature= 5.94°C) the N retranslocation from leaves was recorded (58.6%) than in the cooler year 2018 (MAT= 5.6°C; N resorption= 53.7%). Total leaf N concentration at bud- break stage was found ranging from 2.48% in *A. spectabilis* to 3.29% in *B. utilis*. At the mature leaf stage it ranged from 1.53% (*Q. semecarpifolia*) to 1.89% (*B. utilis*) and at the senescence stage it ranged from 0.63% (*R. campanulatum*) to 1.33% (*A. spectabilis*). N-resorption at the time leaf drop stage was found maximum in *R. camapulatum* (67.4%) and minimum in *A. spectabilis* (42.9%).
- Across the forest stands of five treeline species observed monthly for phenological stages the soil OC was found minimum in August (2.76%) and maximum in October (4.02%). The soil N was recorded ranging from 0.38% (August) to 0.53% (June). Soil temperature was recorded ranging from -2.73°C in January to 12.55°C in August (mean= 6.21°C). Soil moisture was recorded ranging from 17.9% in November to 31.3% in August (mean= 24.2%).
- It can be concluded that the major treeline species of Tungnath respond to increase in atmospheric temperature on earlier onset of bud-break and leafing. Growing period at our study site was recorded greater (4-5 months) than reported (2-3 months) for the timberline in the temperate climates of the world.
- The strong baseline data for about 5 yrs. on phenology and leaf characteristics of the major treeline species generated in this study will serve as a bench mark in future to ascertain the impact of CC and plant phenology. However, studies on soil moisture and temperature, tree-water

relations and other eco-physiological aspects need to be studied to precisely explain the phenological behavior of these species to decipher the impact of CC.

Nutrient resorption from senescing leaves (up to 75%) indicates that it is an important nutrient conservation strategy in treelines. Globally, such studies are rare.

- The study shows that in a harsh treeline environment characterized by heat deficiency, while the length of phenophases is within a limit, functional traits vary widely despite a low species diversity. The maximum value is 166 times of the minimum value for leaf area, 141 times for the leaf mass, and 76 times for stable leaf population and leaf life span. These features make the Himalayan treelines consisting of highly niche-differentiated communities, warranting a complex management scheme, and deeper analysis of the adaptational significance of a morphological traits.

Tree Water Relation

The data was collected over a period of five years for the summer, rainy autumn and winter seasons except the summer and rainy season of fifth year due to covid pandemic. The study site was Tungnath timberline, Uttarakhand, at around 3000-3300 m. The study was extended to Chitkul, HP, a dry inner range site.

Parameters investigated

- **Diurnal change in water potential:** Trees and seedlings were measured during winter season on the lower side of treeline, at every 2 hours interval from 6.30 A.M. to 2.30 P.M.
- **Pressure-Volume Curves (P-V curves**) were developed to calculate osmotic potential at full turgor (OP_f), and at zero turgor (OP_z) and relative water content (RWC%) at turgor loss point (RWC_z).
- **Leaf Conductance** measurements were made seasonally, using AP_4 porometer (Delta-T Devices) in morning (10.30-11.30 A.M) and afternoon (1.30- 2.30 P.M).
- **Forest Biomass and carbon and Fruit/Seed parameters** were also measured.

The study species were: *Abies pindrow, Betula utilis, Quercus semecarpifolia, and Rhododendron campanulatum.* The major findings were as following:

- In all the studied species across all seasons and study period (2016-2020) the predawn water potential (Ψ_{PD}) remained above -1.0 MPa indicating the absence of severe water stress.
- Minimum values of Ψ_{PD} for all species were observed during the pre-monsoon (April-June).
- The rise/stabilization of predawn water potential from winter to spring season at the commencement of phenological activities was a conspicuous feature, which is also observed in lower elevations.
- All species showed an osmotic adjustment between autumn/ winters to spring season.
- In *B. utilis* the adjustment was more than -1.0MPa both at full and zero turgor.
- All broadleaved evergreen species carried out leaf conductance throughout the year. The peak values of morning and afternoon conductance was during rainy and autumn season in almost all

species. The high monsoon values in leaf conductance separates treeline species from lower forest trees.

- Diurnal pattern of water potential during winter season showed pronounced declined between 8.30 and 10.30 am across all tree species and this decline in water potential ranged between -0.71±0.02MPa and -2.25±0.07 MPa. The replenishment of water potential began after 10.30am that as sunlight strikes the leaves transpiration commences and exceeds the absorption rate as it was impeded by frozen soil around roots. Subsequently, as frozen soil water gets thawed with rise in temperature the water potentials begin to rise.
- The magnitude of diurnal change across all species was maximum during the rainy season except in *Q. semecarpifolia*. This is another differentiating feature of treeline.

- At Chitkul, the dry inner Himalayan site the morning leaf conductance of trees in autumn season were exceptionally higher than at Tungnath site. In *R. campanulatum* it was 783.8±105.4 m mol m^{-2} sec^{-1} and in *B. utilis* it was 667.1±123.1 m mol m^{-2} sec^{-1}. The seedling leaf conductance for these species was also exceptionally high 1147.7±59.0 and 1323.3±100.4 m mol m^{-2} sec^{-1}. The leaf conductance dropped by 70% in the afternoon.

- Towards the lower limit at 3300m at Tungnath total tree biomass was 568.23 t/ ha inYr1 and 579.35t/ha in Yr2. At upper limit of Tungnath treeline tree biomass was 394.41 t/ha in Yr1 and 400.4t/ha in Yr2. The carbon sequestration rate was 5.58 t C $ha^{-1}yr^{-1}$and 3.0 t C $ha^{-1}yr^{-1}$respectively. The values are very high, possibly because in Himalaya winters are mild.

Tree ring width chronology

The study analyzed the response of tree ring growth to climate change across three principal elevation transects across the IHR (i) Daksum-Sinthan, a non-monsoonal site with low annual precipitation in J&K; (ii) Chopta-Tungnath area, a strongly monsoonal site with moderately high precipitation and dry pre-monsoon in UK; and (iii) Tholung-Kisong transect, a relatively wet monsoonal site in Khangchendzonga Biosphere Reserve in Sikkim. It also analyzed the past climate variability in timber line and its possible impacts on the timberline tree species of IHR.

In the Himalayan region, very few dendroclimatic studies have been conducted at the tree-line elevations. Though low temperature is the most obvious limiting factor for life at high latitudes trees, there is increasing evidence that moisture balance, which depends on both the amount and the seasonal distribution of precipitation inputs and evaporative losses, can also be an important factor. The pre-monsoon period has been shown to be critical also for broad-leaved trees growing at tree-line ecotone.

For chronology development and climate-growth relationships relatively older trees growing under the stressed conditions were selected for the sample collection. To procure the datasets on age stand structures, a number of trees were cored along the transect irrespective of tree size. Subsequent steps included cross-dating and standardization, chronology development and analysis of tree growth characteristics, determination of climate–tree-growth relationships, and age stand structure and tree-line dynamics.

Tree-ring Chronologies and Local/Regional correlation of chronologies:

The tree-ring width chronologies (TRWC) of *Abies spectabilis* (fir), *Pinus wallichiana* (pine) and *Cedrus deodara* (deodar) were developed from three studied sites. The chronology of deodar from Kinnaur covered 259 years (1759-2018 CE). Significant positive correlation ($r = 0.59$; $p < 0.01$) between two fir chronologies of Kashmir indicates a near similar growth behaviour in the area. Relatively low correlation value ($r = 0.41$; $p < 0.01$) between pine and fir chronologies of Kashmir area suggests differential growth response of tree species.

Tree growth Relationship with Glacial Mass Balance data:

In the Kashmir region, RWI of both fir and pine showed negative correlation with glacier mass balance data of Kashmir region. Positive correlation ($r = 0.51$) between tree growth and glacial mass balance data could indicate snow suitability for the growth of deodar trees.

Century scale Reconstruction of Soil-moisture and vegetation health variability:

For Kashmir the significant correlation between RWI of fir and April-May-June soil-moisture (AMJ-SM) makes it must suitable for reconstruction. The reconstruction goes back to 1785 C.E. and explained 42.5% of the actual AMJ variance during the calibration period 1980–2016 C.E. Using the developed relationship, the July-August NDVI of the past 300 years has been reconstructed for the Tungnath area. Different phases of low and high NDVI years indicating changes in the vegetation health were identified for the past 300 yrs (1733–2016 CE) at the ISM dominant Tungnath area.

Chopta-Tungnath transect (Uttarakhand):

The DBH-age linear relationship equation model $Y = 287.72x$ (Eq –A) could be used to approximate the age of rotten and uncored fir trees growing above the 3100 m asl altitude. Considering the youngest individual recorded at elevation ~3331 m elevation, the average shift rate was calculated as 9.8 m/decade.

Daksum-Sinthan transect, Kashmir, J&K

Correlation between DBH and age of 67 fir trees growing around Daksum (2300-2500 masl) was positive ($r = 0.57$, $p<0.01$) with 31% variability explained.

Key results:

- The warm spring months and less number of snow days at Tungnath could lead to early initiation of wood formation in fir as compared to Kashmir.
- At Tungnath site the temperature of November and February months have significant role in growth trend of silver fir during last century (1901 till 2014 AD). The high (low) growth phases correspond with high (low) temperature years. Similar growth trends since last century has also been observed in the Himalayan fir from other studies (Borgaonkar *et al.* 2011; Chhetri & Cairns 2016; Singh & Yadav

2000) and Tibet (Liang *et al.* 2011).

