A rapid inventory of indicators of climate change in the middle Himalaya

The role of anthropogenic activities on climate change has emerged as a much debated issue globally. Although the climate has always been changing, and species and ecosystems have responded to these changes, it is the rapidly increasing rate of climate change which has been of concern to the global community of late[1]. The Copenhagen climate change summit, held in December 2009, amply demonstrated the fact that climate change is one of the major challenges being faced by the international community[2]. Studies on climate change have indicated that global average temperature has shown an increase of approximately 1.4°F since the early 20th century[3]. Similarly, global mean sea levels have been rising at an average rate of approximately 1.7 mm/yr over the past 100 years. Warming temperatures have also led to the melting of glaciers and ice sheets, and the rate of the glacial retreat has increased in the past decade[4–7]. The increasing concern is that the future rate of climate change will be much faster than in the past and will produce combinations of temperature and precipitation that have no previous analogues[8]. The resulting adjustments by species to the changing climate and accompanying disturbance regimes will challenge our ability to use available natural resources[8], more of the adaptation strategies than mitigation. The Bali Action Plan identifies adaptation as one of the building blocks required for a strengthened future response to climate change[9,10]. Consequently, it is imperative for nations to prepare, develop and implement their national adaptation strategies.

Already there are evidences to indicate that the Himalayan region is warming at a higher rate than the global average rate[3,11]. As a consequence, many important forest species are likely to fail to regenerate if the synchrony between their seed ripening and commencement of monsoon rains is broken due to climate change[12]. Studies have suggested that changes in plant phenology (like advancement of flowering in *Rhododendron arboreum*) and movement of species (like *Tagetis minuta, Lantana camara* and *Eupatorium* spp.) to higher ridges may be the earliest responses to modest climate change[13,14].

The present study has been taken up for a rapid inventory of such changes occurring in the middle Himalaya. Villages and nearby forests between altitudes 600 and 2200 m were visited for the study (Figure 1). The survey was mostly through door-to-door personal interviews with individual households ($n = 42$) covering various age groups, gender mixes, different occupations with emphasis on older persons, and direct field labourers. An open-ended questionnaire was designed to identify the evidences of changes in climate for the past decade, impact of cropping pattern, vegetation types and regular lifestyle. The responses were validated by matching them from different groups. The survey was conducted during October–December 2009 to collect the indicators and evidences of impact of climate change, if any.

One of the main findings of the study was the preponderance of invasive alien species in most of the forest areas in the region. The presence of *Eupatorium* sp. (locally called Kaali ghaas and Cancer ghaas) in both open and degraded forests as well as some of the well-stocked forests was reported (about 5–10 years back) by most of the locals in the study area. It was also reported that whereas earlier the species was confined to an altitude of 1000 m, it has slowly invaded areas up to an altitude of 1800 m, preferring wet and moist regions; in contrast to the other major invasive alien species, *L. camara* which prefers open, sunny areas. Most open, degraded areas and sunny blanks in the forests, even up to altitudes of 1500 m, are infested with *L. camara* which, due to the increasing dry spells in the winters, is moving upwards.

The survey also showed that flowering in *Rhododendron* (*R. arboreum*) is reported to be 1–2 months earlier (January–February instead of March–April); at the same time, the size of the flower has reduced from about 7–8 inches to 4–5 inches. Early ripening of berries in the Kaphal tree (*Myrica sapinda*, *Myrica*

