CLIMATE CHANGE AND ALPINE FLORA IN SIKKIM HIMALAYA

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ABSTRACT

For the past three decades; there is a popular aphorism that "The global warming is the end result of climate change". Melting of glaciers; rising of sea levels and increasing temperatures at global level have caused visible effects in the Himalayan region also and the subject of my study has been to identify the biological response to these changes in the Himalayan region. The mountain ecosystem has been found to be the most fragile in the world. The mountains have experienced continued warming above the global average during the last century. The biological responses of alpine plants to climate change have shown increasing climatic stress for many alpine plant species. The climate change over long periods has significantly affected the vegetation structure, community composition and ecosystem dynamics. The climate induced shifts in the distribution of species across a broad range of alpine species have been compiled from various studies. An increase in species richness of vascular plant at summits during the last century has been identified. Also, the late flowering alpine plants are flowering more prodigiously as a result of increase in growth period as phenological responses of alpine plants to global warming.

The tree line ecotone comprising of sub-alpine conifer forests is ascending due to effects of global warming

Primula denticulata - the alpine meadows of Sikkim harbor 58 of the total 102 species of Primulas recorded in the country

The climate of the earth is dynamic and has been continuously changing during the course of its evolution. The climate undergoes changes either due to natural forcings from anthropogenic influences and/or from a combination of both. Studies have shown that earth's annual global mean surface temperature has warmed up by about 0.61±0.16°C between 1861 and 2000 (Folland et al. 2001) (Figure 1). Scientists confirmed natural variabilities alone not to be taken as cause of increase in earth's temperature as the computer based climate-model experiments using natural-only forcings failed to reproduce global warming scenarios observed in the recent decades (Stott et al. 2000; Widmann & Tett 2003). The abrupt increase in temperature since 1900 (these studies conclude) can only be explained by increase in radiative forcing due to anthropogenic activities. The period of post industrial revolution (i.e. post-1900) witnessed sharp increase in the production and release of greenhouse gases (CO_2, NO_2, CH_4 etc.) into the atmosphere (Ramaswamy et al. 2001). The race for rapid economic development the world over (powered especially by fossil fuels) is likely to contribute

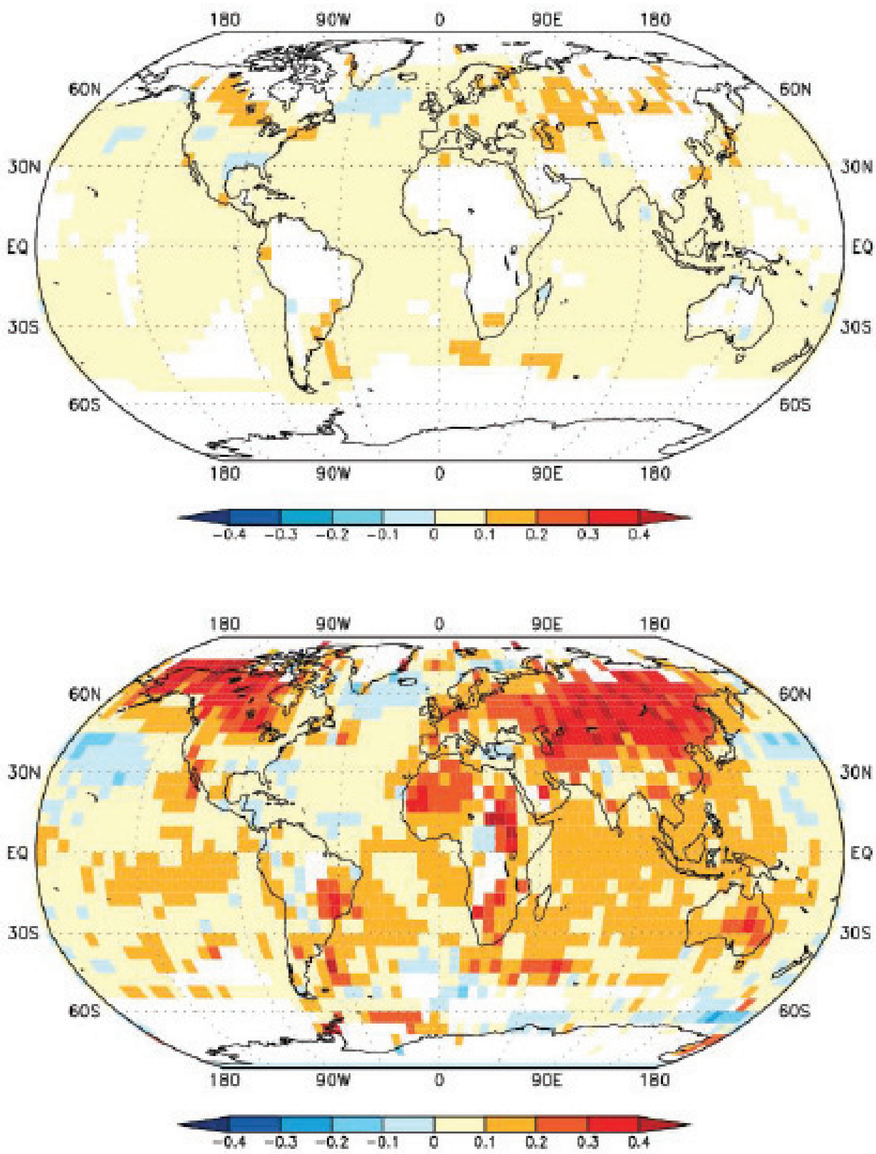


Figure 1: The figure shows global trend in temperature. Source: Joint institute for the study of atmosphere and ocean, University of Washington

to more warming during the 21st century (Cubash et al. 2001). For the 21st century (IPCC) has projected temperature change between 1.1 and 6.4 °C.

In response to recent climatic warming, the glaciers have started melting (Lowell 2000), the Greenland ice sheet is reducing (Krabill 2000), permafrost in cold regions has started disappearing (Overpeck et al. 1997) and sea levels have reportedly risen (Warrick et al. 1993). From the ecological point of view the climate change has significantly affected the vegetation structure, community composition and ecosystem dynamics both in terms of evolution and extirpation of species. A wide range of taxa has been found to show an upward range shift globally either in latitudinal (Hickling et al. 2005) or altitudinal (Wilson et al. 2005) gradients.

The present article reviews the global studies focusing the biological response of alpine plants to climate change with respect to Sikkim Himalaya.

WARMING OF GLOBAL MOUNTAINS

Mountains constitute centres of endemism for biodiversity, harbouring endangered species and ecosystems. Mountains are the most fragile ecosystem amongst all other ecosystem in the world (Diaz et al. 2003). Mountains are experiencing continued warming of more than the global average since late 19th century (Theurillat & Guisan 2001; Beniston 2003). An increase of 0.6°C has been reported for the tropical Andes from 1939 to 1998 at the rate of 0.1°C/ decade (Vuille & Bradley 2000). Where as there is an increase of 0.9°C for the Pyrenees from 1880 to 1950 at rate of 0.11 °C/ decade (Bucher & Dessens 1991), there is an increase of 1.1°C for the European Alps from 1890 to 1998 (Böhm et al. 2001).

The mountains are predicted to continue warming at an alarming rate. Using Intergovernmental Panel for Climate Change (IPCC) emission scenarios, Nogues et al. (2007) have predicted the magnitude of future rise in the temperature during the 21st century on the global mountains (Figure 2). Projected average temperature changes vary between 2.1 °C to 3.2 °C (0.26°C to 0.4 °C/ per decade) for 2055 and 2.8 °C to 5.3 °C (0.25°C to 0.48 °C/ per decade).

WARMING OF HIMALAYA

Some authors have reported rapid warming of Himalaya during the last century and it is estimated to be approximately 2-3 times the global average (Shrestha et al. 1999; Liu & Chen 2000). The analysis of data of maximum temperatures from the meteorological stations installed during 1977-94 at different elevations in Nepal showed an overall increase in temperature, ranging from 0.62°C for the Himalaya and 1.09°C for Trans-Himalaya (Shrestha et al. 1999). The warming trends in winter (mean and maximum temperatures) have been reported to be consistent in Himalaya and the Tibetan plateau (Kumar et al. 1994; Shrestha et al. 1999; Liu & Chen 2000; Edward et al. 2003). Increase in winter maxima of 0.61 °C, 0.90 °C and 1.24 °C per decade has been recorded for Nepal, Himalaya and Trans-Himalaya (Shreshtha et al. 1999). These studies provide clear evidence of Himalayan warming linked to global climate change. There are reports of 5–15% increase in monsoon precipitation in Himalaya which is affected by global warming comparative studies. However the ambient air temperature was recorded by Hooker in 1849-50 during his botanical explorations to Sikkim Himalaya in his book "The Himalayan Journal". Hooker's temperature data is available for three altitudinal bands (i) 3200-3500 m, (ii) 4400-4600 m and (iii) 5300-5555 m. He reported mean of the warmest month for the three altitudinal bands as 10 °C, 4.4 °C and 0.1 °C respectively. Similarly the mean of the coldest month reported by him for the three altitudinal band was -4.4 °C, -11.67 °C and -17.78 °C respectively. The lapse rate which indicates temperature decline at an altitudinal gain of every 100 m was 0.82 °C/ 100 m in 1850.

