Impact of climate change on floral composition in the Western Himalayan region and adaptive strategies thereof

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Introduction

The Himalayan region is the planet's highest ecosystems, and home to the world's diverse and unique genetic diversity. India's recognition as a 'mega-biodiversity' country derives partly from the Himalaya distinguished as a global biodiversity 'hotspot' wherein out of 6000 endemic plant species, 2532 species occur (Rao, 1994). The floristic diversity according to Nair (1977) 35% consist of South-East Asian & Malayan, 8% temperate, 1% steppe, 2% African and 5% Mediterranean and Iranian elements. Owing to huge temporal and spatial variations in its climate and physiographic conditions, the Western Himalayan region houses five agro-ecosystems out of 21 agro-ecosystems exists in India (Sehgal et al., 1990). The floristic diversity is further enriched through variety of traditional agro-ecosystems, human ethnic races and other wild forms. The mountain flora has evolved under the extremities of weather particularly the low temperature and toady the same flora is under the influence of climatic warming. It is a paradox that an 'improvement' in conditions which were thought of as 'harsh' before, is suddenly considered dangerous (Korner, 2009). Thus, the real issue is that the ongoing and expected climatic changes are much faster than what evolution and migration are commonly able to track. The scientists have found 'mountain regions' as excellent laboratories to study the impact of climate change because no other single region in the world provides a better picture of structural variation of vegetation under the influence of altitude. This paper is based on preliminary studies conducted on the impact of rising temperature and altered precipitation/snow on vegetation structure including alien invasive weeds, alterations in phonology of plants and rejuvenation ability of some temperate species. The study is still continuing to come out with more valid conclusion on the impact of climate change on the vegetation structure.

Physiographic features of the Western Himalayan region

The Western Himalaya have four major physiographic regions, namely (i) Shivalik hills or outer Himalaya (up to 1000m); (ii) Middle or lesser Himalaya (~60 to 80km wide and altitude averaging 2000m); (iii) inner or greater Himalaya (~120 to 140km in width and altitude averaging 3500m, and (iv) Trans-Himalayan region (~40km wide and includes arid, temperate areas of Ladakh Division, upper Kinnaur, Lahual–Spiti, Bharmour and Pangi in Chamba and beyond Niti and Mana in Chamoli and Uttarakashi in Uttarakhnad. These are further sub divided into ten sub zones (Sidhu *et al.*, 1997) based on rainfall, potential evaporation, actual evaporation, length of crop growing in agriculture, soils and water hydrology. The region is, however, comparatively drier, hence characterized by drought hardy and cold loving plants.

Floristic diversity

The variation in altitude, climate, topography and edaphic conditions, account for nine major forest types out of the total 16 types that occur in India (Champion and Seth, 1968). The vegetation comprising evergreen forests with pure stands of deodar (*Cedrus deodara*) fir (*Abies pindrow*), spruce (*Picea smithiana*), blue pine (*Pinus wallichiana*) and also found mixed with Ban oak (*Quercus leucotrichophora*) Moru oak (*Quercus himalayana*), Kharsu oak (*Quercus semicarpifolia*), Rhododendron, Juniper and *Betula* in the temperate to sub alpine region. In the Siwalik, the vegetation comprises *Acacia* forest and *Bauhinia* species, mixed with semi evergreen forest and sub-tropical chir pine (*Pinus roxburghii*) while broad leaved are dominated by *Shorea robusta* with *Dalbergia sissoo*, *Mallotus philippinensis*, *Toona ciliata*, *Eucalyptus*, *Ficus* sp , *Jacaranda* sp., and some fruit plantations.

Agro-forestry specie like *Grewia* species, *Morus* species, *Bamboos, Bombax ceiba, Albizia siris, Celtis australis* are important in the agricultural landscape.