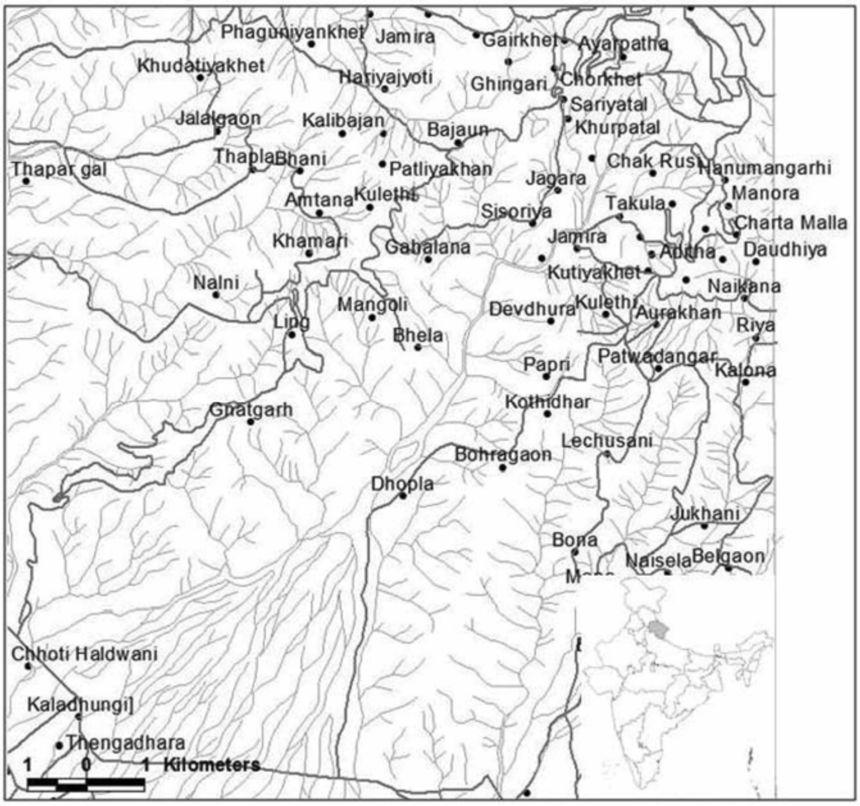

Figure 1. Location of the study area.

nagi), from May–June to March–April also reflects the phenological changes taking place in tree species of the area. Other wild berries like Hinsalu (*Rubus ellipticus*) have also shown signs of early, but reduced fruiting and an overall reduction in total yield. Traditional and important tree fodder species like Utees (*Alnus nepalensis*), Kwiral (*Bauhinia variegata*), Kanol (*Bauhinia purpurea*), Gethi (*Boehmeria regulosa*), Garur (*Olea glandulifera*), Sandan (*Oogenia oogenesis*), Mehal (*Pyrus pashia*), Chamkharik (*Carpinus viminea*), etc. on which the local communities are heavily dependent, have also shown a marked decline in productivity. However, the possibility of these changes being driven by non-climate factors cannot be ruled out.

In agriculture, the effect of climate change is most noticeable because a majority of the villagers in the area are dependent on rainfall. The common perception of the villagers was that the erratic rainfall pattern has led to a change in the traditional crop patterns and also in the expected yields of major crops and vegetables[15]. It was reported that the prolonged dry spell in winter has delayed the time for sowing of wheat (*Triticum aestivum*). Generally local varieties of wheat are planted in the non-irrigated areas, and hybrid varieties like var. 332 are cultivated in the irrigated area. In some areas wheat had not been sown as late as December. Many farmers reported abandoning the cultivation of wheat in favour of cash crops such as onion, garlic, cabbage, etc., which appears to be more for economic benefits. The yields of other traditional winter crops such as chana (*Cicer arietinum*), masoor (*Lens culinaris*), etc. are also reported to have shown a marked decline in recent years. For the last 5–6 years scanty winter rainfall has been observed in the area, which has not only affected the yield of major winter crops but has also had a bearing on soil fertility, as the absence of run-off water has prevented the flow of nutrient-rich forest litter to the agricultural fields. No snowfall has been reported from village Bajoon (1600 m) for the last 8–10 years. Similarly, there has been no snowfall in Lingadhar settlement of Adhora village (1550 m) since 1993. Earlier good harvest of wheat in the area was attributed to snowfall during winter, but gradually there has been a decline in the yield. Similarly, during the kharif season, reduced yields have been attributed to untimely and unseasonal rainfall, where June–July have been relatively drier, but heavy rainfall has been recorded in late September and October. The latter has specially been highly damaging to the standing crops in the fields. Such an unseasonal rainfall pattern is slowly becoming common in the area, which has led to a disturbance in the crop cycle. Declining yields were also reported in case of urd (*Vigna mungo*), black soyabean (Bhatt; *Glycine max*), etc.