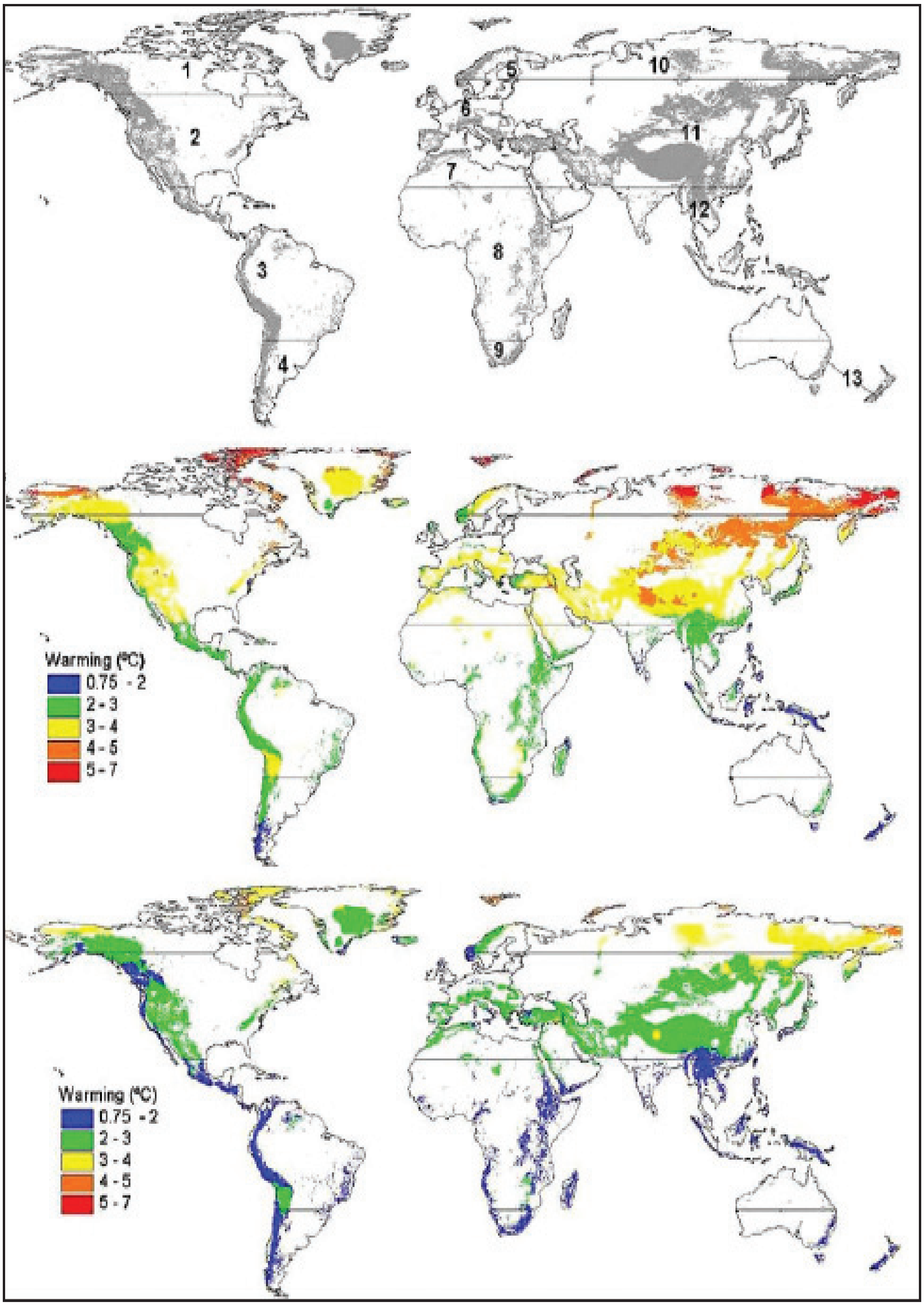


Figure 2: Projected warming of different mountain system of the world for 2055 (A1FI—second; B1—third) after averaging the five AOGCM for two IPCC warming scenarios. (1) America high-latitude mountains at northern hemisphere; (2) America mid-latitude mountains at northern hemisphere; (3) America low-latitude mountains; (4) America mid-latitude mountains at southern hemisphere; (5) Europe high-latitude mountains; (6) Europe mid-latitude mountains; (7) Africa mid-latitude mountains at northern hemisphere; (8) Africa low-latitude mountains; (9) Africa mid-latitude mountains at southern hemisphere; (10) Asia high-latitude mountains; (11) Asia mid-latitude mountains; (12) Asia low-latitude mountains; (13) Australia and New Zealand

(Follard et al. 1990; Meehl et al. 1996; see also Shreshtha et al. 2000). A further increase in rainfall by 10-20% is predicted for 2100 using different climatic predictive model for Eastern Himalaya (Figure 3).

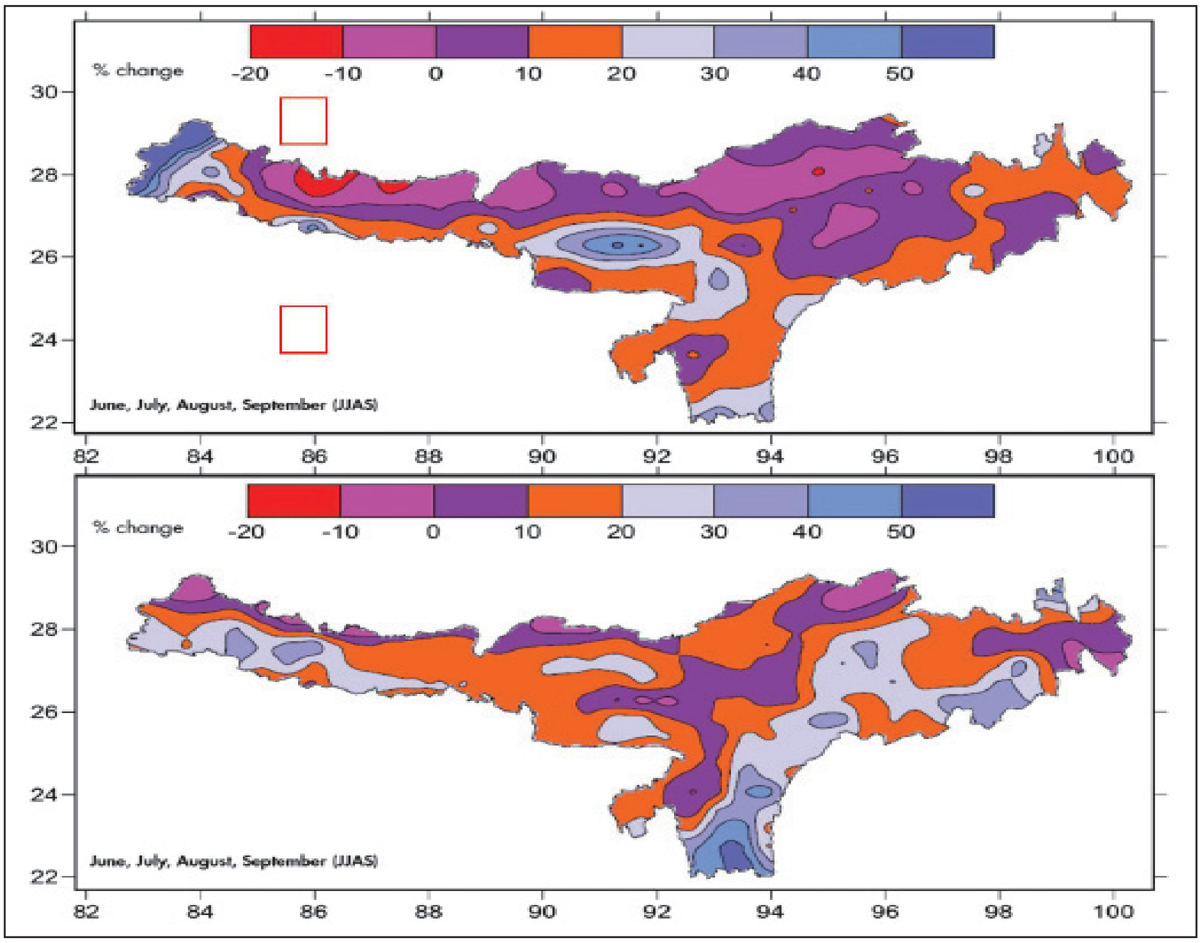


Figure 3: Spatial distribution of scenarios of simulated future monsoon precipitation (change as %) over the Eastern Himalayan region according to the HadRM2 model (2041-2060, top) and the PRECIS model (2071-2100, bottom)

WARMING OF SIKKIM HIMALAYA

There is absence of long-term temperature data for Sikkim especially at higher altitudes. There are some open sources from where climatic data as global monthly min/ max temperature and precipitation can be obtained. From the global data, the temperature data for the area of interest can be cropped. One of the widely used open sources from where climatic data can be obtained for Sikkim at a resolution of 30 arc-seconds (~1 km) is Worldclim (http://www.Worldclim.org/ current.htm).

For the recent time period scenario (1950-2000) average maximum temperature for Sikkim, as sourced from Worldclim data, was 8.088 °C varying from -10.89 °C to 28 °C (± 8.27 °C). The average minimum temperature was 0.248°C varying from -23.44 °C to 18.10 °C (± 7.55 °C). According to the CCMA (Climate Modelling and Analysis) B2A warming scenario, annual mean temperature of Sikkim is likely to increase by 1.82 °C for 2050 and 1.93 °C for 2080. For 2050, average minimum and maximum temperatures are projected to increase by 0.8 °C and 2.8 °C respectively and for 2080 by 0.93 °C and 2.95 °C respectively. The current annual precipitation over Sikkim was found to be 768.5 mm, varying from 0 to 3150 mm (± 911 mm) which is projected to increase by 4.09% and 8.91% through 2050 and 2080 respectively. For 2050, the annual precipitation is projected to be 800 mm; varying from 0 to 3362 mm (± 960 mm) and for 2080 the annual precipitation is projected to be 837 mm varying from 0 to 3509 mm (± 1016.3 mm).