- The positive relation of growth with soil-moisture of pre-monsoon and summer months suggest the critical role of soil-moisture during early growing period.
- Trees growing at higher elevations and near tree line ecotone are more sensitive towards the katabatic winds blowing through glaciers.
- The reconstruction of soil moisture could identify the variations in soil moisture for the past two centuries.
- Densification of fir forest within treeline ecotone during 20th century and static tree-line structure for the past few decades were observed.
- The annual tree-rings of trees of fir, pine and deodar were found sensitive to climate variabilities. The developed tree-ring width chronologies (TRWC) extended to 317 years (1700-2016 CE) for Tungnath, Uttarakhand; 462 years (1555-2017 CE) for Kashmir, and 259 years (1759-2018 CE) for Kinnaur Himachal Pradesh.
- The observed regional scale variation in growth response of fir growing at ISM influenced Tungnath (Uttarakhand) and WD influenced Kashmir (J&K). The warm spring months and less number of snow days at Tungnath could lead to early initiation of wood formation in fir as compared to Kashmir.
- Differential **growth response between pine and fir tree species growing in the same Daksum area at Kashmir.** Pine trees perform better than fir on comparatively drier and sun facing slopes under low soil-moisture conditions than fir which is otherwise a moist taxon.
- A positive relation of growth with soil-moisture for the pre-monsoon apparent. Therefore, the moisture availability by the melt of winter snow during pre-monsoon months (FMA) could be favorable for the growth of treeline trees. The increase in temperature of these months could lead to high evapotranspiration that might produce stress conditions for the growth of treeline trees if enough soil moisture is not available.
- During the cool-dry years/phases the cool katabatic winds reduces the growth of trees growing at the treeline within the glaciated valleys. This could help in identifying the cold years beyond the instrumental records.
- At Tungnath, decline in the growth of *Abies* for the past four decades and also observed decline of NDVI corresponds with the decline trend in soil-moisture. The pre-monsoon drought conditions could be retard the radial growth in trees and also the vegetation health.
- The anthropogenic activities in the form of clearing of high girth class and old aged trees for timber is evident by presence of trees of relatively younger girth and age at lower altitudes (<3000 masl) at study sites.
- Presence of mixed girth and age class in the stands of fir trees growing in the studied transects with uneven girth-age class distribution showed the significant biomass storage potential in the forests of treeline ecotone.
- Despite climate warming, the static behaviour of fir tree-line in the Tungnath transect, Uttarakhand

might be the affect of anthropogenic activities, grazing activities by herbivores and also the low summit height with thin soil cover.

- Also, the observed no regeneration of fir above the present fir limit but the presence of few seedlings within the fir ecotone could be related to mixed response to climate and other local factors.

Early snow melt impact and snow manipulation experiment

Early snowmelt and changes in snow deposition are predicted to be the major impacts of climate change in high mountains. This change can directly influence plant ecology and biodiversity. The research mainly deals with the effect of early snowmelt (i) on herbaceous plant community near treelines at Tungnath site of Uttarakhand, (ii) finding of snow manipulation and warming, and (iii) phenological responses of plant community to warming.

The parameters measured were species composition, community striucture, phenophases, species diversity, and plant growth.

(a) **Effect of early snow melt:** In this, two microsites differing in the time of snowmelt were compared. The early snowmelt (ESM) microsites had exposed convex topography and the late snow melt microsites had sheltered, concave topography. ESM and LSM microsites were investigated in two belts, namely Low Snow Cover (LSC) and High Snow Cover (HSC) belts. During the study period the number of snowfall days ranged from 29-38 days.
In ESM species richness was higher (19.7-24.0 species per quadrat) than LSM (15.0-20.7 species per quadrat). The ESM had higher plant density in low snow zone.
However, patterns changes during growing season and across altitudinal belt to an extent indicating that the late snowmelt microsites are able to recover rapidly after melt water availability in terms of species richness.

(b) **Phenology:** As for phenology at community level, in timberline belt vegetative phase peaked in June, flowering and fruiting in August and senescence in October in treeline ecotone vegetative phase peaked in July while other phases did not change; and in alpine belt the vegetative peak shifted a bit again (July-August).

- Open Top Chamber (OTC) experiment indicates that species might respond positively to increase in winter temperature with less or no snow fall. But the long-run effect could be severe and different.
- There were more unique species in timberline zone (19) than treelin ecotone (7) and alpine meadow (6). **So a disruption of timberline under the influence of global warming would adversely affect biodiversity.**
- **With increase in elevation nativity of species increases from 70% (in timberline) to 85% in alpine zone.**

(c) **Long term changes**

Comparison with past data indicates that vegetative phase has lengthened by 40 days (based on 13 common species) both because of early growth initiation and delayed termination of vegetative phase.

In a number of species fruiting was delayed and shortened. It suggests that when growth period was short and consequently conditions were stressful, species resorted to reproduction early.

(d) **Role of woody cover**

Microsites are also affected by slope tree crown cover and the presence of krummholz species like *Rhododendron campanulatum*, which varied in cover from 20% to 60%. The thick cove of krummholz delayed the snowmelt and increased the snow cover duration which was 70-85 days when krummholz cover was 35% and 45-60 days when krummholz cover was 60%, 55-70 days when krummholz cover was 35% and 45-60 days when krummholz cover was 20%.

> ***Note:*** *Conducting experiments and observing changes in plant communities and ecosystem are very challenging in remote areas of Himalaya, often resulting in the concentration of studies at a few accessible sites. In Himalaya, logistics are poor even in most accessible treeline sites. Whatever, little research infrastructures are developed are abandoned once the project culminates. There is a need to develop mechanism for long term data collection, storage and sharing.*

Livelihood Interventions

Despite being high and remote, timberline ecotones have been under anthropogenic stress since time immemorial. Firstly, because of the people's dependence on natural vegetation for subsistence economy, and secondly because of religious and cultural tourism. Our study was largely based on the villages connected with treelines of Tungnath, which are subject to traditional summer grazing, tourism and local collection of firewood, fodder, timber, forest floor litter, and medicinal plants. In recent years the collection of what is called "*Keera Jari*" (*Cordyceps sinensis*) is an additional source of anthropogenic pressure. Our study showed that (i) unlike the low elevation areas of Uttarakhand and several parts of Nepal, human out migration from Tungnath is not substantial, hence day-to-day pressure on natural ecosystems, including timberline and adjacent ecosystems continues to be unabated, (ii) There is a substantial scope for improving people's livelihoods by initiating economic enterprises which are compatible with the needs of local people and local condition. People's choices are rapidly changing in view of globalization and cultural changes. The drudgery associated with the collection of fodder, firewood, and other natural resources from forests is getting accepted.

In the three study villages (Makkumath, Sari, Huddu, Tala-Ushara), summer tourism accounted for 47.3% of the total income generated at household level. The other income sources were running shops (33.8%), physical labour (12.8%), government jobs (3.2%), and cash from horticultural (2.6%) and agricultural crops (0.16%). Though horticulture is still weak, its contribution is more than that of agriculture (2.6% vs

0.16%). Here, whole tree cutting is uncommon, and trees are mostly lopped for firewood and fodder to feed livestock. Litter collection from the forest floor for fertilizing crop fields is still widely practiced.

The influx of tourists has increased recently, resulting in the growth of newly constructed dhabas, restaurants (shops and lodges), and biomass extraction for other purposes than agriculture from forests. Singh et al. (2010) reported that about 14 temporary dhabas (small shops) are established every year at Chopta, Tungnath lasting for about 5-6 months during tourist season (from May to October). Due to the tourists, the use of fuelwood is 10–14 ton per household per year compared to regular household consumption of 7-10 ton fuelwood per year in the villages. Over 90% of firewood and 62% of leaf fodder were extracted from the nearby forests.

In community-based interviews, 91% of respondents felt that the village forest stock was depleting and 30% emphasized that “drastic” forest degradation has occurred over the past 25 years.

Local communities around treelines are highly diverse, needing varied training and skill development streams. Some livelihood interventions were managed in two villages (viz., Makkumath and Sari) of Chopta (Tungnath region) which dealt with off-season vegetable production, mushroom cultivation, floriculture, vermi composting, and rainwater harvesting. Among them, off-season vegetable cultivation in polyhouses was most favoured (adopted by 120 families even with little persuation), followed by mushroom cultivation. Sadly, the COVID-19 pandemic damaged our efforts to expand above interventions. What we could learn was that people in treeline connected areas are keen on using new interventions.

Because of the huge economic benefits, 52 to 98% of households in the villages of Himni, Ghes, Wan, Kanol, Suto and Tolma in Chamoli district were involved in the seasonal collection of *O. sinensis*. In some areas both quality and quantity of the caterpillar fungus are on decline.

There is an evidence to suggest that several wild mammals have shifted to higher areas including the treeline not because of climate warming but as a response to anthropogenic stresses around tourism sites in lower areas. The transport network is also causing disturbance, disrupting corridors, impacting wildlife movement, and causing mortality (Sathyakumar et al. 2016; Bhattacharya et al. 2020).

While day-to-day biomass collection is declining with increasing income from tourism (56-fold increase in tourists in Uttarakhand over the last five decades), roads and traffic impact wildlife populations by increased mortality, reduced connectivity and habitat degradation (Teixeira et al. 2020). In another valley of Uttarakhand (Upper catchment of Gori river, Johar valley between 80° to 81°5'E Longitudes, and 29°5' to 30°N Latitudes), blue sheep have been pushed to the rugged mountains with sub-optimal habitat because of pastoralism (Bhattacharya et al. 2020). Policy interventions are needed to strengthen the conservation of treeline areas by building a healthy relationship between tourism and biodiversity. In biodiversity rich areas, tourism can not be allowed to expand into a “mela form”. Alternative options could be to support honey production based on *Apis cerana*, bee which forages many flowering plants during summer. Several lessons can be learned from the interventions of AT India in those areas in this direction. AT India’s work shows that honey production can easily be managed through women, who mainly populate some villages. While marketing honey the consumers should be made aware of the pollination service of bees, and the cost of maintaining pesticide-free landscape to maintain the organic chastity of honey. This should be declared an ecosystem service and pleaded for getting payment for providing (i) organic honey; (ii) beefing up pollination by keeping the landscapes free from chemicals and saving threatened organisms; and (iii) promoting gender cause.

Policy issues and new research questions

In the Himalaya, climate change studies have largely focused on glaciers, and the hydrological changes that are likely to result from changes to the cryosphere. Somehow, the treelines which are adjacent to the snowfields of the Himalaya have remained sidelined in the climate change discourse and programmes.