Reduction in yield has also been reported in traditional vegetable crops such as potato, ginger, peas, beans, etc. and at the same time the crop maturation period has shifted 1–2 months earlier. For instance, in Lingadhar settlement, the crop maturation period for potato is now reported to be one month earlier. Earlier, sowing was being done in March, whereas the crop matured in August–September. In recent years, the crop has begun to ripen in July. The yield, however, has reduced from the earlier 2–2.5 tonnes to about 1.2 tonnes for every 80 kg potato tubers planted. The size of Gaderi (*Colocasia esculenta*; type of yam (taro) common in the hills) has reduced over the years and most locals attribute it to the changing weather pattern. It was reported that earlier the size of Gaderi was commonly about 9–10 inches and weighing about 2–3 kg, whereas currently it had reduced to 4–6 inches and its weight has reduced to 250–500 g.

In fruiting trees, both the pear and peach (Nashpati and Aroo), flowering and fruiting have shown changes in recent years. The pear tree (*Pyrus communis*), which flowers in July, has now been observed to show signs of flowering and scant fruiting even in December and January. Similarly, peach (*Prunus persica*), which flowered in March, has also shown signs of flowering and fruiting in December and January. Apiculture had been taken up by a few farmers earlier, but of late it has been reported that there is a decline in apiculture. Though this decline and the overall scarcity of bees is generally attributed to a decline in horticultural crops, pests and the increasing use of chemicals (pesticides) and fertilizers (mostly urea), an equally important factor cited was the abnormally high temperatures during the summer months resulting in a disruption in the bee life cycle.

In the social health front, much evidence could not be collected; however, a general perception towards malaria was seen. Until now *Anopheles* mosquitoes have failed to effectively breed above 1500 m altitude[16]. However, increasing temperatures, along with human movement and transport of food from lowland areas, will promote their upward movement and pose a threat of malaria even at such altitudes.

There is increasing awareness about climate-change issues at the rural level in the hills of the middle Himalaya. Local perceptions are mainly driven by the way climate affects the immediate surroundings and livelihood of the people, rather than from any direct measurements of climate change. Many of the respondents attributed the changes occurring in and around them to erratic rainfall and changes in temperature regimes in the area for the past decade or so. The earlier climate pattern, recognized as normal, included periodic low rainfall during March mid-summer, peak rainfall during July–August, and moderate rainfall/heavy snowfall during December/January. The climate change perceived in recent decades is mainly due to erratic rainfall patterns with little precipitation in March–April, a shift in peak rainfall time from July/August to August/September, and little or late winter precipitation (in January/February). A general increase in summer temperatures is also perceived as leading to drier conditions and water scarcity.

The present study has shown that there is a considerable gap in our knowledge regarding the natural resources, their vulnerability to climate change and the lack of systematic monitoring, documentation or research. Some indicators of climate change in the area have been described above, which need further analysis. These indicators could form the basis of adaptation strategies needed for combating long-term effects of climate change. Developing such adaptation strategies would require a four-tiered structure incorporating global, national, regional and local linkages; with the local linkages being derived from further field studies. Adaptation strategies based on these local indicators would also be crucial in enhancing the UNDP framework, which also supports the use of biotechnology as an adaptation strategy[10]. In addition, adaptation strategies should also involve education of the communities on how to cope with the changes occurring in their immediate environment.

Adaptation strategies should be prepared keeping in view that they will help the community to understand the effect of such changes. Recording and inventorying these changes will be the first step towards developing adaptation strategies.

1. Loarie, S. R., Duffy, P. B., Hamilton, H., Asner, G. P., Field, C. B. and Ackerly, D. D., *Nature*, 2009, **462**, 1052–1055.
2. Editorial, *Nature*, 2009, **462**, 957.
3. Shrestha, A. B., Wake, C. P., Mayewski, P. A. and D. B. J. E., *J. Climate*, 1999, **12**, 2775–2787.
4. Crowley, T. J., *Science*, 2000, **289**, 270–277.
5. Alley, R. B. *et al.*, *Science*, 2003, **299**, 2005–2010.
6. IPCC, *AR4: Climate Change 2007. Mitigation of Climate Change*, Cambridge University Press, Cambridge, 2007.
7. National Climatic Data Center, www.ncdc.noaa.gov/indicators; accessed on 4 January 2010.
8. Spittlehouse, D. L., *For. Chronicle*, 2005, **81**, 691–695.
9. UNFCCC Report on Bali Conference, http://unfcc.int/meeings/cop_13/items; accessed on 4 January 2010.
10. UNDP, *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies, and Measures*, Cambridge University Press, New York, 2004.
11. Jianchu, X., Shrestha, A., Vaidya, R., Eriksson, M. and Hewitt, K., ICIMOD Technical Paper, ICIMOD, Nepal, 2007.
12. Singh, S. P., www.climate-leaders.org/wp-content/upload/climatechange-spsingh.pdf; accessed on 4 January 2010.
13. Moza, M. K. and Bhatnagar, A. K., *Curr. Sci.*, 2005, **89**, 243–244.
14. Maikhuri, R. K., Rao, K. S., Patnaik, S., Saxena, K. G. and Ramakrishna, P. S., *ENVIS Bull. – Himalayan Ecol.*, 2003, **11**, 1–9.
15. Vedwan, N. and Rhodes, R. E., *Climate Res.*, 2001, **19**, 109–117.
16. Craig, M. H., Snow, R. H. and le Sueur, D., *Parasitol. Today*, 1999, **15**, 105–111.

