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An unusual composition of the plant species towards zone of ablation (Tipra glacier), Garhwal Himalaya

The snowline in the Himalayas is rising ceaselessly due to regional and global climate change. Upward rising of snowline leads to the formation of moraines. Due to extreme environmental conditions, the existing vegetation of the moraine is scanty and marked with different ecological adaptations. Ablation zone of the glaciers is covered by a thick pile of supra glacial moraine and characterized by several serrac ice sections, melting into pools of supra glacial lakes, ice caves and dead ice mounds because of subsidence and the fast-degenerating nature of the glaciers[1,2]. Dynamic and perennial ice bodies of the Himalaya are directly concerned with climate and climatic changes[3]. Temperature changes observed in the high Himalayas reflect mass and volume of the glacial ice[4,5]. Tipra glacier (30°36′–30°47′N and 079°33′–079°44′E) along with its tributary glaciers, i.e. Ratavan, Saptshring and four other cirque glaciers supply ice melts to the Pushpawati river and makes the valley rich in its unique floral wealth, the renowned 'Valley of Flowers'. Tipra glacier is bounded by a well-preserved series of lateral and recessional moraines (Figure 1 *d* and *h*), indicating past extension of the glaciers[6,7]. High alpine ecosystems are generally sensitive, and even small environmental changes can cause obvious changes in vegetational development[8]. This can largely be attributed to the differences in topography, physiognomic conditions, altitudinal ranges, and different climatic or biotic features[8]. It is evident that when global and regional climatic conditions are changed, plants shift their habitat to optimum adaptive elevation from conventional altitudes[9], thus producing new communities (Table 1).

The study was carried out during April–September 2009. The two broad geomorphic units, viz. glacio-fluvial (3700–3800 m) and glacial zones (3800–4000 m) were identified to study the impact of glacial retreat. The objectives were to examine the extension of plants upslope due to reduced mass and volume of the glacier, together with vegetational composition, succession and shift towards the line of equilibrium (ELA). A total of 30 quadrates (glacio-fluvial = 15 and glacial zones = 15) were randomly laid and studied. The plant species have been identified by consulting the Herbarium of Botanical Survey of India, Dehradun, Herbarium of Forest Research Institute, Dehradun and the Garhwal University Herbarium, Srinagar-Garhwal.

The expansion of plants in the glacial moraines is controlled by the disappearance of glacial mass, volume, area and length[10]. From 1962 to 2002 recession rate[7] of Tipra glacier was 13 m/yr, which increased to 21.3 m/yr during 2002–2008. More recently, the glacier retreat was found to be 45, 83 and 535 m during the years 2006–2008, 2002–2006 and 1962–2002 respectively[6,7]. The areas where glacial retreat (about 663 m) took place during the last 46 years are now occupied by upward shift of vegetation. Plant density in glacial environment is strictly determined by climatic and edaphic factors[1]. The glacio-fluvial zone showed greater number of plant species in a unit area than the glacial zone (Figure 1 *e–h*). It is clear that recessional moraines of the glacio-fluvial zone (Figure 1 *d*) provide a nursery and open-up new habitats and niches[2]. *Trigonella emodi* (5445 individuals/m^2) and *Anaphalis triplinervis* (5355 individuals/m^2)

Table 1. Composition of herbaceous vegetation near dead ice mounds (3800 m) and beyond snout (3865 m)

