Climate Change and India: Vulnerability Assessment and Adaptation

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7. Vulnerability and Adaptation to Climate Change in the Forest Sector

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Summary

Forests meet nearly 40% of the country's energy needs and 30% of the fodder needs. It is estimated that approximately 270 million ton (Mt) of fuelwood, 280 Mt of fodder and over 12 million m^3 of timber and several non-timber forest products are removed from forests annually. About 200 million people depend on forests for their livelihood directly or indirectly. The value of goods and services provided by the forest sector is estimated to be Rs. 25,984 crore. Climate is one of the most important determinants of vegetation patterns, and thus there is a need to assess the possible impacts of climate change on the Indian forestry sector to develop adaptation measures at the local, regional and national level.

In the present study, a process-based model BIOME-3 is used to project vegetation changes in the country by the year 2050, using both GCM and RCM projections for climatic change (chapter 3). Quantitative estimates of projected changes in forest biome types can be obtained on the basis of the number of RCM grids (out of a total of about 1500) that change from one biome type into another. Under the climate scenario driven by 1% compounded annual increase in CO_2 concentration, about 70% of the grids and concomitantly existing forests are likely to experience a change (64% when CO_2 and aerosols are taken into account). The biome type most seriously impacted is the Dry Savanna with about 62% of it, mainly lying in the northern/central parts of India, likely to be converted into Xeric woodland (Dry Thorn Forest), while another 24%, mainly in the northwestern parts, is likely to change to Xeric Shrubland. In general, increased CO_2 is expected to lead to an increase in the net primary productivity. This has an effect of converting grassland into woodlands and woodlands into forests. Thus, in the region with a relatively large temperature increase, dry and moist savannas are likely to be replaced by xeric vegetation, while in the areas with a lower temperature increase and enhanced rainfall, the moist savannas seem to be transformed into Seasonal Tropical Forests. However, the northern part of the country has largely been transformed into agriculture and thus the Savannas occupy only a small geographical area.

The other biome type to be affected is the moist savanna located in the northeast and some of the parts of southern India. This is likely to be converted into Tropical Seasonal Forest (about 56%), mostly in the northeast and Xeric woodland (Dry Thorn Forest) (about 32%) mostly in south India, depending on the change in the quantum of rainfall. The Tropical seasonal forest, especially in the northeast, is likely to change into Tropical Rain Forest due to a large increase in rainfall expected to take place in that region. The changes expected in the colder regions are also along similar lines,

with the tundras likely to change to boreal evergreens, and boreal evergreens into temperate conifers.

Under a lower CO_2 increase scenario (0.5% per year instead of 1%), the changes in vegetations are rather modest, with only about 36% of the grids showing shifts in vegetation type. The types of changes in vegetation, however, are rather similar in all these situations. Thus, though there is some uncertainty on the magnitudes of the projections of change based on GCMs and RCMs used, the direction of change is likely to be similar.

The paper also discusses existing forest policies that decrease the vulnerability of forests to climate change, such as the Forest Conservation Act (1980), Wild Life (Protection) Act (1972 and 2002), afforestation programmes, and Joint Forest Management. Some of the potential silvicultural practices that could reduce vulnerability and enhance resilience are promotion of natural regeneration in degraded forest lands and mixed species forestry on degraded non-forest lands, anticipatory planting of species along the latitudinal and altitudinal gradient, *in-situ* and *ex-situ* conservation of plant and animal species, implementation of fire management practices, adoption of short rotation species and practices, and sustainable harvest practices for timber and non-timber products. Institutional mechanisms for building technical capacity, and long-term research on climate change impacts of forests should also be initiated.

7.1 Introduction

Climate change is one of the most important global environmental issues likely to impact natural ecosystems and socio-economic systems. The Intergovernmental Panel on Climate Change (IPCC, 2001a) projects that the global mean temperature is likely to increase between 1.4° and 5.8° Celsius (C) by the year 2100. This unprecedented increase is expected to have severe impacts on the global hydrological systems, ecosystems, sea level, crop production and related processes. The impact will be particularly severe in the tropical forest areas, which mainly consist of developing countries. The most important socio-economic linkage of climate change and forests is the likely adverse impacts of projected climate change on forest ecosystems, biodiversity, biomass production and ultimately, the livelihoods of forest dependent communities and economies.

Climate is probably the most important determinant of global vegetation patterns with significant impacts on forest ecology (including biodiversity), forest distribution and productivity (Krischbaum et al., 1996). Local, regional, and global changes in temperature and precipitation can influence the occurrence, timing, frequency, duration, extent, and intensity of disturbances (Baker, 1995; Turner et al., 1998). Disturbances, both human-induced and natural, shape forest systems by influencing their composition, structure, and functional processes. A number of climate-vegetation models have also shown that certain climatic regimes are associated with particular plant communities or groups (Holdridge, 1947; Thornthwaite, 1948; Walter, 1985; Whittaker, 1975). It is, therefore, logical to assume that changes in climate will alter the configuration of forest ecosystems (IPCC, 1996b; Solomon, 1986). A change in mean annual temperature, as small as 1°C over a sustained period is sufficient to bring about changes in species composition as well as distribution of many tree species (Davis and Botkin, 1985; IPCC, 1996b). Under a supposed doubling of atmospheric CO_2 concentration (a "2 X CO_2 climate"), current global models project that a substantial fraction of existing forests will experience climatic conditions under which they do not currently exist, possibly leading to new vegetation types (IPCC, 1996b). According to another review, even under the least dramatic climate change scenarios, ecological impacts on forests can be anticipated (Markham and Malcolm, 1996).

The projected impacts of climate change, therefore, have implications on forest product flows, trade as well as forest management (Solomon et al., 1996). Forests, particularly in the tropics, are subjected to anthropogenic pressures leading to degradation and loss of forest ecosystems. Impacts of climate change will be additional to these stresses, possibly compounding the impacts. Even though the ability to project regional differences in impact is still emerging, the consequences of climate change are projected to be more drastic in the tropical regions.

Currently there is little information on the impacts of projected climate change on forest biodiversity, biomass production, and ultimately forest product flows, particularly at the regional and local levels. The secondary impacts on local communities, local economy or regional economy are even less understood. Although the Second Assessment Report of the IPCC (1996b) attempted to assess the socio-economic impacts of climate change on forests, it did not generate any new useful information. This was largely due to the absence of studies at the local, regional and even at the national level.

To minimize adverse impacts, particularly socio-economic, there is a need to plan and implement adaptation and mitigation strategies in the developing countries. In order to plan and implement the various adaptation measures, it is important to identify vulnerable ecosystems. This will aid in formulation of strategies to combat climate change as well as adapt and mitigate the effects of climate change.

Given the significant dependence of local people and economies on forests in India, there is a need to assess the possible impacts of climate change and develop adaptation measures at the local, regional and national level.

7.2 Forest Ecosystems of India

7.2.1 Area under forests in India

India is one of the 12 mega diversity countries having a vast variety of flora and fauna. It commands 7% of world's biodiversity and supports 16 major forest types, varying from the alpine pastures in the Himalayas to temperate, sub-tropical and tropical forests, and mangroves in the coastal areas.