Under storey vegetation dominated by shrub species such as *Lantana camara*, *Carissa spinarium, Murraya koenigii, Myrsine Africana, Berberis asiatica, Rubus ellipticus, Justicia adhatoda, Dodonea viscosa, Juniperus communis* and *Rosa webbiana*. Among herbs, many essential oils yielding and medicinal plants such as *Aconitum* species, *Dactylorhiza hatagirea*, *Picrorhiza kurrooa*, *Rheum australe*, *Ephedra gerardiana*, *Hyoscyamus niger*, *Atropa acuminata*, *Podophyllum hexandrum*, *Saussurea lappa*, *Gentiana kurroo* and other grass and weedy plant species like *Ageratum conyzoides* and *Parthenium hysterophorus, Cynodon, Arundinaria, Bothriochloa, Chrysopogon, Cymbopogon, Casia* and many flowering annuals dominate the vegetation.

The region is equally rich in domesticated plant biodiversity as it houses about 135 cultivated plant species and 360 wild edible food plants, which may be source of fruits, flowers, flower buds, leaves, leafy tops, roots, stems or tubers etc (Sharma and Rana, 2005). The important genera dominate the domesticated species are *Pyrus, Prunus, Sorbus, Ribes, Rubus, Hordeum, Elymus, Eremopyrum, Avena, Aegilops, Allium, Vicia, Lepidium, Carum, Bunium, Linum, Cicer, Cucumis* and *Trichosanthes.* The rich genetic variability also occur in wheat, maize, rice, barley, buckwheat, amaranth, chenopods, proso-millets, field peas, lentil, faba bean, french bean and rajmash.

Material and Methods

The study sites were selected in Shimla and Kinnaur districts where floral boundaries and/or floral shifts are visible and also represent areas with less human disturbances. Since about decade, this region has witnessed sea changes in the land use and cropping patterns. Further accurate records of plant distribution before 100 yrs (Collet, 1902) for most of the areas along with meteorological data are available. Sampling strata decided based on the differences in growth form, physiognomy and structure of the vegetation and variation in dominant species (Mishra et al., 1980). Surveys to sites were conducted and vegetation analysis was carried out by laying random quadrat of 10x10 m size for trees layers and each quadrat was further subdivided into 5m x 5m and 1m x 1m sample plots to examine the shrubs and herbs, respectively. The structured questionnaire to collect information from people on the change in vegetation and land use patterns due to climate change or anthropogenic factors also prepared used.

Results and Discussion

The climatic factors such as temperature and precipitation change in a region beyond the tolerance of a species phenotypic plasticity, then distribution changes of the species may be inevitable (Lynch and Lande, 1993). There is already strong evidence that plant species are shifting their ranges in altitude and latitude as a response to changing regional climates (Parmesan and Yohe, 2003; Walther et al., 2002). The present study showed that the hill ecosystem is highly vulnerable both due to geological reasons and increased anthropogenic pressures and these effects may well be exacerbated due to the impact of climate change occurring mainly through increased temperature and altered precipitation patterns. Warming trend is evident from sayings of age-old households and past references; apt to mention few: “snowfall occurs in Garhwal at 4000ft whereas in extreme west Himalaya, it is still lower” (Hooker and Thompson, 1855), “If there is no rainfall, Shimla temperature raises as high as 26.7°C in shade” (Thompson c. 1840 in Collet, 1902), “Spring begins in Shimla in April” (Gamble c. 1890 in Collet, 1902), etc,. In contrast, presently in western Himalaya, temperate belt ranges from 1800m (lowest altitude of possible snowfall) to 3700m asl (where tree-line ceases), temperature goes up to 30°C and spring starts in second fortnight of March. The climatic records of Shimla show warming of 0.54°C in the past 100 years (Dubey et al., 2003). Mean annual temperature of 13^0C and 12 frost free days are added for the past 100 years 1900-1999 in Skardu region of Pakistan (Archer, 2001).

Upward shift of plant species and change in composition

In this context, it was observed that many typical temperate species reported a century back as common are not at all traceable in their original locality, rather found either in their upper limit or occur at higher elevation than the original locality and/or with shrunken distribution. For instance, *Aconitum heterophyllum, Lilium polyphyllum, Sorbus lanata, Swertia chirayita, Androsace* spp., etc. as frequented by Collet in 1902 in and around Shimla hills are not being observed now. Instead, they are found at 600-800m above. Three plants viz. *Aconitum heterophyllum, Lilium polyphyllum,* and *Swertia chirayita* were searched for three years in their mentioned locations, but we could not collect even a single plant. This excludes the impact of human factor because some locations still have zero external disturbances. Shift in cultivation of apple towards higher elevation due to reduced chilling hours and cultivation of cabbage, peas, and other flowers and vegetables because of increased temperature and consequently lengthened growing period in cold arid region also witnessed the change in cropping patterns. This supports the claim that rising temperature and poor chilling has caused shift and change in cropping patterns.