	Glacio-fluvial zone (3700–3800 m asl)		Glacial zone (3800–4000 m asl)	
Botanical name	Density	IVI	Density	IVI
Anaphalis triplinervis (Sims.) C.B. Clarke	5355	75	1080	45
Bistorta affinis (D. Don) Greene	3465	34	705	20
Corydalis meifolia Wall.	195	3	120	5
Epilobium latifolium L.	3735	61	1530	107
Kobresia royleana (Nees) Boeck.	285	4	105	5
Malaxis cylindrostachya O. Kuntze	75	2	45	4
Meconopsis aculeata Royle	75	2	45	4
Oxyria digyna (L.) Hill.	255	4	525	25
Pedicularis oederi Vahl	330	5	60	3
Poa supina Schrad.	495	6	105	3
Potentilla cuneata Wall. ex Lehm.	270	2	75	5
Saxifraga stenophylla Royle	210	4	105	5
Saxifraga jacquemontiana Decne.	105	2	315	12
Selinum vaginatum (Edgew.) C.B. Clarke	255	2	–	–
Solidago virgaurea L.	195	2	–	–
Thymus linearis Benth.	1305	11	–	–
Trigonella emodi Benth.	5445	28	–	–
Cicerbita macrorhiza (Royle) Beauv.	105	3	–	–
Cremanthodium arnicoides (Wall. ex DC.) R. Gd.	45	2	–	–
Dactylorhiza hatagirea (D. Don) Soo	45	2	–	–
Androsace sarmentosa Wall.	2535	14	–	–
Euphrasia officinalis L.	870	6	–	–
Gentiana argentea (D. Don) Griseb.	255	2	–	–
Geranium wallichianum D. Don ex Sweet	105	3	–	–
Geranium polyanthes Edgew. & Hk. f.	180	3	–	–
Pedicularis pectinata Wall. ex Benth.	360	4	–	–
Picrorhiza kurrooa Royle ex Benth.	1005	7	–	–
Pleurospermum densiflorum (Lindl.) C.B. Clarke	105	2	–	–
Potentilla atrosanguinea Lodd. ex Lehm.	330	4	–	–
Corydalis govaniana Wall.	–	–	75	3
Pleurospermum candollei (DC.) C.B. Clarke	–	–	45	3
Rhodiola wallichiana (Hk.) Fu.	–	–	450	20
Saxifraga sibirica L.	–	–	270	7
Stellaria decumbens Edgew.	–	–	585	20
Arenaria bryophylla Fernald	–	–	45	4

IVI, Importance value index.

have shown maximum density, whereas minimum density was indicated by *Cremanthodium arnicoides* (45 individuals/m^2) and *Dactylorhiza hatagirea* (45 individuals/m^2), in the glacio-fluvial zone. Surprisingly, *Epilobium latifolium* (1530 individuals/m^2) and *Anaphalis triplinervis* (1080 individuals/m^2) have maximum mean density and *Arenaria bryophylla* (45 individuals/m^2) and *Meconopsis aculeata* (45 individuals/m^2) have minimum mean density in the glacial zone (Table 1). Extreme glacier wastage at the fringe of the shrinking glacier and discovery of herbaceous vegetation close to the ELA were unexpected. Importance value index (IVI) expresses the dominance and ecological success of a species with a single value in a community[1]. In this context, *Anaphalis triplinervis* (75) and *E. latifolium* (61) have maximum, whereas *D. hatagirea* (2) and *Cremanthodium arnicoides* (2) have minimum value in the glacio-fluvial zone. *E. latifolium* (107) and *Anaphalis triplinervis* (45) have maximum and *Corydalis govaniana* (3) and *Pedicularis oederi* (3) represented minimum value in the glacial zone (Table 1).

Snow avalanches are a common phenomenon in the valley side slopes. They usually erode the surface of the mountain slopes and carry with them seeds, stolons, roots, rhizomes, tubers, suckers, bulbs and finally deposit these propagules over the glacial surface[10]. At the same time thin supra-glacial deposits of soil over the longitudinal and transverse crevasses act as a nursery for migrated propagules (carried by the avalanches) to sustain life and open new habitats over the glacial slope (Figure 1 *a–c*). In the summer season snow and ice melt due to high intensity of the sun rays. And this melt water facilitate the establishment of reproductive bodies. The glacial slope along with supra-glacial deposits have their own soil depth (about 1 m on snout, 0.5 m mid and 0.3 m below ELA). Furthermore glacial mass produced by weathering (mainly physical and chemical) have fertile soils for growth of the vegetation. Cold climatic condition and frost actions are the most active geomorphic processes in this region, which result in the development of large scree fans in the valley-side slopes along with frost heaves, tors, and pattern ground with a thin veneer of soil[6,7]. The glacio-fluvial zone has a number of landslide scars, scree fans and debris slide (Figure 1 *d*). These scree fans and debris cones are inhabited under an acropetal succession and shift induced