- Notably, the treelines, being biotic systems store varied information that can help us understand climate change dynamics over time. Biotic systems could, in turn, also influence the course of climate change at a landscape level. Tree population dynamics and tree-ring growth reveal considerable information about the pattern of climate change.
- Treelines along with biotic belts of nival plants, meadow species and timberline biota make up a highly complex system with variously interconnected components, which includes some of the most attractive but threatened mammals like the snow leopard as well as rare lower plant groups like lichens growing on a leaf blade. The **'treeline ecotone complex'** is a dynamic system, and understanding its intricacies and complex interactions will require taxonomists of various disciplines, ecologists who can work in remote areas, and researchers and practitioners who can address various issues ranging from tourism to glacier retreat and the thawing of permafrost.
- There is a need to recognize **treeline as a separate and principal entity of conservation and management** in view of the following: (i) treelines are present and apparent throughout the Himalaya, with an extraordinary length and variability in geographical position, (ii) treelines vary a lot along their lengths in their response to climate change, and (iii) have high corridor and habitat values for all forms of organisms.
- **An independent authority for treeline conservation, management and regulation (ATCMR)** may be established. This system should be developed for the entire Indian Himalaya high enough to have treelines, such as in Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh.
- While developing the ATCMR, it is important to involved army personnel and researchers and local communities as partners and collaborators, given their presence and traditional knowledge. Researchers and local people could be other partners in management. They may collaborate to develop a citizen science.
- **Treeline ecotone should be expanded to include adjoining biotic and abiotic zones.** The management of treelines should be considered along with connected biotic zones namely alpine

meadows and nival/subnival belts, and abiotic components such as permanent snow/glaciers and permafrost, which provide water to biotic systems.

- There is a need to develop **training material** on treeline management and conservation for stakeholders at different levels, such as forest department personnel, biodiversity management committees, NGOs, and army and para-military personnel.
- Develop short courses on treelines and climate change for schools and college level students.
- Treeline-based tourism should be carefully developed and monitored.
- **A policy provision is required to build upon the research infrastructure that a project like IHTRP has created. Here research infrastructure is a broad term, it includes data collection which can be continued following the methods already in place with some adjustments, instruments placed in the field, and a research scholar familiar with the sites and research methods. From our present project, long term data collection can be managed with about Rs. 50 to 60 lakhs per year. The services of the project coordinator could also be availed.**
- Long-term data from several representative sites would be required to understand how climate change is affecting elevation-dependent warming and temperature lapse rate (TLR).
- ***The two types of Himalayan timberlines:*** Following our this study, there is a need to recognize two distinct types of treelines in the Himalaya: the island type treelines (ITL) in the outer ranges, and the continuous treelines (CTL) in the inner /main Himalayan ranges. Policies and studies should be based on their special features.
- Treelines and mountain summits are likely to experience changes in species composition, species accumulation, migration and extinction due to climate change impacts. We need to mark and maintain permanent plots to monitor species flux around summits and phenological changes/disturbances on a long-term basis. While doing so, sites should be chosen to appropriately represent outer ranges as well as inner valleys, which differ in treeline elevation, climatic conditions, and treeline dimensions. As our remote sensed data indicates, mountain summits in the outer ranges are expected to be more vulnerable to climate change.
- ***Strengthen transboundary cooperation and expanded team science:*** Greater research networking is required to capture Himalaya-level variability in treeline dynamics and climate change impacts. This would require greater research cooperation and alignment of research purposes and approaches across borders. Team research should be expanded to include research for several Himalayan countries and shared transboundary landscapes and measures should be taken to build team science culture. A few research scholars/field assistants could be trained to collect comparable data in the different countries.
- Globally, **tree-water relation studies** in treelines are scanty partly because treelines are not considered to be water stressed. Studies on tree ring growth in relation to precipitation and drought, particularly pre-monsoon drought, indicate that the upward shift of treelines is partly restricted because of the intensification of pre-monsoon droughts.

It is clear that we need to better understand tree-water relations of treeline species in the Himalaya and consider treelines of both moist outer ranges and dry inner valleys. Methodologically, the research should consider both water potential and selected parameters as well as dendrochronogical studies with focus on climate relationships.

- A timberline that is unable to go upslope in a warming climate (can be called an arrested timberline) would get too warm to retain some basic timberline characteristics, including species composition. What would be the fate of alpine meadows and species near the mountain summits?
- Between broadleaved and conifer species, which are going to be favoured in treeline areas in a warming climate? Past records indicate that a warming climate phase has favoured broadleaved trees.
- What would be the role of livestock grazing in maintaining the diversity, structure and function of alpine meadows? How do we manage competition for resources between livestock and wildlife?
- What would be the **asylum value of the timberline ecotone** for threatened species? Do we need to develop a science of **assisted migration** to save critically threatened species? How do we create **topographical refugia** for species threatened by climate change?
- What are the likely ecosystem services of timberlines in a warming world and how are they likely to be impacted?
- How outmigration depopulation is likely to affect treeline ecology? Conversely, how to avoid unsustainable pressure of tourism?

Linking the findings

Here we have made an attempt to find out how linkages between different study components help improving our understanding of the Himalayan Timberline (Figure 1). The study sheds light on treeline responses to climatic warming in terms of treeline shift, timberline dimension and timberline forms. The timberlines in outer ranges around mountain summits occur like circular or semi-circular island (ITL). They are short strips often less than 10 km. In contrast, the timberlines in inner areas, parallel to permanent snowline are seemingly unbroken **hundreds of kilometers long (CTL) across the Himalayan Arc**. The two timberline types, differ in temperature and precipitation and responses to climate change. Traversing the high mountains in a zigzag fashion CTL generally are 6-8 km long per/1 km crow flight distance. Along their hundreds of kilometers length, the timberline shows an upward shift between only 5-11% portions of the timberline lengths across the Indian Himalayan regions/states (from Kashmir to Sikkim), but that amounts to 120-319 km. So, generally the Himalayan timberlines are stationary, but they are advancing upslope in some parts at the decadal rates between 26 m and 50 m during last 38 years. Since, the timberline sites have warmed rapidly, the ‘arrested’ timberline ecosystem are subject to higher temperatures and precipitation changes. At Tungnath site the growing season mean temperature was about 3°C higher than that of climatic treelines. Its consequences could be tree densification, increased biomass, depleted soil organic matter and effect of increased evapotranspiration loss among the others (Figure 3).

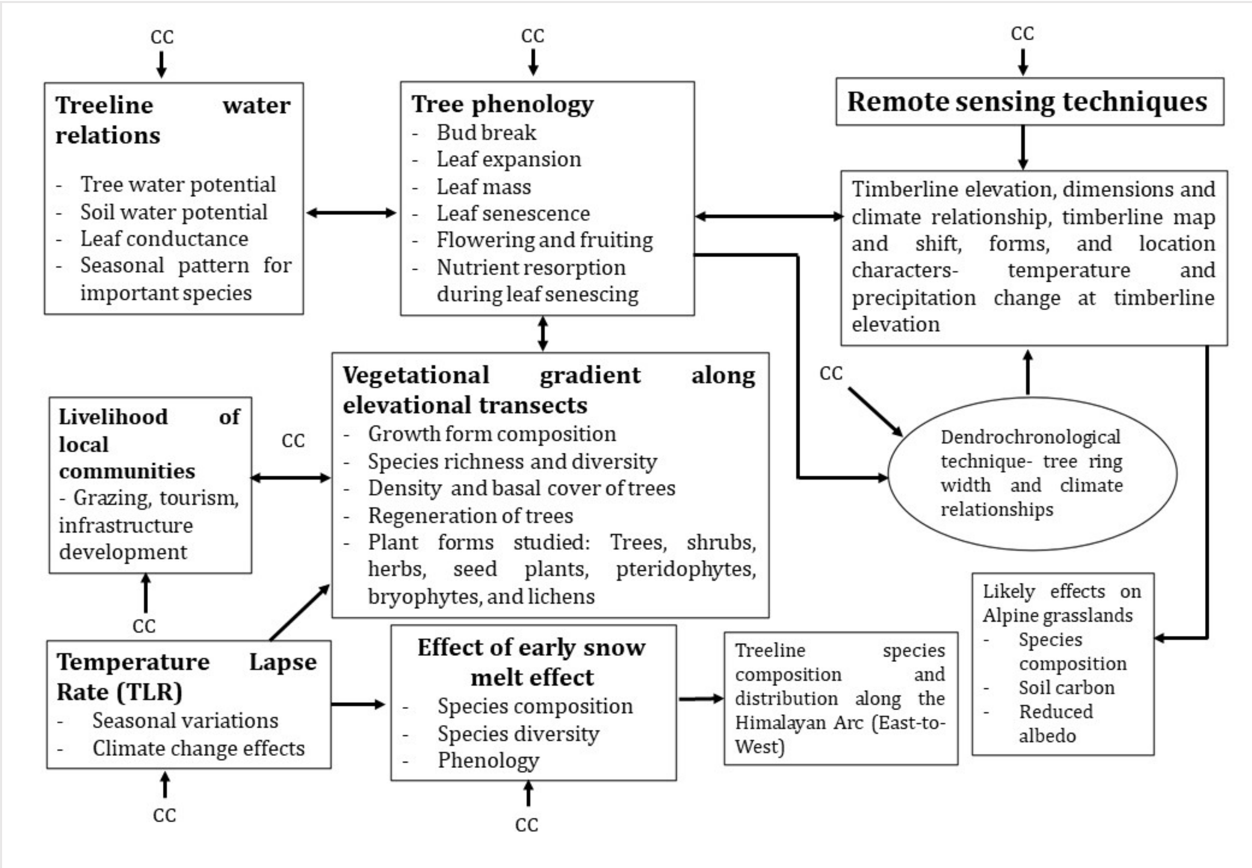


Figure 3 A schematic representation of various study components (mostly studied in IHTRP of NMHS) linked with timberline in Himalayas. All the components are under climate change (CC) effect, however, change in biotic communities along with snow cover and snow melt may affect climate by affecting albedo and carbon assimilation and storage.

- Our research raises several new questions pertaining to treeline water stress. The **tree water relation** data indicate that tree are not water stressed, the predawn Ψ always remaining above -1MPa. Compared to this, in mountain forest ecosystems predawn Ψ frequently goes down below-1MPa, particularly during pre-monsoon months (March to June beginning). In contrast, dendrochronological studies based on tree ring growth of hundreds of years indicate that pre-monsoon drought frequently suppressed tree growth and could become severe enough to cause tree mortality. The study on treeline water relation raises two more questions. It is intriguing that in treelines, monsoon (July- September) is the time when both tree water potential and daily change in the tree potential are the highest. This contrasts with forest tree species of the Himalayas in which during monsoon months the tree water potential is the highest, but the daily change in tree Ψ is negligible. In treeline the large daily change in Ψ during monsoon could be because the trees are shallow rooted, soil remains cool in early hours of the day causing drop in water potential or stomal control of trees is weak. In certain cases, the leaf conductance exceeds the rate 1000 m Mol m^{-2} sec^{-1} which is far more than forest trees in general attain in the Himalaya. How common is the exceptionally high rate of leaf water conductance, and what is its significance call for investigation? In a nutshell, this study shows that the research on tree water relations should be extended to more sites and tree species, as tree water relations is a relevant research field for understanding treeline dynamics in the Himalayas where droughts frequently occur.