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Elevational reduction of plant species diversity in high altitudes of Garhwal Himalaya, India

Pioneer work of Humboldt in the 19th century initiated interest among the scientists, to collect plants from high altitudes throughout the world[1]. The Himalayan high altitudes having the highest located alpine zones on earth were also explored. Many plant collectors have collected plants from high altitudes of Garhwal Himalaya[2], and the altitudinal distribution of higher plants in the Himalaya has been discussed by some workers[1,3–9].

The term 'high altitude' is used here to indicate land above 3000 m altitude in the Garhwal Himalaya. This land includes the uppermost montane zone, subalpine zone and alpine zone, and constitutes a floristically rich area least disturbed by anthropogenic activities due to inaccessibility and sparse human settlement. The high altitudes are the uppermost vegetated areas on the mountains. Here, the rich higher plant diversity (angiosperms and gymnosperms) of the montane zone gradually reduces to zero through treeline ecotone, alpine zone and nival zones (Figure 1).

The richness of organismic taxa declines with elevation and alpine plant diversity decreases with increasing altitude[2,10,11]. Along altitudinal gradient in subalpine–alpine zones, reduction in the number of species is calculated as 40 species per 100 m elevation[12] for vascular plants; this rate ranges between 15 and 45 species per 100 m in Europe[13]. This rate, surprisingly, does not differ greatly across a wide range of mountains. However, the rate of decline in Indian Himalayan region is not known which we have attempted to find here.

The altitude range of a species is the upper and lower limit of its occurrence[6] on mountain slopes. The altitudinal range or vertical distribution of species occurring above 3000 m asl (high-altitude areas) was determined for various plant species on the basis of: (i) field surveys during 1992–2008 in various high-altitude areas of Garhwal Himalaya; (ii) consultation of three important regional herbaria, viz. Forest Research Institute, Dehradun (DD); Botanical Survey of India Northern Circle, Dehradun (BSD) and Garhwal University Herbarium, Srinagar Garhwal (GUH), and (iii) consultation of authentic literature about high-altitude plants of Garhwal Himalaya[5,6,14–33].

Altitudinal distribution of all plants (angiosperms and gymnosperms) was recorded at an interval of 200 m, from 3000 to 5400 m asl. Plant species also occur above 5400 m, but explorations and collections above this altitude are few, making available data less reliable. Above this altitude, which is almost above the snowline, vegetation in the form of stable populations is absent and only individual plants are found in specialized niches[4]. These isolated individuals found up to 6400 m asl often profit from local microclimatic peculiarities and their natural uppermost limits are 1000 m lower[11]. A total of 690 species belonging to 272 genera and 74 families were studied for altitudinal distribution by two different approaches.

In one, following Korner[12], the number of species, genera and families above a particular altitude was plotted against different altitudes (Figure 2 *a*). Figure 2 *a* gives a trend indicating continuous decline in the number of species, genera and families with increasing altitude. However, decline in genera is less steep and least steep in families, indicating the presence and persistence of specialized genera and families in high altitudes. Three different rates of decline between 3200 and 5400 m are apparent: (i) steep decline between 3200 and 4600 m, 38.5 species/100 m, (ii) less steep between 4600 and 5200 m, 21.16 species/100 m and (iii) least steep decline between 5200 and 5400 m, 4 species/100 m. Above 5400 m altitude very few species are