IMPACT OF WARMING ON ALPINE FLORA

Plant life in the mountains is mainly constrained by physical components of the environment. The mountainous vegetation especially at the uppermost limit (known as 'alpine' zone) encompasses vegetation that occurs above the natural high altitude treeline and below the snowline. Low temperature is the main controlling factor of alpine plant life on a mountain ecosystem. The alpine zone is a critical repository of biodiversity, harbouring high number of endemic and endangered species (Körner 2003; Viviroli & Weingartner 2004; Woodwell 2004). Alpine plants are the most suitable indicators to assess the consequences of climate change in species distribution (Lesica & Steele 1996; Walther et al. 2002; Körner 2003; Walther 2003).

The tree lines in European mountains have been recorded to have moved upward by nearly 200 m since the early twentieth century (Grabherr 2010) (Figure 4). Furthermore, in European mountains the plant cover of dwarf shrubs in alpine areas has increased and become more continuous towards higher elevations; following the first warming peak of the century (Cannone et al. 2007) (Figure 5).

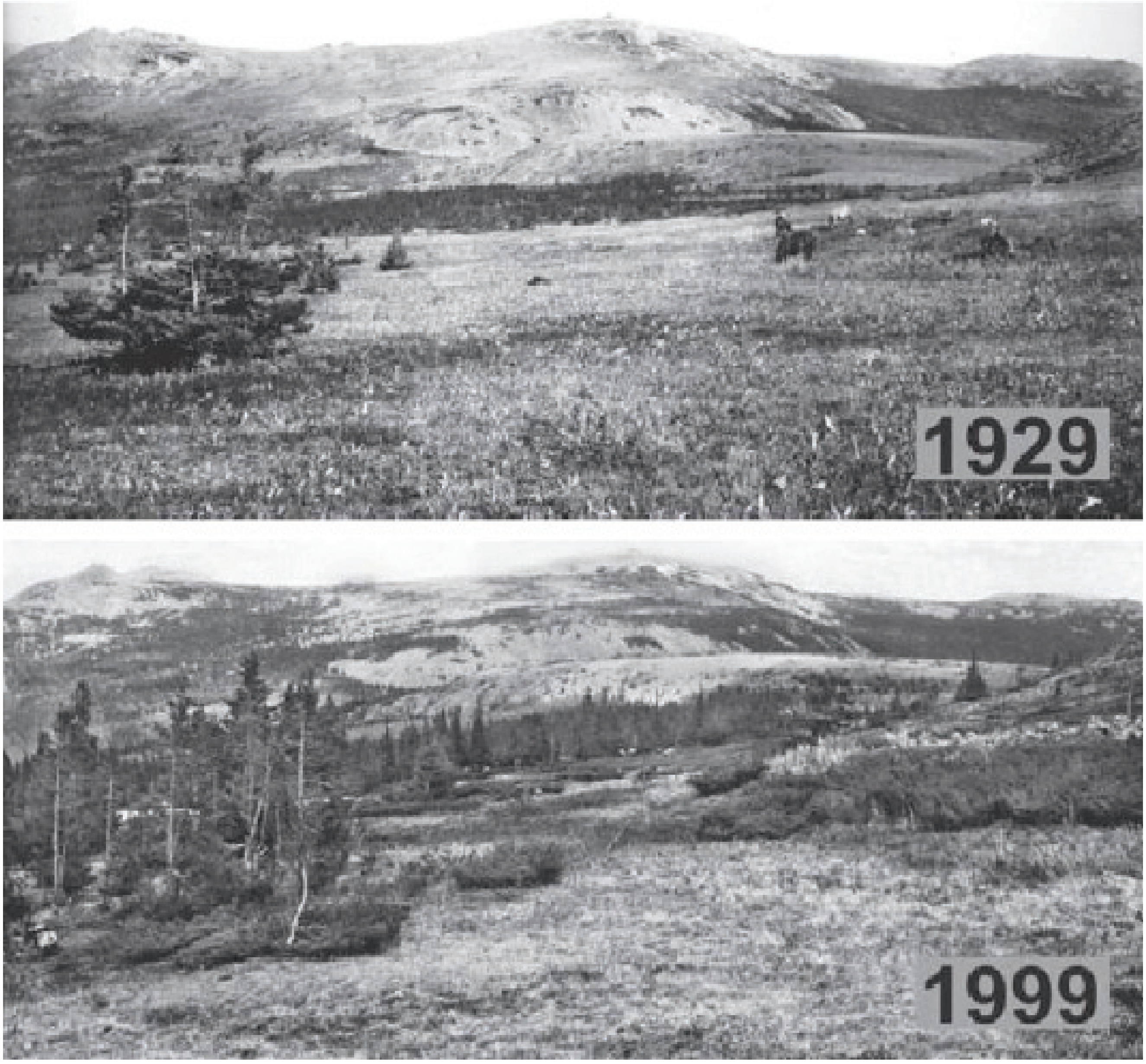


Figure 4: Examples of evidences that treeline ecotones have been affected by climate warming during the past century: (a) Iremel Mts. in the southern Urals, Russia, in the early 20th century. (b) Filling of the treeline ecotone and upward movement of tree species in the late 20th century (Grabherr et al. 2010)

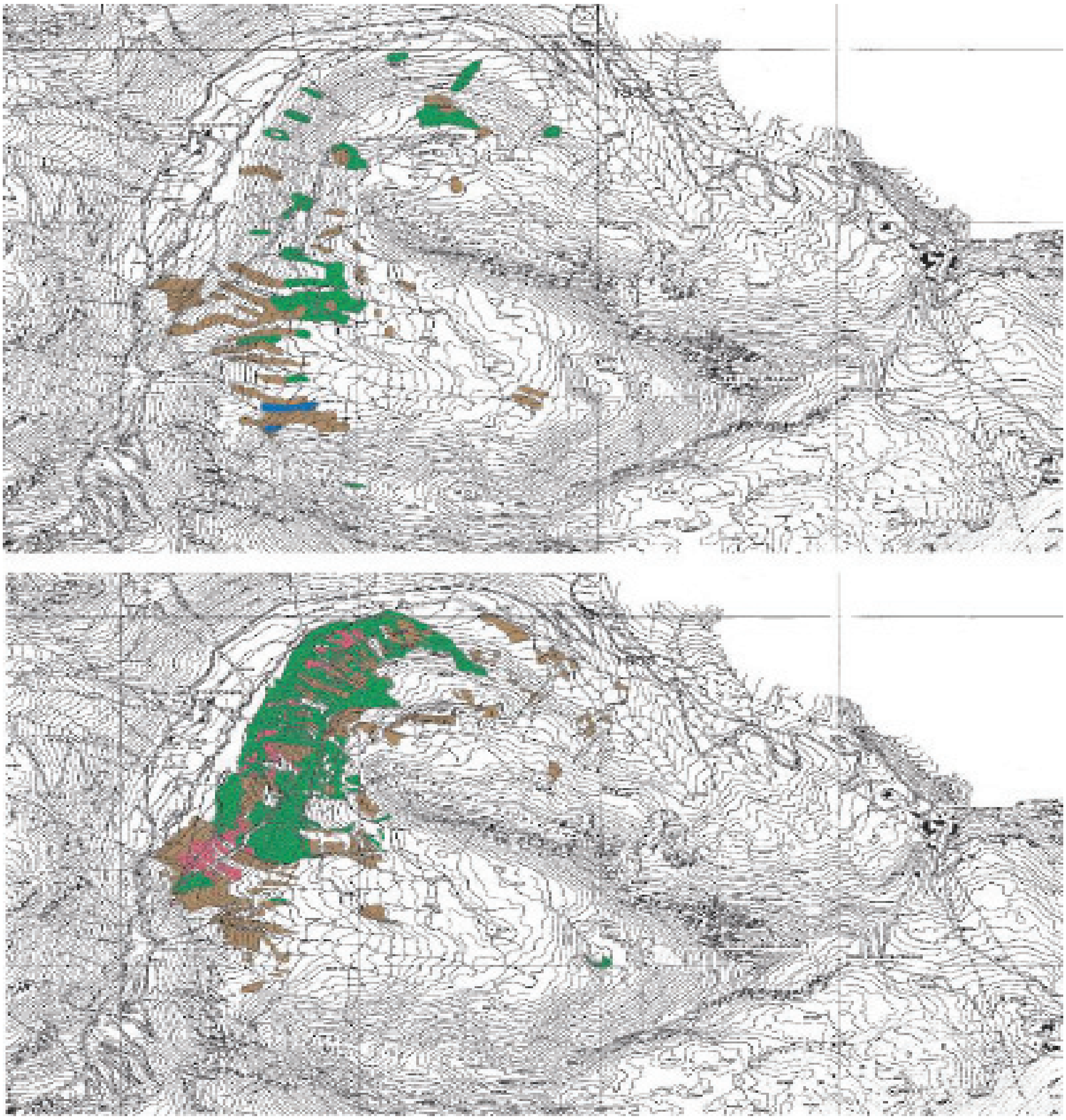
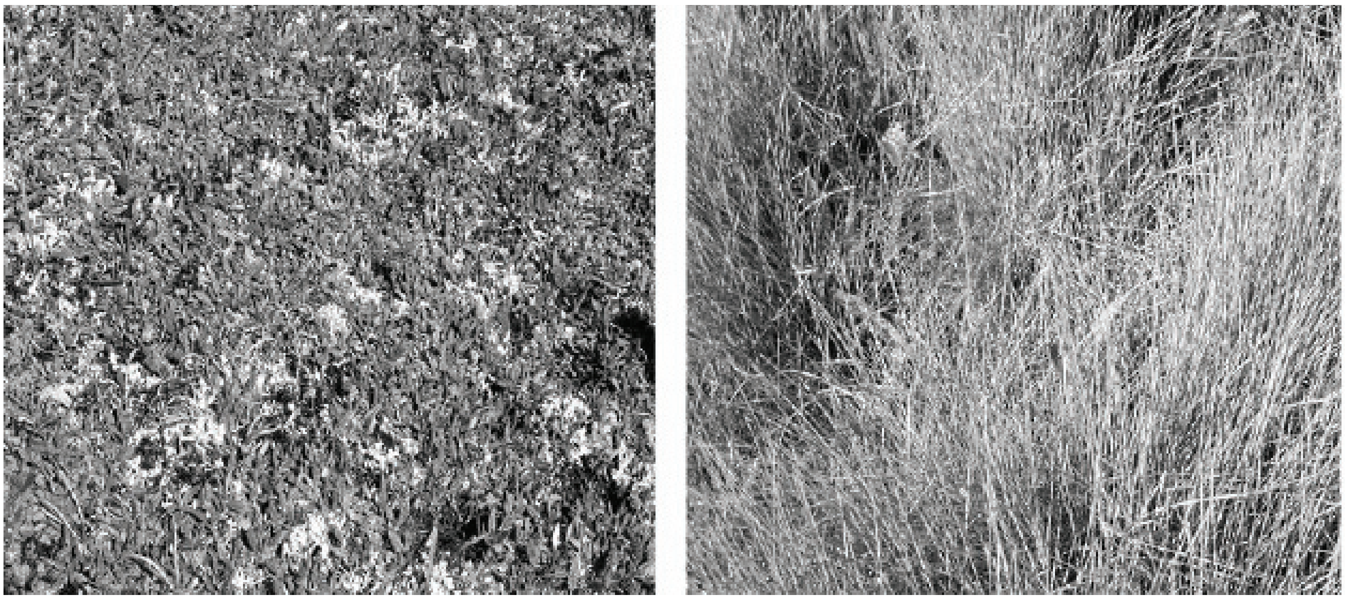


