ASSESSMENT OF VULNERABILITY OF FORESTS, MEADOWS AND MOUNTAIN ECOSYSTEMS DUE TO CLIMATE CHANGE

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Introduction

Vulnerability may be defined as the extent to which environmental and economic changes influence the capacity of human and ecological systems to respond to natural and socio-economic shocks. The most vulnerable systems would be the ones that are most exposed to perturbations, have limited capacity of adaptation and are least resilient (Liechenko and O'Brien, 2002). As climate change is coupled with other global changes, vulnerability needs to be evaluated against a background of dynamic flux of both anthropogenic and biophysical factors. Vulnerability of mountain ecosystems assumes more importance when one realises that impacts of global change in mountains will have profound effects not only on hill people but also those in the adjoining plains. This article deals with the issues related to vulnerability of forests, meadows and natural ecosystems with emphasis on the Himalayan mountain system.

Predictions of climate change: limitations of scientific models

Precision of predictions about vulnerability to global changes will depend on our understanding on nature and magnitude of these changes. Capacity of available scientific tools to predict climate change is limited, more so in the mountains. Studies of Brazel and Marcus (1991) in northern Himalaya show that Oregon State University model and UK British Meteorological model predict increased aridity on the humid slopes and reduced aridity on the arid slopes, while Goddard Institute Space Studies model and Geophysical Fluid Dynamics Laboratory model bring out the opposite trend. The uncertainty associated with scientific predictions about climate change may be qualified as irremediable for all practical purposes. Hence, corrective actions will have to be tentatively identified based on an imperfect knowledge base and revised with improvement therein (Steffen et al., 2002).

People's perceptions: an alternate approach to track climate change trends

Many traditional communities have responded to changing environments (Grove, 1996). Analysis of indigenous knowledge could provide insights on changing climate and its impacts. Deductions from people's perceptions, however, will be limited to a time scale, which is within the range of human memory. Farmers may hide or provide inaccurate information and hence cross-checking of their perceptions are warranted (Sen et al., 2002). People's perceptions derive not from any direct measurements of climate but from the way climate affects their immediate surroundings and livelihood. For people in central Himalaya, a 'good climate' meant: sporadic low rainfall during March-mid-May, peak rainfall during July-August, moderate rainfall/heavy snowfall during December/January and absence of cloud burst events. People consider onset of monsoon to be more uncertain compared to other phases of rainfall. Climate changes felt in the recent decades included a shift in peak rainfall time from July/August to August/September and winter precipitation from December/January to January/February, increase in frequency of cloud-burst and warming (Table 1).

Table 1. People's perceptions on climate change in central Himalaya

Kind of change	Evidence
Warming	Decline in snow fall period, depth and persistence, decline in apple yield, success of cabbage/pea/ tomato cultivation in high elevations in recent years, shortening of maturity period

	of winter crops, increased pest infestation
Decline in rainfall during March-May	Large scale mortality, abandonment of *Panicum miliaceum* in rainfed area, declining yields of Amaranths
High rainfall during August/September instead of the normal peak in July/August	Damage to rainy season crops when they are close to maturity, increased frequency and severity of landslides
Winter precipitation in January/February instead of December/January and decline in intensity of snow fall	Delayed sowing of winter crops, decline in barley and wheat yields
Increase in instances of cloud burst	Heavy losses of life and property

