Herbaceous Vegetation Structure and Phenology at Treeline Ecotone in Relation to Natural Snowmelt

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Bhupendra S. Adhikari and Rahul Kumar

Abstract

This study aims to find out the impact of early natural snowmelt on diversity, composition and phenology of herbaceous vegetation of treeline ecotone (3200–3300 m asl) at Tungnath, Uttarakhand Himalaya. Based on orography, four sites were selected across the treeline ecotone and within each site, two microsites based on snowmelt timing were identified. Across the sites, 86 species were recorded at and around treeline ecotone, 90% were perennial forbs, 84% were hemicryptophytes and 70% were native. Both herb species richness and species diversity were higher in exposed microsites. The total plant density ranged between 82 and 626 individuals m^{-2} in exposed and 69–288 individuals m^{-2} in unexposed microsites showing that a warming climate might favour an increase in richness and diversity. The early phenophase was noticed in the majority of species in exposed than at unexposed microsites. The timing of different phenophases varied among the sites. Comparing this study with previous studies either in the same or similar study areas based on 13 common species indicates that timing and duration of vegetative and flowering phenophase have advanced and lengthened, while fruiting and seed maturation have shortened presumably because of the increase in mean minimum temperature. This indicates that species might adopt different adaptations to a warming climate.

B. S. Adhikari (✉) · R. Kumar
Department of Habitat Ecology, Wildlife Institute of India, Dehradun, Uttarakhand, India
e-mail: adhikaribs@wii.gov.in

17.1 Introduction

The high mountain ecosystems are under tremendous pressure at present because of habitat destruction, landscape modification and loss in biodiversity (Korner 2003; Bruun et al. 2006) and are under the threat of climate change (Beniston 2003; Pauli et al. 2012). Some of the major consequences of climate warming are early snowmelt, increase in soluble N deposition in high mountain habitats, limitation of plant growth and diversity in terrestrial ecosystems (Hättenschwiler and Körner 1997; Tørseth and Semb 1997) may restrict plant growth in alpine species (Hiltbrunner et al. 2005; Gong et al. 2015). 'Alpine' is commonly used in a broad sense for the treeless areas above a low-temperature determined treeline in the high reaches of mountains, characterized by low temperature, precipitation in form of scanty rainfall, blizzard and snowstorms, high wind velocity and high intensity of ultraviolet (UV) radiation (Nautiyal et al. 2004). A treeline ecotone is a transition zone between a closed canopy upright forest (timberline) and low growing primarily herbaceous alpine. The treeline zone, elevational limit of a tree, is often controlled by temperature. This limit is directly affected by drastic drop in allocation of energy gained via photosynthesis (Körner 1998) and is modulated by several factors such as seasonal snowpack duration, winds, precipitation, soil and high intensity of UV radiation (Nautiyal et al. 2004). Due to the extreme climate, plants adapt to these conditions and in general are dwarfed, stunted, woolly or spiny, and develop a mosaic patch of different life forms (Walker et al. 1994). The community structure and composition show that seasonal fluctuations are strongly influenced by the extent to which periodic phenomena in the individuals are adjusted to each other (Kershaw 1973). The resulting hypothesis is that as the climate warms, trees will move up the slope towards higher reaches. Several studies have shown such geographic responses (Lloyd and Fastie 2002).

Snow is an important environmental factor controlling micro-climate and plant growth (Wipf 2010) and acts as an insulator during the cold season, protecting the plants and soil underneath (Sturm et al. 1997). The increase in soil moisture at the initial stage of the vegetative period due to early snowmelt changes the community composition, species richness and the occurrence patterns of individual species (Korner 2003; le Roux et al. 2013). Snow duration and extent determine the beginning and length of the growing period, and meltwater provides water and nutrients that are crucial for plant growth (Jones et al. 2001). To upland ecosystems, snowmelt timing, depth and duration of the snow cover are of special importance as they define the start and duration of the potential growing season (Inouye and Wielgolaski 2003), the temperatures under the snow (Pomeroy and Brun 2001) and characteristics of alpine plant communities (Korner 2003).

In alpine and arctic systems, plant communities' occurrence is closely associated with spatial snow distribution patterns (Odland and Munkejord 2008), showing the importance of snow depth and snowmelt with season length in structuring communities as changes in the snow cover can have a wide range of species-specific effects on alpine tundra plants (Wipf et al. 2009). Several workers (Campbell et al. 2005; Sturm et al. 2005) suggested that the snowmelt controls the

biochemical, microbial and plant processes during winters, which persisted well into the growing season (Weih and Karlsson 2002). An early snowmelt results in the longer growing season and higher growing degree days, but it also increases frost damage (subzero temperature), earlier dehardening resulting in higher frost sensitivity (Inouye 2000; Gorsuch and Oberbauer 2002).

The changing climate has been affecting high altitude plant communities (Wipf and Rixen 2010) and plant phenology (Smith et al. 2012), which can potentially impact ecosystem services they provide (Winkler et al. 2018) and the range-restricted species (Parmesan 2006), particularly in polar and higher elevation (alpine) regions. The other drivers of change, such as extreme events, drought and forest fires, and anthropogenic disturbance have further intensified impact on the structural and functional attributes of alpine vegetation communities that harbours large number of high-value medicinal, aromatic and threatened plants (Xu et al. 2009; Singh et al. 2011). Therefore, alpine plants are sensitive to climate change and are considered as good indicators for understanding its impacts (Pauli et al. 2007) as compared to other ecosystems (Malik and Nautiyal 2016).

In the Himalayan region, the studies related to assessing the ecological impacts of winter precipitation (snowmelt) on alpine plant communities are very limited (Adhikari et al. 2018). Therefore, considering the gap, in this study we analyse the impact of snowmelt water and snow cover on phenology and structural and functional attributes of herbaceous plant communities at treeline ecotone.
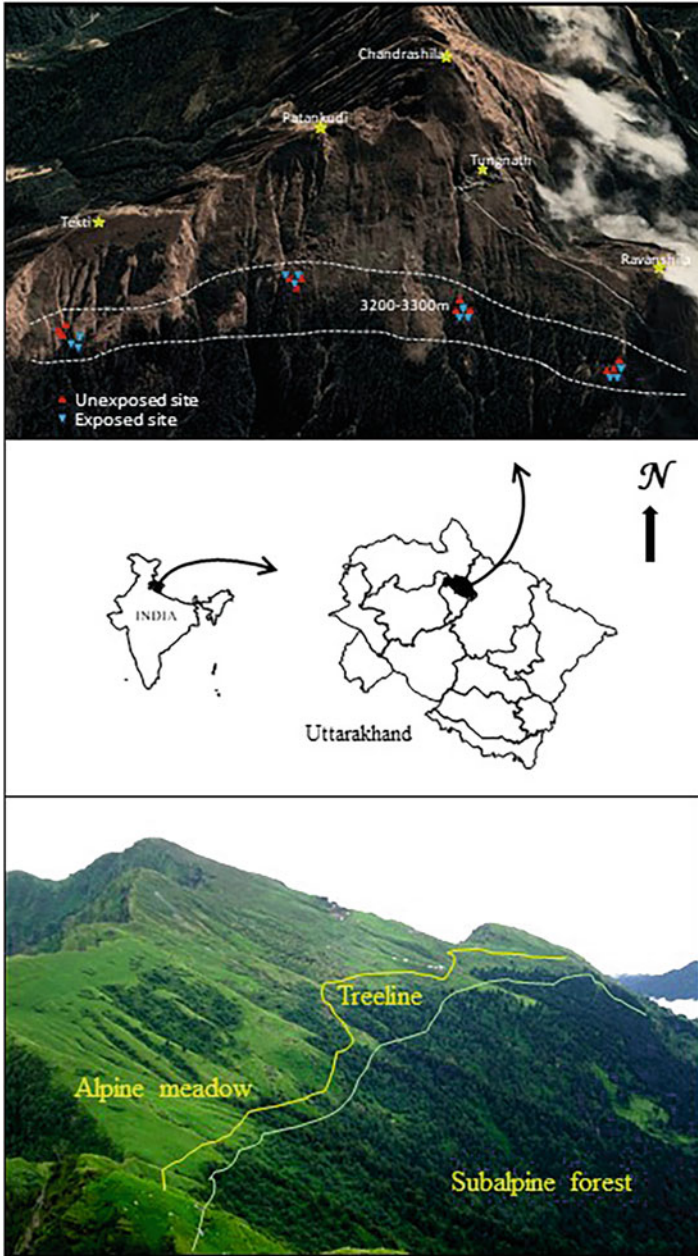
17.2   Study Area

