Impact of Climate Change and Coping Strategies in Nanda Devi Biosphere Reserve (NDBR), Central Himalaya, India

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Introduction

The Indian Himalaya is a vast mountain system with a geographical area of about 5,91,000 sq.km representing 18% area of the country and is important part of the global system. The Himalayan region is one of the most dynamic and complex mountain ranges in the world due to tectonic activity and they are vulnerable to global climate change and increasing human activities. Because of altitudinal variation in the Himalaya, climate differs from high to low elevations, similarly natural resources, water etc. Global change, whether generated from climate, land use change, biological invasion, global economic forces etc. will certainly affect the relationships that are part of the land and economies of the Himalayan region. Uncertainties about the rate and magnitude of climate change and potential impacts prevail but there is no question that it is gradually and powerfully changing the ecological and socio-economic landscape of the region. The protected area network in the Himalayan region comprises of three biosphere reserves, 18 national parks and 71 wildlife sanctuaries occupying 9.2 % area of Indian Himalaya (Maikhuri and Rao, 2005). The fact that India is recognized as one among twelve mega biodiverse regions of the world, which is mainly due to presence of the Himalaya. The rich biodiversity of the region to great extent, owes its existence to age old cultural values of the society, wherein, protection of the various life forms maintained through sacred groves and village communities efforts.

Recognizing that global change and in particular global warming has and will have serious impacts on biophysical environment and the socio-economic conditions and livelihoods of people in Himalaya and adjacent plain areas. It will also affects species composition and diversity, habitats and the occurrence of rare and endangered species as well as invasive species in high altitude areas, thus jeopardizing the conservation value of Himalayan protected areas and their wider environment (Maikhuri *et al*., 2000,2001; Rao *et al*., 2002; Nautiyal *et al*., 2001). Further it is impacting glacial retreat – thereby affecting freshwater supplies etc.

Intergovernmental Panel on Climate Change (IPCC) projects that climate may warm globally by 1.4 to 5.8^{o}C by the next 100 years. The climate change would cause global sea to rise between 0.09 to 0.88 m by 2100 and enhance the extreme events like excessive rain, flash floods, droughts, cyclones and forest fires. Assessment by Indian scientists show that over the Indian region, the warming may be about 2.1 to 2.6^{o}C in the 2050s and 3.3 to 3.8^{o}C in the 2080s. While the rainfall is projected to increase, there would be variations in its spatial pattern, with some pockets showing increasing and others experiencing decline in rainfall (Ravindranath *et al*., 2004).

Accepting that global change occurs at rates unprecedented in recorded human history for which people inhabited in buffer zone of NDBR in particular and Himalaya in general need to develop adaptation mechanism and coping strategies in various economic sectors i.e., agriculture, forestry, pastoralism, medicinal and aromatic plants and wild edibles collection/cultivation/conservation, processing and value addition, marketing, tourism and mountaineering etc. so as to ensure equitable livelihoods for people living in this region (Saxena, 2004). However, the capacity to adapt varies considerably among regions and socio-economic groups and will vary over time. Therefore, enhancing adaptive capacity is a necessary condition for reducing vulnerability, especially for the most vulnerable regions and socio-economic groups. These groups are already under pressure due to population growth, resource depletion, and socio-economic inequalities.

Therefore, the present paper discusses the impact of climate change on agriculture, transhumant pastoralism, forest and alpine meadows and tourism. Besides, the local people perception and knowledge which they acquired over a period of time (mostly old aged people) was recorded as an evidence on some of the above aspects and considered important indicator in the context of climate change in Nanda Devi Biosphere Reserve in particular and central Himalaya in general. The coping and mitigation strategies were also discussed in detail which was based on the extensive action research through participatory approaches carried out by the authors over last 18 years in NDBR.

Study area, people and climate

Nanda Devi Biosphere Reserve (NDBR), a world heritage site is one of the unique area, have high ecological, cultural, religious, spiritual values and rich biodiversity, and covers a total area of 5860.69 km2 with two core zones, viz. Nanda Devi National Park (624.62 km^2) and the world famous 'Valley of Flowers National Park' (87.50 km^2). The buffer zone (5148.57 km2) has the famous religious places such as Badrinath Shrine and Hemkund Saheb and inhabited by 47 villages where traditional societies are residing (**Figure 1**). The socio-cultural fabric is an interesting as the natural environment itself. Local inhabitants belong to two ethnic groups, viz. Indo-Mongoloid (Bhotiya group) and Indo-Aryan (Khasa group). These communities practice marginal subsistence agriculture and animal husbandry. Small wood based cottage industry is also a source of their income (**Table 1-2**). The reserve area spreads across three districts of Uttarakhand i.e. Chamoli, Bagheshwar and Pithoragarh. It is one of the unique areas, with high ecological, cultural, spiritual values and rich biodiversity and has a long history in attracting nature lovers or eco-tourists. The diverse ecosystems in NDBR harbours a tremendous array of floral and faunal diversity and includes about 400 species of trees, 570 species of herbs and shrubs, 86 species of mammals, 534 species of birds and 54 species of reptiles and amphibians. Many of these species are rare and endangered (**Table 3**). Sacred sites and religious places (i.e. Shri Badrinath Dham and Shri Hemkund Saheb) abound in the NDBR where deities reside in forests, meadows, rivers, lakes and mountains. Between 2001 and 2005 it was listed that on an average every year about 5.2 lakh people visited Shri Badrinath dham and 1.6 lakh to Shri Hemkund Saheb as religious tourists.

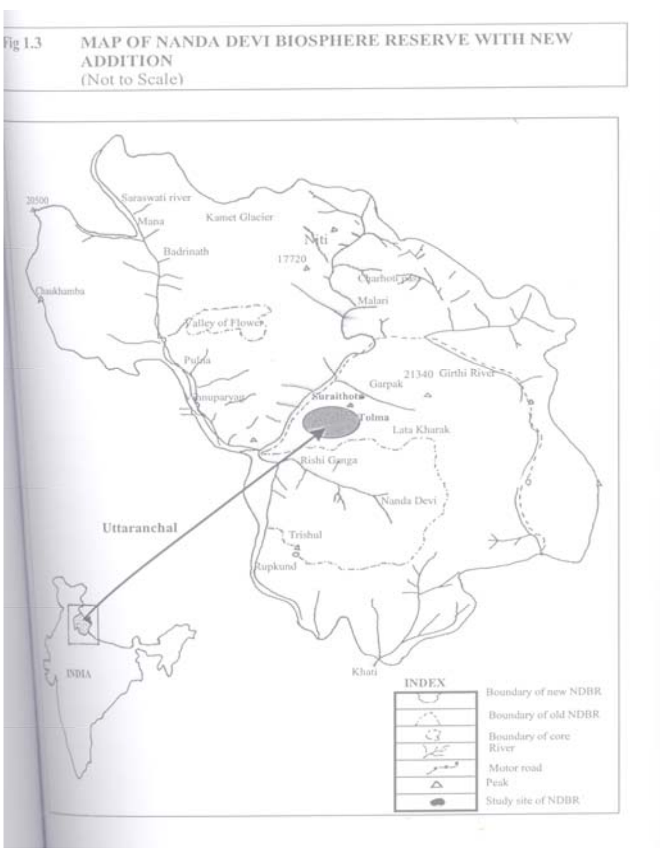


Figure 1. Location Map of Nanda Devi Biosphere Reserve.