Figure 5: Shrub distribution in 1953 (top) and 2003 (bottom) in the Stelvio Pass area (central Italian Alps, elevations more than 2650 m). Brown = dwarf shrub association (*Loiseleurietum–Cetrarietum*); green = mosaic between the dwarf shrub association (*Loiseleurietum–Cetrarietum*) and the alpine grassland; blue = mosaic between the dwarf shrub association (*Loiseleurietum–Cetrarietum*) and the snowbeds (Cannone et al. 2007)

Studies of other plant communities have revealed lower elevational dwarf-shrubs, sedges and meadows (which comprise late successional stages of community development) to have increased their cover at high altitudes at the expense of pioneer snowbed communities (Gou et al. 2008; Kelly & Goulden 2008). Also graminoid and forb species have shown the strongest growth responses by increased reproductive effort to experimental warming (Klanderud & Totland 2005) (Figure 6).

Figure 6: Four years of experimental warming and nutrient addition altered the (left) high-diversity *Dryas octopetala* heath



(control plot; C) to (right) a low-diversity community dominated by graminoids (warming combined with nutrient addition; TN). Source Klanderud & Totland (2005)

There has been upward migration of species and increase in species richness at summits during the last century (Walther et al. 2005) (Figure 7 a and b). The average upslope migration rate of 25– 45 m per decade for the alpine plant species, depicted higher rates for species with wind-dispersed and smaller sized reported.

Figure 7 (b): Change in species richness of the investigated mountain summits. Legend: × = 1900s; ♦= 1980s; ● = 2003;

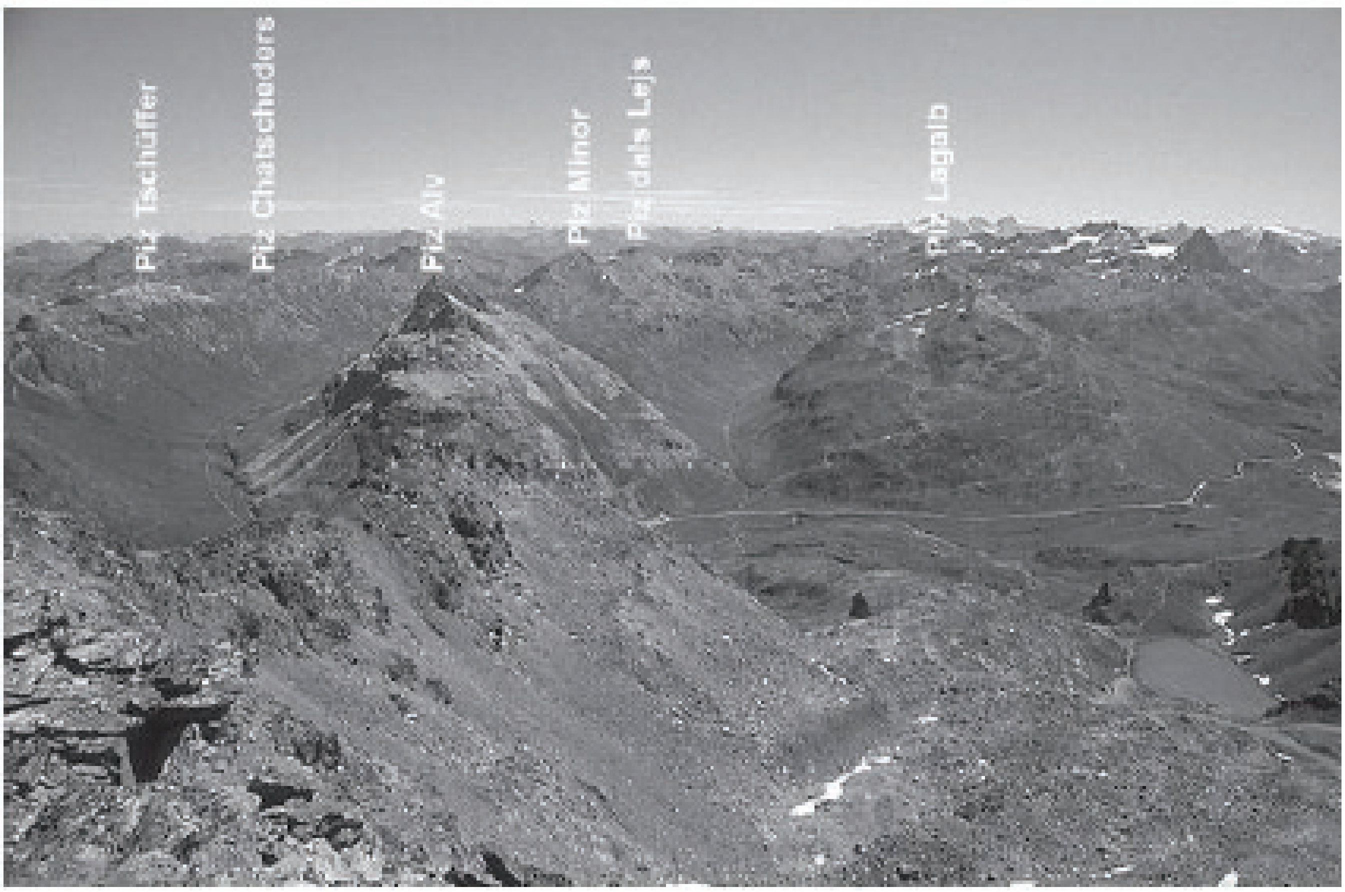
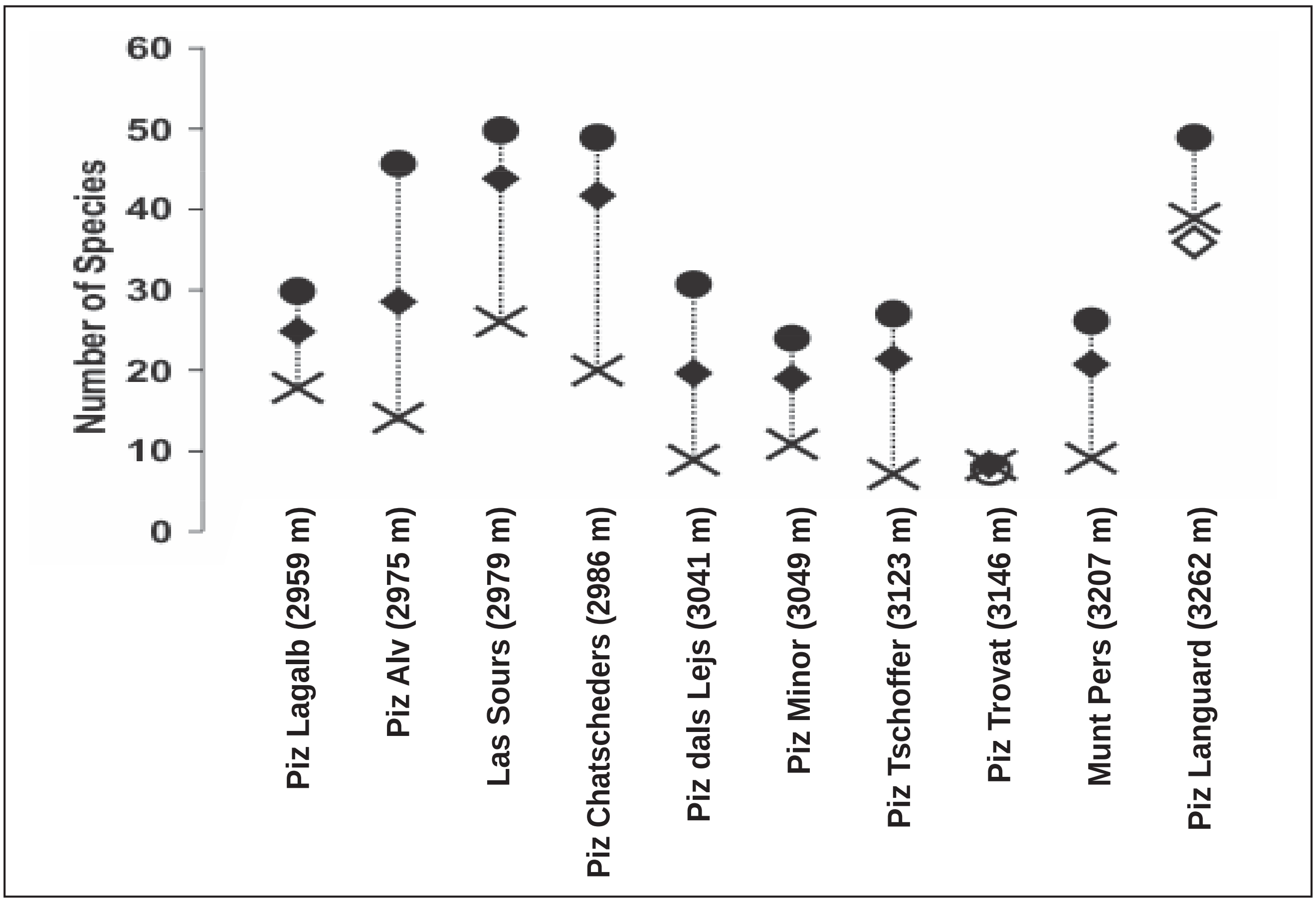