- Along the Himalayan Arc, from about 70° to 100°E longitude and more, we estimated the presence of **58 tree species which is quite impressive**, given that globally treelines are likely to have about 150 tree species. The species richness increases eastward, and Hengduan mountains are the areas of species diversification. Birch (*Betula utilis*) which is largely western Himalayan species could be vulnerable to climate change in areas which are warming rapidly and losing moisture. While the upward species shift under the influence of climate warming is important, horizontal species shift of treeline species along the Himalayan Arc is relevant to species survival, and community dynamics.
- While measuring **temperature lapse rate** (TLR) along the elevational gradients, we were struck by marked spatial and seasonal differences in it. The sudden drop of TLR from autumn to December warrants further investigations. More importantly, how this drop in TLR affects vegetation and individual species is even hardly perceived. Are treeline species requiring chilling are on way out because of a warming December? This may influence the pattern of species richness along the elevational gradients which is still not adequately understood.
- The elevation at which **species richness peaks and the pattern of species richness** in relation to elevation vary considerably across the Himalayan Arc, and taxonomical and functional groups of plants. That Sikkim has fewer forest herbs than Kashmir is contrary to the existing understandings, hence needs to be verified by more sampling. Up to a considerable elevation, Himalayan forests can realize large biomass values (as indicated by the tree basal area exceeding 50 m^2 ha^{-1}, up to 2800-3000 m), confirms that they are closer to tropical forests than temperate forests in attributes. We need to examine what makes a region rich in lichens? How important are lichens and mosses of treelines for wild mammals? The increase in endemism with elevation signifies the conservation importance of treeline and adjoining ecosystems.
- The project has generated important phenological information on bud break, leaf expansion, leaf senescence, and nutrient resorption, which could be used to monitor climate change effect on them. How trees widely varying in physiognomy coexist in the harsh treeline environment warrants detailed investigations. Almost each treeline site has a conifer with a densely packed leaves of several years of lifespan on a thick twig (e.g., *Abies spectabilis*), a deciduous broad leaf species with sparse leaves on thin twigs (e.g., *Betula utilis*) and large leaved small tree species of varying longevities around a year or so (e.g., *Rhododendron campanulatum*). How they are likely to be affected by warming, snow depletion and progression of lower elevation species? The mild

winters of Himalayas have contributed to the presence of high treelines in the region. The global warming seems to further reduce the 'bite of winters', leading to increase in lower elevation taxa in the treeline environment of the Himalayas. Himalayas might have more forest cover with a greater capacity to store carbon in biomass as a result of climate warming. However, such a change may accelerate warming by decreasing albedo. Tree growth may be combined by the greening of subnival areas, getting released by glacier melt to reduce albedo. The global warming and resultant depletion of snow might increase species richness and productivity in meadows, but we have little idea of the long term consequences of the loss of snow loss.

Where do we go from here?

- By its very nature "treelines under the influence of Climate Change (CC)" is an area of long-term research and management. There is a need to recognize **Himalayan treeline as a separate entity of conservation and management.** While glaciers, because of climate change might melt out and disappear from several areas, treelines are likely to stay in many areas, advance upslope only partially and get modified variously. Then, the changes in treeline ecosystems may themselves affect the course of climate change through regional change in albedo and carbon stock. In contrast to glaciers, treelines are not a captive of climate change, it too can affect climate change.
- The present project has developed a massive infrastructure for treeline research in terms of expertise, establishment of permanent transects and plots for monitoring changes, and data to build on further studies. By using these infrastructures the various national missions focused on Himalayas can cost effectively support further treeline research cost effectively.
- There is a **need to create a treeline ecotone authority** for its conservation and management, particularly to **promote cooperation among the Himalayan countries and Indian Himalayan states**. The universities could join hands to run courses on Himalayan treeline based on the various publications of the project, which include a manual for methods, a book on '*Interpreting Himalayan Treeline in a Changing World*', apart from many research papers. A beginning could be made with creating an online course. An institute like GB Pant National Institute could expand its mandate by including treeline research and awareness for conservation. This particular institute has expertise in plant and microbe diversity, and its presence in different parts of the Indian Himalayan Region. There is a need to take a macroecological approach involving several representative sites and effective monitoring.

2 INTRODUCTION

2.1 Background of the Project (max. 500 words)

Globally the ecotones are valued as landscape corridors for the migration of organisms, as barriers or facilitators of flow of energy and matters across them, habitats of high biological diversity (di Castri et al 1988), and as potentially most sensitive areas susceptible to climatic change (Neilson 1991). In mountains, the timberline comprises one of the most recognized ecotones separating temperate forest from alpine grassland biomes. This ecotone has attracted considerable attention of scientific community world over in view of the sensitivity of the zone to climatic change. Responses of this ecotone to climate change can be observed in terms of changing tree growth, recruitment, and species composition (Hofgaard et al. 2009). These structural parameters are influenced by multiple abiotic factors (e.g. temperature, precipitation, slope exposure, radiation, wind, moisture) including factors outside the growing-season (Hofgaard et al. 2009).

In spite of its proven indicator and other values, the timberline in the Himalaya could not get desired attention of researchers. The initial studies, as available in fragmentary forms, highlight the conservation significance of this ecotone. For instance, the primary data obtained on patterns of spatial distribution and occurrence of floristic elements at Timberline Zone (TLZ) of Kumaun have highlighted the conservation significance of this zone both at local and regional level (Rawal & Dhar 1997, Dhar 2000). Subsequently the data sets generated for TLZ forest communities of west Himalaya have revealed uniqueness of community structure and responses of vegetation against anthropogenic disturbances (Gairola et al. 2009, 2015, Rai et al. 2012). More recently, Schickhoff et al. (2015) have tried to evaluate Himalayan timberline for its climate sensitivity. The fact, however, remains that the Himalayan timberline is poorly known both for its life support and climate change indicator values. More importantly, this zone has never been analysed for understanding its societal values. Take an example of important high-altitude pilgrimage sites (i.e., Badrinath, Kedarnath, etc.) which are located in potential timberline areas. All high latitude tourist destinations start beyond the timberlines. The transhumance pastoral communities rely significantly on resources within and immediately below and above the timberline. However, no attempt has been made to assess the contribution of timberline resources for sustenance of all these activities in the higher Himalaya. Therefore, in order to realize the full potential of this zone, one needs to think beyond identification of priority biodiversity elements, conservation sites/habitats and patterns of communities and species. What is really needed is to understand the indicator value of this zone. Short-and-long term monitoring of ongoing processes of changes in structural (e.g. patterns of abundance, physiognomy, biomass, recruitment, phenology and population structure etc.) and functional (e.g., patterns of productivity, organic matter accumulation, inorganic inputs and movement of nutrients through soil and plants components, and processes of colonization of aliens, etc.) properties of biodiversity components will be one of the options for identifying/ understanding these values. Also, the participatory action research on socital and livelihood relevance of timberline in higher Himalaya would be important for holistically capturing the potential of this important ecotone in the Himalaya.

While considering the above, and realizing the diversity of bio-physical systems across low to high altitude (temperature) gradient and east to west precipitation gradient, it becomes imperative to focus on: (i) the altitude gradient which plays significant role in determining the climatic conditions, especially the temperature, and subsequently the biodiversity patterns, and (ii) the precipitation gradient that varies significantly from east to west Himalaya. This calls for understanding patterns well below and above the timberline, and also from comparable altitude sites in different precipitation zones of the Himalaya (i.e., east to west Himalaya).

2.2 Overview of the Major Issues to be Addressed (max. 1000 words)

Besides being an effective indicator of climate warming, changes in timberline have implications to decline in biodiversity, provisioning of ecosystem services, such as medicinal plants, grazing sites for migratory livestock, snow melt water fed springs and religious tourism. The shrinkage in Himalayan glaciers due to global warming has drawn most of attention, largely because of its impact on water availability to people and the rate of warming itself, however, the depleted snow melt water is also going to affect ecological attributes of timberlines and local people who depend on it for their livelihoods. Therefore, timberline zones in the Himalayas need to be studied holistically to formulate mitigation strategies and conservation of important taxa and gene pool upon which the livelihoods of people depends. Since the timberline varies considerably along the East-to-West Himalayan arc, and it involves a complex assemblage of ecosystems, it can be investigated meaningfully by undertaking a coordinated and multi-site study. There is also a need for cross-learning of indigenous practices of timberline use and management by the local communities and build their capacity on sustainable use of resources and seek their participation in conservation of timberline ecosystems and long-term sustenance of their livelihood.

The present 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 through treeline ecotones, tree water relations, tree phenology, tree ring chronology and plant growth in relation to snow melt under the influence of climate change. Apart from research on several aspects the following interventions was involved in the project:

(i) Timber line ecotone (including alpine and sub-alpine vegetation, can be called Timberline Ecosystem Assemblage - TEA) will be intensively studied for various parameters of vegetation-climate-human interactions (as outlined under the Objectives section) by a multi-disciplinary team of researchers at three principal sites across the IHR.

(ii) Measurements of climate and environmental parameters at the three principal sites. This will provide an insight into defining the elevation dependent changes in climate variables.

(iii) Conduct of field experiments on (a) removal of snow from the experimental plots to examine the impact of the absence of early snow melt water and intensified drought on growth and life cycle of alpine plants to understand survival strategies of plants and to understand long-term changes, and management requirements; and (b) conduct tree-water relation experiment on important timberline species.

(iv) Training modules will be developed to impart training to local people, particularly the pastoral communities (i.e., Gaddi herders) and women for sustainable use of timberline resources (right from harvesting to processing, value-addition and marketing) to build capacity of local people for livelihood enhancement and income generation.