This study was conducted in Tungnath which lies in the upper catchment of Alaknanda (one of the two tributaries of river Ganga) and Mandakini rivers of Uttarakhand, India (Fig. 17.1). Alpine meadow communities consisting of forbs, grasses and sedges occur in Tungnath region along with *Rhododendron campanulatum* krummholz. A year is divisible into four seasons, viz. short summer (May to June), monsoon (July to mid–September), autumn (mid-September to October) and long winter (November–April). The period with snow cover is of about 4–5 months (December–April) and snowmelts during April–May between 3200 and 3300 m asl. The snowfall is staggered in the study region and area to become inaccessible.

17.3   Methods

17.3.1 Study Design

Treeline ecotone at Tungnath region (Photographs 17.1 and 17.2) is almost 2 km long lying between 3200 and 3300 m asl predominated by *Abies spectabilis* and *Quercus semecarpifolia* forests along with *Rhododendron* krummholz. Four summits namely Ravanshila, Chandrashila, Patankudi and Jhabra were selected based on the orographic lift for the natural snowmelt experiment (Table 17.1).

Fig. 17.1 Location of plots in exposed area (blue) and in depressed area (red) and study area in Tungnath region, Garhwal Himalaya

Photograph 17.1   Data collection from treeline ecotone region, Western Himalaya

Photograph 17.2   Treeline Ecotone region in Tungnath, Western Himalaya

Table 17.1 Characteristics of selected sites in treeline ecotone (3200–3300 m) in Tungnath region. CC: Canopy cover

Parameters	Ravanshilla	Chandrashilla	Patankuri	Jhabra
Site characters	Wide open edge with few scattered trees	Open slope with trees	Depressed slope with trees	Depressed slope with trees
Dominant species (canopy cover)	*Abies spectabilis* (7%) and *Rhododendroncampanulatum* (20%)	*Abies spectabilis* (15%) and *R. campanulatum*(35%)	*Quercus semecarpifolia* and *Abies spectabilis* (20%) and *R. campanulatum* (60%)	*R. arboreum* and *Quercus semecarpifolia* (15%) and *R. Campanulatum* (40%)
Slope (°)	35–40	30–35	40–55	35–45
Aspect	North	North-west	North-west	North-west
Soil moisture (0–20 cm; July)	48% ± 2.4%	45% ± 2.1%	45% ± 3.1%	46.5% ± 2.5%
Rock cover (%)	25	35	55	30
Wind velocity	Very high	High	Low	Low
Snow depth (m)	0.6–0.9	0.8–0.9	1.0–1.2	0.8–1.0
Snow melt	Very fast	Fast	Slow	Medium
Snow duration (days)	Exposed: 47.3 ± 1.4 Unexposed: 58.0 ± 1.5	Exposed: 58.7 ± 3.2 unexposed: 67.7 ± 1.4	Exposed: 74.7 ± 2.9 Unexposed: 79.0 ± 3.0	Exposed: 57.7 ± 1.4 Unexposed: 74.7 ± 2.9

These summits were further divided into two major snow cover regions (high snow cover: hereafter referred to as HSC and snow depth 1.0–1.5 m during January comprised of Patankudi and Jhabra summits and low snow cover: hereafter referred to as LSC and snow depth 0.6–1.0 m during January comprised of Ravanshila and Chandrashila summits). At each site, a plot (50x50m) was selected at the base of summits between 3200 and 3300 m asl. Within the selected plot two different microsites (namely, Exposed microsite: hereafter referred to as EX with canopy cover <20% and Unexposed microsite: hereafter referred to as UX with >20% canopy cover) were identified based on snowmelt timing. The UX microsites had higher snow deposition due to snowdrift and longer snow stay period due to *krummholz* cover resulting in late snowmelt (delayed 4–14 days). Within each microsite, 3 random quadrats (1x1m each) were permanently laid with a distance of 10–12 m to record plant abundance, richness and diversity.

17.3.2 Lifespan

The recorded plants were categorized based on their lifespan into the following categories: annuals, plants that live for one growing season, perennials; plants that grow and bloom over spring/summer season and die every autumn/winter and grow again from their rootstock; and biennials, plants which complete life cycle in two growing season, germinate, grow and survive through winters and next year grow more, bloom and die.

17.3.3 Growth Form Categories

The direction and extent of growth and branching on the main-shoot axis or axes determine the growth form of a plant. The plants were classified following Pérez-Harguindeguy et al. (2013) under the following growth forms, viz. climber, dwarf shrub, semi-basal, short-basal, erect leafy and tussock to compare with other studies conducted in western Himalaya.

17.3.4 Life Form Categories

Following Raunkier (1934) the plants were assigned to various life-form classes, viz. phanerophyte (surviving buds or shoot apices are borne on shoots into the air), chamaephyte (surviving buds/shoot apices are borne on shoots very close to the ground), hemicryptophyte (surviving buds/shoot apices are situated on the soil surface), geophyte (surviving buds/shoot apices are below soil surface) and therophyte (complete their life cycle from seed to seed and die within a season).

17.3.5 Nativity

The place of origin/first record of the species where it occurs naturally indicates the nativity of the species (Anonymous 1883–1970), while the introduction of the species in an area happened through anthropogenic activities and has not previously occurred in that area are known as 'Non-Native'. We used Index Kewensis Plantarum Phanerogamarum (Anonymous 1883–1970) to know the nativity of a species.

17.3.6 Species Richness, Diversity and Evenness

Species richness was taken as a count of the total number of species in a particular area. The diversity was calculated after Shannon and Wiener (1949). If Pi is the proportion of individuals (from the sample total) of species i, then diversity (H′) is

$$H' = - \sum_{i=1}^{s} (Pi)(\mathrm{lnPi})$$

where P is the proportion (n/N) of individuals of one particular species found (n) to the total number of individuals found (N), ln is natural log and s is the number of species.

Evenness index was calculated using Pielou (1975).

$$Ep = \frac{H'}{H' \max}$$

where H' is Shannon & Wiener diversity index, $H' \max = \ln S$, is the natural log of S.

Sorenson Similarity Index (Is) between different sites was calculated following Sorensen (1948).

$$Is = \frac{2C}{A + B} \times 100$$

where Is the Sorenson Index of Similarity; C, the common species to both comparable sites; A, the total number of species in site A; and B, the total number of species in site B.