The State of Forest Report, 2001 (FSI, 2001) reports the forest cover in India as 67.6 Mha, constituting 20.6% of the geographical area. This is composed of 41.7

Mha (12.7%) of dense forest, 25.9 Mha (7.9%) of open forest and 0.4 Mha (0.14%) of mangroves. The forests in India are termed "dense" if canopy density is 40% and above; and "open" if lands are with tree cover of canopy density between 10 and 40%. Mangroves are salt tolerant forest ecosystems found in inter-tidal regions in estuaries and coasts. There is another 4.73 Mha scrub in addition to a reported forest cover of 67.6 Mha.

India has a periodic satellite based forest-monitoring programme and the forest area assessment is published once every two years since 1986. The area under forests in India remained stable at around 64 Mha during the period 1986 to 1994. However, a decline in forest area was reported during the period 1995-97. Forest loss rates have been estimated by taking the difference in gross forest area between two-satellite assessment periods. In India, if tree crown cover declines below 10% it is considered non-forest. Shifting cultivation, which is practiced largely in the northeastern region of India, is considered as deforested land and the regenerating fallow land is considered as gain in forest area.

7.2.2 Forest types in India

According to the Forest Survey of India, the recorded forest area of India has been classified as Reserve Forests, Protected Forests and Unclassed Forests. Area under forests, according to the latest assessment for 2001 is 67.6 Mha, with reserve forests accounting for about 42 Mha.

Champion and Seth (1935,1968) have classified the forests of India into the following broad categories; i) tropical forests, ii) montane sub-tropical forests, iii) montane temperate forests, iv) sub-alpine forests, and v) alpine forests. These have been further classified into 16 sub-types (Fig. 7.1). The dominant forest types are the tropical dry deciduous forest (38%) and tropical moist deciduous forest (32%). The other important forest types are tropical evergreen, tropical thorn, sub-tropical pine and alpine forest.

The Forest Survey of India has classified forests into 22 strata, based on the dominant tree species. The areas under these forest strata are given in Table 7.1. The dominant forest type is the 'miscellaneous' category, accounting for 66% of total forest area, where no dominant species could be identified. The approximate extent of forests on functional basis is: Protection Forests - 10 Mha; Production Forests – 15 Mha; Social Forests - 25 Mha and Protected Area Network - 14.8 Mha. Social Forests here do not include the small blocks of woodlands (less than 25 ha), trees in strips and farms.

7.2.3 Importance of forest ecosystems in India

Forests play an important role in environmental and economic sustainability. They provide numerous goods and services, and maintain life-support systems. Some of the major life-support systems of economic and environmental importance are given below:

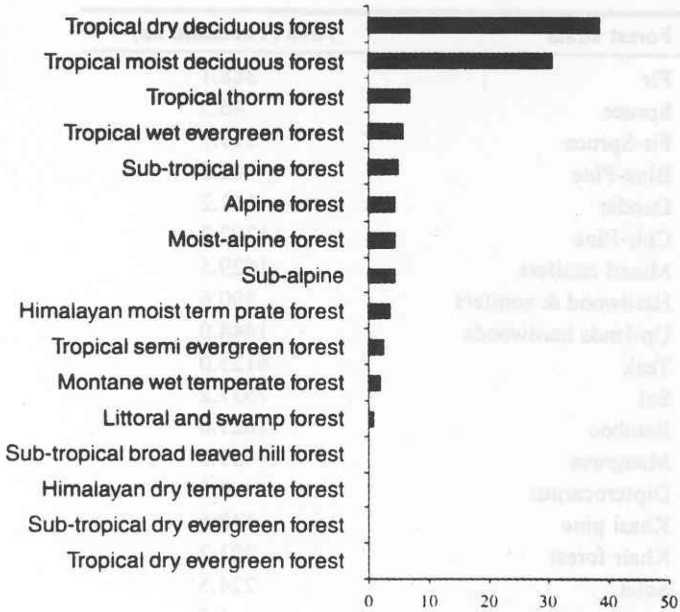

Fig. 7.1 Different forest types in India
Source: Champion and Seth, 1935

Biodiversity: The forests support a wide variety of flora and fauna. More than 5150 species of plants, 16,214 species of insects, 44 mammals, 42 birds, 164 reptiles, 121 amphibians and 435 fish species are endemic in the forest ecosystem of India (MoEF, 2001). However, in recent times, heavy biotic pressures have started to exert tremendous stress on natural resources and hence many of the plant and animal species are under various degrees of threat. In order to conserve these, a wide Protected Area Network, comprising 80 National Parks and 441 Sanctuaries have been created on about 14.8 Mha of forests, representing about 4.5 per cent of the geographic area of the country (MoEF, 2001).

Biomass supply: Forests meet nearly 40% of the country's energy needs and 30% of the fodder needs. It is estimated that approximately 270 million tons (Mt) of fuelwood, 280 Mt of fodder and over 12 million m^3 of timber and several Non-Timber Forest Products (NTFPs) are removed from forests, annually (Planning Commission, 2002-2003).

Livelihoods to forest dependent communities: In India there are about 15,000 plant species out of which nearly 3,000 species (20%) yield NTFP (Maithani, 1994). NTFPs activities hold prospects for integrated development that yield higher rural incomes and conserve biodiversity while not competing with agriculture (Sharma, 1992). Millions of forest dwellers and agricultural communities depend on forests for a range of non-timber forest products such as fruits, nuts, edible flowers, medicinal

Table 7.1 Area under different forest strata during 1994 (Thousand hectares)

Forest strata	Area (Thousand ha)
Fir	388.1
Spruce	46.5
Fir-Spruce	119.7
Blue-Pine	408.2
Deodar	141.2
Chir-Pine	1302.2
Mixed conifers	1629.5
Hardwood & conifers	500.6
Up-lands hardwoods	1444.0
Teak	6125.0
Sal	7537.2
Bamboo	1021.0
Mangrove	459.8
Dipterocarpus	6.8
Khasi pine	148.6
Khair forest	201.2
Salai	224.5
Alpine pastures	6.7
Miscellaneous forest	40731.6
Western Ghats (evergreen forest)	376.7
Western Ghats (semi-evergreen)	280.8
Deciduous	236.1
Total	63336.0

Source: FSI, 1995

herbs, rattan and bamboo, honey and gum. Further, all forest sector activities are labour intensive and lead to rural employment generation.

Gross domestic product (GDP): The value of goods and services provided by the forest sector is estimated to be Rs. 25,984 crore. Of the Gross Domestic Product of Rs. 23,000 crore, approximately 54% is from fuelwood, 9% extraction from industrial wood, and 16% from NTFPs. Eco-tourism and carbon sequestration account for 14% and 7% respectively (Planning Commission, 2002).

7.3 Review of IPCC Impact Studies

7.3.1 Projected climate change at global level

Some of the critical projected changes in climate parameters according to the Third Assessment Report of the IPCC (2001b) are as follows:

- The CO_2 concentration in the atmosphere is projected to be in the range of 540 to 970 ppmv by 2100

- The global average surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100
- The global average water vapour concentration and precipitation are projected to increase during the 21st century with greater year-to-year variation in precipitation
- Global mean sea level is projected to rise by 0.09 to 0.88 meters between 1990 and 2100
- Occurrence of extreme events such as hot days, intense precipitation, droughts, cyclones, hurricane, storms etc., is projected to increase.