2.3 Baseline Data and Project Scope (max. 1000 words)
NA

2.4 Project Objectives and Target Deliverables (as per the NMHS Sanction Order)

Project Objectives	**Quantifiable Deliverables**	**Monitoring Indicators**

(i) To characterize and map timberline zone in the IHR using satellite and ground base observations including smart phone applications (ii) To determine the temperature lapse rate (TLR) and pattern of precipitation along altitudinal gradients in different precipitation regimes across the IHR; (iii) To study plant diversity, community structure, tree diameter changes and natural recruitment pattern along the three principal sites in the IHR; (iv) To understand tree phenological responses, nutrient conservation strategies and tree-water relations in response to warming climate; (v) To study relationship between tree ring growth and past climatic changes in different climate regime across IHR; (vi) To understand the impact of depletion of snow-melt water on	(i) Creation of database and knowledge products on vegetation science and tree-soil water relations of timberline in 3 principal sites (J&K, Sikkim and Uttarakhand). (ii) Improved understanding depicted from thematic maps and database of timberline ecosystem as a special conservation entity and implication to sustainable management and livelihood enhancement. (iii) Improved understanding of future changes in timberline vis-a-vis climate change and human uses (iv) Attempt creation of climate-smart conservation models at the selected sites. (v) Awareness and Training material/ knowledge products for sustainable use of resources for improved livelihood. (vi) Promotion of Citizen Science through engagement of community groups	(i) Monitoring in comparison to the baseline information to be provided by proponent (ii) No of long term monitoring sites/ plots established in 3 states (Nos.) (iii) Datasets generated (data on taxonomic diversity quantified by species richness, as well as by richness, evenness, diversity, dominance, and rarity at generic and family levels No./ sites). (iv) Publications of knowledge products (No.) (v) High resolution digital maps depicting changes in timberline (Nos. with time series) (vi) Climate smart conservation models developed (Nos.) (vii) Community groups trained (Nos) (viii) Awareness camps/ programs organized (Nos.) (ix) Human use of timberline ecosystems and its contribution to livelihoods (Nos./ Area)

growth of tree seedlings, grasslands species composition and selected functional processes; (vii) To promote participatory action research (Citizen Science) on innovative interventions to improve livelihoods, women participation in conservation and management of timberline resources.		

3 METHODOLOGIES, STARTEGY AND APPROACH

3.1 Methodologies used for the study (max. 1000 words)

A list of study components along with purpose with regard to Indian Himalayan Timberline Project (IHTR).

The study sites were Kashmir, Uttarakhand and Sikkim

Study components	Purpose and remarks
Mapping the timberline in the 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 snow melt is likely to affect species growth and species richness in meadows.

3.2 Preparatory Actions and Agencies Involved (max. 1000 words)

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, tree ring width chronology, climatology, ecology, and community livelihoods. The 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 Paleobotany, Lucknow, and Central Himalayan Environment Association, Nainital. Several brain storming workshops along with field visits were conducted to workout methods, time schedule,

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 to interdependence in studies. For example, to find out the impact of pre-monsoon drought on treeline ecosystems we measure and analyzed 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, Annexure attached). The coordinator continuously monitored and influenced the progress on each research component during the entire course of the study.

3.3 Details of Scientific data collected and Equipments Used (max 500 words)

Timberline Mapping

- Multi-platform, multi-resolution satellite images were procured. On the back drop of digital elevation models these images were analyzed for physiographic and altitudinal variation in the tree line ecotone zones in different latitudes and altitudes in different states of the Indian Himalayan region. Ground points through field samplings were integrated in GIS platform to enrich the vegetation attributes to spatial dataset obtained from satellite images.
- A software based application was developed to be used in cell phone/ tablets in the field which can capture a scene (photo) and tag the attributes of its location (GPS, date, time, and altitude) and transmit to the server database while in range of mobile connectivity. These ground points were tagged to the spatial map for visualization and realizing ground situation (species, phenology) while interpreting results. This photo database will serve as baseline for future on account of spatial advancement and changes is phenological bevahior of species.

Temperature Lapse Rate

- Present study dwells on the orographic processes driving the temperature and precipitation distribution in the monsoon and nonmonsoonal regimes of the Himalaya through systematic data collection of 5 years at three sites (one each at J&K, Uttarachal and Sikkim) at different altitude zones between 2000 m a.s.l. and 3700 m a.s.l.
- *Meteorological setup and topographic classification*: After selection of suitable sites for instrumentation, the temperature-relative humidity sensor and rain gauges were installed to record the long term time series data for the study. Based on the location type, stations were classified in different zones (e.g. flat terrain, valley, river basin, sloping ground, hill top, etc.) through subjective visual comparison with elevation using DEM. The high resolution time series data on temperature, relative humidity and rainfall was generated for the different study sites.
- *Quality control, processing of the data and determination of co-linearity:* The observed high resolution data on different parameters was checked for quality control using standard mathematical/statistical methods. In order to investigate the relationship between temperature and latitude, longitude, and elevation, multiple regressions were performed to allow additional factors to enter the analyses separately so that effect of each can be estimated.
- *Estimation of Temperature Lapse rate (TLR) and Precipitation Gradient (PG):* Relationship between maximum, minimum, and mean temperatures with elevation were derived base on multi-colinearity analyses. A temperature-elevation relationship was established using regression method. Precipitation gradient (PG) was analyzed as a function of elevation, distance along the valley/catchment, latitude, and longitude both annually and seasonally. Since near surface TLR varies on seasonal time sacles because of changes in sensible heat flux and different climatic

settings which determines diversity in the lapse rate, therefore spatial and temporal variability in TLR for different monsoonal regimes in Himalaya will be examined and TLR for different seasons for the study area was determined. Similarly, the observed time series data of rainfall was used to characterize precipitation gradients

- *Analysis of controlling factors on the temperature lapse rate:* The distinction between wet and dry conditions is extremely important in controlling lapse rates near the surface. Therefore, the relationship between TLR with rainfall, cloud cover, and the saturation vapour pressure lapse rate was studied to find the controlling factors on the temperature lapse rate.

Vegetation Sampling

- The selected altitude transects were divided into altitudinal bands of 100-m intervals. Four to five plots of appropriate size were established in each of the elevational bands and their size shall be kept constant so as to control for sampling effort and area. Sampling plots (20 x 20 m) were established at each of the sites/bands in order to minimize variation in slope, orientation and rockiness. Each plot was divided into sub-plots, each of 5 x 5 m^2. All vascular plant species were recorded from each subplot.
- Taxonomic diversity was quantified by species richness, as well as by richness, evenness, diversity, dominance, and rarity at generic and familial levels. Presence/absence data for all the species belonging to angiosperms, gymnosperms, bryophytes, ferns, lichens was collected from each of the sampling sites located in the elevation zones employing quadrat method. Functional biodiversity, which reflects variability in ecological attributes among species or individuals, was quantify the functional diversity of an assemblage to provide insight about functional uniqueness, redundancy, and complementarity, and offer clues to the resistance or resilience of ecosystems. Trait data for the plant species recorded in the plots was:

Growth form	Trees (>2 cm dbh, height 5-15 m), tree saplings (<2 cm dbh, height 2-5 m), shrubs (height <2 m) and herbs (height <0.5 m).
Life span	Annual/Perennial
Stem tissue	Plant with woody stem/Plants with herbaceous stem
Leaf longevity	Evergreen leaves/Deciduous leaves

- Phylogenetic diversity, representing variation in evolutionary history among species, and is based on the evolutionary distance between species in a phylogeny (i.e. time since divergence from a common ancestor, was examined using following metrics along the altitudinal gradient taking into account co-occurring species from all the families. Phylogenetic and functional turnover (beta diversity) was calculated.

- For recruitment studies, adequate number of plots were set up in different timberline forms and data loggers were placed in each plot to measure air and soil temperatures. Besides other parameters related to soil moisture, soil pH, organic carbon etc. were measured employing standard methods. Seedlings of important species present in each plot were recorded. Plots were searched thoroughly for a definite period in order to standardize search effort across plots. Plots were mapped and positions of all seedlings recorded. The height of each seedling was measured and notes on the condition of seedlings to assess changes in health over time were recorded. Growth rates (RGR) were calculated based on measurements made at the beginning and end of the growing season each year, and survival rates were expressed as the percentage of seedlings surviving in the plots over the study period.

Phenological Studies

- Populations of dominant timberline forming tree species (e.g., *Abies spectabilis, Betula alnoides, Rhododendron campanulatum, Quercus semecarpifloia*, etc.) along the altitudinal gradient encompassing both the aspects (NW and SE) in the timberline ecotone was marked for periodical phenological observations on selected phenophases. Observations were taken rapidly (bi-weekly interval) during active phenological activity such as spring and autumn. A pheno-calendar of these species was maintained.
- Representative shoots of these marked trees were tagged for monitoring leaf characters (viz., leaf population and leaf area changes) at periodical intervals.
- Sufficient leaves of a single flush from the marked population were collected and brought to laboratory for calculations on leaf area and leaf mass changes at monthly interval. Specific leaf area (SLA) and specific leaf mass (SLM) was calculated.
- Leaves thus collected for leaf area and leaf mass change was analyzed for nitrogen concentration in laboratory employing standard methods.
- Meteorological data of the past several years existing with Indian Meteorological Department, Pune; Regional Institutions such as ICAR, Central Water Commission and website, etc. will be procured/purchased. Meteorological data (temperature, rainfall and atmospheric humidity, etc.) of the past at least three decades collected from various sources was subjected to trend analysis and correlated with several phenological and other structural and functional datasets of forest ecosystems collected under the project. Standard statistical tests was employed to discern the CC impact on various parameters of forest ecosystem responses.

Water relation studies

- Soil water potential was measured once on each sampling date. Soil samples were collected from 10 and 60 cm depth at six representative locations in each site.

- Twig water potential of seedling/sapling/trees was measured (pre-dawn and mid-day) during the pre-monsoon drought period and early winters to assess the influence of water potential (which can reach lethal levels) in influencing shoot die back and other plant physiological parameters. Twig water potential (ψ) was measured with a pressure chamber (PMS Instrument Co. model 1000, range 70 bars) following (Tewari, 1999, Zobel et al. 2001).
- Osmotic adjustment potential of different sized individuals of timberline species was estimated by developing p-v curve to assess the survival potential of species and their upward /downward shifts. From PV curves, the osmotic potential at full turgor, the osmotic potential at zero turgor was identified.
- Measurements of leaf resistances and estimates of transpiration rates for timberline species are rare. The strong dependence on water balance is essential as drought effect may impact growth, leaf conductance and photosynthesis. Measurements were made repeatedly, using Licor –portable photosynthesis system. Data were collected from 05 leaves/ individual on the sunny sides of tree and from approximately similar height monthly, in the morning and afternoon (11 A.M & 2 P.M) following Tewari (1998).
- Visual assessment of leaf and shoot damage particularly during spring after winters.
- Tree Girth, Wood Density and Specific leaf mass (SLM) The girth measurements of 10 individuals of different size on each site were measured at different seasons following Reich and Borchert (1984). Specific leaf mass (SLM) was estimated in five leaves from three branches of 10 marked individuals in each sites following Poudyal (2014).