Many of the lower elevation plants now occur in higher altitude *viz*. *Pinus longifolia* (100yrs back upper altitude in record is 1800 vs. current 2200m), *Woodfordia fructicosa* (1500 vs. 2000m), *Boehmeria platyphylla* (1500 vs. 2200m), etc. Also rise in tree-line is evident from few plants such as *Cotoneaster microphylla* (3700 vs. 4400m), *Betula utilis* (3500 vs. 4000m), *Pinus wallichiana* (3000 vs. 3800m). Evidence of upward migration of vascular plants and progressive replacement of cold temperate ecosystem by Mediterranean ecosystem was observed at high mountain sites in the Alps (Penuelas and Boade, 2003). Upward movement and subsequent colonization as regular member especially of families such as Caryophyllaceae, Compositae and Chenopodiaceae at higher elevation was observed in north-western Himalayan region (Mani, 1978). Dubey *et al.* (2003) observed higher rate (19m/decade on south and 14m/decade on north slope) of upward shift of *Pinus wallichiana* at Saram, Parbati valley (HP) in comparison to other species records in Alps and elsewhere, where maximum upward migration has been recorded to be around 4m/decade (Grabherr et al., 1994; McCarthy et al., 2001). Long term distributional changes in plants due to climatic change were reported by many workers (Ross et al., 1994; Sturm et al., 2001; Chapin et al., 1995; Turner, 1990; Warren and Niering, 1993). According to Coope (1995), most of the species appeared to shift their distribution through tracking the changing climate, rather than staying stationary and evolving new form. It is predicted that climate change will remain one of the major drivers of biodiversity patterns in the future (Sala et al. 2000; MEA 2005 and Pressey et al. 2007) and middle zones would be of great importance for identifying possible future boundary shifts and predicting the fate of species in the higher altitudes (Kazakis et al*.,* 2006).

On the contrary, the species inhabiting alpine tops in the cold arid region are narrowly distributed and have limited scope to march upwards with the temperature rise, thus facing highest risk of extinction. Species depending on snow cover for protection would be exposed to frost (being experienced in Sangla valley for the last 2-3 years), and others which require winter chilling for bud-break may not get sufficiently low temperature over sufficiently long period (Benniston 2003, Parmesan and Galbraith 2004. For instance, important economic plants of alpine and cold arid region such as sea buckthorn (*Hippophae* sp.), Bhojpatra (*Betula utilis*), *Cotoneaster* sp. *Juniper* sp., *Cicer microphyllum, Linum perenne, Arnebia benthamii, Nordostychus jatamansi* etc. are narrowly distributed thus are highly vulnerable. It is further argued that these species lacks suitable corridors to move in the response of changing weather conditions. Under the circumstances, it will likely be critical to protect migration corridors and elevation gradients or even conservationists will likely need to transplant some rare species to new locations – either in the wild or in botanic gardens – that have appropriate climate conditions. The rhododendrons and other woody species of lower ranges have begun to invade alpine meadows, thus composition of plants in meadows is certainly going to change. In brief, the alpine belt is likely to be affected by several factors including glaciers melt, enhanced hydrological cycle, erosion and others mass movements, species migration and more movements of people.

Change in phenological responses

Changing environments are expected to lead to changes in life cycle events, and these have been recorded for many species of plants (Parmesan and Yohe, 2003). Many plant species are also responding to climate change by advancing the onset of leaf burst, flowering, and fruiting, delaying leaf drop and insect pollinated plants flowering earlier than wind pollinated plants (Fitter and Fitter, 2002; Willis et al. 2008; Menzel and Fabian, 1999; Menzel 2000). In some cases like *Erigeron mutlicaulis*, *Thymus serphyllum* and *Dicliptera bupleuroides*, flowering period as mentioned by Collet (1902) in 'Flora Simlensis' is seemingly altered. The data recorded on different varieties of peach, apple and kiwi showed that flowering was considerably delayed in the year 2008 when winter temperature was very low while it was early in 2006 and 2009 when winters were comparatively warmer (Table 1). The Rhododendrons flowered in early February in 2009 than early to mid March in previous years at Shimla. The overall average advancement of flowering of 2.5 days was statistically related to a local increase in night time temperature of 0.2-1.2^{0}C in 89 species (Abu-Asab et al., 2001).