Impacts of climate change on forest, meadows and mountain ecosystems

Conventional scientific hypothesis testing cannot be used to elucidate ecosystem responses to climate change. Impacts can be inferred based on responses of limited species/area to factors such as higher temperatures and CO_2 levels, and on differentiation of ecosystem in space as related to climatic variability (Table 2). However, responses to step increase in CO_2 level over short-term in enrichment experiments may not precisely reflect long-term responses to slow increase in the biosphere (Luo and Reynolds, 1999). Recent experiments with mature tree stands do show that growth stimulations to CO_2 enrichment are unlikely to be long-term responses (Norby et al., 2001), a conclusion also supported from the trends in non-structural carbohydrate pool which indicates degree of carbon limitation in trees (Korner, 2003). In Himalaya, high altitude areas (>3000 m amsl) show present CO_2 level close to pre-industrial levels and valleys at lower elevations close to present global average (Saxena and Purohit, 1993). Thus, impact of CO_2 enrichment will vary spatially. Decline in biomass accumultion with decline in elevation in alpine species of Himalaya like *Aconitum balfourii* and *Aconitum heterophyllum* (Nautiyal, 1996) suggest that their growth is not limited by low CO_2-low temperature conditions. Warming enhanced growth of *Allium stracheyi*, *Arnebia benthamii* and *Dactlyorrhiza hatagirea* and reduced growth of *Angelica glauca* and *Rheum emodi*, though these species resemble in their ecological distribution (Rajsekaran et al., unpublished). Rawat and Purohit (1991) observed that stomatal conductance was regulated more by endogenous rhythms than by atmospheric conditions in some alpine species. Thus, an uncertainty is inherent to conclusions on long-term ecosystem responses based on scaling-up of short-term experimental observations on a few species.

Table 2. Ecological responses of plants to climate change and their implications for vulnerability and adaptation

Change driving factor	**Impacts and implications**
Increase in photosynthesis and water use efficiency as a result of increase in CO_2 concentration	More intact forests at lower elevations will respond to a greater degree compared to degraded forests at higher elevations. Evergreen early successional fodder trees will respond to a greater degree compared to deciduous timber trees. However, shortening of life span of leaves, changes in biomass allocation patterns/ architecture and poor quality litter (high C/N ratio) production may counter balance the CO_2 enrichment effect. Medicinal herbs and fuelwood/fodder trees which coppice profusely are not likely to be as much down-regulated as those that are not utilized or that are used but coppice poorly. Higher CO_2 concentration can induce self-compatibility in otherwise self-incompatible species, species composition will change due to reduced fitness of many species over time.
Increase in temperature	Warming induced stimulation of growth will increase with increase in elevation. It may result in higher yields of some crops if warming is not coupled with water and nutrient stress, but will not be favourable for alpine speices, which require chilling for germination and fruiting. Leaf life span reduces with increase in temperature in the north-eastern Himalaya but an opposite trend is observed in the western Himalaya suggesting varied patterns of changes in leaf dynamics in response to warming. *Quercus leucotrichophora*, a species with high ecological as well as socio-economic values, shows low acorn production at lower elevation compared to higher elevations and hence is likely to be negatively affected by warming.
Change in precipitation	Ecosystems with clayey-loamy soils, high soil organic matter and higher degree of water stress in north-western Himalaya will be more responsive than the ones with sandy soil, low organic matter content and low water stress in the north-eastern Himalaya. Late successional species with a greater capacity of storing resources in root system will have advantage in coping with the nutrient stress. If shedding of leaves is a strategy to avoid low temperature and related water stress, increase in rainfall coupled with increase in temperature is likely to increase the life-span of leaves.
Change in phenology	Reduction in length of dry season under higher temperature-rainfall scenario may intensify competition for shared pollinators or may increase density of some pollinators which may compensate for overlap of flowering. As proportion of evergreen and deciduous species or winter, summer and spring flowering species and of wind pollinated and insect pollinated species is not uniform across the region, impacts of climate changes on ecosystem properties mediated through phenological changes will vary within the region. As most locally valued species have a poor soil seed bank, they will be threatened if seed production on a landscape scale declines.
Change in soil carbon stock	Higher rates of removal of leaf litter and deadwood from forest floor with increase in population pressure coupled with higher soil respiration under warmer regimes will reduce downward movement of organic carbon more so in open environments.
Upward movement of biomes	Upward progression of species in response to warming is almost certain, but the rates of range expansion are difficult to predict because of interaction of climate and non-climate factors determining species abundance. As responses to temperature differ by species and elevation, new altitudinal belts of vegetation would differ from the present pattern. Alpine vegetation, particularly on convex slopes is likely to be most sensitive to warming. The proportion of grasses, forbs and shrubs are likely to increase and that of sedges to decrease with warming leading to changes in economic and ecological functions of meadows.
Changes in species composition	Competitive interactions are intensified under elevated CO_2. Vines may profit more. A climbing invader like *Mikania micrantha* may reduce tree growth. Species with narrow niches will undergo stress and will have lesser chances of survival compared to wide niche species. Migration of species to favorable niches will be limited by habitat fragmentation.