7.3.2 Projected climate change impacts

Some of the impacts on forest ecosystems as summarized in the Third Assessment Report of the IPCC (2001b) are as follows:

- Populations of many species that are already threatened are expected to be at greater risk by the synergy between stresses of changing climate and land-use change that fragments the habitats
- The latest vegetation distributional models suggest that mass ecosystem or biome movement is most unlikely to occur due to different climatic tolerance of species involved, different migration abilities and the effects of invading species
- Species composition and dominance will be altered, resulting in ecosystem changes
- Some species that are currently classified as "critically endangered" will become extinct, without adaptation
- Terrestrial ecosystems appear to be storing increasing quantities of carbon. Productivity gains are occurring due to changes in climate parameters as well as changes in uses and management of land
- Global timber market studies that include adaptations through land and product management suggest that climate change will increase timber supply and consumers will benefit from lower timber prices, while producers may gain or lose depending on regional changes in timber productivity and potential dieback effects
- In arid or semi-arid areas (dry forests, woodlands and rangelands) where climate change is expected to decrease the available soil moisture, biomass productivity is expected to decrease. Increased CO_2 concentration may counteract some of these losses
- Forests will replace some wetlands.

7.4 Review of Indian Studies

The assessment of impacts of climate change on forests is important as these changes cause a shift in forest boundaries, and changes in productivity and forest product flow, thereby affecting trade and economy. Further, assessments at the regional level, particularly seasonal changes reveal the likely direction of change and aid governments and communities to plan and adopt strategies in the face of a changing climate.

There is much interest among researchers as well as policy makers in such studies. Policy makers as well as forest managers need information, so that they can develop short and long-term strategies to adapt to and to mitigate the adverse effects of climate change. Ravindranath and Sukumar (1998) in their paper on "Climate change and tropical forests in India" made a very preliminary assessment of the impact of projected changes in temperature, rainfall and soil moisture following two earlier studies: Ravindranath et al. (1997) in the Western Ghats and Deshingkar et al. (1997) in Himachal Pradesh. The methodology and conclusions are briefly presented in the following sections.

7.4.1 National level assessment of climate change impacts on forests

The assessment is based on climate model outputs by Hulme and Viner (1995) for the tropics and Lal et al. (1995) for the Indian sub-continent. We discuss in this section the findings of the study by Ravindranath and Sukumar (1998). The study considered two scenarios: i) increase in greenhouse gas concentration (Hulme and Viner, 1995) and ii) increase in greenhouse gas + aerosol concentration (Lal et al., 1995). The projections were made for the southern, central, northwestern and northeastern zones of India.

Under Scenario I, a shift in vegetation type along the altitudinal as well as west-east gradient is predicted for the Western Ghats in southern India. In the montane regions, the stunted evergreen forests (or *sholas*) could potentially expand into the grasslands with an increase in temperature and reduction in the incidence of frost. However, in the absence of proper management, the present-day plantations of exotics such as wattles (*Acacia spp.*) could invade the grasslands. Longer dry spells may cause increase in dry season fires, threatening the moist and dry deciduous forests. On the other hand, forests in central India may potentially become *moister* forests due to increased rainfall and soil moisture during the southwest monsoon. For example, teak (*Tectona grandis*) that is characteristic of a dry belt may be replaced by sal (*Shorea robusta*), a typical moist forest species over time.

The changes in northeast India with diverse tropical, sub-tropical forests and moist grasslands are unclear and a wide variability in the various climate parameters is predicted. The projected increase in temperature during all seasons is predicted to cause a shift in lower altitude tropical and sub-tropical forests upward to temperate forests, resulting in contraction or dying of some temperate forests. However, the forests in the northeast are community controlled and subject to shifting cultivation at very high rates. This might override any climate-related impacts. Conversely, the dry deciduous and dry thorn forests of northwestern India may have no significant changes in forest type or productivity as no change in soil moisture storage is projected for the region.

Under Scenario II (GHG plus aerosol model), a change in precipitation pattern is projected that will weaken the Indian summer monsoon. No significant change in winter precipitation is expected. Compared to Scenario I, the potential impact of CO_2 and aerosol forcing on forests is very different. With increase in temperature and decrease in summer rainfall, the central Indian forests will face soil moisture stress and increasing mortality of trees, inducing shifts from moister to drier forest types. Similar trends are indicated for northern India, including the forests on the Himalayan slopes, the foothills and the northeastern states. No major changes are indicated for the forests of southern India.

To conclude, under the Hulme and Viner scenario, productivity of tropical forests will increase, thereby increasing diversity. An opposite situation will exist under Scenario 2. In any case, increase in forest species turnover is indicated, potentially resulting in large-scale decline of biodiversity and extinction of species (Philips and Gentry, 1994). The resulting population depends on the rate of change of climate and time available for species and populations to adapt to change, and shift vegetation boundaries.

7.4.2 Regional assessment of climate change impacts in India

Realizing the importance of studies at the regional level, two studies were conducted in the Western Ghats region – in the Nilgiri Biosphere Reserve and the Uttara Kannada district (Ravindranath et al., 1997), and Himachal Pradesh in northern India (Deshingkar et al., 1997).

Impact of climate change on forest ecosystems of the Western Ghats: The Western Ghats chain of mountains run parallel and close to the west coast of India. The Ghats are home to numerous indigenous peoples and cultures, and in recent decades have been transformed substantially by development. Indeed, this transformation is threatening the very stability of the natural ecosystems of the Ghats, the source of all major river systems in peninsular India. Climate change is an added dimension to rapid ongoing changes in this region.

The Western Ghats have been identified as one of the "hot spots" of global biodiversity. They harbour an estimated 3500 species of flowering plants, which constitute 27% of the total plants described from India. Of the 15,000 species of flowering plants described from India, 12% are endemic to peninsular India. There are as many as 1932 taxa, which are endemic and have a large representation in the Western Ghats. The endemics are concentrated in families such as Poaceae, Rubiaceae, Acanthaceae, Orchidaceae and Fabaceae. Diversity and endemism are well represented in the animal groups also.

Projections for the Western Ghats were based on projections from various General Circulation Models (GCMs), incorporating greenhouse gas forcing, which have been summarized by Kelly (1996). The scenarios were derived from two sets of climate models following the method of Hulme (1994) and they provide a guide to the change in regional climate that may be experienced for the years 2020, 2050 and 2080.

For each of the three years, 2020, 2050 and 2080, three scenarios have been presented defining the range of uncertainty in the underlying projections. These are based on:

Case 1: the central scaling factor and the moderate climate sensitivity global-mean temperature projection.

Case 2: the lower scaling factor and the low climate sensitivity global-mean temperature projection in the case of temperature projections or the high climate sensitivity global-mean temperature projections in the case of precipitation projections.
Case 3: the upper scaling factor and the high climate sensitivity global-mean temperature projections.

For assessing ecological impacts, the Case 1 scenario is taken to represent the "most likely" estimate, while combinations of the Case 3 temperature projections and the Case 2 and 3 precipitation scenarios are also considered as these represent the "worst case" estimates.

Vegetational changes in the Western Ghats: To assess the vegetational responses to climate change, a simple empirical-statistical model based on present day correlations between climatic (mean temperature and precipitation) and vegetation types of the regions was developed. A likely change in area under different forest types was assessed for the "most likely scenario" or the "moderate climate sensitivity" and "central scaling factor" for the years 2020 and 2050. Vegetation response under the "worst case scenario" or "high climate sensitivity" and "lower scaling factor" was also assessed for the year 2050.