Table-1. The total area and number of buffer zone villages of NDBR as per revised notification

Total area	5860.69 sq.km.
Core zone	717.50 sq.km.
Buffer zone	5148.57 sq.km.
No. of buffer zone villages	47
Other settlement	Badrinath Dham & Hemkund Sahib
Altitude	1800- 7817
Total population of buffer zone villages*	10909

*Based on 2001 census

Table - 2. Global recognition, status and conservation history of NDBR

Sanctuary	1937
Nanda Devi National Park	1982
Nanda Devi Biosphere Reserve	1988
Nanda Devi National Park declared World Heritage Site.	1992
Inclusion of Valley of Flower National Park in NDBR	2000
UNESCO’s World Network of Biosphere Reserve	2004
Valley of Flowers declared World Heritage Site	2005

Table -3. Status of flora and faunal diversity

Total No. of species reported	
Trees	400
Herbs, shrubs, fungi, lichens and bryophytes	570
Birds & Mammals	534
Reptiles & Amphibians	54
Insects	200

From a geomorphological point of view, the buffer zone occupies the whole Rishi Ganga catchment (a tributary of the Dauli Ganga) and Alaknanda catchment up to Vishnuprayag which is encircled by higher Himalayan peaks, among wich is India's second highest peak, Nanda Devi, in the northern part of the reserve. The climatic year consists of three seasons –Summer (April-June), rainy season (June- September) and winter (October - March). Average annual rainfall is 928.81 mm. About 47.8% of annual rainfall occurs over a short period of two months (July-August) featuring a strong monsoonic influence. The maximum temperature ranges from 11^0 C to $24\ ^0$ and minimum from 3^0 C to 7.5^0 C. The altitudinal range of the biosphere reserve varies from 2100 masl to 7817 masl.

Climate change impact on traditional hill agriculture

Agriculture is a minor land use in terms of spatial extent and practiced only on 0.7 percent (21.15 km^2) of the total geographical area of the NDBR. Inaccessibility, environmental heterogeneity, biological, socio-cultural and economic variations in the NDBR have led to the evolution of diverse and unique traditional agroecosystems, crop species, and livestock, which help the traditional mountain farming societies to sustain themselves (Maikhuri *et al*., 2001). During recent past, as a result of rapid changes in land use caused by socio-cultural and economic changes and various environmental perturbations the crops biodiversity of the buffer zone agriculture has changed steadily (**Figure 3**). The land use change in the reserve is significant and affects a whole range of issues. These encompass concerns such as global warming and climate change, biodiversity depletion, biological invasion, growing human population, imposition of conservation policies, land degradation and hydrological imbalances (Maikhuri *et al*., 2001). The changes are closely linked with the issue of sustainability of socio-economic development since they affect the natural resources. However, the change from traditional subsistence agriculture to cash crop-based agriculture has been advancing in the last few years. The area under cultivation of many traditional crops has been reduced and some others are at the brink of extinction (**Figure 3**). Consequently, the ecological and economic security of the traditional agriculture of this area appears to be in jeopardy, as in other parts of the Central Himalayan mountains (Maikhuri *et al*., 1996; Palni, 1998; Semwal, 1996). The response of the agriculture crop production in the high altitude region to the climate change varies according to crop composition, edaphic conditions and the cropping pattern. Degradation of the soil and soil moisture is one of the major challenges for agriculture in high altitude regions. Recently the decline in soil moisture due to early snow melting, glaciers recession and more exposed to heat stress has adverse impact on the performance of agricultural crops in the high altitudes. Increase in soil temperature relatively affect the availability of soil moisture, which is required for early growth of the crops in these cold, dry climatic region particularly during sowing period of the crops. High temperature also affects the physiological condition and survival ability of the crops. Traditional crops cultivated in these regions include legumes, cereals, pseudo-cereals, potato, mustard etc. (Nautiyal *et al*., 2003).

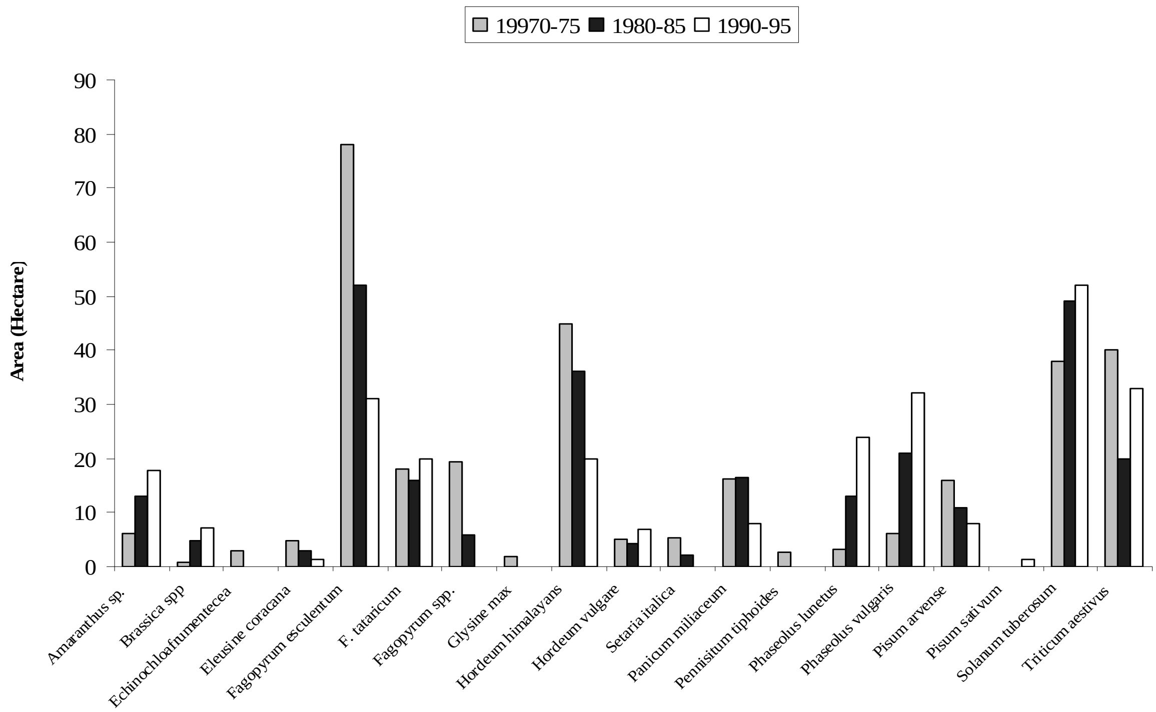


Figure -3. Change in area (ha) under different crops at three points of time.