17.3.7 Simper

The contribution of each species to the dissimilarity (%) between two groups was calculated from the Bray–Curtis dissimilarity matrix through SIMPER analysis in PAST.

17.3.8 Phenological Observations

The phenological changes were observed visually to monitor how the species respond to climate variations on a monthly interval. Therefore, records of various phenophases such as growth initiation, vegetative phase, flowering, fruiting, seed formation and senescence of each species were taken from May to October in 2017 following the Biologische Bundesanstalt Bundessortenamt und Chemische Industrie (BBCH) scale (Hess et al. 1997). The complete existence of a particular phenophase was considered if 5% of the individuals showed that phenophase within the plot. Based on growth initiation time, the plants were divided into two categories: early growth species (up to mid-May) and late growth species (mid-May to June). The phenology of each species was observed within quadrats under each category in adjacent areas with similar micro-environment within selected plots to minimize the effect of herbivory.

17.4   Results

Plant growth period (the period from the beginning of growth to the time when about 80% of plant shoots senesced) was 6 months from mid-April to mid-October. Soil moisture values (45–48%) observed during the peak growing period (July) showed that it is not a limiting factor for plant growth. The number of snowfall days during winter months (December to April) in 2016–2017 was 39 days.

17.4.1 Lifespan Category, Growth Form, Growth Cycle and Life Form

Across the sites and within EX and UX areas, a total of 86 plant species were recorded, of which 90% were forbs and remaining 10% were climber (1%), shrub (3%) and grasses and sedges (6%), while 90.6% were perennials followed by annuals (8.2%) and biennials (1.2%; Table 17.2). Of the total species, 53% species were early growing (germination before July) while 47% were late growing species

Table 17.2 Per cent contribution of different growth cycle/growth forms (86 species)

Growth cycle	Total species (%)	Growth form (%)					
		Tall forbs	Med. forbs	Short forbs	Climber	Shrub	Grass & sedge
Short	5	7	–	4	100	–	–
Intermediate	31	52	15	25	–	67	–
Long	64	41	85	71	–	33	100
Total species (%)	100	34	23	33	1	3	6
Early growing (before May)	53	17	78	76	100	33	60
Late growing (after May)	47	83	22	24		67	40

(germination after June). Growth forms of the species were highest for semi basal/
short basal followed by erect leafy, dwarf shrub and climber/shrub/tussock. The
maximum species had a long growth cycle (LGC) followed by an intermediate
growth cycle (IGC) and a short growth cycle (SGC). Among various growth
forms, tall and short forbs contributed the maximum followed by medium forbs
and others (climbers, shrub/undershrub, grasses/sedges; Table 17.2). The majority of
the species recorded in this study were native to the Himalayan region (70%)
indicating a high conservation value of treeline in the Tungnath region.
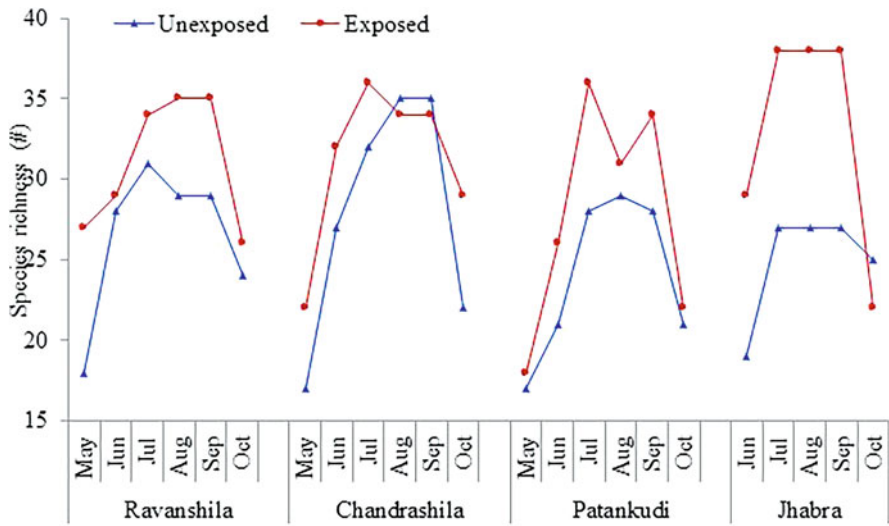
17.4.2 Species Richness and Diversity Patterns

The species richness was almost equal in EX and (74) and UX (72) microsites. In
general, it was noticed that the richness of the herbaceous species increased across
the months from May to September (44–80 species, respectively) and then declined
in October (56 species).

The species richness attained a peak between July and September (77–80 species)
and 60% of species were common to both EX and UX microsites. Generally, species
number in a month was markedly higher in EX microsite than in UX microsite,
particularly in Jhabra (EX: 38, UX: 27) in July. Two-way ANOSIM showed
significant variations in species richness between sites ($r = 0.93$) and across months
($r = 0.91$).

At EX microsites the species richness was highest in July for Chandrashila,
Patankudi and Jhabra, while in August for Ravanshila. In UX microsites, species
richness was highest in July for Ravanshila and Jhabra and in August for
Chandrashila and Patankudi (Fig. 17.2). This could be because these microsites
are dominated by krummholz, protecting species against environmental factors
prevailing in other microsites. In general, species richness was higher in EX than
UX microsites, probably due to the absence of canopy cover, ample sunlight and less
competition for resources.

The diversity values from 2.10 to 3.11 in UX microsites and 2.41 to 3.21 in EX
microsites and peaked during July for both EX and UX microsites (Fig. 17.3). The
change in diversity after July was due to the senescence of early growth cycle
species.

The evenness values ranged from 0.46 to 0.77 in UX microsites and 0.40 to 0.68
in EX microsites. The evenness values for Ravanshila, Patankudi and Jhabra sites
showed a similar distribution pattern in both EX and UX microsites, while in
Chandrashila species were much more evenly distributed in UX microsites. This
could be due to the favourable condition for growth and dominance of *Ranunculus,
Fragaria, Oxygraphis, Trachydium* and *Prunella* over other species.

Fig. 17.2 Patterns of species richness (#) across spatio-temporal scale at treeline in Tungnath region
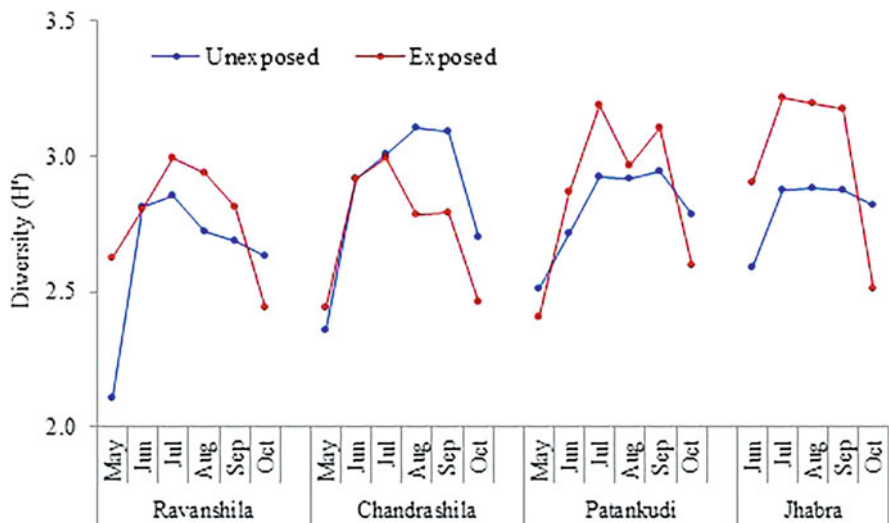
Fig. 17.3 Patterns of species diversity (H') across months in Tungnath region