Under the most likely scenario of climate change i.e. with increased temperature and precipitation, a shift towards moister types of vegetation is projected for the years 2020 and 2050 for Uttara Kannada. However, a decrease in area of the dry deciduous (by 37%) and moist deciduous (22%) forests due to a shift from dry and moist deciduous types to semi evergreen and evergreen types is projected for the same period (Table 7.2).

Table 7.2 Projected changes in area under different forest types in Uttara Kannada under changed climate regimes

Forest Type	Baseline Area (km^2)	Most Likely Scenario (2020) Temp + 0.3°C Rainfall + 3%	Most Likely Scenario (2050) Temp + 0.7°C Rainfall + 7%	Worst Case Scenario (2050) Temp + 1°C Rainfall – 7%
Evergreen	1089	1284 (+ 17.9%)	1582 (+ 45.4)	1761 (+ 61.8%)
Semi evergreen	2092	2205 (+ 5.4%)	2261 (+ 8.13%)	1583 (– 24.3%)
Moist deciduous	2265	2055 (– 9.27%)	1779 (– 21.5%)	2045 (– 9.71)
Dry deciduous	478	380 (– 20.5%)	302 (– 36.8%)	535 (– 11.9%)

Source: Ravindranath et al., 1997

Consequently, the area under evergreen and semi evergreen forest types is projected to increase by 45% and 8% respectively by the year 2050.

In the Nilgiri Biosphere Reserve, under the most likely scenario, an increase in evergreen, moist deciduous and dry thorn forest types and a decrease in montane forests or grasslands and dry deciduous forests are projected (Table 7.3 Typically, there is a sequential shift from dry deciduous through moist deciduous to wet evergreen forest with increase in moisture as a result of increasing rainfall. As a result, there is a decrease in dry deciduous forest (36%) by the year 2050, as a result of some shift to moist deciduous forest in response to increased precipitation, while some parts shift to dry thorn forest as a consequence of increasing temperature. The area under montane forests or grasslands is also projected to decline by 7% by the year 2050, in response to increasing temperatures.

Under the worst case scenario of increased temperature and decreased precipitation it, is expected that drier types will increase in area, at the expense of moister forest types during 2050 in Uttara Kannada (Table 7.2). A similar trend is projected for the Nilgiris also with the driest forest type increasing (33%) at the expense of dry deciduous forest (– 48%). A modest change is projected for other vegetation types for the year 2050 (Table 7.3).

Table 7.3 Projected changes in area under different forest types in Nilgiris under changed climate regimes

Forest Type	Baseline Area (km^2)	Most Likely Scenario (2020) Temp + 0.3°C Rainfall + 2%	Most Likely Scenario (2050) Temp +0.6°C Rainfall +4%	Worst Case Scenario (2050) Temp +0.9°C Rainfall -8%
Evergreen	585	664 (+ 13.4%)	714 (+ 22%)	563 (– 3.7%)
Moist deciduous	895	1021 (+ 14%)	1136 (+ 26.9%)	1046 (+ 16.8%)
Dry deciduous	1624	1179 (– 27.4%)	1032(– 36.4%)	850 (– 47.7%)
Dry thorn	2083	2350 (+ 12.8%)	2339 (+ 12.3%)	2767 (+ 32.9%)
Montane/grassland	289	280 (– 3.1%)	268 (– 7.3%)	263 (– 9.1%)

Source: Ravindranath et al., 1997

However, the simple statistical model used has limitations compared to process based models. Therefore, these changes in vegetation types may be considered as a direction of change rather than precise estimates. Also, the response of a particular type of vegetation to climate change is dependent on several factors, such as proximity of seed source, animal dispersal agents, topography and also the degree of fragmentation of the forest. Therefore, depending on the influence of the several factors mentioned above, two patches of a single vegetation type might respond differently.

Change in climate will, therefore, result in shift in forest boundaries and change in area under the different forest types. There will also be corresponding shifts in distribution of plant species, the magnitude of which could not be predicted because of the absence of a transient response model. Forests may decline due to death of trees, apart from shifts in forest types under the worst-case scenario.

7.4.3 Socio-economic impacts of climate change

The impact of climate change on forest product flows was assessed for the "most likely scenario". In Uttara Kannada as well as the Nilgiris, the level of dependence of communities on forests is quite high and a large diversity of products is gathered for household as well as commercial purposes. The diversity and financial value of the gathered products is varied among the different forest types.

In Uttara Kannada, under the most likely scenario, the aggregate quantity of non-timber forest products (NTFPs), potentially available for extraction is likely to increase in the evergreen and semi evergreen forest areas with projected increase in area under these forest types. For the district as a whole, the financial value of potentially extractable NTFPs is projected to increase marginally with increase in area under high income yielding moister forest types and decline in area under comparatively low income yielding dry forest types. The aggregate quantity of potentially extractable NTFPs is projected to; i) increase in the expanding evergreen and moist deciduous forest types, and ii) decline in the dry deciduous, dry thorn and montane forest areas. There will, therefore, be an increase in income from potentially extractable NTFPs with the income per hectare likely to increase by about 22%. This conclusion is based on an assumption of equilibrium response of vegetation to climate change. However, there is uncertainty regarding the transient response of vegetation to climate change and this could lead to forest dieback and loss of vegetation. Conversely, fuelwood and timber production may increase due to increased productivity as a result of increased CO_2 fertilization and nitrogen deposition.

Impact of climate change on forest ecosystems of Himachal Pradesh: A study on climate change impacts on forest based land-use systems was conducted in Himachal Pradesh (Deshingkar et al., 1997). The objectives of the project were to: i) determine possible long-term impacts of climate change on forests, ii) determine how these changes might affect forests, local communities and economies, and iii) identify and assess feasibility of sustainable adaptation strategies.

There are nine major groups of vegetation or biomes in Himachal Pradesh ranging from xerophytic woods in the lower dry parts to tundra in the high and cold mountains. The BIOME-3 (Haxeltine and Prentice, 1996, see Section 7.4.3 for details) model was used to predict what plant types can occur in a given environment and to select potentially dominant types amongst them.

The results of the BIOME-3 model indicate that there are likely to be significant changes in cover and location of the different forest types. The extent and pattern of change varies with time as well as climate sensitivity. Time series projections indicate that temperate, deciduous, cool mixed and conifer forests are likely to migrate and undergo changes in area by the middle of the 21st century. By 2080, there could be significant changes in all the biomes considered, although it is unclear as to what extent the biomes may contract or expand under different degrees of climate change.

Under moderate climate projections, the total area under tree cover in all biomes except the tundra and xerophytic woods in Himachal Pradesh is projected to increase by 11%. The tundra forests show a uniform downward trend with sharp reduction in area by early 2020. By 2080, more than 70% of the area under tundra forests is projected to decline under the moderate scenario. This implies that the meadows in the higher parts of Himachal Pradesh will shrink drastically and re-establish in the northeast direction. The area under temperate deciduous and cool conifer forests are also predicted to decrease over time, with temperate deciduous forests in the lower limits being replaced by evergreen warm mixed forests. Chir pine is likely to emerge as the dominant species in the temperate deciduous forests. Conversely, the area under Taiga is projected to increase and also establish in the higher latitudes and eastern direction at the expense of tundra and wooded tundra.