In high altitude areas, the global shift in the environment is leading to rise in temperature and in very near future, however, it will bring more opportunities particularly of cash crops like tomato, cabbage, chilly, peas and medicinal plants etc (Saxena *et al*., 2004). However, reduction in winter snowfall and spring rainfall and melt-water flows will produce a soil moisture deficit which could limit any increase in yields resulting from temperature increase. It is believed that even minor changes in the temperature could have a major impact on the severity of the diseases. *Amaranthus* crop is most vulnerable to climate change as it observed during recent past that this crop is severely attacked by a disease called *Hymenia rickervalis* (parn jalak keet) between 1000 – 1800m asl whereas between 2200 – 2800masl it is performing well. It is assumed that low rainfall during July and high temperature and humidity particularly in 1-2nd week of September providing favourable condition to moth (insect). Besides crops such as traditional legumes (cowpea, *Vigna* spp.) important summer legume crops grown between 1000-2000m asl is facing the problem of fruit setting etc. It is also may be due to shift in peak rainfall time and other climatic factors as revealed by the farmers of Alaknanda valley. Many other crops were infected with pest and insect diseases. Diseases like rust and blight were commonly found in the cereals and potato crops, while legumes like *Phaseolus* spp. were infected through the soil borne insects such as *Coleoptera* species locally called *Uksa*. These insects damage the crops in early stage of seed germination. One of the reasons for the occurrence of disease in these crops of this region could be favourable climatic conditions i.e. increase in moisture or humidity or milder winter (between 500-1500 masl) in the lower region. Some of the knowledgeable farmers and villagers interviewed indicated that the occurrence of the disease could be due to the lack of poor soil in these areas. Besides, early snowfall at maturation stage of the crop in the months of October and November also damage the crop yield and creates problem in their storage and transportation. High altitude agriculture of this region is definitely in transition and rise in temperature in future may enhance the agricultural productivity in this region.

Impact of climate change on transhumant pastoralism

Animal husbandry constitutes an important component of the rural economy of the Himalayan region. Livestock feed is derived from grazing and crop by-products. Livestock provide a wide range of services and products including draught power, manure, wool and supplementary nutrition (Maikhuri and Ramakrishanan, 1990, 1991; Maikhuri, 1992, 1993, 1996). Furthermore, livestock are closely linked to the social and cultural lives of rural poor for whom animal ownership ensures sustainable farming and economic stability. In spite of environmental compulsions and hardships of high altitudes, the spectrum of livestock diversity in this region is wide, rich and varied. This is evident from the presence of different types and breeds of sheep, goats, cattle, horses, yak, mules, poultry, etc.

Enforcements following establishment of Nanda Devi National Park in 1982 and establishment of biosphere reserve in 1988 and the changing socio-economic conditions forced local people (particularly in the vicinity of the core zone) to reduce their livestock holding due to decline in resource availability. It has directly affected the local economy in general and wool based traditional handicraft in particular (Maikhuri et.al., 1998b). At the same time, many pastures have been severely grazed by the livestocks from outside the buffer zone villages.

The population of livestock reared by the inhabitants of the NDBR buffer zone villages has showed a drastic decline in the period 1970-1975 and 1990-1995. This was due to sharp reduction in the sheep and goat populations and near extinction of yak breeds in the area (**Figure 4**). However, other animal populations such as dairy cattle horse, and mules, also reduced, but did not show drastic change. Analysis of data for the entire buffer zone indicate a marginal change in the number of families owning or rearing bullocks and cows, whereas those owning or rearing sheep and goats showed a drastic decline.

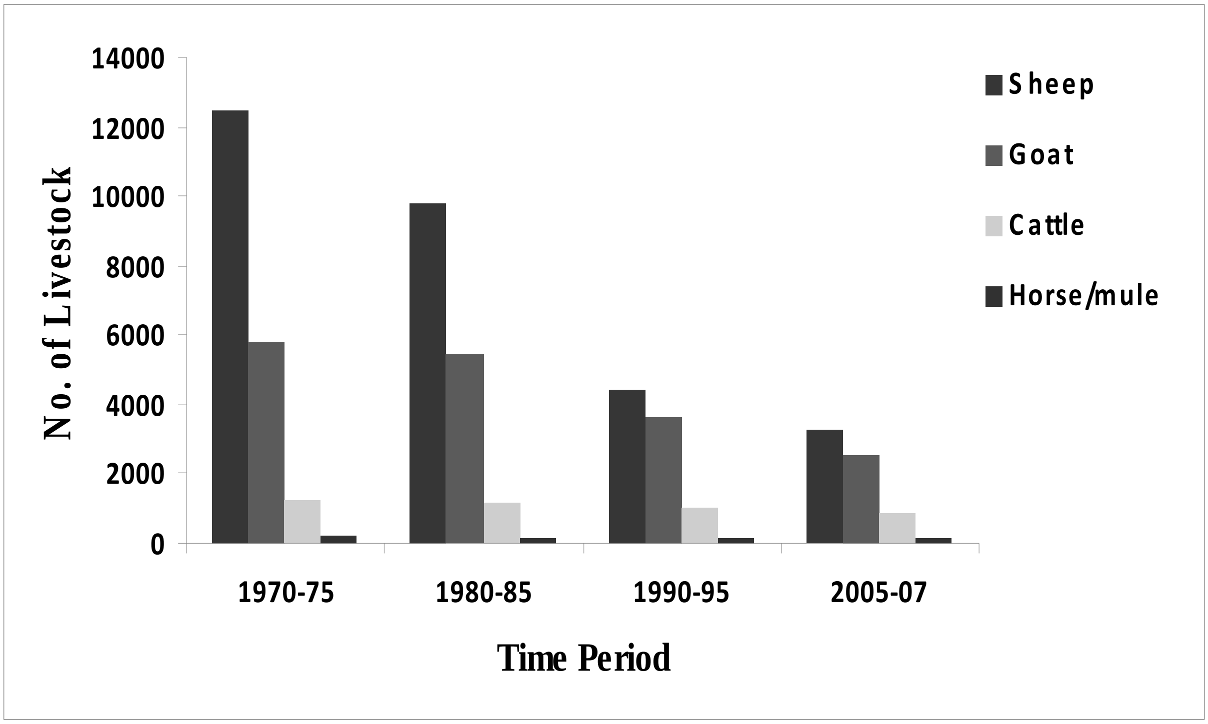


Figure 4. Changes in livestock population between the 1970-75 to 2005-07 period as reported by the people of Niti valley (10 villages).

Before the area was brought under conservation in 1982, all 15 pastures of the region, with an area of about 6188 hectare were available to about 21,000 animal units (1 animal unit is equal to 1 head of cattle, which is equivalent to 0.01 goats or sheep, 1.26 buffalo or yak and 2.67 horses or mules) grazing in the area . Soon after the declaration of National Park and later Biosphere Reserve, only 7 pastures with a total area of 2433 hectares remained available to about 14,500 animals units. This is equal to stocking density of 6 animal units per hectare of pastureland, as against about 3 animal units per hectare of pastureland before 1982. Managing the numbers of sheep and goat is essential for managing stock densities. Local people manage the animals by reducing their numbers, either by selling them to other consumers for meat production or by using them for local meat production.

Transhumant pastoralism in the NDBR buffer zone has undergone change: improved access and service to previously remote areas; disruption of the traditional trans-Himalayan trade network, an increase in tourism and alternative employment opportunities for local inhabitants, and a general settling down of many transhumant pastoralists, with a corresponding reduction in spatial mobility for livestock herds. Similar scenarios are also reported from Tibet and elsewhere in the study region.

In general, the livestock population showed a decreasing trend Yak and Yak breeds disappeared from households in the region and were seen only on government farms. This is due to the non-availability of yak for procreation after trans-Himalayan trade was halted and the loss of utility that limited spatial mobility in the post -1962 period. The increased emphasis on livestock resulted in diversification on sheep breeds through introduction of Tibetan varieties mainly between 1950 and 1960, and Himachal varieties after 1962. This has resulted in the erosion of traditional breeding knowledge in the region (Farooquee and Rao, 1999).