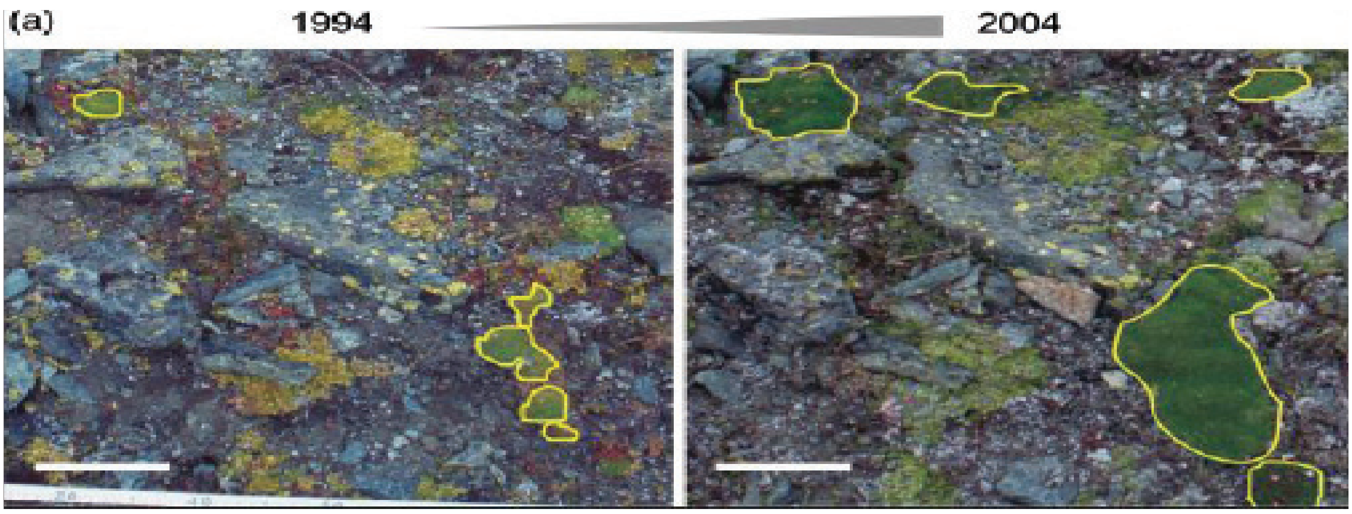
Figure 7 (a): High mountain peaks of the long-term multiple summit vegetation monitoring series in the Bernina area, eastern Alps, Switzerland (Walther et al. 2005)



open symbols: (P. Trovat, P. Languard) indicate (temporary) decrease in species number.

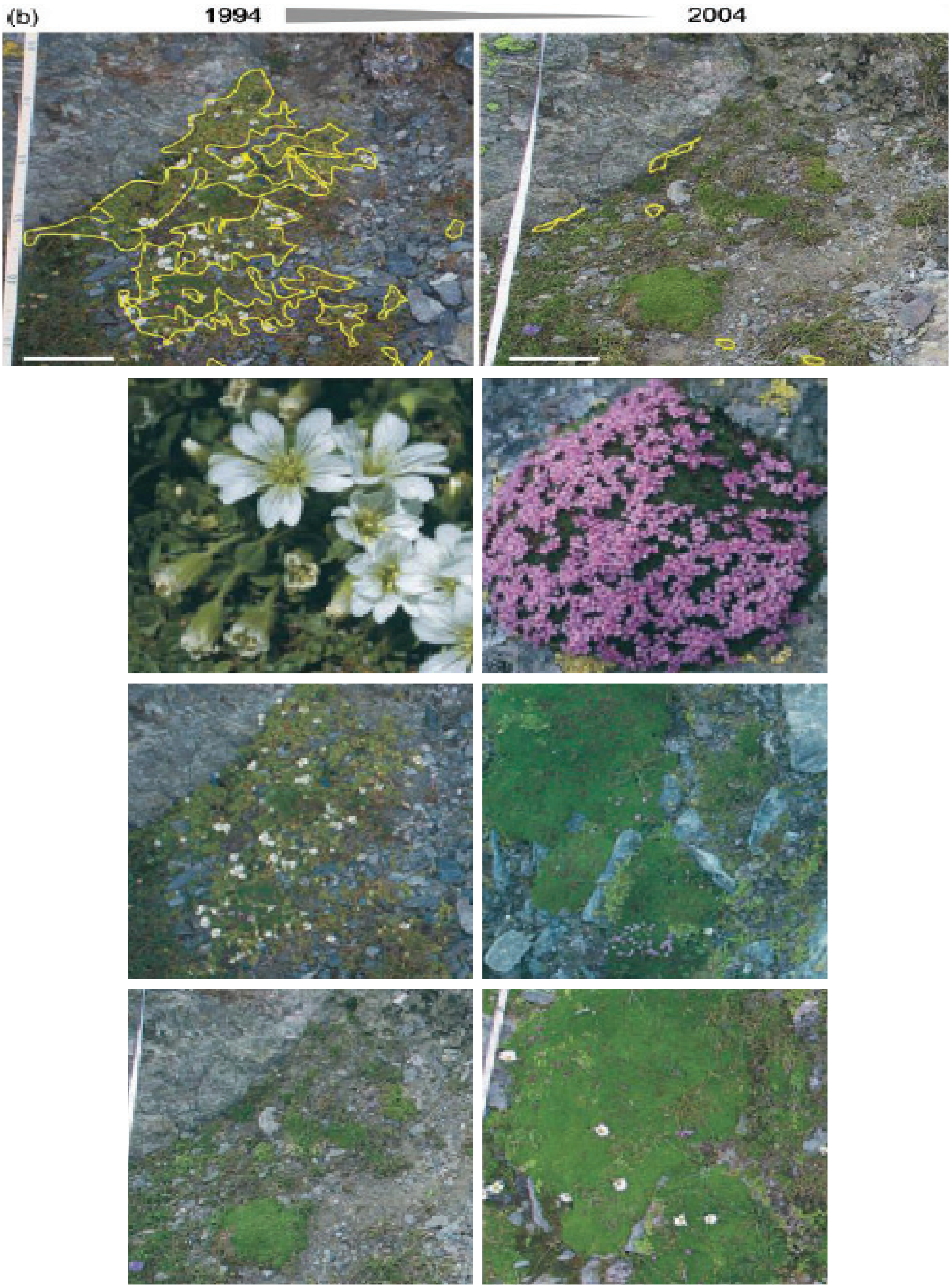
Responding to observed changes in plant species richness on high peaks of the European Alps, an extensive setup of 1m×1m permanent plots was established at the alpine-nival ecotone (between 2900 and 3450 m) on Mount Schrankogel, a GLORIA master site in the central Tyrolean Alps, Austria, in 1994. Ten years after the first recording, average change in vascular plant species richness from 11.4 to 12.7 species per plot, an increase of 11.8% (or of at least 10.6% at a 95% confidence level) was reported (Pauli et al. 2007) Figure 8 (a) and (b).