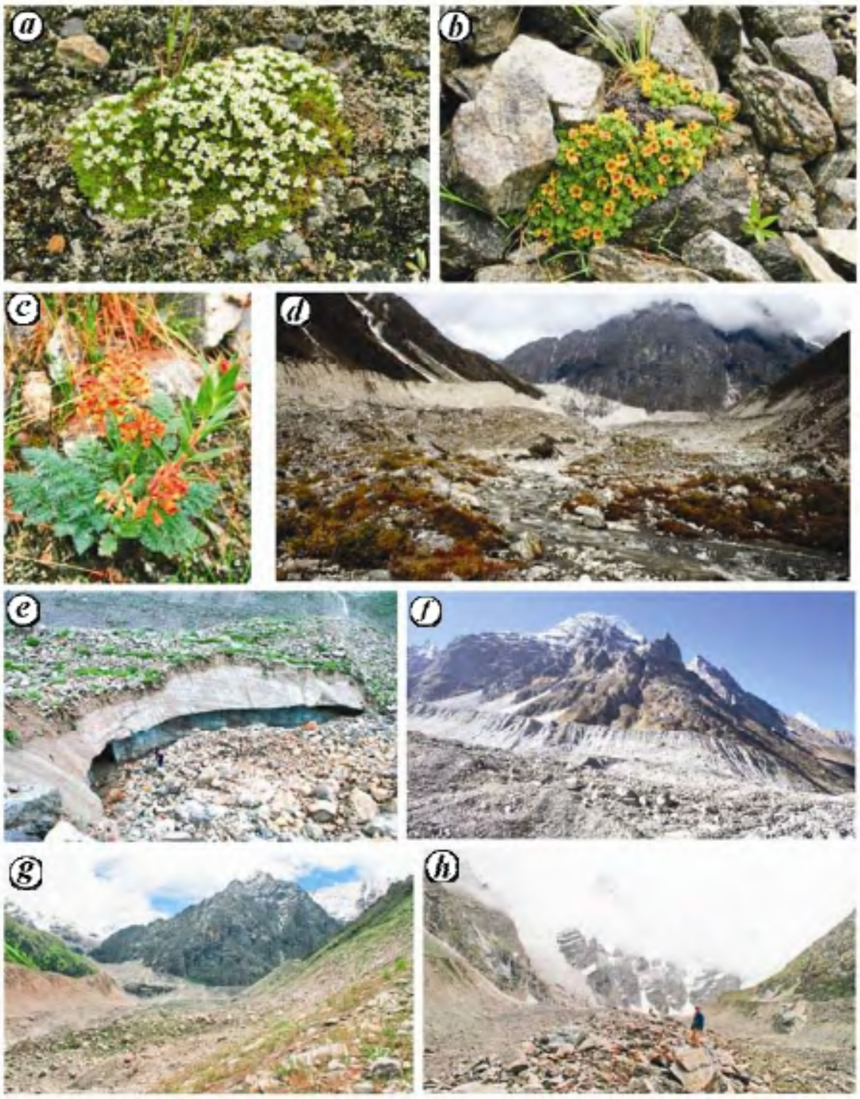

Figure 1. Plants surviving beyond snout (3865 m) and below the line of equilibrium (4320 m) of Tipra glacier. ***a***, *Arenaria bryophylla*. ***b***, *Saxifraga jacquemontiana*. ***c***, *Corydalis meifolia*. ***d***, Dead ice mounds at 3800 m. ***e***, Plants existing over ice cave. ***f***, Above confluence at 3900 m. ***g***, Wide view of Tipra glacier. ***h***, Close to line of equilibrium (above 4000 m).

by recent climatic and glacial variation[10]. Chaujar[3] observed that due to glacial retreat, the vacated areas are initially trapped through lower flora such as lichen habitats, which ultimately tend to convert into higher plants. In addition, plants move to the upper approaches (sometimes downwards) apart from their definite conventional habitat[11–17].

Due to these natural phenomena (rapid retreat of glacial mass, volume, area and length as well as upward shift of the vegetation) the face of the Himalayan glacial complex is changing. Although Gaur *et al.*[1,2] recorded phyto-sociological data in front of the Chaurabari glacier in Kedarnath Valley, the present study is significant because it covers the area beyond snout (3865 m) and above the confluence of the Ratavan and Tipra glaciers at 3900 m (Figure 1*f*). On the basis of the present evidence, we can predict that angiospermic herbs might spread upslope near ELA (4320 m) in the near future.

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