17.4.3 Site and Microsite Similarity

The similarity among sites was highest between Ravanshila and Patankudi (66%) followed by Ravanshila and Chandrashila (65%), Chandrashila and Patankudi (63%), Ravanshila and Jhabra (62%) and Chandrashila and Jhabra (50%). The

Table 17.3 Similarity between months in exposed areas in upper inverted triangle and in unexposed areas in lower triangle

Months		Exposed microsites					
		May	June	July	August	September	October
Unexposed microsites	May	**100.0**	83.1	80.9	74.2	74.2	65.2
	June	81.0	**100.0**	92.6	81.5	85.2	66.7
	July	73.4	86.0	**100.0**	90.9	96.4	74.5
	August	70.9	86.0	95.4	**100.0**	91.7	71.6
	September	65.8	82.0	91.7	97.3	**100.0**	84.8
	October	63.3	62.0	66.1	68.5	81.7	**100.0**

Bold values represent the similarity for the same month

reason could be the similar number of species present in Ravanshila (45), Patankudi (46) and Jhabra (42), which is much less than the species present in Chandrashila (66). The micro-climate of Ravanshila and Patankudi is different than that of Chandrashila, which lies in between and have an admixture of micro-climate of both sites, which may lead the species to move in, hence the richness is high. Although the similarity between EX and UXmicrosites was 82% as a whole, the similarity between EX and UXmicrosites within each site was much less (Chandrashila 31%, Patankudi 34%, Ravanshila 36% and Jhabra 38%). Across months, the similarity was highest between microsites during peak growing season (July–September; Table 17.3).

SIMPER (Similarity Percentage) analysis suggested the primarily responsible taxa (species) for observed differences between groups of samples, that is, snow cover region and microsites. The overall dissimilarity between HSC and LSC region was 56.8% and the maximum contribution was generated by following species in decreasing order: *Ranunculus > Trachydium > Oxygraphis > Carex > Fragaria > Potentilla polyphylla > Prunella.* Comparing average dissimilarity between EX and UX microsites of HSC and LSC region, the average dissimilarity was 63% contributed in EX microsites by 5 species (*Ranunculus > Trachydium > Oxygraphis > Carex > Prunella*); however, in UX microsite it was 59.2% generated by 11 species (*Fragaria > Potentilla polyphylla > Ranunculus > Trachydium > Poa > Galium > Anemone > Polygonum filicaule > Polygonum vccinifolium > Carex > Lysimachia*).

Across sites the overall average dissimilarity in UX microsites was 64% between months and 72% between sites; however, in EX microsites it was 59% and 67%, respectively. Within sites, the maximum contribution to dissimilarity (up to 50%) as follows:

EX microsites: *Ranunculus > Trachydium > Carex > Oxygraphis > Fragaria > Anaphalis > Prunella > Koenigia > Anemone.*

UX microsites: *Fragaria > Ranunculus > Polygonum > Carex > Bistorta > Trachydium > Anemone > Poa > Polygonum > Circea > Potentilla.*

17.4.4 Habitat Preference of Plant Species

The species like *Bistorta amplexicaulis, Fragaria nubicola, Geranium wallichianum, Potentilla atrosanguinea* and *Viola biflora* were present in all microsites. The species specifically present in all UX microsites were *Myriactis wallichi* and *Veronica cana*, while *Anaphalis nepalensis, Kobresia, Oxygraphis polypetala, Polygonum filicaule, Potentilla lineata, Potentilla polyphylla* and *Selinum vaginatum* occurred in EX microsites. The distribution of certain species was restricted to few sites, such as *Bupleurum longicule, Rubus nepalensis, Swertia speciosa, Synotis alata, Arenaria, Euphorbia* sp. and *Taraxacum officinale* in Ravanshila; *Aster methodrus, Viburnum glanduliflorum, Swertia auriculata, Arisaema propinquim, Ligularia amplexicaulis, Halenia elliptica, Senecio graciliflorus, Trillium govanianum, Smilacina purpurea* and *Aster albescens* in Chandrashila; *Thalictrum foliolosum, Primula edgeworthii* and *Ligularia sibirica* in Patankudi and *Rumex nepalensis, Cynoglossum glochidiatum, Primula redii, Morina longifolia, Cerastium cerastoides* and *Persicaria nepalensis* in Jhabra. *Aster methodrus, Viburnum glanduliflorum, Arisaema propinquim, Ligularia amplexicaulis, Thalictrum foliolosum, Hemiphragma heterophyllum, Halenia elliptica, Trillium govanianum, Smilacina purpurea, Clematis, Parochetus communis, Galium asperifolium* and *Caltha palustris* were found in UX microsites, and *Swertia auriculata, Rumex nepalensis, Aster albescens, Cynoglossum glochidiatum, Primula redii, Ligularia sibirica, Goodyera repens, Persicaria nepalensis, Corydalis cornuta, Caltha palustris, Trachydium roylei, Gaultheria trichophylla, Gentiana argentea, Gentiana tubiflora, Gerbera gossypina* and *Morina polyphylla* in EX microsites.

17.4.5 Community Structure

In all microsites, the herbaceous communities in the initial phase were different in UX microsites. In Ravanshila and Jhabra sites, *Fragaria* and *Ranunculus* dominated the community in UX microsites, respectively and showed changes in August onwards in Ravanshila, while *Ranunculus* dominated the community throughout the growing period in Jhabra. It was interesting to note that in Chandrashila, the community changed after August, while in Patankudi the species dominance changed throughout the growing period in UX microsites. The community in Chandrashila and Jhabra was dominated by *Ranunculus* throughout the growing period in EX microsites, while *Anaphalis* dominated in Patankudi throughout the growing period, except May and August. *Ranunculus, Fragaria, Oxygraphis* and *Trachydium* dominated the vegetation in EX microsites of Ravanshila (Table 17.4).

Plant density among the sites (Chandrashila, Ravanshila and Patankudi) was more on EX microsites than on UX microsites, except Jhabra where the density values were not affected by exposure (Fig. 17.4). In moist microsites, water was not a limiting factor. In Chandrashila and Ravanshila microsites, plant density at EX