Figure 8 (a) : Photo comparisons illustrating changes in species cover; (a) increasing: *Silene exscapa* (3110 m); (b)



decreasing: *Cerastium uniflorum* (3024 m); white bars indicate 10 cm (Pauli et al. 2007).

Figure 8 (b): Changes of alpine and nival species between 1994 and 2004 at Mt. Schrankogel, Tyrol.



(a) (left): the nival species *Cerastium uniflorum* in 1994 (mid) and 2004 (bottom) showed a drastic decline;
(b) (right): the alpine species *Silene exscapa* in 1994 (mid) and 2004 (bottom) was increasing in cover (Grabherr et al. 2010)

ALPINE FLORA OF SIKKIM HIMALAYA

The entire state of Sikkim comprising Teesta basin can be classified as a high altitude basin as more than 59% of its catchment lies above 3000 m. Generally, slopes of the basin are steep with slopes above 30% constituting more than 52% of the basin area. On an average, 10.32% of the basin is either rocky cliffs or escarpments with more than 70% slope. The basin area under 15-30% slope is 8.61% and only 4.37% of the basin constitutes areas with slope up to 2%. A broad view of the alpine landscape of Sikkim is presented in Figure 9.

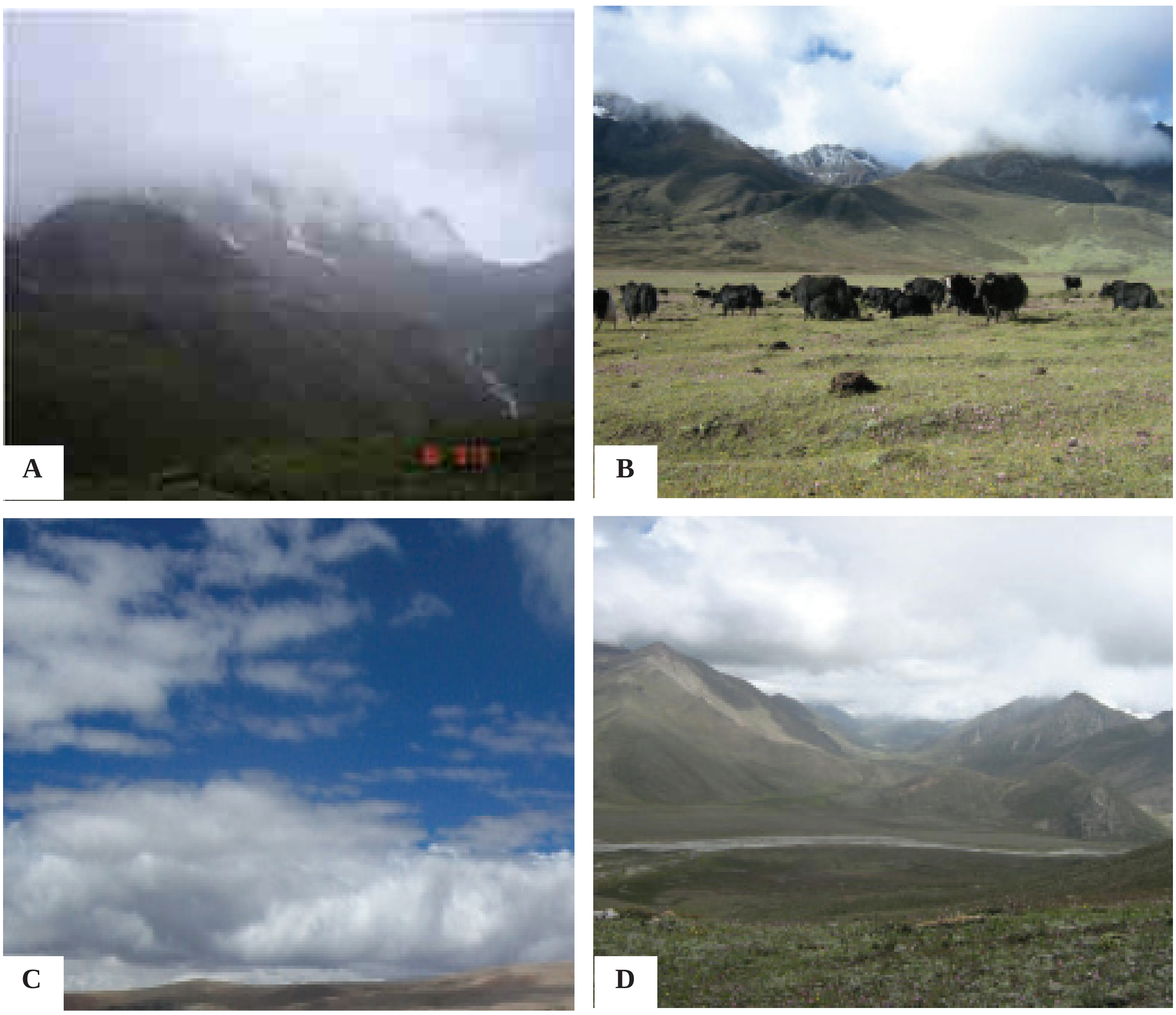


Figure 9: A broad view of landscape and alpine vegetation from North Sikkim. (A) the steep sloping greater Himalayan ranges at the lower elevation of alpine bands (B) the alpine meadows the intermediate elevation of the alpine bands (C) the dry alpine steppe at the highest elevation of the alpine band in the trans Himalayan region (D) glaciated valleys

The alpine Sikkim Himalaya clearly exhibits great variety of plant diversity and represents nearly 30% of the total flora of Sikkim. In total, alpine flora belonged to 60 families and 297 genera which contribute 60% of the total alpine plant families and 10% of all the alpine genera known worldwide (Körner 1999). The total number of vascular plant species recorded across the alpine zone in Sikkim (1400 ± 75 species) is more than double of that recorded for the European Alps, New Zealand Alps and the Rocky mountains region (600-650 species) (Mark & Adams 1973; Hadley 1987; Ozenda 1993). This observation clearly shows higher speciation rates in the Himalayan alpine genera (e.g., *Saxifraga, Primula* and *Potentilla*). Notably, Sikkim Himalaya represents one of smallest regions in terms of geographic area, yet has the highest number of species per sq km. This is clearly a result of sharp altitudinal changes within short geographic distances (Pandit et al. 2007). Furthermore, this high degree of taxonomic richness is attributable to factors such as tectonic uplift followed by geographic isolation, glaciation/ glacial retreat, habitat heterogeneity and varied history of migrations and evolution (Kikuchi & Ohba 1988; Miehe 1988; Körner 1995).

STRUCTURAL AND FLORAL COMPOSITION OF ALPINE SIKKIM

The total number of flowering plant species enumerated from alpine EH was 1700 ± 200 species with 430 ± 10 genera and 73 ± 5 families. The alpine zone of Sikkim Himalaya harbored 1300 species, belonging to 297 genera and 60 families. On a broad basis the vegetation of the alpine Sikkim can be classified into three major bands moving towards north which can be categorized as: (i) **AB1**: lower altitudinal alpine zone (Shrubland); (ii) **AB2**: intermediate altitudinal alpine zone (meadows); and (iii) **AB3**: highest altitudinal alpine zone (trans-Himalayan alpine steppe). Varied plant life forms and community organizations can be observed for all these alpine bands. The AB1 is dominated by phanerophytes and chaemophytes, AB2 is dominated by geophytes, hemicryptophytes and cryptophytes and AB3 is dominated by hemicryptophytes.

The available plant life form in the region include cushion forming communities such as *Arenaria polytrichoides*, *Anaphalis cavei*, *Leontopodium monocephalum, L. brachyactis,* and *Arenaria bryophylla*, graminoids such as *Kobresia royleana, K. nepalensis, K. cappilifolia, Agrostis sp.* and *Calamagrostis sp.*, tussocks or tufts such as *Kobresia schoenoidesa, Carex parva* and *Stipa purpurea;* 'solifluction acrobats' (Meihe 1996) adapted to unstable scree with long roots and stems trailing along the snow and debris (e.g., *Gentiana urnula, Eriophytum wallichii*, and *Veronica lanuginosa*); herbaceous perennials or geophytes and therophytes (e.g., *Aconitum heterophyllum, Aletris pauciflora*, *Bistorta macrophylla, Cortia depressa, Cynanthus incanus)*; low-growing creeping prostrate woody shrubs or dwarf-shrubs or chamaephytes (e.g., *Cotoneaster* sp., *Lonicera* spp., *Spiraea arcuata, Hippophae tibetana, Potentilla fruticosa*); and dense wooly forms (e.g., *Saussurea graminifolia, S. sericea, S. graminifolia, Onsoma hookeri, Glechoma nivalis*). Some of the prominent representative species and plant life-forms of alpine Sikkim Himalaya are given in **Fig. 10**.