As system of land use, pastoralism requires access to a variety of different ecological niches. Loss of only a small but vital resource such as alpine grazing lands or village commons in the lower valleys can upset the delicate balance on which survival dependent. As a result of conservation of land use in the alpine area and intensified production in the lower valleys, transhumant pastoralist lost most of the available grazing areas. To adjust to this situation, the livestock population was also reduced. However, the reductions were not sufficient to keep grazing intensity at the required optimum of about 0.3 hectare per animal unit (Negi *et al*., 1993).

As mentioned above, livestock management also involves important relationship with low altitude (Tarai-Bhabhar tract). Currently, the lowland Tarai region experience dry conditions from December-May (with the exception of winter storms). Although changes to the seasonal distribution of rainfall are highly uncertain, the low rainfall or no rainfall during winter would seriously jeopardize the long standing regime by which some families send their livestock to the low lands for the winter and early spring it is also important for fertility maintenance for those lower areas. In the event of an increase in temperature in the Tarai belts and low altitude and also lower rainfall in these areas would become under increased pressure to provide adequate winter grazing. At their point, existing institutional arrangements for grazing control may well be inadequate and thus appropriate institution is required. This could provide viable option for pastoralist economies.

Climate change at high altitude production as their forage quantity and quality would be seriously affected particularly transhumant pastoral production system, increasing disease and disease spreading pests (transmission of wind borne foot and mouth disease viruses) reducing water availability and making it difficult to survive in extreme environments.

Vegetation status of forest and alpine meadows

In the NDBR, the dominant forest types are pine, oak mixed (pine-oak), deodar, bluepine, conifer mixed, birch/fir and juniper along with scrubland and alpine and low altitude grasslands. The forested area in NDBR is only 10 to 11% but in terms of biological diversity is very important. The extent of forest was 632.21 km^2 (10.75%) in 1986 and 636.51 km^2 (10.90 %) in 1999. These figures indicate an increase of 4.30 km^2 in the forest area over a period of 13 years (1986-99). However, there are significant changes in density and extent, which are dealt separately under land transformations. In terms of forest area the conifer mixed forest ranks first (178.26 km^2 in 1986 and 178.06 km^2 in 1999) followed by birch /fir, Juniper, deodar, and oak, mixed and pine. In terms of density, the open forest (all the types included) area was 225.74 km^2 followed by closed forest (221.91 km^2) and degraded forest (184.76 km^2) in 1986. There is a significant improvement in the forest density as shown by 1999 results. The closed forest was 267.86 km^2 area followed by open forest (244.03 km^2) and degraded forest (129.39 km^2). Grasslands/ grazing lands in the study area could be delineated separately as alpine/sub alpine pastures (called as alpine grasslands) and low altitude grasslands with the aid of altitudinal information. The grassland/grazing land accounts for 275.11 km^2 area of which alpine grasslands occupy 271.57 km^2 and low altitude grasslands show a meager extent (3.01km^2) in 1986. In 1999, however, a 0.27km^2 decreases in the extent was observed (Murthy *et al*.,2004).

Impact of climate change on forest and timberline vegetations

Forests play an important role in environmental and economic sustainability and provide various goods and services and maintain life support systems. Forest vegetation store large amounts of carbon in trees, under- story vegetation and soil and thus maintains the atmospheric temperature ambience through evapo-transpiration. While warming will drive biomes upwards, changes in ranges of species are also certain. There are several sources of uncertainty to forest which species are most likely to be threatened or favoured partly because the importance of non-climatic factors in influencing vegetation dynamics has not been given due consideration in the prediction models (Higgins *et al*., 2003).

In some locations, timberline vegetation represents exclusively evergreen conifers while in some it represents totally deciduous broad leaved trees (Purohit, 2003). In NDBR the *Betula utilis, Abies pindrow* and *Rhododendron companulatum* are the native species of timber line and have complex, spatial habitat of medicinal and aromatic plants and wild edibles. Timberline, the most prominent and significant ecological boundary where the sub-alpine forests terminates, has been identified as sensitive zone to environmental change and could be effectively modeled/monitored for future climate change processes.

In the high altitude regions 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/amplitude may be exterminated if they fail to compete with new arrivals under warmer regime and or to expand their ranges. Mid altitude species (1600-2000 masl) such as *Pinus roxburghii, Cedrus deodara, Cupress torulosa, Quercus dialtata, Q. semicarpifolia, Q. leucotricophora,* and *Rhododendron arboretum* have a wider altitudinal spread as compared to alpine /sub alpine species and hence extermination of the former is less likely compared to the latter (Saxena *et al*., 2004). Several other species of the temperate zone include *Abies pindraw, Acer caesium, Betula utilis, Salix sikkimensis, Sorbus foliolosa, Taxus baccata, Rhododendron campanulatum, Prunus cornata, Populus ciliate* etc. occur between 2800- 33000 masl and grows in moist, cool condition where soil is rich with humus (Purohit, 2003).

Pinus wallichiana (kail) and *Cedrus deodara* (deodar) are most valuable tree species in the buffer zone villages as the wood is very resistant to rot and is most preferred timber for house constructions. The decrease in snowfall and rainfall in the study area are probably negatively affecting deodar species. However, *Pinus wallichiana* has a wider altitudinal range as compared to other Himalayan conifers and is capable of surviving a wide range of environmental conditions. Some of these characteristics may make this species more adaptable to climate change than Deodar and other tree species growing in this altitudinal zone. The local people of buffer zone villages i.e., Lata, Reni, Tolma etc. and authors have noticed that during recent past (15-16 yrs) Kail and Raga had been regenerating and spreading faster than other species beyond and above Tolma, Lata, Kaga and Garpak villages located between 2600 to 3000 masl.

Change in future climate in the study area is likely to negatively affect both species which could lead to a decline in the area under both these species or a shift in their ranges towards higher altitudes. In addition, many important tree species in timber line zone of the biosphere reserve have already been listed in the category of rare and endangered i.e. *Taxus buccata*, Junipers spp. and *Betula utilis*. These species were over exploited legally or illegally to large extant during recent past (**Table 6**), high rate of destruction and influence of the changing climate have made their existence worse (Purohit *et al*. 2002). *Betula utilis* (locally called Bhoj) have socio-cultural and religious value to the people inhabited in the region. Its bark is used as a paper plates for serving food during religious ceremonies and resin extracted from stem have huge medicinal properties (Purohit *et al*., 2002). It is also considered a keystone species of a timberline ecosystem and forms the upper limit of forest vegetation ascending to an altitude between 3200-4000 masl in the biosphere reserve. The *Betula utilis* is high light demanding and grow in areas of heavy snowfall but have a poor soil seed bank, there could be large scale local extinction of these species if seed production on a landscape scale decline (Saxena *et al*., 2004).

The resident of Garpak and Phagti village of buffer zone did note that in the recent past, the stem and leaves of *Betula utilis* growing in association with *Abies pindrow, Rhododendron campanulatum, Taxus buccata* between 3300 to 3600m asl damaged severely by defoliators moths insect (not yet identified). The resident of above villages attributed this insect attack on Bhoj may be due to less snowfall in the past 8-10 years and gradual increase in temperature. The overall prediction is that certain biomes such as the Oak mixed/conifer mixed/Deodar and blue pine/ Birch forest are likely to show marked expansion regardless of the degree of change in climate. In general, the species composition in the new biomes will be different from the existing ones and increased occurrence of fire, erratic rainfall/snowfall and anthropogenic pressure may inhabit the ability of some species to migrate and establish in new locations (**Table 6**). As altitudinal belts differ in topographic and geological attribute influencing species dominance and distribution, landscape scale composition of forests observed at present is going to be different from the future scenario.