Tree Ring Width Chronology

- *Tree-ring sampling, cross-dating, and standardization:* Following standard methods suggested by Fritts (1976), increment cores were collected using tree ring increment borers (preferably of Haglof make) along the altitudinal gradient at least three representative sites in timerline zone of three Himalayan states so as to make samples highly representative for the study area. The cores were collected from base and at breast height (1.3m) from tree of the each identified species. Tree-ring widths were measured to an accuracy of 0.01 mm using a LINTAB measuring system (Rinntech, Heidelberg, Germany); locally missing rings / false rings was given a value of zero.
- *Chronology development and analysis of tree growth characteristics:* The tree-ring width series of each individual tree was transformed to a dimensionless time series. The two-thirds/cubic spline approach was used for standardization of chronologies to remove growth trends related to the geometry of adding radial increments (Cook and Peters 1981). The resulting time series of each site was averaged into site standard chronologies. Several descriptive statistics, including mean series inter-correlation (R_{BAR}) and expressed population signal (EPS) was used to qualify the site chronologies within a common interval. Principal component analysis (PCA) was conducted using

chronologies for all sites to identify the extent of common growth variation through time.

- *Determination of climate–tree-growth relationships:* To determine the climate–tree-growth relationships, correlations with bootstrapped confidence intervals (Biondi and Waikul 2004) were calculated between the nine site chronologies (three from each states) and their PC1 (as predictands), and monthly climate data (as predictors) obtained from the station time-series data/ gridded data (source: TRMM/ CRU). Since in Himalaya station data for long term meteorological records are very few and scanty, therefore, in the absence of station data monthly gridded climate data obtained from the CRU TS 3.0 (climatic research unit, time-series data sets, version 3.0) at 0.5^0 spatial resolution (Mitchell and Jones, 2005) or data from Tropical Rainfall Measuring Mission (TRMM) was used. In such a case, an average of climate data sets from nearest CRU/TRMM grids were used to represent the regional monthly mean temperature and monthly sums of precipitation. Partial correlation was used to measure the linear relationship between two variables, such as tree-ring widths and pre-monsoon precipitation. The tree ring chronologies developed was compared for three different climate regimes represented by J&K, Uttarakhand and Sikkim. Further, to assess climate-growth relationships, standard correlation function (CF) analysis was applied (Fritts, 1976); the statistical significance and stability of the CFs was evaluated with a bootstarp procedure.

Snow Removal Experiment

- *Species diversity pattern:* Functional diversity of extant vascular plants considering volume, shape and boundaries via joint consideration of six traits that together captured the essence of plant form and function was assessed. Recently developed techniques such as thermal imaging of mountain slopes and miniature data loggers was used for precise measurements of both surface and soil temperatures, which provide an opportunity to compare species thermal preferences based on the indicator values with actual micro-habitat conditions in alpine terrain.
- *Biomass, Production, nutrient cycling and Carbon sequestration:* Various methods were followed for biomass and production (viz. Singh et al. 1975, Sala et al. 2001, Boeck et al. 2008, Guo 2007), nutrient cycling (Debeux et al. 2007, Nitschke et al. 2014, Ying-Zi 2013) and carbon sequestration (Ponce-Hernandez et al. 2004, Lal, 2004, 2005, 2013).
- *Study on Phenological patterns:* The phonological studies were conducted based on the well established studies (Molau et al. 2005, Lambert et al. 2010, Smith et al. 2012, Kimball et al. 2014), as well as traditional methods.
- In addition, a specific snow-removal experiment has been designed to see the Impact of the changes in snow-melt water on ecosystem of timberline assemblage

Livelihood Interventions

- Participatory Rural Appraisal (PRA) was performed for taking inputs from the community in regard to the condition of their natural resources, especially forests and grasslands, NTFPS, dependence over natural resources, and their views regarding the manner in which training were conducted.
- Willingness to participate and adopting the appropriate livelihoods options for further replication was the basic criteria for the selection villages/other stakeholder groups. Onsite (village-level) workshops were conducted to make public aware about the resources and possible repercussions of climate change on these resources.
- Various rounds of consultations were organized with the village communities to form a base for activities in VPs areas. Village level institutions were strengthened for effective management of natural resources and establishing livelihood activities.
- As an entry point activities and for trust building with the communities livelihood intervention based on natural resources and local needs were demonstrated with focus bamboo based activities and integrated activities on agriculture, forest resources and livestock considering the gender issues.
- The identified forest types were mapped jointly by scientists and community members using a mobile GIS system. For this, the entire boundary of the forest type was visited and coordinates marked at all canopy openings.
- The entire field exercise comprising the collection of data necessary for carbon estimation was done in collaboration with community who were trained on forest survey techniques.

3.4 Primary Data Collected (max 500 words)
As mentioned above.

3.5 Details of Field Survey arranged (max 500 words)
As per the methodology and mentioned in detailed reports (See Annexure).

3.6 Strategic Planning for each Activities (max. 1000 words)
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, tree ring width chronology, climatology, ecology, and community livelihoods. The 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 Paleobotany, Lucknow, and Central Himalayan Environment Association, Nainital. Several brain storming workshops along with field visits were conducted to workout methods, time schedule, 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 to interdependence in studies. For example, to find out the impact of pre-monsoon drought on treeline ecosystems we measure and analyzed 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.

3.7 Activity wise Time frame followed [using Gantt/ PERT Chart (max. 1000 words)]

Objectives/Activities	Years/Quarters															
	Year-I				Year-II				Year-III				Year-IV			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Objective – I: ***To characterize and map timberline zone in the IHR using satellite and ground based observations including smart phone applications***																
Recruitment of project staff / Procurement of field / lab. Items, including satellite data	■	■	■													
Timberline Mapping of Five States & Ground truthing				■	■	■	■	■	■	■	■	■	■	■		
Workshop & Training				■						■						
Software Development & Testing			■	■	■	■	■	■	■	■	■					
State wise Map Printing												■	■	■	■	■
Launch of Application Software										■	■					
Data compilation, synthesis and integration with other components									■	■	■	■	■	■	■	■
Reports (Annual/FTR)				■				■				■				■
Objective – II: ***To determine the temperature lapse rate (TLR) and pattern of precipitation along altitudinal gradients in different precipitation regimes across the IHR***																
Recruitment of project staff / Procurement of field / lab. Items, complilation of secondary data	■	■														
Selection of sites for met stations and installation		■	■													
Data generation from field sites and quality control, processing of the data				■	■	■	■	■	■	■	■	■	■	■		
Data analysis for micro/ meso-scale temperature and precipitation variability						■	■	■	■	■	■	■	■	■	■	
Estimation of TLR and precipitation gradient													■	■	■	■
Report (Annual/FTR)				■				■				■				■

Objective – III: ***To study plant diversity, community structure, tree diameter changes and natural recruitment pattern along the three principal sites in the IHR***																
Recruitment of project staff / Procurement of field / lab. Items																
Standardization of field sampling approach																
Establishment of altitudinal transects along with study plots																
Sampling for timberline ecotones structure/composition																
Floristic surveys along elevation gradient																
Vegetation community structures along altitude gradient																
Study of recruitment and establishment of plots for study of key plant species in timberline ecotone																
*Ecophysiology of key plant species in timberline ecotone																
Synthesis of taxonomic, functional and phylogenetic dimensions along the elevation gradient and response of species to climate change																
Preparation & organization of national workshop																
Workshop proceedings & policy/programme briefs																
Reports (Annual/FTR)																
** Site specific study – J&K*																
Objective – IV: ***To understand tree phenological responses, nutrient conservation strategies and tree-water relations in response to warming climate***																
Recruitment of project staff / Procurement of field / lab. items																

Selection of sites / species for detailed field work																
Marking of trees of selected species and recoding of phenophases																
Data collection on pheono-phases, leaf characters of selected species																
Micro-climatic data collection during field work																
Collection of leaves for nitrogen analysis																
Laboratory investigation on leaf area and leaf mass and nitrogen																
Soil & plant water potential measurements																
Monitoring leaf conductance/ Photosynthesis rate and relating it with drought stress																
Measurements of leaf resistances and Rate of transpiration																
Measuring tree girth, wood density and specific leaf mass (SLM)																
Data compilation, syntheses, integration with climatic data																
Report writing (annual & FTR)																
Objective – V: ***To study relationship between tree ring growth and past climatic changes in different climate regime across IHR***																
Recruitment of project staff / Procurement of field / lab. Items																
Literature review, selection of site and tree species																
Collection of increment cores from J&K, UK and SK																
Laboratory analysis, cross-dating, and standardization of cores and preparation of results																

Collection of increment cores Comparison of chronologies from all sites of three states, Modeling the climate–tree-growth relationships for three sites																
Report writing (Annual & FTR)																
Objective – VI: ***To understand the impact of depletion of snow-melt water on growth of tree seedlings, grassland species composition and selected functional processes***																
Recruitment of project staff / Procurement of field / lab. Items																
Selection of sites and reconnaissance survey																
Assessment of species diversity patterns																
Assessment & Monitoring of Biomass, Production, nutrient cycling and Carbon sequestration																
Phenological studies																
Experimentation on snowmelt water																
Data compilation, synthesis and establishing patterns																
Report writing (Annual & FTR)																
Objective – VII: ***To promote participatory action research (Citizen Science) on innovative interventions to improve livelihoods, women participation in conservation and management of timberline resources***																
Recruitment of project staff / Procurement of field / lab. Items																
Selection of villages/stakeholder groups and needs assessment																
Dependence assessment and potential resource documentation																
Field level workshops and consultations																
Development of stakeholder oriented learning and																

interpretation modules																
Needs assessment based livelihood improvement interventions (pilots only)																
Awareness creation events and promotion of citizen science based activities																
Analysis and synthesis of results/data																
Report writing (Annual & FTR)																
Project Management Unit (PMU)																
PMU made functional (space, staff, & necessary procurements)																
Disbursement of annual budget to each partner																
Inception workshop –IW (harmonization of approaches for sampling, synthesis and reporting)																
Development of standard formats/protocols based on IW																
Repository of global literature on subject																
Annual reviews (partners' synergy building and review meetings)																
Mid-term review and evaluation workshop (Expert evaluation of progress in each component and corrective measure)																
Liaison with partners and NMHS PMU																
Policy papers/Synthesis documents/approach papers etc																
Result dissemination and impact assessment (each component)																
Establishing national & global linkages for long-term sustainability																