IMPACT OF WARMING ON ALPINE FLORA OF SIKKIM HIMALAYA

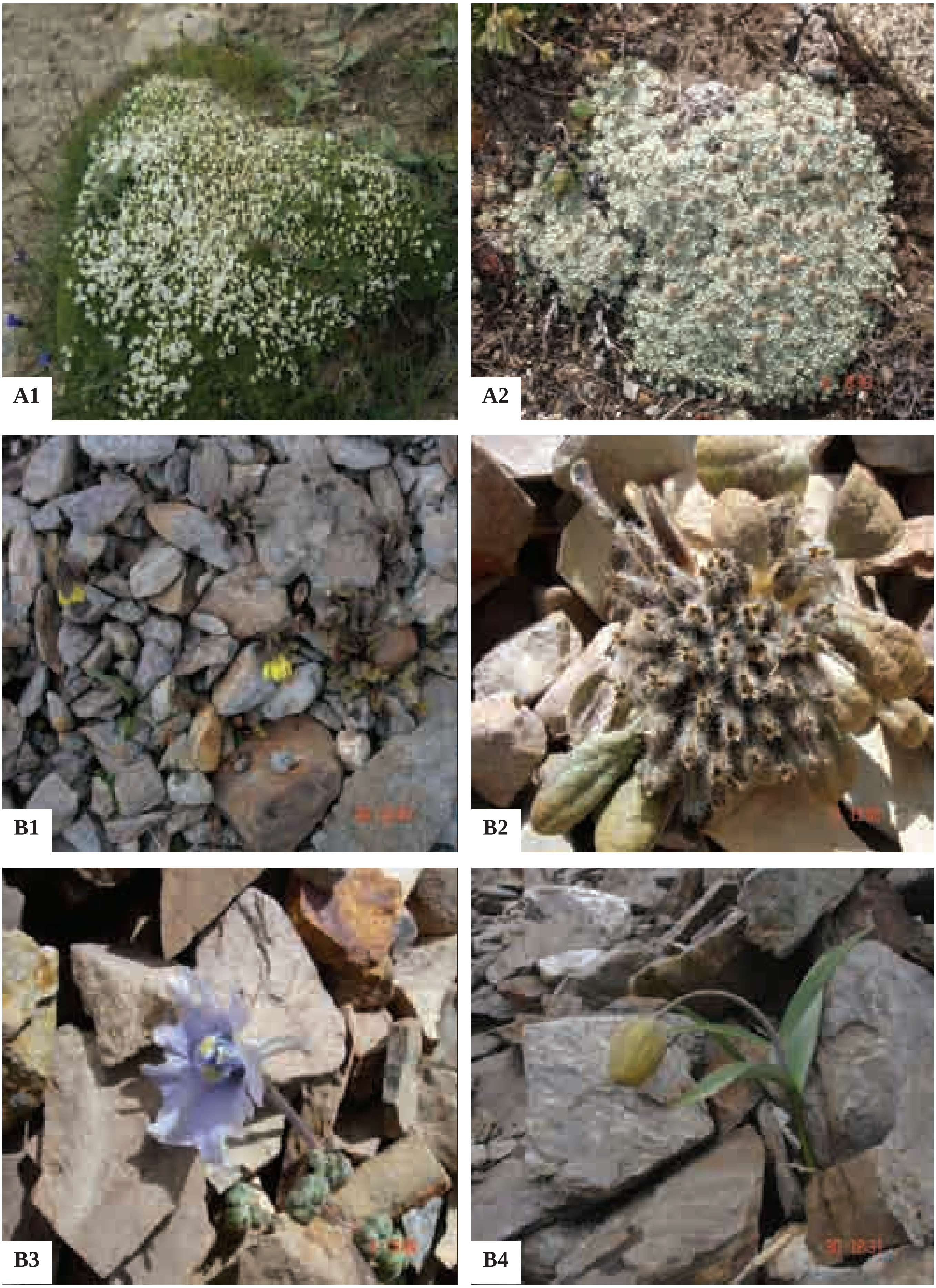
Alpine plant life is proliferating and the mountain world appears to be changing at a rate higher than ever and considering the warming trends in Sikkim Himalaya it is going to be no exception. The warming of the Sikkim Himalaya during the last century has resulted into upward migration of the range margins of the species from AB1 zone. With the projected future warming, the Environmental Niche Model predicts that the area of AB1 will increase further. The model predicts more greener and dense AB1 zone under 2050 and 2080 climatic warming scenarios. The AB2 zone of alpine meadows occupies the ecotone between lower elevation shrubland and the higher elevation alpine steppe. The alpine meadows harbor the highest species richness amongst the three elevational zone in the Sikkim Himalaya. The increased species richness in the recent times is attributable to the migration of shrubs from the lower elevational zone of AB1. It is plausible to suggest that these ingressions and early colonization of shrub elements in alpine meadows reflect northward migration of woody elements under the impact of warming. The alpine steppe (AB3) are characteristically different from those of lower and intermediate elevation zones as the species of the region are more characteristic of the Tibetan elements than Eastern Himalayan. The Environmental Niche Model (ENM) predicts decrease in total area of the extreme northward alpine steppe under warmer and moister climatic condition by 2050 and 2080. The most conspicuous model output is the contraction and transformation of alpine steppe communities into alpine meadows.

Lastly, and more importantly, the endemic species occupying the highest elevational bands (5000- 5500 m) and having narrow range extents (less than 500 m) are likely to face extirpation because no more areas are available for the spatial redistribution of such species. Here it should be noted that this prediction turns more crucial under the fact that the alpine regions of Sikkim occupy many threatened plant species (Table 1). The likely disappearance of these species is likely under the projected climatic warming scenarios in Himalaya.

Thus it is concluded that a general concern can be that the status quo of the mountain habitats in Sikkim is threatened and that projected future warming might cause extensive biodiversity and ecosystem loss. In this respect long-term observational data series focusing on plant-cover responses to climate change are indispensable for generation of ecologically sound, consistent and illustrative facts concerning the potential effects of global climate change on alpine Sikkim Himalaya. Similarly information about vegetation dynamics in the alpine ecosystems is extremely crucial for a comprehensive understanding of their current and possible future states. An understanding of the community patterns and their spatial distribution, especially in relation to the environmental variables is essential to understand specific responses of the alpine communities to global warming. It is important to report and record such events in a timely manner for conservation planning and biodiversity management purposes.

Table 1: The list of the threatened plant species with known occurrences from the alpine regions in Sikkim.

S.No	Plant species	Status	Occurrence
1	*Acronema pseudotenera*	Indeterminate	Momay Samdong (North Sikkim)
2	*Angelica nubigena*	Indeterminate	Chola, Yakla (East Sikkim)
3	*Pternopetalum radiatum*	Indeterminate	Yumthang, Sebu Valley (North Sikkim)
4	*Lactuca cooperi*	Endangered	Sikkim
5	*Areneria thangoensis*	Vulnerable	Thangu, Chugya (Sikkim)
6	*Juncus sikkimensis*	Rare	Sikkim
7	*Lloydia himalensis*	Rare	Sikkim
8	*Aphyllorchis parviflora*	Rare	Lachen, Yumthang (Sikkim)
9	*Didiciea cunninghamii*	Endangered	Lachen valley (Sikkim)
10	*Cypripedium elegans*	Rare	Sikkim
11	*Aconitum ferox*	Vulnerable Endemic	Sikkim
12	*Picrorhiza kurrooa*	Vulnerable	Sikkim
13	*Oreopteris elwesii*	Rare	Lachen (North Sikkim)


A1
A2
B1
B2
B3
B4

C1

C2

D1

D2

E1

E2


F1


F2


G1


G2


H1


H2

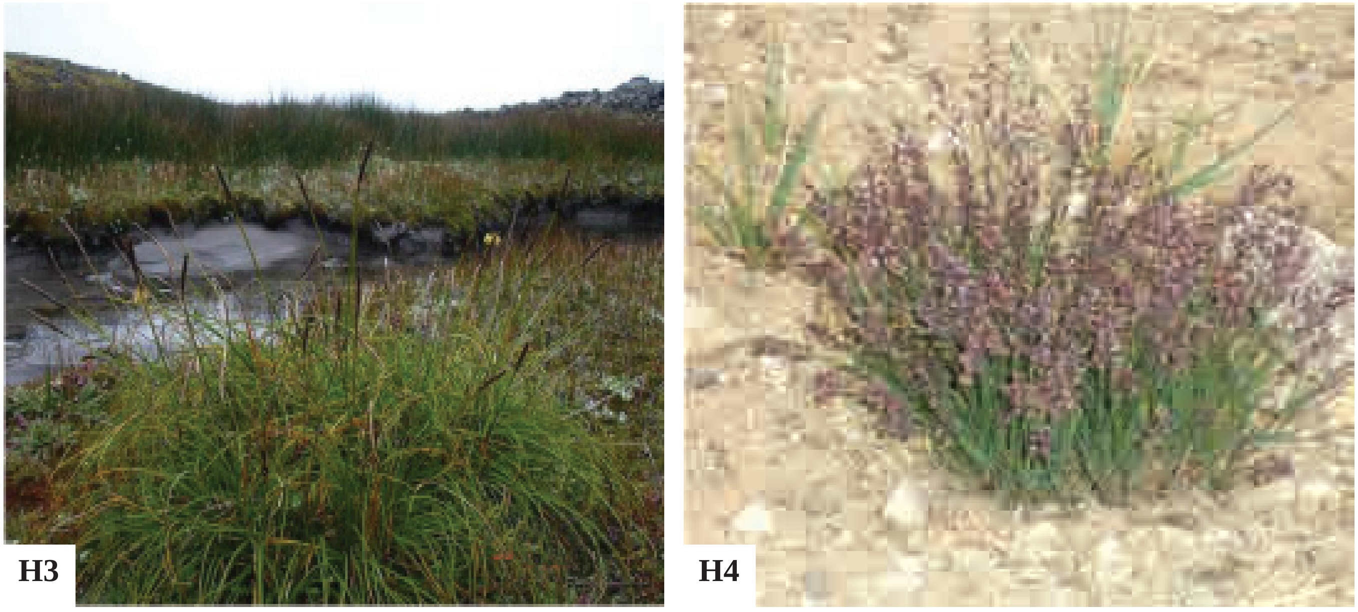


Figure 10: The flowering plants showed varied adaptations in alpine environment in response to low temperature condition. The life forms include cushion-making communities (A1: *Arenaria sp*., A2: *Leontopodium nanum*); 'solifluction acrobats' adapted to unstable scree (B1: *Crementhodium humile*, B2: *Christolea sp*., B3: *Delphinium glaciale*, B4: *Fritillaria delavayi*); low-growing, creeping prostrate woody shrubs or herbs (C1:*Berberis sp*., C2: *Koenigia nummularioides*); grey or silver leaves to reflect damaging UV radiation (D1: *Saussurea gnaphaloides*, D2: *Marmoritis sp*.); desertic characteristics like thorns (E1: *Pycnophyllum sp*., E2: *Prezwalskia tangutica*); reduced size (F1: *Sedum sp*., F2: *Erysimum sp*.). The common life form in the alpine Sikkim include shrubs in AB1 zone (G1: *Rhododendron setosum*, G2: *Salix sikkimensis*); graminoids (grasses, sedges, etc.) tussocks or tufts in AB2 and AB3 zone (H1-*Juncus concinnus*, H2: *Poa calliopsis*, H3: *Kobresia stiebritziana*, H4: *Poa setulosa*)