Table 17.4 Temporal changes in herbaceous community at different sites within unexposed and exposed areas. Species sequence arranged with decreasing density values

| Site	Microsite	Months					
		May	June	July	August	September	October
Ravanshila	EX	Ranunculus-Fragaria	Trachydium-Oxgraphis	Oxgraphis-Ranunculus	Ranunculus-Trachydium		
	UX	Fragaria-Ranunculus	Fragaria-Polygonum		Fragaria-Carex		
Chandrashila	EX	Ranunculus-Carex			Ranunculus-Trachydium		
	UX	Bistorta-Fragaria				Trachydium-Circaea	
Patankudi	EX	Nepeta-Caltha	Anaphalis-Polygonum		Carex-Anaphalis	Anaphalis-Carex	
	UX	Polygonum-Caltha	Bistorta-Caltha	Polygonum-Bistorta		Lysimachia-Bistorta	Bistorta-Potentilla
Jhabra	EX	–	Ranunculus-Fragaria				Ranunculus
	UX	–	Ranunculus-Poa				Ranunculus
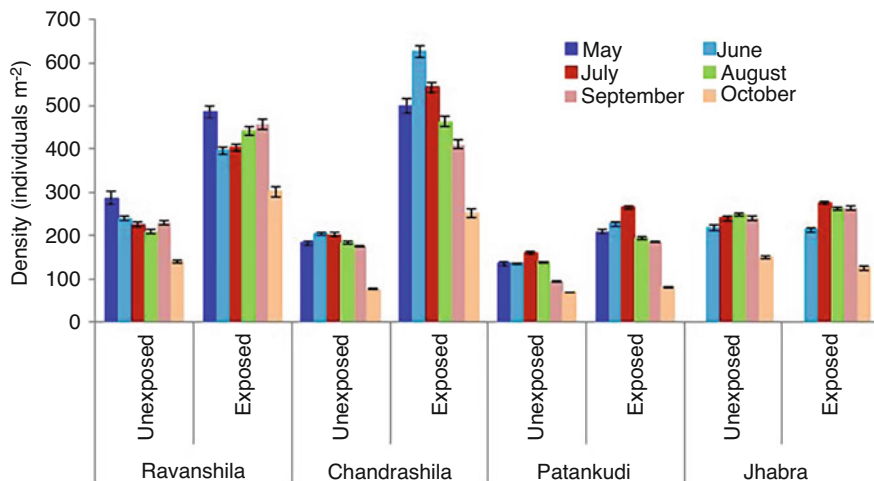
Fig. 17.4 Density (individuals m^{-2}) at different sites across the months at treeline in Tungnath region

microsites was more than twice than that on UX microsites. The snow effect was minimized because of the shadow of higher summit in Patankudi and Jhabra which resulted in faster snowmelt in Ravanshilla and Chandrashilla (45–65 days) as compared to Patankudi and Jhabra (55–80 days) for EX microsites. Plant densities generally were high initially in June–July, then declining from there with some deviations.

17.4.6   Phenological Trends across Microsites

The micro-climatic conditions, which include environmental conditions (aspect, slope, moisture, soil texture, ambient and soil temperature, rainfall etc.) and topographical features (gentle, steep, boundary/rocky) and anthropogenic factors (grazing, trampling, collection of NTFP) influenced the phenophases. The relationship between growth initiation and snowmelt was evident in several micro-sites. Growth in species was initiated immediately after the snowmelt in May. For example, immediately after snowmelt, *Anemone rivularis, Fragaria nubicola, Gentiana argentia, Lysimachia prolifera, Oxygraphis polypetala, Plantago major, Rannunculus hirtallus, Selinum vaginatum, Trachydium roylei* and *Gaultheria trichophylla* were observed in flowering, while *Arenaria, Caltha palustris, Carex setosa, Nepeta govaniana, Polygonum filicaule, Potentilla polyphylla, Primula denticulata, Trachydium roylei* and *Plantago himalaica* were in bud development phase. The timing of different phenophases varied among microsites and it was quite similar between Ravanshila and Chandrashila and between Patankudi and Jhabra, while more variability in phenophases was observed in extreme sites, that is, Ravanshila and Jhabra.
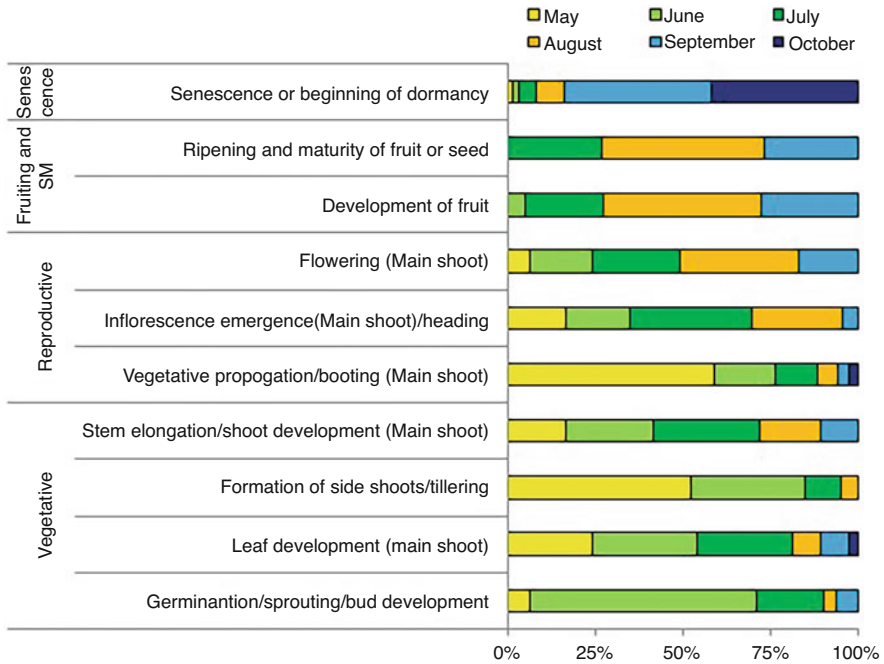
Fig. 17.5 Phenophases of species at temporal scale as per BBCH scale

In the early growing season (May–June) only vegetative and reproductive phenophases were observed in all the microsites, all phenophases were recorded from the mid-growing season (July–September; Fig. 17.5). *Goodyera ripens* germinated in EX microsites only during August and *Epilobiumroylei* showed vegetative reproduction in UXmicrosites in September only. Fruiting started in June (*Trachydium roylei* and *Plantago himalaica*) in EX microsites and in UX microsites it started in July and last till September.

Oxygraphis polypetala and *Ranunculus hirtelus* showed dual reproductive phenophase in months of May–June and August–September in both EX and UX microsites, while *Fragaria nubicola* showed dual reproductive phase in the month of June and August in EX microsite only. Of the total 86 species, only 23 species (26.7%) showed fruit and seed maturation phases. The absence of fruiting and seeding phenophase in most of the species (73.3%) at both EX and UX microsites and the abovementioned species in UX microsites may be due to an increase in mean minimum temperature in Tungnath region, which favours longer vegetative and reproductive phenophase.

17.5 Discussion

The precursor to initial plant growth is snowmelt water, which was received by the microsites in the form of snowfall (39 days; 4 days in December 2016 and 35 days during January to April in 2017), before the onset of monsoon. Due to heavy rainfall in recent years (241.1 ± 43.2 cm) (maximum in September) during 2008–2010 (Adhikari et al. 2012) and 370.7 cm (maximum in July) for 2017 (GBPIHE) in the region helped species to delay their senescence. The other reason could be much variation in temperature (minima and maxima) in the past (7.7 °C in October to 12.2 °C in June in 1984 (Sundriyal et al. 1987) as compared to 2017 and 2.4 °C in July to 9.9 °C in October (GBPIHED). Similarly, the mean monthly temperature was too high (13–23 °C) during the growth period (June to September) in the past (1988–1998) by Nautiyal et al. (2001) as compared 9.6 to 12.6 °C in 2008–2010 (Adhikari et al. 2012).

Comparing this study with that Nautiyal et al. (2001), we found a decrease in Long growth cycle (LGC) species and an increase in short growth cycle (SGC) and intermediate growth cycle (IGC) species for tall forbs. The percentage of LGC species increased and IGC species decreased for medium forbs, while SGC was absent in this study. For short forbs, per cent LGC increased, while IGC and SGC decreased in this study as compared to Nautiyal et al. (2001). We also noticed increase in LGC and IGC species in grasses/sedges, a climber was observed in LGC in this study.