Table 1. Minimum and maximum temperature and corresponding date of flowering in peach, apple and kiwi from 2005-2009

Month	**Min. & Max. temperature (^{o}C)**				
	2005	**2006**	**2007**	**2008**	**2009**
December	6.8-16.3	2.4-16.8	3.5-15.9	8.5-17.5	10.6-19.2
January	0.4-11.7	4.1-12.5	0.8-20.5	-1.7-17.3	5.5-20.6
February	3.1-11.8	3.2-17.0	-0.2-18.1	-0.4-21.8	5.0-24.8
March	7.3-17.9	7.5-21.3	0.2-25.8	8.2-23.1	10.0-27.4
Peach					
Flordasun	4.2.2006	1.2.2006	14.2.2007	16.2.2008	28.1.2009
Apple					
Oragun spur	22.2.2005	18.3.2006	10.4.2007	15.4.2008	2.3.2009
Kiwi	5.4.2005	1.4.2006	10.4.2007	12.4.2008	14.3.2009

Overall spring flowering events have advanced by 8 days over the past 60 years in Canada (Beaubien and Freeland, 2000). In Boreal region, a 12 days longer greening period was reported in a 20 year study from 1981-1999 (Myneni et al., 1997, Zhou et al., 2001 and Lucht et al., 2002) while in Japan cherries are currently flowering earlier than they have at any time during the previous 1200 years, probably the longest annual record of phenology from anyplace in the world (Richard et al., 2009).

Effects on regeneration of species

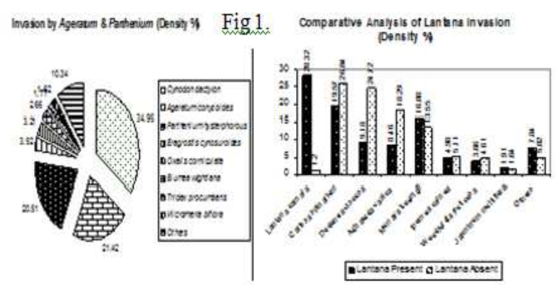
The temperate species in general require chilling or otherwise stratification (remained under snow for 2-3 months) of seeds to germinate. If such conditions are not met, the rejuvenation of species hammered largely. The data collected on the number of saplings and adult plants of *Quercus leucotrichophora*, *Rhododendron arboreum* and *Cedrus deodara* in the Shimla forests showed considerable reduction in the number of saplings compared to adult trees (Table 2). In the alpine region, big trees are noticed in their original distribution but not the saplings and the juvenile stages in case of *Prunus cornuta, Corylus jacquemontii* and *Pinus gerardiana*. These species would find difficult to regenerate and march upward in such a situation. The poor winter precipitation also hammers seed germination of many species, for instance, the number of individuals of *Cyclanthera brachystachya* (meetha karela) reduced significantly in the year 2009 as compared to 2007 and 2008 because of poor precipitation in winter. Similarly, the fruit set in temperate fruits was reduced by 40-80% as compared to normal years (observations made at experimental farm of NBPGR RS Shimla). These climatic variation have also been reported to cause new genetic and morphological characters which could result in the evolution of new

Altitudinal range	Plant Species	No. of saplings	No of adult tree
1500-2000 m	*Quercus leucotrichophora*	28	154
	Rhododendron arboreum	2	14
	Cedrus deodara	18	40
2000-2500 m	*Quercus leucotrichophora*	17	45
	Rhododendron arboreum	6	20
	Cedrus deodara	32	116

phenotypes within a particular population (Bor, 1960). We noticed various morphological forms of *Malus baccata, Vigna vexillata, Cotoneaster microphylla, Pyrus pashia* in western Himalaya.