The overall prediction is that certain biomes such as the evergreen warm mixed forests and taiga are likely to show a marked expansion regardless of the degree of change in climate. Likewise, tundra and wooded tundra will probably shrink under all possible scenarios. In general, the species composition in the new biomes will be different from the existing ones and increased occurrence of fire, erratic rainfall and anthropogenic pressure may inhibit the ability of some species to migrate and establish in new locations. The model projects decline in economically and socially important species such as Deodar, Cedar and Oak due to increased climatic and biotic interactions. Species such as Blue and Chir Pine may, however, increase in number due to elimination of competing species.

7.4.4 Social and economic impacts of change in climate

The transformation of a forest base has far-reaching impacts on rural communities and the local economy. The contribution of forests to the local economy in Himachal Pradesh is very small, at 2%. However, the role of forests in day-to-day subsistence needs and some indirect benefits accruing to the agricultural sector is enormous. The study was conducted in three zones - sub alpine, moist temperate and sub-tropical chir pine, to reflect the variations in subsistence and economic activities. For example, in the sub-alpine forest zone, livestock rearing was the major economic activity. Likewise, the other two zones supported different activities such as animal husbandry, mushroom cultivation, apple cultivation etc.

The decline in area under sub-alpine vegetation due to establishment of taiga will shrink the grasslands available to the Gujjars and Gaddis – traditional nomadic graziers. In the sub-tropical region, an increase in xerophytic species will affect livestock maintenance, the backbone of the subsistence economy in the region. Since fodder requirements are met from the forests, a change in vegetation will decrease the availability of grass and leaf fodder.

Thus, climate change could have a negative impact on the living standards of communities residing in the forest zones, as sources of income decrease in number and profitability. Thus, there will be an overall decrease in incomes, although there might be an increase in income from chir pine resin industry. Combined effects of climate change and anthropogenic or biotic pressure will aggravate shortage of timber, fuelwood and fodder.

7.4.5 Summary of other impact studies

Teak, an important wood product throughout tropical Asia, and in Java, is shown to be sensitive to variations in climate (Whetton and Rutherford, 1996). In a case study of the southern Indian state of Kerala, Achanta and Kanetkar (1996) link the precipitation effectiveness index to net primary productivity of teak plantations. Using climate scenarios generated by ECHAM3, they estimate that a projected depletion of soil moisture is likely to cause teak productivity to decline from 5.40 to 5.07 m^3/ha/year. The study also shows that productivity of moist deciduous forests could decline from 1.8 to 1.5 m^3/ha/year.

7.4.6 Paleoecological studies

Paleo-vegetation and climate data provide important clues to how natural vegetation could respond to future climate changes. There are very few paleo-vegetation studies in the tropical forests of India and data needed to analyze climate change impacts are not available. However, there have been a few studies in the desert environment of northwest India (Swain et al., 1983 and Singh et al., 1990)

Evidence for past changes in climate and vegetation in the Western Ghats during the past 20,000 years are available from carbon stable isotopic studies of pollen in the Nilgiris (Vasanthy, 1988) and coastal Uttara Kannada (Caratini et. al., 1991) and peat deposit studies in the Nilgiris (Sukumar et. al., 1993; Sukumar et al., 1995). Study of pollen by Caratini et al. (1991), in Uttara Kannada suggests that the grasslands spread with the onset of an arid phase about 3500 years BP. However, it is unclear if the change was entirely due to natural climatic changes or due to forest clearing by people. The study of montane forests and grasslands by Sukumar et al. (1993) and Sukumar et al. (1995) indicates significant shifts in the extent of grassland and forest with temperature and CO_2 concentration increase leading to increased precipitation during monsoons (also see Robinson, 1994). The study also shows that the balance of C3 and C4 plants fluctuated as a result of climate change in the Nilgiris.

7.4.7 Limitations of studies of climate change impact assessments in India

The few studies conducted in India faced limitations of regional climate projections at finer grid scales, access to only equilibrium models and lack of climate, vegetation, and soil data needed for projecting impacts of climate change on vegetation. Tropical forests such as those in the Western Ghats are highly diverse with vegetation changing every few kilometers. However, equilibrium models such as the BIOME (Prentice et al., 1992), MAPPS (Neilson et al., 1992) and TVM-IMAGE (Leemans and van den Born, 1994) have been applied to model changes in global biome boundaries and thus may have limitations for regional scale assessments. BIOME projects an increase in potential area under tropical rain forest but no change in the dry forest. This climate impacted shift is unlikely because the predicted rate of change over the next 100 years is so fast that species will not be able to adapt and there will be widespread forest dieback. Succession might take several decades or a century, even in the absence of climate stress (Solomon et al., 1993).

Dynamic forest models are required to simulate the transient response of vegetation to climate change as each species or plant functional type responds differently. In a rapidly changing climatic environment, there will be no chance for plant communities to reach equilibrium or climax stage and they will be dominated by early to mid-successional species.

As a prerequisite to identifying finely tuned adaptation strategies, research on the impacts of climate change on forests needs to be strengthened (IPCC, 1996b). There have been significant efforts to improve the methods, models and scenarios for generating more accurate estimates of the future climate, its impact and cost of damages, and for formulation of appropriate adaptation measures. Global or continental level or even national level assessments are not adequate for policy making. Country and particularly regional level impact assessments are necessary for formulation and implementation of adaptation policies and strategies. This requires developing methods and models, generation of local climate, land use and, vegetation data, etc. An improved understanding of the effects of changing temperature, water availability, ambient CO_2 concentrations and photoperiod on the establishment, growth, water use efficiency, stomatal conductance and biomass allocation of forests is needed. The potential rate of migration of several species also needs to be studied. Such data for several species of temperate and boreal regions during the late Pleistocene and Holocene have been calculated to be 0.04 km and 2 km per year, respectively (Davis, 1976, 1981, 1986; Ritchie and MacDonald, 1986). Similar data for tropical species is, however, lacking.

7.5 Models for Climate Change Impact Assessment

7.5.1 Types of models

The models developed to explore the impact of climate change on vegetation fall into two broad categories:

Empirical-statistical models: These attempt to elucidate the relationship between existing climate and the existing vegetation. Some of these look at broad vegetation type (e.g., evergreen forest, deciduous forest, etc.), and try to delineate the range of climatic factors (rainfall, temperature, etc.) favourable to these types. Once such a correspondence is obtained with a reasonable degree of reliability, it is possible to use it to project the distribution of these vegetation types for any future climate scenario. A comparison of such a projected distribution with the existing one can then serve as a basis for assessing the impact of climate change as expected under that scenario. A similar approach is also attempted for specific species. By examining the existing and projected patterns of distribution of assemblages of such species, a more detailed evaluation of the impact is possible, since qualitative as well as quantitative differences in the species composition of the assemblages can also be included in the analysis. Recently, more sophisticated methods of pattern recognition (e.g., use of neural networks, genetic algorithms etc.), originating in the field of artificial intelligence are also being applied to the problem of the impact of climate change.

Simulation models: Simulation models, both deterministic as well as stochastic, explicitly evaluate the temporal changes in the various components of the system (such as root/shoot biomass, soil moisture levels, concentrations of different pools of nutrients) from one time step to the next. Equilibrium models predict the final composition, biomass etc expected at a location based on the input parameters (such as precipitation, temperature, radiation, soil carbon). Dynamic models, on the other hand, enable one to track the changes expected during the course of the time interval used in the simulation. These models vary greatly in their spatial scales, fundamental processes included in the model, degree of complexity, etc.