Hemicryptophyte (83.5%) was the predominant life-form which is in conformity with other studies conducted at similar elevations in the alpine region of Garhwal Himalaya (Nautiyal 1996, Nautiyal et al. 2001; Sundriyal et al. 1987; Rawat 2007; Dad and Khan 2010; Vashistha et al. 2011, Kumar et al. 2016; Table 17.5). In general, the life-form spectrum of an area is affected by the grazing intensity as well as anthropogenic factors. The proportion of hemicryptophytes increased in the study area over the last three decades as compared to previous studies (Sundriyal et al. 1987), showing better adaptability of hemicryptophytes to grazing, trampling and other environmental factors, viz. wind, heavy rainfall/erosion, heavy frost than that of other life forms. The proportion of chamaephytes was reported to be high in Rudranath region (31%) by Ram and Arya (1991), in Central Himalaya (47%) by Pangtey et al. (1990) and in Yusmarg (46%) by Dhar and Kachroo (1983), could be due to less rainfall than that of this study site.

The nativity, first record/origin of the species and endemism of any biogeographic province denotes the high conservation value of the area (Anonymous 1883–1970). In Western Himalaya, very few studies (Samant et al. 1998, 2001; Samant and Joshi 2005) on nativity and endemism of the species are available. It indicates that the dominance of native species is quite prevalent in the region, while the introduction of non-natives due to livestock grazing, tourism and fuelwood collection in the region does not have any impact. The alpine meadows struggle with heavy tourism influx, high grazing intensity and exploitation of natural resources, such as high-value medicinal plants, imbalance the natural ecosystems. Samant et al. (1998) opined that the areas with a high percentage of native species

Table 17.5 Comparison of Raunkaier's life forms at various locations in Greater Himalaya. Numbers in parenthesis are the total number of species

Study area	Life form[a]						Reference
	Ph	Ch	He	Hy	Ge	Th	
Panwalikantha	8.3	6.8	44.7	–	35.0	5.3	Nautiyal (1996)
Central Himalaya (snowline)	–	46.7	30.0	–	18.3	5.0	Pangtey et al. (1990)
Yusmarg	10.4	46.4	25.4	–	10.2	6.2	Gupta and Kachroo (1981)
Tungnath	–	27.0	43.0	–	18.0	12.0	Sundriyal et al. (1987)
Tungnath (#171)	6.4	10.5	48.0	–	29.2	12	Nautiyal et al. (2001)
Tungnath (Grazed area; #68) Tungnath (Ungrazed area; #65)	4.4 6.2	16.2 15.4	50.0 49.2	- -	26.5 26.2	2.9 3.1	Vashistha et al. (2011) (26.47%), 26.2
Rudranath (#142)	2.8	31.0	24.6	–	28.9	12.7	Ram and Arya (1991)
Valley of flowers (#525)	7.5	6.1	68.4	0.4	11.8	5.0	Rawat (2007)
Tons valley (#761)	29.1	22.2	2.1	8.6	2.6	17.8	Rana et al. (2002)
Kashmir	5.7	13.8	48.3	–	13.8	18.4	Dad and Khan (2010)
Upper Dhauli Valley (#495)	11.9	5.1	61.4	0.2	10.5	11.1	Kumar et al. (2016)
Normal	46.6	9.0	26.0	2.0	4.0	13.0	Raunkaier (1934)
Tungnath (Treeline; # 86)	2.4	3.5	83.5	–	2.4	8.2	Present study

[a]Life form: *Ph*: Phanerophyte, *Ch*: Chaemophyte, *He*: Hemicryptophyte, *Hy*: Hydrophyte, *G*: Geophyte, *Th*: Therophyte

deserve more conservation, while due to overexploitation and habitat degradation allow the introduction of non-natives, which leads to less conservation value of the area. The loss of a native and endemic species can be due to direct competition between native and non-native plants, the introduction of non-natives in the area which alters ecosystem properties drastically (Vitousek 1986) and further leads to the community dominated by exotic annuals and through succession process (Stylinski and Allen 1999). The species richness across various sites in western Himalaya is reported to range from 27 to 56 species per site (average 30.5 ± 8.3 species; Rawat 2007), thus species richness of this study site (49.8 ± 5.5 species) is well within this range. The species richness values in this study per square meter (UX and EX microsites between 12.5 and 18.6 and 16.8 and 21.0 species m^{-2}, respectively) are similar to that (15–21 species m^{-2}) reported for Zemu valley in Sikkim by Tambe (2007). It shows that in alpine herbaceous communities the species richness does not differ between Tungnath, Uttarakhand and in Sikkim site, though in lower elevations Sikkim is far more species-rich than Uttarakhand. Across all microsites and months plant density ranged between 69 and

626 individuals m^{-2} in this study, which are higher than the values reported for the entire western Himalaya (152 $\pm$ 90 individuals m^{-2}) by Rawat (2007) and herb density reported for treeline zone (123–239 individuals m^{-2}) by Rai et al. (2012).

The average diversity ranged from 2.77 to 2.83 for this study, which are less than that reported for herb layer of treeline zone (3.06–3.25) by Rai et al. (2012), for south or south-east facing slopes of the Greater Himalaya (3.01–3.30) by Rawat (2007) and treeline gap (3.23) by Kala et al. (1998). The values of this study are higher than the values reported by Rawat (2007) for the entire greater Himalaya (2.1–2.4), Kala et al. (1998) for Valley of Flowers NP (2.47), Singh (1999) in Upper Tirthan Valley (2.39) between 3200 and 3300 m, Adhikari (2004) for Nanda Devi NP (0.587–2.088) and Tambe (2007) for the alpine landscape of Khangchendzonga NP (1.44–2.48), could be due to high grazing pressure and more moisture in the study area. Similar observations were also observed for high arctic tundra by Park et al. (2018).

It is interesting to note that while only 7 species were responsible for more than 50% dissimilarity between HSC and LSC regions, just 5 species contributed for dissimilarity of EX microsites between HSC and LSC against 11 species for UX microsites. Furthermore, all 5 species of EX microsites (*Ranunculus, Trachydium, Oxygraphis, Carex* and *Prunella*) contributed to the overall dissimilarity between HSC and LSC, while only 4 species (*Fragaria, Potentilla polyphylla*, *Ranunculus* and *Trachydium,* later 2 species common with EX microsites) out of 11 species contributed to overall dissimilarity. These 5 species search for places with ample sunlight and moisture, so that they can grow gregariously (> 50 individuals m^{-2}, mean average), as they are LGC species. Compared to the above 5 species, *Fragaria* and *Potentilla polyphylla* love to grow in moist and shady places with moderate abundance (30–45 individuals m^{-2}, mean average).

It is interesting to note that in EX microsites of Ravanshila, Chandrashila and Jhabra sites, *Ranunculus* contributed more for dissimilarity, while *Anaphalis* for Patankudi. This could be due to the fast melting of snow in the first three sites and late melting in Patankudi (Table 17.1). Among sites, *Fragaria* for Ravanshila and Chandrashila, *Bistorta* for Patankudi and *Ranunculus* for Jhabra contributed the most. It is evident that the contribution of these species is directly related to fast snowmelt and less grazing in the treeline ecotone of Ravanshila and Chandrashila, and high grazing pressure and late thawing of snow in Patankudi and Jhabra.