Alien invasive weedy species

Biological invasion of native flora in agriculture and forest land use, waste and community lands, road sides, railway tracks and wetlands is becoming of increasing concern worldwide, and may have gene pool to ecosystem wide impacts (Drake et al 1989; Raybould and Gray 1994; Honig et al., 1992). The convention on Biological Diversity (CBD) 1992 has recognized biological invasion as second worst threat to biodiversity after habitat destruction (Jenkins 1999); it may soon surpass the damage done by habitat destruction and fragmentation (Reddy, 2008). This hill regions had not witnessed much biological invasions till 1970s, but in the last about 30 years the three most invasive species viz. *Lantana camara* (lantana), *Parthenium hysterophorus* (congress grass) and *Ageratum conyzoides* (billygoat-weed) have invaded and altered community structure and population dynamics of native flora and fauna of the Shivalik hills. And scores of others like *Ageratina adenophora* (crofton weed), *Bidens pilosa* (hairy beggarticks), *Polygonum polystachyum* (the Himalayan knotweed), *Solanum chacoense* (wild potato) and *Cyclanthera brachystachya* (meetha karela) are at an early stage of invasion even at higher elevations, attributed mainly to rising temperature. The study showed that the individuals of species like *Lantana* and *Parthenium* have not only outnumbered the native vegetation but have shifted upwards. The vegetation analysis in Shiwalik hills showed that *Lantana camara* constituted 28.32% of the total shrub species while *Ageratum conyzoides* (21.42%) and *Parthenium hysterophorus* (20.51%) together accounted for 41.93% of the total herb species (Fig 1). The populations of economic plants like *Carissa spinarium, Adhatoda vasica, Dodonea viscosa, Cassia tora*, many grasses, medicinal herbs and wild flowers has reduced significantly (Fig 1).



Adaptation strategies

With so many evidences of rising temperature, the argument would be – what kind of adaptive strategies we shall be looking for. Before, we jump to formulate any adaptive strategy, the climate change has to be understood holistically in terms of 'cause and affect' relationship. Climate change has been there in the history rather I would say 'the lovely planet mother earth' is a result of climate change i.e. from a fire boll to cool and calm lap. But, what happened in the last say 50 years that we have become so worried? The climate change is in fact an 'outcome or result' of large number of anthropogenic factors with which humanity is well versed. At present, the rate at which demographic and sociopolitical changes are taking place in response to global changes is outstripping the ability of species, traditional approaches and coping mechanisms to respond. Therefore, any adaptive strategy formulated without taking into consideration these anthropogenic factors, will not work to mitigate the expected impacts of climate change.

Nevertheless, scientist need to identify several traits associated with tolerance to abiotic stresses and other phenmoics attributes. Substantial variation in root traits, water use efficiency, amount of water transpired, transpiration efficiency, osmotic adjustment, stem water soluble carbohydrates, stay-green, and leaf abscisic acid have been reported in many plant species. There are significant new demands for crop improvement programmes to combat climate change, focused on the development of varieties with greater resistance levels to abiotic extremes and relevant to problems and conditions 10-15 years down the line. We also need to develop high resolution models, comprehensive and accurate set of data, accurate assessment of different ecological and weather parameters, their frequency of re-occurrence and stability as well and construction of different weather scenario over time, diagnostic studies on vulnerability and adaptation to climate change in the context of sustainable development, identification of species specific climate sensitive ecological niches. Plant migrations suggest that some species will likely migrate to areas with appropriate climates, but many plant species will not be able to migrate fast enough to keep pace with current rates of warming especially poor competitors, species with narrow distribution (cold arid region) and most of the high valued species have least adaptability, hence highly vulnerable. Particular attention needs to be paid to those species on which people livelihoods are currently depend, and who would be the least able to adapt in the absence of concerted public action to the contrary. Domesticated plant biodiversity need to be promoted and maintained on farm so that genes can continue to evolve, adopt and respond to the expected climatic changes. Indigenous diversity possessing genes and combination of genes for desirable traits provide a buffer output in times of drought, flood and disease attacks. Support farmers to continue developing locally adapted genotypes though on farm management which relies on farmers' long practiced experimentation and knowledge. Conserve the optimum level of diversity *ex situ* as backup / insurance to climate change and improved communication and dissemination of knowledge of climate changes and options to adapt to them

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