Impact of climate change on alpine meadows

Alpine meadows/grasslands are used extensively for grazing during summer season (May-October) by various groups of local and transhumant pastoralists and are also an important reservoir of high altitude medicinal and aromatic plants (MAPs). This ecosystem generally found above 3800m asl in NDBR where climate is characterized by the high degree of complexity due to the interaction between the high mountain peaks and atmospheric precipitation that is mainly in the form of snow, which covers the ground for 5-6 months in a year (Purohit, 2002)**.** The growth period is very short and very sensitive to temperature changes. The main herbs and fodder species found in this zone are *Potentilla, Geranium, Fritillaria, Lilium, Corydatis, Cyananthus, Anemone, Ranuuculus, Impatiens* etc. (Kala *et.al*., 1998) and the important medicinal plants are *Aconitum heterophyllum, Dactylorhiza hatagirea, Nardostachys grandiflora, Picrrohiza kurrooa, Angelica glauca, Allium* spp. etc. (Maikhuri *et.al* 1998, Nautiyal *et al*., 2001). The distribution of alpine grasses and MAPs and their composition and associations are determined by topography, shade and soil moisture, slope, light intensity, snowfall and intensity of grazing and other biotic pressures.

The transformation of an alpine meadow base has far reaching impacts on traditional transhumant and local communities and their livelihood as its contribution in day- to -day subsistence needs and some indirect benefits accruing to agricultural sector is enormous. The decline in productivity and area under sub-alpine vegetation due to the shift of timberline vegetation would replace the alpine grasslands available to transhumant pastoralists and traditional communities.

In NDBR, high altitude areas (>3000 masl) 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 accumulation 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 and low temperature conditions. Warming enhanced growth of *Allium strecheyi, Arnebia benthamaii, Pleurospermum anglicoides* and *Dactylorhiza hatagierea* and reduced growth of *Angelica glauca* and *Rheum emodi,* though these species are similar in their ecological distribution (Kandari, 2005).

Rawat and Purohit (1991) observed that stomatal conductance was regulated more by endogenous rhythmus than by atmospheric conditions in some alpine species. In alpine - sub alpine areas, Junipers are found to prefer drier limestone areas rich in calcium and *Rhododendron campanulatum* in moist areas with calcium poor schist (Puri, 1960). When considering the likely impact of future climate change on alpine grasslands various factors to be considered which include changes in temperature, precipitation, soil moisture as well as direct response of grasses to enhanced atmospheric $CO_{2.}$ The effects of increased CO_2 on grasses/plants also depend on the C_3 and C_4 photosynthetic pathways of plant species in a community.

C_3 plants such as many bunch grasses of cool temperature region may increase photosynthetic rate up to 1000 ppm CO_2 or beyond and therefore, show enhance growth rate in increase CO_2 concentration (Pearey and Ehleringer, 1983). In contrast, plants with C_4 photosynthetic pathways are already saturated by CO_2 at current atmospheric levels and expected to show little increase in the growth with rising CO_2 level (Wooward *et al*., 1991). Increasing atmospherics CO_2 levels therefore, should favour C_3 plants over C_4 grasses, but projected increase in temperature would favour C_4 plants. The outcome of climate change would thus be region and location specific and involve a complex interaction of various factors. The alpine grasslands of the NDBR could also be impacted by rising temperatures that would promote the upward migration of woody plants from lower elevations.

The 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. During recent past some of the alpine landscape in Niti valley is eroded due to glacier melting, avalanches and landslides, which favour to extend the distribution of *Polygonum polystachyum*, a fast growing herbs, mostly found on fresh eroded slopes and avalanche tracks (Kala *et al*., 1998). The other successful invaders found in these habitats are species of *Lonicera, Rosa* and *Ephedra*. In the Dunagiri-Satopanth areas, local people of the buffer zone villages i.e. Dunagiri, Tolama, Mana, Malari etc. have observed the retreat of the glaciers, based on their keen observations of about 20-25 years.

Socio-economic impact of forest and alpine meadows due to climate change

The traditional communities and local people of the buffer zone of NDBR depends on the different forest types and alpine meadows for various bio-resources mostly used in agriculture, livestock, traditional health care system, cosmetic, medicines, food and other small industries (Maikhuri et al., 2000, 2001; Nautiyal *et al*., 2001) and medicinal and aromatic plants (MAPs) and NTFPs for household as well as commercial purposes. The bioresource diversity particularly MAPs and NTFPs collected/processed and their economic value were evaluated following the current market rates (Table 4). Presently, alpine meadows/temperate forest and sub alpine areas serve as a treasure of MAPs of high value-low volume. Table 5 provide summary of the MAPs and NTFPs species used, their purpose and any change in their availability and status over the past 15-20 years (Maikhuri et.al., 2001). Due to future impact of climate change in sub-alpine and alpine areas would negatively affect those species that require higher level of soil moisture to thrive, leading to a decline in their area or would shift towards higher elevations where their existence will be in danger.

Table 4. Harvest (mean±SE) of important wild products in villages near to and away from the core zone of the Nanda Devi biosphere Reserve. Results of t-test comparisons of harvests from near

the core zone with those away from it: values with different superscript letters are significantly different ($p<0.05$) within rows.

Botanical name	**Local name**	**Estimated price (Rs/kg)**	**Harvest (Kg household^{-1} year^{-1})**		**Change in status/ availability**
			Near to core zone (n=23)	**Away from core zone (n=9)**	
*Aconitum heterophyllum**	Atis	175	0.08±0.03	0.18±0.12	Decline
Allium spp.	Sedum/Faran	200	1050±0.97	13.58±0.75	Stable
*Angelica glauca**	Chippi	150	3.16±1.09	3.28±1.15	Decline
Bergenia ligulata	Shilphori	60	0.24±0.12	0.15±0.10	Decline
*Betula utilis**	Bhojpatra	150	0.30±0.25	0.42±0.12	Stable
Cedrus deodara	Deodar	50	1.10±0.25	1.25±0.24	Stable
*Dactylorhiza hatagirea**	Hathazari	550	0.05±0.01	0.05±0.02	Decline
Fagopyrum dbotys	Ban-oggal	10	1.96±0.89	2.64±0.95	Stable
Hippophae rhamnoides	Amesh	110	0.30±0.12	0.75±0.35	Decline
Juglans regia	Jungli Akhrot	50	2.52±0.24	3.65±1.75	Stable
Megacarpaca polyandra	Barmao	30	14.24±1.56	19.35±0.98	Stable
Morchella esculenta	Guchhi	6000	0.97±0.35	0.84±1.22	Decline
*Nardostachys grandiflora**	Mashi	250	0.05±0.01	0.06±0.02	Decline
Poeonia emodi	Chandra	30	6.27±0.56	8.85±1.22	Stable
*Picrorhiza kurrooa**	Katuki	150	0.14±0.10	0.18±0.34	Decline
Pleurospermum angelicoides	Choru	150	1.60±0.72	1.72±0.52	Decline
Prinsepia utilis	Bhinkal	125	0.92±0.84	0.54±0.40	Stable
Prunus persica	Kirol	200	1.20±0.25	0.85±0.32	Stable
*Rheum australe**	Dholu	80	0.04±0.02	0.06±0.03	Stable

Ribes himalayense	Darbag		0.62±0.35	0.52±0.35	Stable
Rumex hastatus	Chalmore	15	1.22±0.92	1.94±0.94	Stable
*Saussurea costus**	Kut	150	0.65±0.30	0.92±0.21	Decline
Smilacina purpurea	Puyanu	25	12.52±1.25	11.59±1.52	Stable
*Thamnocalamus spathiflorus**	Ringal	5	110.50±15.87	77.84±5.23	Decline
*Taxus baccata**	Thuner	250	4.96±0.65	3.92±1.21	Decline
Viburnum cotonifolium	Ghenu	40	2.95±078	1.96±0.95	Stable
Cordyceps sinensis	Yartsa Gamba	2.5 – 3.0 lacs	0.89±0.31	1.01±0.20	Decline

*Medicinal and aromatic plants and wild edibles exploited to the verge of extinction (Maikhuri *et al*., 2000).