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While warming will drive biomes upward, changes in ranges of species are also certain. There are several sources of uncertainty to forecast which species are most likely to be threatened or favoured partly because the importance of non-climate factors in influencing vegetation dynamics has not been given due consideration in the prediction models (Higgins et al., 2003). In Himalaya, moraines exposed as a result of glacial retreat due to warming will drive alpine species upward but colonization may be constrained by erosion and nutrient limitations. The dominance of tree species such as *Abies*, *Betula* and *Acer* spp. derives from their physiological adaptations to extremely low temperatures. These species with narrow ecological niche may be exterminated if they fail to compete with the new arrivals under warmer regime and/or to expand their ranges. Mid-altitude species such as *Pinus roxburghii*, *Cedrus deodara*, *Cupressus torulosa*, *Quercus* spp. and *Rhododendron arboreum* have a wider altitudinal spread as compared to alpine/subalpine species and hence extermination of the former is less likely compared to the latter. *Quercus* dominates on southern steep slopes and conifers on northern dip slopes. *P. roxburghii* is largely confined to areas with quartzite and conglomerates. *Aesculus indica* and *Alnus nepalensis* forests seem to represent edaphic rather than climatic climax. In alpine areas, Junipers are found to prefer drier limestone areas rich in calcium and Rhododendrons in moist areas with calcium-poor schists (Puri, 1960). As altitudinal belts differ in topographic and geological attributes influencing species dominance and distribution, landscape scale composition of forests and meadows observed at present is going to be different from future scenario. Low altitude/foot hill forests dominated by *Shorea robusta* are not likely to be as sensitive as higher elevation vegetation because this species can withstand much warmer-humid/dry climates.

One way of assessing the impacts of climate change could be to make an inventory of land-cover changes and identify their causal factors. Such an approach (Table 3) showed a greater influence of non-climate factors compared to climate factors in Himalaya. Indeed, farmers' perceptions are likely to be biased towards responses of agricultural crops, components of natural ecosystems that affect their livelihood or that are very conspicuous such as *Rhododendron arboreum* with mass production of large red flowers. Advancement of flowering in *R. arboreum* and upward expansion of *Tagetis minuta*, *Lantana camara* and *Eupatorium* spp. seem to be driven primarily by climate change. Nonetheless, possibility of modification of climate change driven changes by those driven by non-climate factors cannot be ruled out.

Upland agriculture: a threat to forests and meadows

Agriculture is a minor land use in terms of spatial extent but has significant influence on vulnerability of forests and meadows that supply livestock feed and manure. Agricultural expansion coupled with changes in management practices is widespread. Local crops/cultivars selected to cope up with the uncertainties of monsoon have suffered the greatest loss due to increasing stress on 'maximisation of income'. Cash crops are being grown where climatic conditions are sub-optimal for them. The ongoing changes in agricultural land use are such that fuelwood and fodder production from cropland is declining while rate of manure (livestock excreta mixed with forest leaf litter) input is increasing. These changes imply increasing pressure on forests and meadows (Maikhuri et al., 2000a). Cash crops like tomato, cabbage and chilly will be favoured in higher temperature-higher rainfall regime and potato under higher temperature-no change/lower rainfall regime.