Reports (Annual and FTR)																

4 KEY FINDINGS AND RESULTS

4.1 Major Research Findings (max. 1000 words)

Here we have made an attempt to find out how linkages between different study components help improving our understanding of the Himalayan Timberline (Figure 1). The study sheds light on treeline responses to climatic warming in terms of treeline shift, timberline dimension and timberline forms. The timberlines in outer ranges around mountain summits occur like circular or semi-circular island (ITL). They are short strips often less than 10 km. In contrast, the timberlines in inner areas, parallel to permanent snowline are seemingly unbroken **hundreds of kilometers long (CTL) across the Himalayan Arc**. The two timberline types, differ in temperature and precipitation and responses to climate change. Traversing the high mountains in a zigzag fashion CTL generally are 6-8 km long per/1 km crow flight distance. Along their hundreds of kilometers length, the timberline shows an upward shift between only 5-11% portions of the timberline lengths across the Indian Himalayan regions/states (from Kashmir to Sikkim), but that amounts to 120-319 km. So, generally the Himalayan timberlines are stationary, but they are advancing upslope in some parts at the decadal rates between 26 m and 50 m during last 38 years. Since, the timberline sites have warmed rapidly, the 'arrested' timberline ecosystem are subject to higher temperatures and precipitation changes. At Tungnath site the growing season mean temperature was about 3°C higher than that of climatic treelines. Its consequences could be tree densification, increased biomass, depleted soil organic matter and effect of increased evapotranspiration loss among the others.

4.2 Key Results (max 1000 words in bullets covering all activities)

- Our research raises several new questions pertaining to treeline water stress. The **tree water relation** data indicate that tree are not water stressed, the predawn Ψ always remaining above -1MPa. Compared to this, in mountain forest ecosystems predawn Ψ frequently goes down below-1MPa, particularly during pre-monsoon months (March to June beginning). In contrast, dendrochronological studies based on tree ring growth of hundreds of years indicate that pre-monsoon drought frequently suppressed tree growth and could become severe enough to cause tree mortality. The study on treeline water relation raises two more questions. It is intriguing that in treelines, monsoon (July- September) is the time when both tree water potential and daily change in the tree potential are the highest. This contrasts with forest tree species of the Himalayas in which during monsoon months the tree water potential is the highest, but the daily change in tree Ψ is negligible. In treeline the large daily change in Ψ during monsoon could be because the trees are shallow rooted, soil remains cool in early hours of the day causing drop in water potential or stomal control of trees is weak. In certain cases, the leaf conductance exceeds the rate 1000 m

Mol m^{-2} sec^{-1} which is far more than forest trees in general attain in the Himalaya. How common is the exceptionally high rate of leaf water conductance, and what is its significance call for investigation? In a nutshell, this study shows that the research on tree water relations should be extended to more sites and tree species, as tree water relations is a relevant research field for understanding treeline dynamics in the Himalayas where droughts frequently occur.

- Along the Himalayan Arc, from about 70° to 100°E longitude and more, we estimated the presence of **58 tree species which is quite impressive**, given that globally treelines are likely to have about 150 tree species. The species richness increases eastward, and Hengduan mountains are the areas of species diversification. Birch (*Betula utilis*) which is largely western Himalayan species could be vulnerable to climate change in areas which are warming rapidly and losing moisture. While the upward species shift under the influence of climate warming is important, horizontal species shift of treeline species along the Himalayan Arc is relevant to species survival, and community dynamics.
- While measuring **temperature lapse rate** (TLR) along the elevational gradients, we were struck by marked spatial and seasonal differences in it. The sudden drop of TLR from autumn to December warrants further investigations. More importantly, how this drop in TLR affects vegetation and individual species is even hardly perceived. Are treeline species requiring chilling are on way out because of a warming December? This may influence the pattern of species richness along the elevational gradients which is still not adequately understood.
- The elevation at which **species richness peaks and the pattern of species richness** in relation to elevation vary considerably across the Himalayan Arc, and taxonomical and functional groups of plants. That Sikkim has fewer forest herbs than Kashmir is contrary to the existing understandings, hence needs to be verified by more sampling. Up to a considerable elevation, Himalayan forests can realize large biomass values (as indicated by the tree basal area exceeding 50 m^2 ha^{-1}, up to 2800-3000 m), confirms that they are closer to tropical forests than temperate forests in attributes. We need to examine what makes a region rich in lichens? How important are lichens and mosses of treelines for wild mammals? The increase in endemism with elevation signifies the conservation importance of treeline and adjoining ecosystems.
- The project has generated important phenological information on bud break, leaf expansion, leaf senescence, and nutrient resorption, which could be used to monitor climate change effect on them. How trees widely varying in physiognomy coexist in the harsh treeline environment warrants detailed investigations. Almost each treeline site has a conifer with a densely packed leaves of several years of lifespan on a thick twig (e.g., *Abies spectabilis*), a deciduous broad leaf species with sparse leaves on thin twigs (e.g., *Betula utilis*) and large leaved small tree species of varying longevities around a year or so (e.g., *Rhododendron campanulatum*). How they are likely to be affected by warming, snow depletion and progression of lower elevation species? The mild winters of Himalayas have contributed to the presence of high treelines in the region. The global

warming seems to further reduce the 'bite of winters', leading to increase in lower elevation taxa in the treeline environment of the Himalayas. Himalayas might have more forest cover with a greater capacity to store carbon in biomass as a result of climate warming. However, such a change may accelerate warming by decreasing albedo. Tree growth may be combined by the greening of subnival areas, getting released by glacier melt to reduce albedo. The global warming and resultant depletion of snow might increase species richness and productivity in meadows, but we have little idea of the long term consequences of the loss of snow loss.

4.3 Conclusion of the study (maximum 500 words in bullets)

- By its very nature "treelines under the influence of Climate Change (CC)" is an area of long-term research and management. There is a need to recognize **Himalayan treeline as a separate entity of conservation and management.** While glaciers, because of climate change might melt out and disappear from several areas, treelines are likely to stay in many areas, advance upslope only partially and get modified variously. Then, the changes in treeline ecosystems may themselves affect the course of climate change through regional change in albedo and carbon stock. In contrast to glaciers, treelines are not a captive of climate change, it too can affect climate change.
- The present project has developed a massive infrastructure for treeline research in terms of expertise, establishment of permanent transects and plots for monitoring changes, and data to build on further studies. By using these infrastructures the various national missions focused on Himalayas can cost effectively support further treeline research cost effectively.

There is a **need to create a treeline ecotone authority** for its conservation and management, particularly to **promote cooperation among the Himalayan countries and Indian Himalayan states**. The universities could join hands to run courses on Himalayan treeline based on the various publications of the project, which include a manual for methods, a book on '*Interpreting Himalayan Treeline in a Changing World*', apart from many research papers. A beginning could be made with creating an online course. An institute like GB Pant National Institute could expand its mandate by including treeline research and awareness for conservation. This particular institute has expertise in plant and microbe diversity, and its presence in different parts of the Indian Himalayan Region. There is a need to take a macroecological approach involving several representative sites and effective monitoring.

5 OVERALL ACHIEVEMENTS

5.1 Achievement on Project Objectives [Defining contribution of deliverables in overall Mission (max. 1000 words)]

Timberline Mapping: In Himalayas two types of timberlines are distinguishable: (i) those which are located in outer ranges around mountain summits (ITL) are far shorter than (ii) those occurring in inner ranges (CTL) which are longer and higher.

- ITL sites are warmer, liable to more increase in temperature for a given elevation than CTL sites, hence more responsive to climate change in terms of upward shift of species.
- Upward shift is related to temperature, as sites showing upward shifts were already warmer and showed a greater increase in temperature than sites not showing upward timberline shift.
- In Sikkim, rainfall has increased between 1977 and 2015, but more in ITL than CTL, which will result in a greater difference in tree species composition with time between the two timberline types.

Temperature Lapse Rate: across much of the Himalaya under the influence of the monsoon, TLR_{min} is low at around -0.5°C/100 m elevation; however, in arid regions it sharply increases (more negative) and generally exceeds -0.6°C/100 m elevation. TLR fluctuates seasonally and on daily basis (Fig. 7.2) indicating highly turbulent condition along an elevation gradient. This atmospheric turbulence might have increased because of global climate change. TLR is useful to understand treeline/timberline formation and dynamics. There is a need to investigate the effect of seasonal differences in TLR on vegetation distribution and plant and ecosystem processes. Elevation dependent warming is likely to further increase under the influence of global climate change, which may threaten the survival of species growing close to mountain summits. In fact, it could drastically alter the composition of alpine ecosystems, particularly the carbon dynamics and carbon stock.

Vegetation Sampling: Though Himalayan region is rich in forest type, floristically it is less woody than the planet on a whole, possibly because of several glaciations it passed through in the geological past. Changes in species diversity in Himalaya are impressive both along the elevation gradients leading to treelines and along the west-to-east Himalayan Arc. Elevation at which species diversity peaks varies from one growth form to another and region to region. Tree species richness peaks well below the treeline elevation, while herb diversity tends to peak at or around treeline elevation. Woody species diversity increases dramatically from the west (e.g., Kashmir) to east (e.g., Sikkim), while herb species richness follows an opposite pattern. Many more representative sites are required to be investigated to capture the heterogeneity in the vegetation characters in Himalaya.

Phenology: Himalayan treeline is characterized by the presence of diverse growth forms: broadleaved deciduous, broadleaved deciduous, broadleaved evergreen, and multi-year evergreen conifers. The limited growth period is the key determiner of leaf phenology of treeline species. To maximize growth within a short period leaf recruitment and leaf expansion are slow but with a considerable overlap in the ranges with mid-elevation tree species. Higher compactness of canopy, more taper in tree stems and stuntedness differentiate treeline species from those of mid-elevation species.

Tree Water Relations: Our study of tree water relations in the treeline shows that the treeline species (TLS) are characterized by: predawn water potential above -1 MPa, strikingly high daily change in water potential during the monsoon months, and high leaf conductivity (all in comparison to lower elevation

Himalayan species). However, even mild water stress may limit growth during summer (pre-monsoon) by restricting leaf expansion as leaves are not fully developed.