7.5.2 Models selected for climate change impact assessment

Previous studies (described earlier in this chapter), primarily focused on the Western Ghats as well as Western Himalayas, were based on the BIOME3 model as well as statistical models developed by us. In the present investigation aimed at examining the impacts at the national level, we have made use of the simulation models. Most of the analysis was carried out using the BIOME-3 model by predicting the equilibrium composition of different vegetation types under two different climate scenarios, as described below. We also attempted to use the dynamic model HYBRID 4.2 (Friend et al., 1997) to enable us to predict the time course of the changes expected in the composition of the vegetation (represented as a collection of a small number of plant functional types) at a few representative locations spread across the country.

7.5.3 Features of BIOME-3

The model BIOME (Prentice et al., 1992) was developed in the 1990s. The version used in the present investigation, BIOME-3, determines equilibrium state vegetation combinations for each location. It combines screening of biomes through application of climatic constraints with the computation of net primary productivity (NPP) and leaf area index (LAI), both based on fully coupled photosynthesis and water balance calculations. The underlying hypothesis of the model is that the combination of vegetation types, which is calculated to achieve the maximum NPP, represents the equilibrium vegetation. Using the data on climatic parameters and soil characteristics, the model predicts the potential biome type likely to dominate at the given geographical location.

The climate at the location is specified in terms of mean monthly values of rainfall, temperature and cloud cover (expressed as percentage). The soil characteristics include the water holding capacity (WHC) and depth of the top soil and sub-soil and the percolation rates. Based on these, the program calculates the WHC of two layers of soil, 0-500mm and 500-1500 mm. to be used for the water balance simulation. The program also reads the latitude, longitude and the altitude of the location, though only the value of the latitude seems to be used in the program (for estimating the quantity of incoming solar radiation).

The model uses nine Plant Functional Types (PFTs):

i. Tropical Evergreen
ii. Tropical Raingreen
iii. Temperate Broadleaved Evergreen
iv. Temperate Summergreen
v. Temperate Evergreen Conifer
vi. Boreal Evergreen
vii. Boreal Deciduous
viii. Temperate Grass
ix. Tropical/warm-temperate Grass

Based on the climatic parameters, the model computes the viability and wherever applicable, the productivity related parameters of the PFTs such as the leaf area index, net primary productivity etc. Based on these, it determines the dominant PFT expected at that location. Also, based on the relative performance of the different PFTs, the model assigns the given location to one of the 18 biomes:

i. Boreal / Cold Deciduous
ii. Boreal Evergreen
iii. Boreal / Temperate Mixed
iv. Temperate Conifer
v. Temperate Deciduous
vi. Temperate Evergreen / Warm Mixed
vii. Tropical Seasonal Forest
viii. Tropical Rain forest
ix. Tropical Dry forest
x. Moist Savanna
xi. Dry Savanna
xii. Tall Grassland
xiii. Short Grassland
xiv. Xeric Woodland
xv. Xeric Shrubland
xvi. Desert
xvii. Tundra
xviii. Ice / Polar desert

Not all of these biomes are seen in India. Figure 7.2 depicts the distribution of vegetation in India based on the Champion-Seth classification, which has a reasonably close correspondence with the biome types. The right panel of Figure 7.2 shows the distribution of biome types expected to prevail in India under the climate corresponding to the 'control' run of the Had RM2 model as described in the subsequent sections.

7.5.4 Features of HYBRID

The process-based model HYBRID was developed towards the end of the 1990s (Friend et al., 1997). It simulates the "daily cycling of carbon, nitrogen and water within the biosphere and between the biosphere and the atmosphere". HYBRID too is based on the competition between plant functional types, two types of grasses (C3

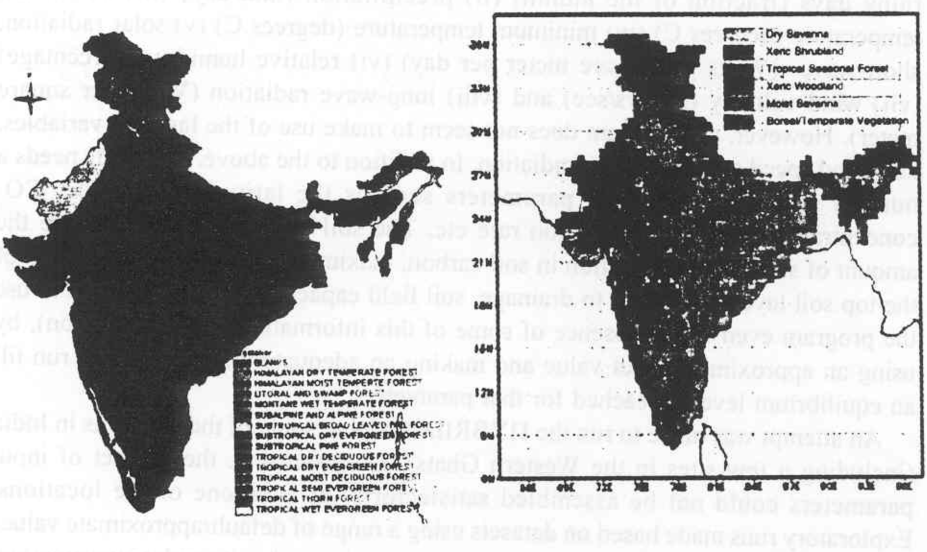

Fig. 7.2 Current vegetation map and map for control run of HadRM2 (see color plates)

and C4 types) and six types of trees obtained by combining two leaf types (Broad leaf and Narrow leaf) and three phenology types (Evergreen, Cold Deciduous and Dry Deciduous) at a location. The competition between different individual trees for light, water as well as nutrients is explicitly simulated, and the growth of different tree parts is explicitly modeled. Mortality as well as regeneration is also taken into account. Since relevant details of the community in a 'plot' (number of individuals of each PFT, biomass/girth corresponding to each individual, status of moisture and nutrients in the soil etc) are available at appropriate time steps (daily for some parameters, yearly for others). HYBRID is ideally suited to explore even the transient changes in the vegetation brought about by the changes in the climate during a relatively short time-span of a few decades.

7.5.5 Data needs for BIOME-3 and HYBRID

The data requirements of BIOME-3 fall into three categories: location, climate and soil. The location information is included in all the climate data files as well, and consists of latitude, longitude and altitude, though the program does not seem to make use of the input values of longitude and altitude. Only three climatic parameters are required, and mean monthly values of precipitation (mm), temperature (degrees C) and sunshine hours (percentage) are supplied in three separate files. The soil parameters needed by the program are (i) the Available Water Capacity (AWC) of the top soil (ii) AWC of the sub soil, (iii) depth of the topsoil, (iv) depth of the subsoil and (v) percolation rate (though a default value of 30 is used by the program if data on percolation rate is not available).

The HYBRID model is much more data intensive. The eight climatic parameters to be included in the input data file are the mean monthly values of (i) the number of rainy days (fraction of the month) (ii) precipitation (mm/day) (iii) maximum temperature (degrees C) (iv) minimum temperature (degrees C) (v) solar radiation, short-wave (Watts per square meter per day) (vi) relative humidity (percentage) (vii) wind velocity (meters/sec) and (viii) long-wave radiation (Watts per square meter). However, the program does not seem to make use of the last two variables, i.e., wind speed and long-wave radiation. In addition to the above, HYBRID needs a number of location-specific parameters such as the latitude, longitude, CO_2 concentration, nitrogen deposition rate etc. The soil parameters required are the amount of soil carbon, variation in soil carbon, maximum water holding capacity of the top soil layer, resistance to drainage, soil field capacity, etc. It is possible to use the program even in the absence of some of this information (e.g. soil carbon), by using an approximate input value and making an adequately long 'control' run till an equilibrium level is reached for that parameter.