Table 3. Common changes in forests/meadows and driving factors identified by people/reported in scientific studies in Central Himalayan region

Kind of change	Change driving factors
Conversion of dense to open forest	Population pressure, market forces, erosion of traditional forest management institutions, limitations of introduced technologies and institutions to fulfill local needs
Dense forest converted to scrub	Intensive timber extraction on steep slopes with poor regeneration capacity, market forces
Degraded forest converted to agricultural land	Increase in livestock population, erosion of traditions favoring diffusion of grazing pressure, failure of formal institutions to check illicit grazing, decline in fodder production on farm land, policies limiting direct economic benefits from forests

Conversion of pastures to agriculture	Population pressure, limitations of forest protection mechanisms, increasing stress on cash crops
Scrub land converted to forest	Protection and plantation of multipurpose trees by local communities
Conversion of grasslands to scrubs	Decline in nomadic grazing due to enforcement and/or cultural change
Increase in multipurpose trees in farm land	Degradation of natural forests, restrictions on access to meadows and forests, policies favouring timber and other industrially important trees, limited indigenous capacity to enhance productivity of community forests
Conversion of agriculture to agrohorticulture	Subsidy on horticultural inputs and marketing
Increase in forest species richness	Strict enforcement of protection
Conversion of oak to pure pine stands	Commercial charcoal making, selective protection of pine to maximise government revenue, ground fire
Domestication of new crops	Emerging market for medicinal plant products, restrictions on extraction from the wild
Expansion of weeds	Habitat changes together with climate change
Phenological changes	Shift in flowering time of *Rhododendron* from March/April to Feb-March due to climate change

Alpine/temperate zones are likely to be the most threatened ones because here replacement of oak forests by pine forest (due to warming driven upward progression of biomes) will reduce quality as well as quantity of forest products needed to sustain livelihood.

Adaptation and Mitigation

I. Conservation of wild biodiversity: strengthening of protected area network

Redundancy associated with species richness is likely to increase the probability of compensation of negative impacts of changing environmental conditions. Conservation of biodiversity is, perhaps, the most desirable need for adaptation and mitigation. Though we have a long history of planned conservation (9% area of Himalaya is legally protected), our knowledge on people-biodiversity-vulnerability linkages is very limited. Unsustainability of traditional grazing is more an assumption than a scientific conclusion (Maikhuri et al., 2000a). Rarity of medicinal species is largely attributed to over-exploitation (Samant et al., 1996), though this could also be due to inherent biological constraints delimiting their populations or to climate change (Simon and Hay, 2003). Ecological capital of protected areas derives from the ethos of sustainable resource use ingrained in traditional practices. Coping with climate risks is an important factor in shaping the indigenous biodiversity management (Table 4).

Table 4. Risks and coping mechanisms in mountain regions

Type of risk	Coping mechanisms
Risks arising from inaccessibility	Local production based food self-sufficiency as the primary goal of agriculture, export of farm/wild products limited to income needed to procure essential products not produced locally
Risks arising from climate variability and extremes: landscape scale adaptation strategy	Agricultural land use limited in extent and adapted to ecological opportunities/constraints; maintenance of a variety of agroecosystem types differing in their abilities to withstand different types of risks, low intensity disturbance in natural ecosystems
Risks arising from climate variability and extremes: farm scale	More intensive cropping in valleys compared to that on slopes, reducing erosion due to cropping by terracing, huge manure input, maintaining proper drainage, diversified crop system and balance between negative

adaptation strategies	(crop-weed competition) and positive effects (availability of fodder, nutrient conservation, soil conservation) of weeds to avoid absolute crop failure in bad climate years, maintenance of multipurpose trees in farm land to ensure availability of forest products when access to forests is constrained by climate
Risks arising from climate variability and extreme events: forest management	Forest resource uses limited to subsistence needs, strict protection of forests and meadows (in the form of sacred forests/meadows) around critical areas
Risks arising from climate variability and extremes: socio-cultural adaptation strategies	Traditions favoring agricultural sustainability, forest resource utilisation-regeneration balance and environmental services, privileges to small holders in respect of income from forest products, exchange of seeds without any profit motive, collective responsibility for maintaining drainage to cope with very high rainfall events

Nevertheless, indigenous practices may succumb to new global forces. Participatory research/management could turn the people's callous/negative attitudes to positive attitudes towards protected areas (Maikhuri et al., 2000a) together with improvement in scientific knowledge related to potential uses of biodiversity for adaptation and mitigation.