REFERENCES

Beniston, M. & Rebetez, M. (1996) Regional behavior of minimum temperatures in Switzerland for the period 1979–1993. Theoretical and Applied Climatology, 53(4), 231-43.

Böhm, R., Auer, I., Brunetti., M. (2001) Regional temperature variability in the European Alps: 1760–1998 from homogenized instrumental time series. International Journal of Climatology, 21, 1779-801.

Bucher, A. & Dessens, J. (1991) Secular trends of surface temperatures at an elevated observatory in the Pyrenees. Journal of Climate 4, 859–68.

Cannone, N., Sgorbati, S. & Guglielmin, M. (2007) Unexpected impacts of climate change on alpine vegetation. Frontiers in Ecology and the Environment, 5(7), 360-64.

Cubash, U., Meehl, G.A., Boer, G.J., Stouffer, R.J., Dix, M., Noda, A., Senior, C.A., Raper, S. &

Yap, K.S. (2001) Projections of Future Climate Change Cambridge University Press, Cambridge, United Kingdon and New York, NY, USA.

Diaz, H.F., Grosjean, M. & Graumlich, L. (2003) Climate variability and change in high elevation regions: past, present and future. Climatic Change, 59(1), 1-4.

Edward, R.C., Paul, J.K. & Philip, D.J. (2003) Dendroclimatic signals in long tree-ring chronologies from the Himalayas of Nepal. International Journal of Climatology, 23(7), 707-32.

Folland, C.K., Karl, T.R., Christy, J.R., Clarke, R.A., Gruza, J., Jouzel, G.V., Mann, M.E., Oerlemans, J., Salinger , M.J. & Wang, S.W. (2001) Observed climate variability and change. In: Climate Change 2001: The scientific basis. Contribution of working group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press.

Corydalis meifolia is found in the high altitude passes and scree zone of the Sikkim Himalaya

Gou, X., Chen, F., Jacoby, G., Cook, E., Yang, M., Peng, J. & Zhang, Y. (2007) Rapid tree growth with respect to the last 400 years in response to climate warming, northeastern Tibetan Plateau. International Journal of Climatology, 27(11), 1497-503.

Grabherr,G., Gottfried, M. & Pauli, H. (2010) Climate Change Impacts in Alpine Environments. Geography Compass 4/8, 1133–1153.

Hadley, K. S. (1987) Vascular alpine plant distributions within the central and southern Rocky Mountains, U.S.A. Arctic and Alpine Research, 19, 242-51.

Hickling, R., Roy, D.B., Hill, J.K. & Thomas, C.D. (2005) A northward shift of range margins in British Odonata. Global Change Biology, 11(3), 502-06.

Kelly, A.E. & Goulden, M.L. (2008) Rapid shifts in plant distribution with recent climate change. Proceedings of the National Academy of Sciences, 105(33), 11823-26.

Kikuchi, T. & Ohba, H. (1988) Preliminary study of alpine vegetation of the Himalayas, with special reference to the small-scale distribution patterns of plant communities University of Tokyo Press.

Klanderud, K. & Totland, Ã.r. (2005) Simulated climate change altered dominance hierarchies and diversity of an alpine biodiversity hotspot. Ecology, 86(8), 2047-54.

Körner, C. & Paulsen, J. (2003) A world-wide study of high altitude treeline temperatures. Journal of Biogeography, 31(5), 713-32.

Körner, C. (1995) Alpine Plant Diversity: A global survey and functional interpretations. Ecological studies (113), 45-62.

Körner, C. (1999) Alpine plant life Berlin: Springer Verlag.

Krabill, W., Abdalati, W., Frederick, E., Manizade, S., Martin, C., Sonntag, J., Swift, R., Thomas, R., Wright, W. & Yungel, J. (2000) Greenland ice sheet: High-elevation balance and peripheral thinning. Science, 289(5478), 428-30.

Lesica, P. & Steele, B.M. (1996) A method for monitoring long-term population trends: An example using rare arctic-alpine plants. Ecological Applications, 6(3), 879-87.

Liu, X. & Chen, B. (2000) Climatic warming in the Tibetan Plateau during recent decades. International Journal of Climatology, 20(14), 1729-42.

Lowell, T.V. (2000) As climate changes, so do glaciers. Proceedings of the National Academy of Sciences of the United States of America, 97(4), 1351-54.

Mark, A.F. & Adams, N.M (1973). New Zealand Alpine Plants. A. H. & A. W. Reed, Wellington.

Miehe, G. (1988) Vegetation patterns on Mount Everest as influenced by monsoon and föhn. Vegetatio, 79(1/2), 21-32.

Nogués-Bravo, D., Araújo, M.B., Errea, M.P. & Martínez-Rica, J.P. (2006) Exposure of global mountain systems to climate warming during the 21st Century. Global Environmental Change, 17(3-4), 420-28.

Overpeck, J., Hughen, K., Hardy, D., Bradley, R., Case, R., Douglas, M., Finney, B., Gajewski, K., Jacoby, G., Jennings, A., Lamoureux, S., Lasca, A., MacDonald, G., Moore, J., Retelle, M., Smith, S., Wolfe, A. & Zielinski, G. (1997) Arctic environmental change of the last four centuries. Science, 278(5341), 1251-56.

Ozenda, P. (1993) Endemism at the level of the whole European Alpine System. Acta Botanica Gallica, 142 (7), 753-62.

Pandit, M., Sodhi, N., Koh, L., Bhaskar, A. & Brook, B. (2007) Unreported yet massive deforestation driving loss of endemic biodiversity in Indian Himalaya. Biodiversity and Conservation, 16(1), 153-63.

Pauli, H., Gottfried, M., Reiter, K., Klettner, C. & Grabherr, G. (2007) Signals of range expansions and contractions of vascular plants in the high Alps: observations (1994-2004) at the GLORIA master site Schrankogel, Tyrol, Austria. Global Change Biology, 13, 147-56.

Ramaswamy, V., & Coauthors, (2001): Radiative forcing of climate change. Climate Change 2001: The Scientific Basis, J. T. Houghton et al. Eds., Cambridge University Press, 350–416.

Shrestha, A.B., Wake, C.P., Mayewski, P.A. & Dibb, J.E. (1999) Maximum Temperature Trends in the Himalaya and Its Vicinity: An Analysis Based on Temperature Records from Nepal for the Period 1971& 8211; 94. Journal of climate, 12(9), 2775-86.

Stott, P.A., Tett, S.F.B., Jones, G.S., Allen, M.R., Mitchell, J.F.B. & Jenkins, G.J. (2000) External control of 20th century temperature by natural and anthropogenic forcings. Science, 290(5499), 2133-37.

Theurillat, J.P. & Guisan, A. (2001) Potential impact of climate change on vegetation in the European Alps: A Review. Climatic Change, 50, 77-109.

Viviroli, D. & Weingartner, R. (2004). The hydrological significance of mountains: from regional to global scale. Hydrology and Earth System Sciences, 8(6), 1017-30.

Vuille, M. & Bradley, R.S. (2000) Mean annual temperature trends and their vertical structure in the tropical Andes. Geophysical Research Letter, 27(23), 3885-88.

Walther, G.R. (2003) Plants in a warmer world. Perspectives in plant ecology, evolution and systematics, 6(3), 169-85.

Walther, G.R., Beißnera, S., & Burga, C.A. (2005) Trends in the upward shift of alpine plants Journal of Vegetation Science, 16(5), 541-48.

Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.M., Hoegh-Guldberg, O. & Bairlein, F. (2002) Ecological responses to recent climate change. Nature, 416 (6879), 389-95.

Warrick, R.A., Barrow, E.M. & Wigley, T.M.L. (1993) Climate and sea level change: observations, projections and implications. xvi, 424p. Cambridge University Press.

Widmann M. & Tett S.E.B. (2003) Simulating the climate in the last millennium. PAGES News, 11, 21-23.

Wilson, J.B. & Roxburgh, S.H. (2001) Intrinsic guild structure: determination from competition experiments. Oikos, 92(1), 189-92.

Woodwell, G.M. (2004) Mountains: top down. Ambio Supplement 13, 35–38.

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Caltha alba occurs in the alpine meadows near Kishong lake in North Sikkim