Tree Ring Width Chronology: Contrary to the inference of tree water relation investigations that the treeline is not water stressed, tree ring width study indicates that water stress during pre-monsoon is of critical importance in the treeline, and climatic warming is likely to intensify it. Analysis based on tree ring counting sheds light on changes in populations over time. Studies on population structure and species regeneration can be used to shed light on the pattern of communities along the elevational gradients, and treeline shifts in a warming climate.

Snow Removal Experiment: Early snow melt due to climate warming would lead to more species richness and productivity in alpine meadows, but in the long run the effect may be different, as snow cover is needed to protect plants from severely cold air and as a source of soil moisture. The warming (OTC) treatment emphasizes that the snow cover gives the protection to plants from cold air. Because of the warm air temperature in OTCs, plants performed well with or without snow cover. However, long-term effects of snow reduction cannot be predicted from our experiments as in long run pre-monsoon droughts may intensify with persistent decrease in snow. Our experiments simply have given some clues, long term and sophisticated experiments would be required to critically access the climate change impact. Rahul, the researcher in this project has become quite familiar with snow and plant relationships, however, there is no mechanism to enable him to prolong his studies.

Livelihood Interventions: Our study showed that (i) unlike the low elevation areas of Uttarakhand and several parts of Nepal, human out migration from Tungnath is not substantial, hence day-to-day pressure on natural ecosystems, including timberline and adjacent ecosystems continues to be unabated, (ii) There is a substantial scope for improving people's livelihoods by initiating economic enterprises which are compatible with the needs of local people and local condition. Policy interventions are needed to strengthen the conservation of treeline areas by building a healthy relationship between tourism and biodiversity. In biodiversity rich areas, tourism can not be allowed to expand into a "mela form". Alternative options could be to support honey production based on *Apis cerana*, bee which forages many flowering plants during summer. This should be declared an ecosystem service and pleaded for getting payment for providing (i) organic honey; (ii) beefing up pollination by keeping the landscapes free from chemicals and saving threatened organisms; and (iii) promoting gender cause

5.2 Establishing New Database/Appending new data over the Baseline Data (max. 1500 words, in bullet points)

Mentioned In Executive Summary.

5.3 Generating Model Predictions for different variables (if any) (max 1000 words in bullets0

NA

5.4 Technological Intervention (max 1000 words)

A software based application was developed to be used in cell phone/ tablets in the field which can capture a scene (photo) and tag the attributes of its location (GPS, date, time, and altitude) and transmit to the server database while in range of mobile connectivity. These ground points were tagged to the spatial map for visualization and realizing ground situation (species, phenology) while interpreting results. This photo database will serve as baseline for future on account of spatial advancement and changes is phenological bevahior of species.

A short film was made and shared widely. Statistical Research training was another area which was used frequently to develop human resource.

5.5 On field Demonstration and Value-addition of Products (max. 1000 words, in bullet points)

Some livelihood interventions were managed in two villages (viz., Makkumath and Sari) of Chopta (Tungnath region) which dealt with off-season vegetable production, mushroom cultivation, floriculture, vermi composting, and rainwater harvesting. Among them, off-season vegetable cultivation in polyhouses was most favoured (adopted by 120 families even with little persuation), followed by mushroom cultivation. Sadly, the COVID-19 pandemic damaged our efforts to expand above interventions. What we could learn was that people in treeline connected areas are keen on using new interventions. As a direct result of these efforts, there are now a number of households which have adopted such technologies and enhanced their income significantly. Under the IHTRP, ~750 community members were trained in diverse fields, such as mushroom cultivation, bird watching, carbon sequestration measurement, bamboo craft, and poly house construction.

5.6 Promoting Entrepreneurship in IHR

NA

5.7 Developing Green Skills in IHR

NA

5.8 Addressing Cross-cutting Issues (max. 500 words, in bullet points)

Mentioned in Executive Summary and detailed reports are annexed.

6 PROJECT'S IMPACTS IN IHR

6.1 Socio-Economic Development (max. 500 words, in bullet points)

- Our study showed that (i) unlike the low elevation areas of Uttarakhand and several parts of Nepal, human out migration from Tungnath is not substantial, hence day-to-day pressure on natural ecosystems, including timberline and adjacent ecosystems continues to be unabated, (ii) There is a substantial scope for improving people's livelihoods by initiating economic enterprises which are compatible with the needs of local people and local condition.
- Policy interventions are needed to strengthen the conservation of treeline areas by building a healthy relationship between tourism and biodiversity. In biodiversity rich areas, tourism can not be allowed to expand into a "mela form".
- Alternative options could be to support honey production based on Apis cerana, bee which forages many flowering plants during summer. This should be declared an ecosystem service and pleaded for getting payment for providing (i) organic honey; (ii) beefing up pollination by keeping the landscapes free from chemicals and saving threatened organisms; and (iii) promoting gender cause.

6.2 Scientific Management of Natural Resources In IHR (max. 500 words, in bullet points)

- Notably, the treelines, being biotic systems store varied information that can help us understand climate change dynamics over time. Biotic systems could, in turn, also influence the course of climate change at a landscape level. Tree population dynamics and tree-ring growth reveal considerable information about the pattern of climate change.
- Treelines along with biotic belts of nival plants, meadow species and timberline biota make up a highly complex system with variously interconnected components, which includes some of the most attractive but threatened mammals like the snow leopard as well as rare lower plant groups like lichens growing on a leaf blade. The 'treeline ecotone complex' is a dynamic system, and understanding its intricacies and complex interactions will require taxonomists of various disciplines, ecologists who can work in remote areas, and researchers and practitioners who can address various issues ranging from tourism to glacier retreat and the thawing of permafrost.
- There is a need to recognize treeline as a separate and principal entity of conservation and management in view of the following: (i) treelines are present and apparent throughout the Himalaya, with an extraordinary length and variability in geographical position, (ii) treelines vary a lot along their lengths in their response to climate change, and (iii) have high corridor and habitat values for all forms of organisms.

6.3 Conservation of Biodiversity in IHR (max. 500 words, in bullet points)

- Treeline ecotone should be expanded to include adjoining biotic and abiotic zones. The management of treelines should be considered along with connected biotic zones namely alpine meadows and nival/subnival belts, and abiotic components such as permanent snow/glaciers and permafrost, which provide water to biotic systems.

6.4 Protection of Environment (max. 500 words, in bullet points)

- In a nutshell, treelines should be declared a separate unit of conservation and management. Research should be carried out to monitor changes that are occurring in the treeline continuum consisting of forests, alpine meadows and nival communities, apart from studies of treelines to capture inter-community exchanges, and responses across communities to climate change impacts. Transboundary cooperation and research collaboration will be crucial for developing a Himalayan perspective on treelines in a changing world.

6.5 Developing Mountain Infrastructures (max. 500 words, in bullet points)

- A policy provision is required to build upon the research infrastructure that a project like IHTRP has created. Here research infrastructure is a broad term, which includes data collection which can be continued following the methods already in place with some adjustments, instruments placed in the field, and a research scholar familiar with the sites and research methods.

6.6 Strengthening Networking in IHR (max. 700 words, in bullet points)

- Strengthen transboundary cooperation and expanded team science: Greater research networking is required to capture Himalaya-level variability in treeline dynamics and climate change impacts. This would require greater research cooperation and alignment of research purposes and approaches across borders. Team research should be expanded to include research for several Himalayan countries and shared transboundary landscapes and measures should be taken to build team science culture. A few research scholars/field assistants could be trained to collect comparable data in the different countries.

7 EXIT STRATEGY AND SUSTAINABILITY

7.1 How effectively the project findings could be utilized for the sustainable development of IHR (max. 1000 words)

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 Himalayan treelines. In this regard following observations may be of help:

i) With regard to research and management, treelines should not be considered in isolation of connected biotic namely alpine meadow and nival and abiotic systems, such as permanent snow area which 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.

ii) The question how climate change is affecting elevation-dependent warming and temperature lapse rate (TLR) calls for long term data from several representative sites.

iii) 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 which gives a coherent picture of various interconnected systems might serve the purpose of managing high landscape Himalayas.

iv) 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.

7.2 Efficient ways to replicate the outcomes of the project in other parts of IHR (Max 1000 words)

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.

7.3 Identify other important areas not covered under this study needs further attention (max 1000 words)

Currently, treeline research is providing new insights into the study of how biota respond to climate change, the relationships between tree ring growth and climate change in various seasons, the role of growth in relation to stress, seasonal variation in temperature lapse rate and the impact of elevation dependent warming, tree-water relations and water conduits in trees, effects of early snow melt, endemism and future changes. We know very little about several areas related to treeline trees, such as: leaf forms specific to treelines, wood density and bark in various tree forms.

7.4 Major recommendations for sustaining the outcome of the projects in future (500 words in bullets)

- **Treeline as a separate entity:** There is a need to recognize treeline as a separate and principal entity of conservation and management in view of the following: (i) treelines are present and apparent throughout the Himalaya, with an extraordinary length and variability in geographical position, (ii) treelines vary a lot in their response to climate change, and (iii) have high corridor and habitat values for all forms of organisms, particularly wild animals. In a warming climate, a species can migrate from lower to higher elevation as well as laterally along the Himalayan Arc. For example, *Betula utilis* may shift towards the eastern Himalaya in a drying climate.
- **Independent treeline authority:** An independent authority for treeline conservation, management and regulation (ATCMR) may be established. This system should be developed for the entire Indian Himalaya high enough to have treelines, such as in Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh.

  While developing the ATCMR, it is important to involved army personnel and establishments as partners and collaborators, given their presence and capacities. Researchers and local people could be other partners in management.

- **Treeline ecotone should be expanded to include adjoining biotic and abiotic zones:** The management of treelines should be considered along with connected biotic zones namely alpine meadows and nival/subnival belts, and abiotic components such as permanent snow/glaciers and permafrost, which provide water to biotic systems. In other words, for all management purposes the treeline should be considered as a **continuum** consisting of forests, timberline, treeline and communities of short statured plants and barren snow and ice areas, all under a state of flux due to climate change. In this continuum, physiognomic dimensions and growth forms vary a lot. However, a closer look will show that the different forms constitute a complex mosaic of small pieces of vegetation. Wild and domestic animals should also be included in this continuum. Here, for all purposes, it is also important to recognize the specific features of two types of treeline viz. island type treeline (ITL), and continuous type treeline (CTL).

8 ACKNOWLEDGEMENT

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