An attempt was made to run the HYBRID model at some of the locations in India (including a few sites in the Western Ghats). Unfortunately, the full set of input parameters could not be assembled satisfactorily at even one of the locations. Exploratory runs made based on datasets using a range of default/approximate values were unsuccessful in reproducing the known vegetation at the site under investigation. Hence, the results described in the present investigation are based only on the simulations carried out using the BIOME3 model.

7.5.6 Choice of climate model and sources of data

Some of the data used in this investigation was obtained from the IPCC Data Distribution Centre (IPCC DDC). For obtaining monthly mean data, the main entry point of IPCC DDC is http://ipcc-ddc.cru.uea.ac.uk/dkrz/dkrz_index.html. The two major alternative scenarios suggested by the IPCC for which such data is available are the IPCC IS92a emission scenario and the IPCC SRES scenario. We have preferred the former one in the present study since some of our earlier analysis was based on it. Data and information was also downloaded from http://ipcc-ddc.cru.uea.ac.uk/cru_data/datadownload/download_index.html.

A number of datasets from modeling centers from different parts of the world (UK Hadley Centre for Climate Prediction and Research (HadCM2), the German Climate Research Centre (ECHAM4), the Canadian Centre for Climate Modeling and Analysis (CGCM1), the US Geophysical Fluid Dynamics Laboratory (GFDL-R15), the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO-Mk2), the National Centre for Atmospheric Research (NCAR-DOE) and the Japanese Centre for Climate System Research (CCSR))are available from this site. The models differ from each other considerably in grid size or resolution. Many of them consider rather coarse grids, with one or both of longitude/latitude greater than 4 degrees. The two models with best resolution are HadCM2 (3.75 by 2.5 degrees) and ECHAM4 (2.8125 X 2.8125 degrees), and seemed the most appropriate for the present investigation. The kinds of variables generated and made available by these models also differ from each other. Of these two models, the climate variable 'percentage of cloud cover' (required to obtain the value of 'percentage of sunshine hours' needed to run the BIOME3 program), was available only for the HadCM2. Secondly, the data at even finer (regional) scale (0.4425 X 0.4425 degrees) was available for HadRM2 derived from HadCM2. We have, therefore, used the projections from the HadCM2 model (Cullen, 1993; Johns et al., 1997) for the analysis.

The data on the projected HadRM2 climate scenarios (and also some of the HadCM2 outputs) were made available by the Indian Institute of Tropical Meteorology, the nodal agency coordinating the climate data requirements of the NATCOM project. Data on soil parameters at 78 locations distributed across the entire Indian region were made available by the Department of Civil Engineering, Indian Institute of Technology, New Delhi.

As mentioned earlier, the GCM model uses a relatively coarse grid (3.75 degrees longitude × 2.5 degrees latitude). As a result, part of the coast of India, and particularly some of the region corresponding to the Western Ghats falls in the grid located in the adjoining Arabian Sea. However, data (mean monthly values) for the control run of the simulations as well as for the Scenario 1, corresponding to the projected GHG emissions (compound increase at the rate of 1% per year from 1990 onwards) are available for the time period 1860 to 2099. Data on the projected climate Scenario 2, which takes into account the GHG as well as aerosols, are also available for the GCM.

The Regional Climate model (RCM) is obtained by downscaling from the boundary conditions of the GCM, and it uses a much finer spatial (0.4425 degrees in longitude as well as latitude, corresponding approximately to a 50 km X 50 km grid) as well as temporal (daily) resolution. However, data for this model are available only for a smaller duration, corresponding to the years 2041 to 2060 both for control as well as Scenario 1. No data are available as yet for Scenario 2. The RCM dataset also contains fewer parameters (e.g. only maximum and minimum temperature and not the average temperature separately)

In addition to the above, actual climate data (monthly values from 1901 to about 1995) for the Indian region, compiled by the Climate Research Unit of the University of East Anglia (New et al., 2000), also at a fine (0.5 degrees X 0.5 degrees, comparable to the RCM) spatial resolution was made use of in the present analysis.

7.6 Vulnerability of Forest Ecosystems in India to Projected Climate Change

The approach used in the present investigation for exploring the vulnerability of forest ecosystems to projected climate change is based on the application of the BIOME3 model to about 1500 grids (50 km X 50 km) across the Indian region. The climate related parameters for these grids are from the Hadley Center Regional Climate Model, as mentioned earlier. The soil parameters for a grid were obtained from the nearest of the 78 locations for which soil data was available[1]. The outputs of the BIOME3 (biome type, net primary productivity, etc.) using climate from the control run of RCM indicated the current situation, while that from the GHG run described the vegetation that was likely to prevail around 2050 under Scenario 1, i.e., under the assumption of 1% compounded annual increase in the concentration of CO_2. The difference in the outputs of BIOME3 at each of the grids was used for assessing the direction and extent of the expected change in the vegetation.

7.6.1 Current patterns of climate parameters

As mentioned earlier, the results of the 'control run' of the GCM as well as the RCM run should correspond to the present climate. One can, therefore, judge the performance of the models by comparing the patterns seen in the climatic variables in the models for the control run with those seen in the CRU dataset representing the present climate.

Such a comparison at the gross level for rainfall is possible by examining Figure 7.3a, b, and c, which show the mean annual rainfall across the Indian region for the CRU data, GCM and RCM respectively. The figure brings out the coarseness of the GCM grid rather vividly. However, the general correspondence between the RCM results and the CRU data seems reasonably satisfactory. Unfortunately, however, the mismatch seems to be rather noticeable in the two regions, which are vegetationally rather important – the Western Ghats and the Western Himalayas. The special

[1] In fact, the sensitivity of the results to the soil parameters was also investigated by assigning several different soil parameters to the grids; the predictions were found to be quite robust