**Market value of 2007.

Ecotourism and climate change

The Himalayan range is a repository for nature lovers, trekkers, mountaineers, saints etc. since time immemorial. The protected areas located in the Himalaya in general and NDBR in particular has great strength to offer in nature based tourism or eco-tourism, pilgrimage and religious tourism activities.

It is interesting that eco-tourism and sustainable development are viewed by many proponents as synonymous or complimentary and have been used as justification and support for future development. Although it has a reference from economics of the tourism industry as a form of nature- based tourism, it has been formulated and studied as an instrument for sustainable and equitable tourism by various institutions and individuals. It has been reported in several case studies that in areas where tourism occurs in mass-form in sensitive ecosystems, severe impacts have resulted. The nature and extent of such impact of tourism depends on the intensity of tourism activity as well as the sensitivity of the impacted ecosystems. Most of the studies show that more severe impacts of tourism on species and ecosystems arises from the infrastructure and building activity involves, rather than from the recreational activities themselves, as in the case of mountain tourism/ pilgrimage performed in Badrinath, Hemkund Saheb (Valley of Flowers), Gangotri, Bhojwasa and Gaumukh areas. The results of studies indicate that in most cases buffer zone

areas are unable to withstand the recreational pressure that eco-tourism generates and the subsequent impacts of further development of infrastructure.
There were a few activities where the eco-tourism programme has been integrated into community development or conservation strategies as is the case of medicinal plant and off-season vegetable cultivation, use of wild edibles and medicinal plants and value addition locally, promotion of home-stay accommodation, locally grown traditional crops as a source of organic foods. Besides, there were other different approaches used to empower and enable communities' capacities to manage their own resources and assets included: community level training, conservation education programmes, campaigning, awareness building, working with villagers and pilot programmes which are ecologically, socio-economically and culturally feasible (Maikhuri & Rao, 2005, 2006).

Climate change could generate both some serious problems but also opportunities for the tourism sector. Obviously, any change in the length and reliability of the winter sports season adjoining to NDBR (Auli- Joshimath) (currently January – February) could be damaging because it attracts domestic and foreign tourists and may have adverse impact on environment of this region and thus required carrying capacity asessment. However, any assessment of this aspect must similarly take account of any likely changes that might take place in alterative destinations. Therefore, tourism/eco-tourism/mountaineering and expedition/trekking in NDBR are another facet of the coping strategy/adaptation mechanism. Overall it may not yet be very significant, but in certain areas such as Niti and Mana valleys it has become an important source, not only for income but challenges to traditional cultures and practices. Some aspects of the trade (i.e. medicinal and aromatic plants, wild edibles, etc) may suffer climate change which may also present new opportunities. Following the experiences elsewhere i.e. Upper Mustang in Nepal (Sharma, 2001, Nepal, 2000), these will call for new arrangement and control structures in order to avoid environmental damage. The successful policy execution in NDBR in particular and other protected areas located in Himalaya in general depend upon a number of factors that requires an appropriate coordination between different departments, the role of the eco-tourism developers and law-enforcing agencies and other stakeholders involved (Maikhuri and Rao, 2005, 2006).

Earlier, tourism revolved around trekking and pilgrimage in NDBR region. However, during recent past the expansion of tourism in the form of adventure tourism, winter sports, expedition to glaciers and adjoining areas mountaineers, nature lovers, saints etc. have increased many fold. It has negative impact on natural resources whereas positive impact on economies of the people inhabited in the buffer zone as well as those depend on this venture. Besides, a wider appreciation of the impact of a leisure culture would include the fact that increasing numbers of people are remaining in buffer zone of BR (Badrinath, Hemkund Saheb, Valley of flowers, Reni, Lata etc.) for much longer periods. Tourism in the biosphere reserves may provide better opportunities of income generation as other primary and secondary production sectors (i.e. agriculture, livestock, NTFPs collection etc.) decline. However, the culture and religion of the traditional and local communities is itself open to pressures which have uncertain outcomes (Maikhuri and Rao, 2005).

These topics debated recently in Joshimath where local communities of NDBR buffer zone villages were encouraged, promoted and motivated to expand their involvement and activities with eco-tourism so as to improve their economy(Maikhuri and Rao,2005).

Therefore, the program formulation for eco-tourism development need to consider the carrying capacity of each destinations and routes being promoted. Planning must be considered for the long-term effects of carrying capacity with short-term returns to the local people. While promoting eco-tourism the critical factors that directly or indirectly affect the carrying capacity need to be taken in account along with the identification of limiting factors such as period for eco-tourism activity, cultural, religious, ecological and biological considerations including visitors behavior patterns and their perceptions.

Field based observations and peoples/farmers perceptions on climate change impact

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 the 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 5).

Table -5. People's perceptions on climate change in central Himalayas.

Kind of change	Evidence
Warming	Decline in snowfall 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 milliaceum* in rainfed area, declining yields of Amaranthus.
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 snowfall	Delayed sowing of winter crops, decline in barley and wheat yields
Increase in instances of cloud burst	Heavy losses of life and property

Another way of assessing the impact of climate change could be to make an inventory of land cover changes and identify their causal factors. Such an approaches (**Table 6**) showed a greater influence of non climatic factors in the Himalayan biosphere reserves. In deed, farmers/peoples' 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. In depth field observation of past 18 years of a team of scientist of GBPIHED, Garhwal Unit, Srinagar and local people perceptions revealed that advancement of flowering, leafing and fruiting time (15-20 days) in the medicinal and aromatic plants (i.e. *Carum carvi, Allium stracheyi, A. humile, Betula utilis, Hippophae rhamnoides, Meconopsis aculeate, Saussurea obvallata*), some prominent wild edible species (i.e. *Rebis orientale* (lepchi), *Rosa webbiana*, *R. sericea* (sedum) has been noticed and is considered most striking evidence of climate change. These plants species are used to cure various ailments and some of them are also used by local people for making juice, squash and pickles. Besides, upward expansion of *Tagetis minuta*, *Eupatorium* spp., *Polygonum* spp., *Lonicera parviflora* and *Berberis aristata* (high altitude spp) and *Ephedra gerardiana* seems to be driven primarily by climate change. The increased incidence of exotic (*Lantana*, *Eupatorium* spp., *Parthenium* etc) and native weeds particularly in lower and mid altitudinal region (between 500 to 2500m asl) is also detrimental to the livelihood of local community as in agricultural areas, these weeds spread rapidly and still spreading which required more human labour to eradicate them. In forest and alpine areas, these species reduce the natural diversity affecting the growth and regeneration of other species those have much value to locals.