In general, phenophases were in advanced stages in EX than in UX microsites, which is similar to the findings of other experiments conducted in similar alpine environments (Wipf et al. 2009; Wipf 2010). Since different species respond differently to snowmelt effect, it indicates that apart from snowmelt, other factors also play major role (Gehrmann et al. 2018), as some contradictions were seen in different phenophases among different life forms. The absence of vegetative phenophase in some species may be contributed by the chilling effect due to frost and early snowmelt, where newly germinated buds either die or move to the next phenophase for stability.

Nautiyal et al. (2001) reported that immediately after the snowmelt 16 species were in the flowering phase, among them *Gentiana argentea* and *Oxygraphis polypetala* emerged early and most dominant in the Tungnath region (mainly alpine). Comparing this study results with Nautiyal et al. (2001) a general shift was observed in the vegetative phase by a month (i.e. June). Over a period of time (from 1984 to 2017) the duration of vegetative phenophase increased from 2 months (Sundriyal et al. 1987), to 4 months (Nautiyal et al. 2001) and 6 months (present study). It was also observed that the phenophase stability and duration was prominent in the studies conducted by Sundriyal et al. (1987) and Nautiyal et al. (2001), but in this study, phenophases overlapped resulting in no clear-cut dominance (stability) of phenophase. As such there was no change in the flowering period, but fruiting and seed maturation ended in September in this study as compared to October during 1988–1998 (Nautiyal et al. 2001). Senescence in this study started in May, which was 2 months prior to that reported by Nautiyal et al. (2001). The longer vegetative phenophase for this study could be due to higher precipitation in recent years (Adhikari et al. 2012; Adhikari et al. 2018) and less difference in minimum and maximum temperature in recent years (Adhikari et al. 2018) as compared to Sundriyal et al. (1987).

Most of the species showed senescence early in UX microsites than that of EX microsites, which may be due to an early drop in temperature in UX microsites than EX microsites. The above discrepancy may be due to a number of reasons like interspecific (early vs late flowering; Petraglia et al. 2014) or intraspecific (collective life form response to snowmelt timing, Khorsand et al. 2015; Livensperger et al. 2016) interactions or maybe due to micro-environmental changes (temperature). Considering early snowmelt (by March) in past few years, it is possible that certain species (*Primula edgeworthii, Anemone rivularis, Gentiana* spp., *Picrorhiza kurroa, Kobresia*) have started their growth in early April high water-absorbing ability at low soil temperature, which might be related to a high level of soluble carbohydrate (Mooney and Billings 1960) in early senescence. The species per cent in senescence increased sharply from August to September in this study is in conformity with the study conducted by Nautiyal et al. (2001).

The phenophases of 10 most common species namely *Anaphalis royleana, Anemone obtusiloba, Bupleurum longicaule, Danthonia cachemyriana, Geranium walliichianum, Oxygraphis polypetala, Pedicularis pectinata, Selinum vaginatum, Taraxacum officinale* and *Trachydium roylei* in this study were compared with the studies conducted by Sundriyal et al. (1987) for the year 1984, Nautiyal et al. (2001) for the year 1988–1998 (11 years; Fig. 17.6) in Tungnath region and Bijalwan et al. (2013) for the year 2008 in Dyara Bugyal. *Anaphalis royleana* had a much longer vegetative phase and consequently delayed flowering in 2017 than in 1984. The flowering period lagged by half month compared to 1984. The fruiting period duration was the same, but the timing of fruiting and senescence lagged behind by a month in 2017 as compared to 1984. *Anemone obtusiloba* had a much longer vegetative phase, and budding and flowering advanced by 1 and 3 weeks, respectively between 2008 and 2017. Fruiting was absent and senescence lagged by a month in 2017 than in 2008 (Bijalwan et al. 2013). In *Bupleurum longicaule*
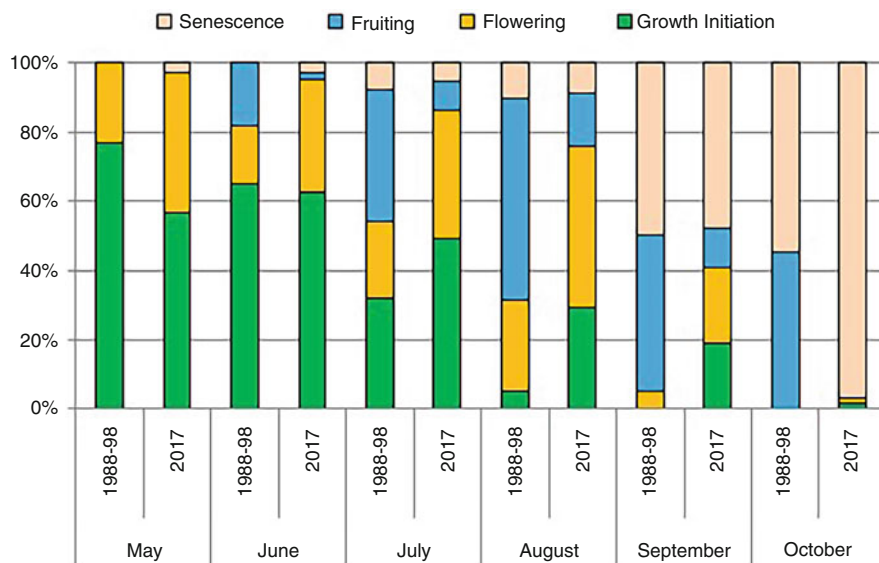
Fig. 17.6 Comparison of phenophases for the year 1988–1998 (Nautiyal et al. 2001) and 2017 (present study) in Tungnath region

flowering and fruiting phases advanced by more than a month and 3.5 weeks, respectively for the year 2017 as compared to 2008 (Bijalwan et al. 2013).