II. Sustainable improvement in traditional agriculture

To avoid the possibility of agricultural land use aggravating the threats from climate change to forests/meadows, interventions enabling improvement in agroecosystem production with reduction in pressure on natural ecosystems are needed.

a. Shifting agriculture

Failure of interventions tried to replace shifting agriculture in the north-eastern Himalaya demand redevelopment of this land use through incremental, rather than quantum change; anything drastic may not find acceptance by the people. To elaborate such an approach, *Alnus nepalensis* is extensively used by tribal societies for soil fertility management. Introduction of this tree could recover all nitrogen depleted due to cropping during a 5 year period compared to a minimum of 10 years required in traditional shifting agriculture. Participatory researches on traditional ecological knowledge can unravel more beneficial keystone species. Sustainability of a shorter cycle would reduce the threats of shifting agriculture to forests (Ramakrishnan et al., 2003).

b. Settled farming

Improvement in traditional agroforestry tree management: Scattered agroforestry trees are distinguishing features of settled upland farming. Lopping is a tool to regulate tree-crop competition for optimizing multiple benefits from the system. Farmers usually lop all branches during winter season when accesses to as well as availability of fodder/fuelwood from forests are constrained by harsh climate. Semwal et al. (2002) have shown that retention of 25% of branches together with increase in tree density in private farmland will improve tree vigour and ecological functions without any decline in crop yields. Research is needed to identify interventions that lead to agricultural sustainability such that pressure on forests is reduced.

Improvement in traditional manuring practices: Manure derived from leaf litter of oak forests supports higher crop yields and labour productivity compared to that from pine forests (Rao et al., 2003). In addition, oak forests are more valuable from the point of view of other tangible and intangible benefits to people compared to pine forests. Rejuvenation of oak forests in degraded lands could thus improve agricultural productivity together with enhancement of forest biodiversity and ecosystem services.

c.Rehabilitation of degraded forest lands

About 59 million ha area of Indian Himalaya is degraded. Though tree planting has been widely promoted, its impact has, by and large, been poor largely because people's needs were ignored. Indeed, people's priorities may not necessarily fall in line with environmental goals. The challenge is to overcome the weaknesses in people's rehabilitation framework through scientific and policy interventions. Plantation of ecologically compatible and locally valued tree, shrubs and herbs/crops, amelioration of soil stresses through improved traditional technologies and involvement of people in implementation and monitoring can enable restoration/conservation of forest/meadow biodiversity and increase in carbon sequestration together with local socio-economic upliftment (Maikhuri et al., 1997, 2000b; Rao et al., 1999; Saxena et al 2001). Indeed, any strategy combining economic and environmental concerns will cost more compared to conventional tree plantations, but investment in the former is more secured. Introduction of 'nurse species' or 'keystone species' would enable accelerated recovery at reduced cost but will be appreciated by people only when they satisfy their immediate needs.

Conclusion

Climate change impacts are to be looked not in isolation but in conjunction with socio-economic issues within the wider framework of sustainable development. For improving national capacity to respond to potential opportunities and constraints related to climate change, the prime requirement is improving the knowledge on impacts, adaptations and mitigation. This can be achieved through coordinated programmes dealing with: (a) long term ecological research so as to identify impacts of climate change on biodiversity-ecosystem function relationships (b) evaluation of interaction of climate change with other global changes such as land use change and economic globalisation (c) exploration of use of biodiversity and associated goods and services for sustainable development.

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