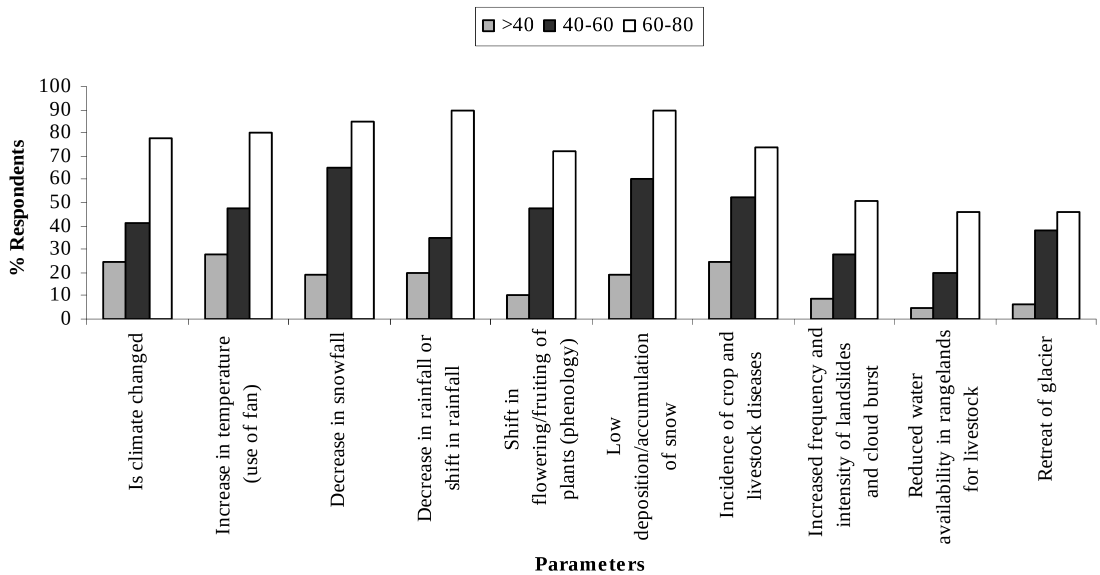
Table-6. Common changes in forests/meadows and driving factors identified by people/reported in scientific studies in Central Himalayan region.

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 agricultural land	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 favouring 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.
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 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 maximize 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
Phonological changes	Shift in flowering time of *Rhododendron* from March/April to Feb – March due to climate change

The old people of the region attributed that there is a significant decrease in snowfall and snow deposition/ accumulation in the Malari, Gamsali, Niti and Dunagiri villages located between 3000-3600 masl. However, their past experiences of 15-20 years indicated that at the time of upward migration to summer settlements they could see their houses/ courtyard/ kitchen garden, footpath etc covered with thick layers of snow (6-8 feet) up to almost second week of May whereas now it is very rare. The recession of the Satopanth, Dunagiri and other glaciers located in the Biosphere reserve is another important evidence indicating the climate change in the region as revealed by the local people involved in trekking and mountaineering activities (**Figure 2**). The most significant evidence that is reduced availability of water resources used for drinking by livestock particularly in several alpine pastures and low altitude forest and grazing areas over a period of 10-15 years as revealed by the transhumant pastoralist communities those are involved in this sector since last so many years. They attributed that this change might be due to a gradual increase in temperature and the consequent drying up of the water bodies. Another important finding that is based on our field observations as well as people experiences that supports the changes in the quality and yield of the traditional crops grown in the region. Farmers have observed that over the past two decades, there has been a decline in yield of some traditional grain and legume crops and horticultural produce i.e. Apple, Khubani, Juglans etc partly due to low input of organic manure derived from forest in the form of leaf litter and partly due to increase in the incidence of pests and diseases. Nonetheless, possibility of modification of climate change driven changes by those driven by non-climatic factors cannot be ruled out.

Figure -2. Local peoples (farmers/pastoralists) perceptions on various climate change related indicators in Nanda Devi Biosphere Reserve (percent of people of different age groups responded in each category of indicator of climate change)



*Total no. of respondent 350 belonging to 10 buffer zone village of NDBR

Coping and mitigation strategies:

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 the Himalayas is legally protected), our knowledge on people – biodiversity vulnerability linkages is very limited. Unsustainability of traditional grazing is more an assumption that a scientific conclusion (Maikhuri et al., 2000a). Rarity of medicinal plant 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 indigenous biodiversity may succumb to new global forces. Participatory research/ management could turn people's callous/ negative attributes to positive attitudes towards protected areas,(Maikhuri et al., 2000a) together with improvement in scientific knowledge related to potential uses of biodiversity for coping and mitigation.

Rehabilitation of degraded forest and abandoned lands

The failure of afforestation and reforestation efforts to develop degraded lands in the Himalayan mountains could be attributed largely to the ignorance of people's essential needs and hence their non-cooperation. People's participation is now considered as a prerequisite to success of any land rehabilitation effort in the Himalaya. The practice and framework developed (Maikhuri *et al*., 1997) for degraded land rehabilitation is now widely accepted, particularly by the locals. It has also been accepted as a major source of inspiration for the Forest Department, policy makers, NGOs, environmentalists, village institutions and other government departments involved in development. More research is required to develop and cultivate species that are ecologically and socio-economically appropriate to further improve the rehabilitation framework developed by Maikhuri *et al*., 1997. Considering the diversity of ecosystems, indigenous knowledge, and socio-economic conditions in the mountains, a rehabilitation strategy has to be location-specific. There is a need for developing rehabilitation models suited to diverse sets of ecological and socio-economic conditions in the Himalaya Mountains (Maikhuri *et al*., 1997; Rao *et al*., 1999; Saxena *et al*., 2001).

Promotion of traditional crops cultivation

In spite of the many virtues of traditional crops, precious genetic diversity, the rivet of ecosystem stability, is gradually being lost (Maikhuri *et al*., 2001). In addition, the region would lose the traditional knowledge of cultivation and the uses of these crops forever and would also lose the chance of being a diverse and nutritive food producing region. *In situ* conservation of traditional crops and cultivars could succeed when these crops are strongly linked with the economic development of hill farmers. Pragmatic multidisciplinary research efforts are needed to evolve farming systems with appropriate selection of crops in view of future climate change which can provide enough quality food and economic security for the people of the region together with conservation of the traditional crop wealth, sustainability of the production systems and environmental conservation.

Cultivation and conservation of medicinal and aromatic plants

Cultivation of medicinal plants at present has limitations due to a number of factors. The most important among them is the availability of material at low prices due to large scale collection from the wild with only collector's labour as input. Other factors responsible for slow pace of technology adoption by the farmers include lack of appropriate agro-technology for the diverse mixtures preferred by the farmers as a contingency measure to ensure some returns even in the bad years, shortage of desired planting materials, long gestation periods and lack of ensured marketing opportunity in remote areas. GBPIHED is one among several organizations which are involved in testing, developing and demonstrating action research to create a conducive atmosphere and relation between farmers, extension officers and research and development institutions. These relationships are thought to be a fundamental tool, allowing scientists to collect appropriate data/ information and to transform them into developed technologies/ products adapted to farmers needs. Though the government of Uttarakhand has introduced policies to promote and strengthen cultivation and conservation together, these policies have not shown desired results. In developing a policy regarding the medicinal plant sector, inputs from all the stakeholders not only provide important insight, but are also necessary for developing effective management plans

Capacity building and skill development in the field of eco-friendly rural technologies

Technologies change is an important instrument in the continuous process of socio-economic development but due to poor access to suitable technologies is one of the main cause of poverty, drudgery and natural resource degradation in the Himalaya. Therefore, establishment of rural technology demonstration and training centre in buffer zone villages could provide viable option for improving yield potential of farm produce, income generation from off- farm activities and thus reduce the existing pressure on forests and alpine meadows and other bioresources (**Figure 5**). The appropriate technologies suitable for high altitude region include protected cultivation, organic compost and bio-fertilizers, off-farm technologies and other supporting technologies (Maikhuri *et al*., 2007a).