Danthonia cachemyriana had a much longer vegetative phase and its reproductive phase delayed by 4 weeks in 2017; however, fruiting was restricted to the last week of August in 2017 as compared to mid-August to mid-September in 1984 (Sundriyal et al. 1987). The senescence advanced by 2 weeks in 2017 as compared to 1984 (Sundriyal et al. 1987). The duration of vegetative, budding and flowering phenophases of *Geranium wallichianum* increased and advanced significantly in 2017 as compared to 2008. In this fruiting was delayed by 2 weeks and senescence advanced by a month in 2017 as compared to 2008 (Bijalwan et al. 2013). *Oxygraphis polypetala* had a much longer vegetative phase up to August in 2017 as compared to 1984, restricted to the first week of May. Budding, flowering and fruiting phases occurred in two different time periods between May–June and late July–September in 2017 as compared to 1984 (Sundriyal et al. 1987) budding and flowering phases were present in May and fruiting in June to early August. Senescence was delayed by one and a half months in 2017 than in 1984 (Sundriyal et al. 1987). The vegetative phase duration in *Pedicularispectinata* increased exponentially while the advancement of budding, flowering, fruiting and senescence phases was observed in 2017 than in 1984. The duration of the vegetative phase for *Selinum vaginatum* increased to early September and the budding and flowering delayed, fruiting phase was absent and there is no change in senescence between 2017 and 2001. The duration for the vegetative phase increased while reproductive and fruiting advanced for *Taraxacum officinale* during 2008–2017. For *Trachydium*
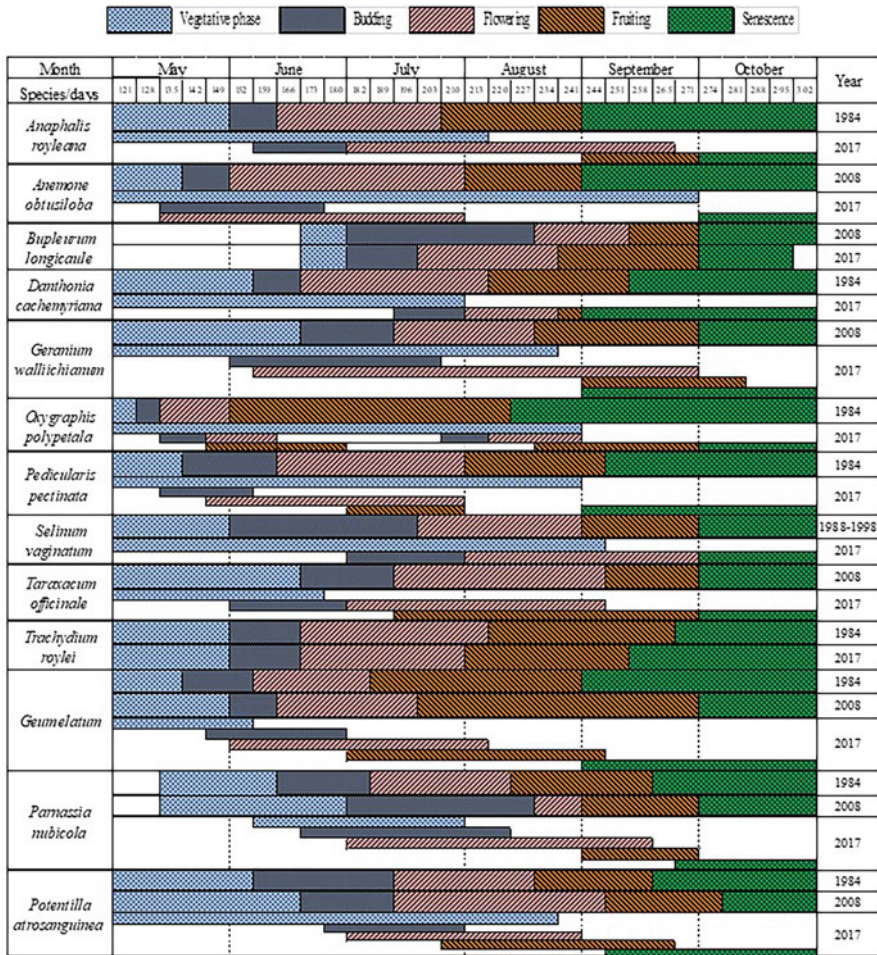
Fig. 17.7 Comparison of phenophases of common species studied during 1984 (Sundriyal et al. 1987), 2008 (Bijalwan et al. 2013) and 2017 (present study)

roylei, the flowering period shortened, and fruiting and senescence phases advanced between 1984 (Sundriyal et al. 1987).

The phenophases for *Geum elatum, Parnassia nubicola* and *Potentilla atrosanguinea* were compared at different sites, viz. Dyara in 2008 (Bijalwan et al. 2013; Sundriyal et al. 1987) with this study (Fig. 17.7). In Tungnath, the vegetative phase of *Geum elatum* extended by 3 weeks, budding lag behind a week, flowering and fruiting advanced by a week and no change in senescence was observed as compared to 1984. However, all the phenophases in Dyara, except the vegetative phase, lag behind 1 to 4 weeks in 2008 (Bijalwan et al. 2013). All phases of *Parnesia nubicola* were delayed by 1–4 weeks in 2017 as compared to 1984 (Sundriyal et al. 1987), while the reproductive phase was delayed as compared to

2008 (Bijalwan et al. 2013). *Potentilla atrosanguinea* had an extended vegetative phase, budding and flowering delayed and fruiting and senescence advanced in 2017 as compared to 1984 (Sundriyal et al. 1987).

The less variation in temperature (minima and maxima) during the peak growth period, that is, July–August helped species to remain in different phenophases for a longer period. A shift of phenophase timing and period was observed in general for the species common to past studies in the study site (Nautiyal et al. 2001; Sundriyal et al. 1987). Early onset of growth initiation and extended vegetative phenophase was observed, could be due to early snowmelt/soil water thawing leading to early soil moisture availability and ambient temperature which favoured early growth as suggested by several workers (Holway and Ward 1965; Kudo 1991; Ram et al. 1988; Kudo and Suzuki 1999; Kudo and Hirao 2006). Flowering and fruiting phenophases have also seen a shift (both advance and lag) in phenophase initiation and duration of the period in general and have extended compared to other studies (Sundriyal et al. 1987; Nautiyal et al. 2001). Variation in the phenophase period at spatio-temporal scale due to orography and micro-environmental variables were also observed (Nautiyal et al. 2001). The snowmelt timing with growth initiation and flowering has been observed (Fareed and Caldwell 1975; Bock 1976; Owen 1976), while ambient temperature during snowmelt was strongly favoured the growth initiation in alpine plants (Holway and Ward 1965; Kudo 1991; Kudo and Suzuki 1999; Kudo and Hirao 2006). The patterns of phenological events vary at spatio-temporal scale from species to species due to micro-environmental variables as well as orography of the region, which were also observed by Nautiyal et al. (2001) and the growth initiation depends on soil water availability due to snowmelt and rise in temperature (Ram et al. 1988).

17.6 Conclusion

The treeline ecotone at the Tungnath region is dominated by native hemicryptophytes. The plant density (325.8 ± 67.3 vs 183.9 ± 23.6), species richness (30.7 ± 1.22 vs 25.9 ± 1.10) and diversity (2.83 ± 0.05 vs 2.77 ± 0.05) were generally higher in EX microsites as compared to UX microsites. The herbaceous community changes across the months in all the microsites, except UX of Ravanshila and EX microsites of Chandrashila and Jhabra. Though the early snowmelt promotes species diversity and phonological events as observed in this study, there is a need for further experimentation on their relationships. The results of this study suggest that the herbaceous species in treeline ecotone are undergoing changes in phenological patterns due to the increase in temperature (minima) and precipitation period in the study area (1984 to 2017) in general. Some of the species entered into two distinct pheno-periods for reproductive and fruiting/seed maturation phenophases within the same growing period (*Oxygraphis, Fragaria* and *Ranunculus*), while some prefer vegetative propagation for continuity rather than progressing through fruiting and seeding instead. The early snowmelt and ambient temperature strongly favour early growth initiation, vegetative and flowering phases in a few of

the species (of the total species (86) 16% in EX and 12% in UX microsites) in April. The availability of snowmelt water followed by monsoon promotes longer vegetative phenophase in most of the species (30% in EX and 31% in UX microsites of the total species). Duration of phenophase in general from the past indicates that they have become longer, while senescence has become truncated. This study provides an insight to the effect of changing climate on alpine vegetation, which requires further investigations to understand the changing dynamics of alpine communities in the light of changing temperature and precipitation regimes. The treeline research in the climate context is increasing and diversifying but important geographical gaps in the context to Himalaya remain. There is a need to shift from traditional monitoring and development and implementation of new tools and techniques to monitor alpine treeline biodiversity. Considering the current state of the literature on higher Himalaya, there is a need for establishing multi-dimensional and multi-institutional long term monitoring projects to understand the impact of changing climate and anthropogenic pressures on peri-glacial vegetation, with a strong emphasis on extreme climatic events in high altitudes ecosystems, viz. timberline, treeline and alpine.

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