Figure- 5. Implementation of participatory action research for adaptation and mitigation of climate change impact.

Box-1

- Cultivation of traditional crops (i.e. buckwheat, nacked barley, Vigna spp., Amaranth, Kidney bean, etc.) and other agro-produce such as vegetables and spice crops are organically produce and preferred more by the tourists during home-stay accommodation and also raw materials is being usually purchased by the domestic tourists.
- Value addition to the medicinal plants (*Allium spp., Angelica glauca, Pleurospermum spp*) locally through semi-processing facilities as a spice and condiments as eco-tourism products.
- Integrated medicinal plant cultivation as part of an ecological rehabilitation strategy and demonstrated in Lata, Peng and Tolma villages through participatory approaches so as to meet conservation goal.
- Bioprospecting and value addition locally of more than twenty five wild edible plant species (i.e., *Hippophae rhamnoides* (Ames), *Prunus persica* (Kirol), *Prinsepia utilis* (Bhenkal) and

aromatic species i.e. *Artemisia nilgariaca*, *A. brevifolia, A. maritime, Jurinea himailica* and *Rhododendron anthopogon*) while making a variety of edible and other products (i.e. Jam, Jelly, Sauce, Squash, Pickles etc.) as a source of income. Sustainable harvesting of some potential wild edibles has been worked out.

- Conservation education include extensions programmes, public campaign, visit of the locals to action research sites, agro-based yield enhancing and income generating activities and demonstration and on-site training in eco-friendly rural technologies for youth and villagers (i.e. polyhouse, shadenet, biocomposting, zero energy cool chamber, water harvesting, polypits etc.).
- Established participatory action research demonstration and training centre at three locations to develop capacities of the various stakeholders in the field of eco-friendly rural technologies, conservation education and climate change impact related issues.
- Climate change impact assessment on vegetation structure and composition in timberline and alpine meadows in some of the areas of NDBR were carried out.

Bioprospecting, conservation and management of wild edibles and NTFPs

Interest in wild bioresources has grown significantly with the increasing awareness in linking forest conservation with rural development and poverty alleviation. Thus the ability of a given wild bioresources to continue meeting both subsistence and market needs however, largely depends upon sustainable harvesting and appropriate management practices. It is realized that in order to influence policy planners and forest management practices one must understand the broader context such as sustainability, extraction rates, growth, yield, and biological possibilities for increasing production and the local variations in the value of wild edible species(Maikhuri et al., 2007b).

Eco-tourism promotion and development

Indian Himalaya particularly central Himalaya, rich religious tourism tradition and adventure tourism potential is enjoying worldwide reputation as an international tourism hotspot. If eco-tourism in this region to be made sustainable, there is a need to moderate policy and guidelines to integrate eco-tourism into local development and biodiversity conservation. Ecotourism in high Himalayan BR i.e. NDBR needs to be vary carefully considered and if eco-tourism and ecological sustainability are to have some compatibility balance needs to be developed between local community development and maintenance of ecosystem services of BR. The results of studies indicate that in most cases buffer zone areas are unable to withstand the recreational pressure that ecotourism generates and the subsequent impacts of further development of infrastructure. Therefore, ecotourism plan of BR integrated with other management plans such as wildlife, fire, vegetation and eco-development plan so as to reduce over all pressure on forest and biodiversity of the BR (Maikhuri *et al*., 2000, 2001, 2002, 2005,2006).

Conservation and management of alpine meadows

The NDBR management authority need reduced livestock densities in the region to allow the area under conservation to regenerate naturally and meet the growing demand for wildlife fodder. Although villages with transhumant pastoralist populations are reducing livestock holdings because of non- availability of grazing resource in winter , the villages that are now settled continued to show increases in the numbers of cattle, which are required for draught power and manure. In addition, the keeping of small ruminants by these people for economic benefits is adding to the growing pressure on village commons and surrounding forest. For effective management of available resource in the region, continuance of transhumance by villages within the limits of carrying capacity is required, as is reduction of cattle populations and replacement of small ruminants with alternative options such as medicinal plant cultivation and organic food production in settled villages. This strategy could provide the required economic benefits to both settled and transhumant populations and also support conservation goals by reducing the overall pressure.

Institutional cooperation, coordination, collaboration and capacity building to address climate change in various sectors

In central Himalayan region particularly Uttarakhand state has many Research and Development institutions with significant infrastructure and scientific/ technical capacity. However, so far these institutions have not much focused on climate change research, which includes modeling, field ecological and biodiversity related studies etc. There is inadequate capacity in several research and developmental institutions working on environmental and conservation issues in relation to climate change (**Figure 5**). There is a utmost need to create awareness and enhance capacities at individual and institutional level and also include other stakeholders i.e. NGOs etc. Local communities depending on natural resources for their livelihood have poor financial, technical and institutional capacity to adapt to adverse impacts of climate change. Therefore, it is important to enhance capacities of local people's (whose survival entirely depends on their surrounding forest vegetation) who are likely to be vulnerable to projected climate impacts.

Research, experimentation and monitoring to increase understanding of climate change impact and coping strategies in Himalayan Protected Areas.

The Himalaya is rich in bioresources potential and has diverse forest and grassland types (i.e. tropical, sub-tropical, temperate, sub- alpine and alpine etc.) subjected to diverse socio-economic pressures. Climate change will be an additional stress on the different vegetation and ecosystem types. In Himalaya, agriculture, livestock, forestry are closely linked and are interdependent sectors, climate is likely to affect all sectors of the rural economy. Currently there is little effort made to understand climate change in a integrated manner were various sector i.e. agriculture, forestry, livestock, pest and diseases, water resources put together so as to bring desired outcome.

Some priority research areas includes:-

1. Documentation of traditional ecological knowledge as well as people knowledge ad experiences about the pattern of climate change towards its impact on forest, agriculture, livestock and humans through participatory approaches so as to provide possible indicator of change.
2. Effect of climate on seasonal variability and reliability and climate extremes affecting agriculture production, forestry and water resources.
3. Interface with policy issues, administration, local communities and research and academic institutions regarding the broad aspects of adaptation options and livelihood.
4. In- depth study in more number of relatively undisturbed plot in forests and alpine meadows along an elevational gradients needs to be undertaken with major emphasis on phenological variations of species commons to plots to predict the response of plants for the possible climate change.
5. Establish permanent sample plots in different forest types along an elevational gradients for effective and comprehensive monitoring programme to track the response of both at community and species levels to changing climate.
6. Capacity building of the researchers/scientists in the field of climate change and modeling studies.
7. Conduct in-depth studies on genetic diversity of traditional mountain crops which may provides a platform to identify suitable thermal and drought tolerant cultivars for meeting climate change.
8. Develop appropriate whether and meteorological stations on important and sensitive biomes and ecosystems type with regional projections of climate parameters for developing regional climate models.

9. Studies to assess and project natural resource utilization pattern and factors and key drivers contributing bioresources degradation.

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