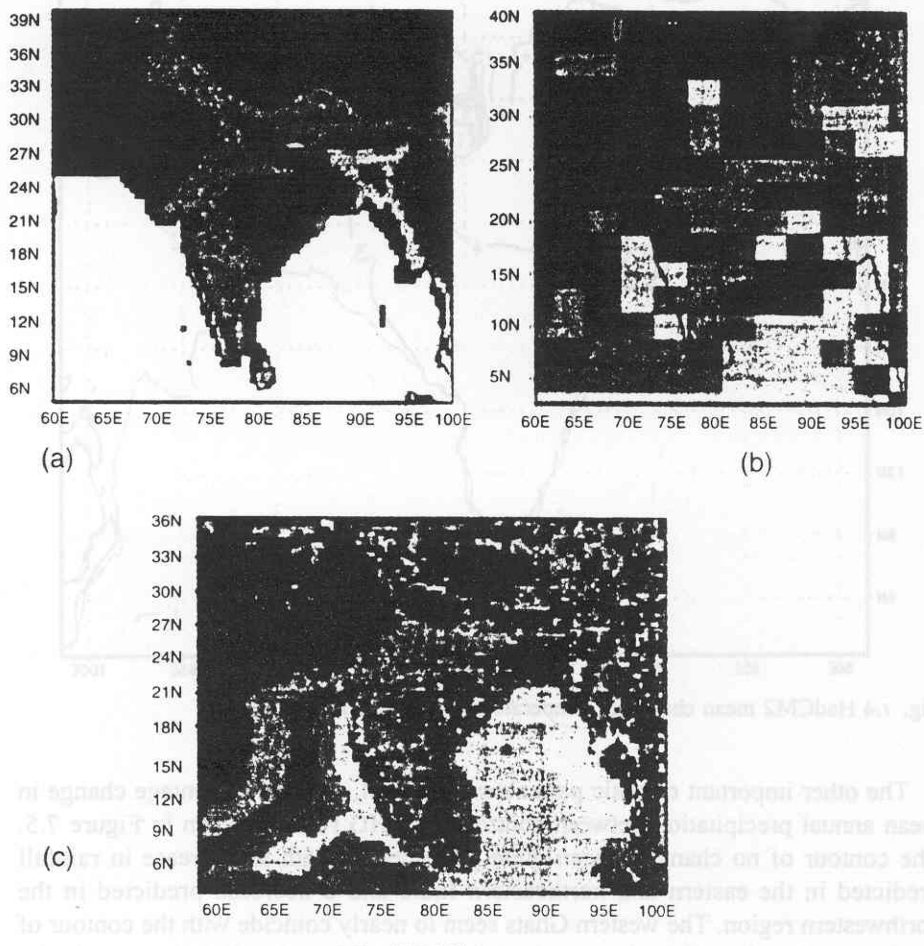

Fig. 7.3a CRU mean annual rainfall 1901-1996
Fig. 7.3b HadCM2 control run mean annual rainfall, 2041-2060
Fig. 7.3c HADRM2 control run mean annual rainfall, 2041-2060 (see color plates)

topography of these regions, wherein large changes in altitudes are known to occur at distances much less than 50 km (i.e., the resolution of the grid) may partly account for this discrepancy.

7.6.2 Projected climate parameters

The change in the climate, expected on the basis of Scenario 1 in the RCM, can be best illustrated by examining the contours of the differences in climatic variables. Thus, as seen from Figure 7.4, the average annual temperature is likely to show an increase of at least 3 °C over most of the southern and central India. The rise is likely to be even more in the northwestern part of the country, while the northeast may experience a slightly lower rise. There is some aberration near 81° E and 28° N, but the region is rather small and unlikely to affect the overall inferences.

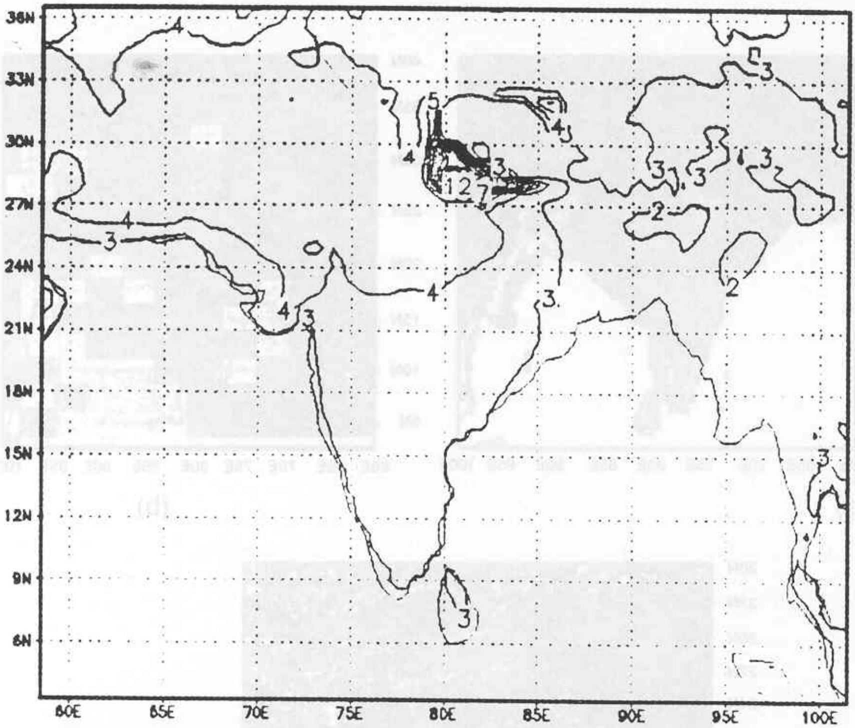

Fig. 7.4 HadCM2 mean change in temperature (GHG-CTL)

The other important climatic parameter is rainfall, and the percentage change in mean annual precipitation between control and GHG runs is shown in Figure 7.5. The contour of no change is seen quite prominently, with an increase in rainfall predicted in the eastern and northeastern India and a decrease predicted in the northwestern region. The western Ghats seem to nearly coincide with the contour of no change, though a slight decrease in the northern part and a slight increase in the southern part of the Western Ghats is indicated.

Another kind of comparison that may be meaningful is between the mean annual profiles. This could be done, for example, at specific locations. Alternatively, to see the effect of climate change more clearly, one can examine the changes in the mean profile in say Scenario 1 as different time intervals. Figure 7.6 shows the profiles for precipitation and temperature for the country as a whole for the years 2000, 2030, 2050 and 2080 for the GCM Scenario 1. The overall constancy of the profile as well as the steady increase in temperature and decrease in rainfall can be clearly seen from the diagram.

Uncertainties associated with climate projections: It is important to emphasize that the extent of changes in vegetation estimated in the present report have rather large uncertainties associated with them. The major contribution for these comes from the uncertainties associated with the projection of the climate models.

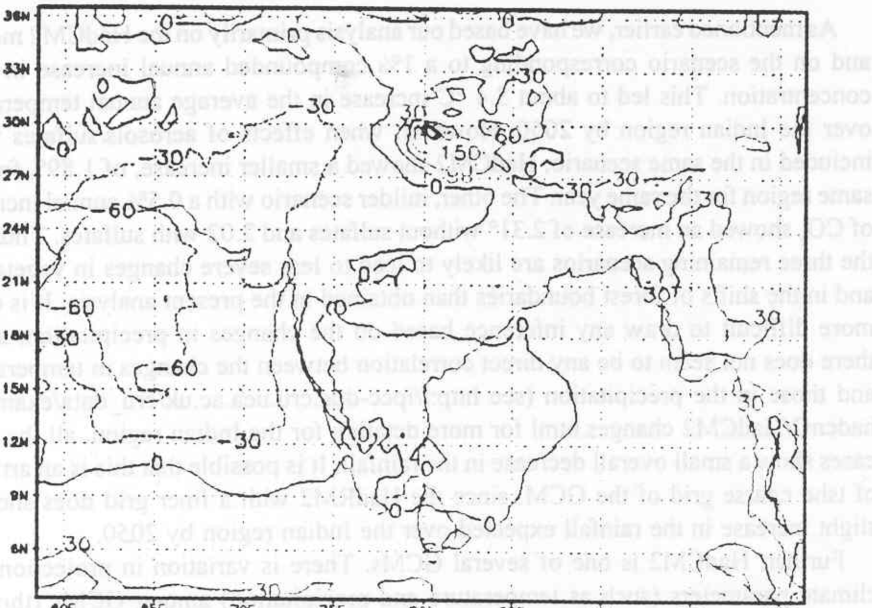

Fig. 7.5 HadCM2 mean percentage change in rain (GHG-CRL) * 100 / CTL

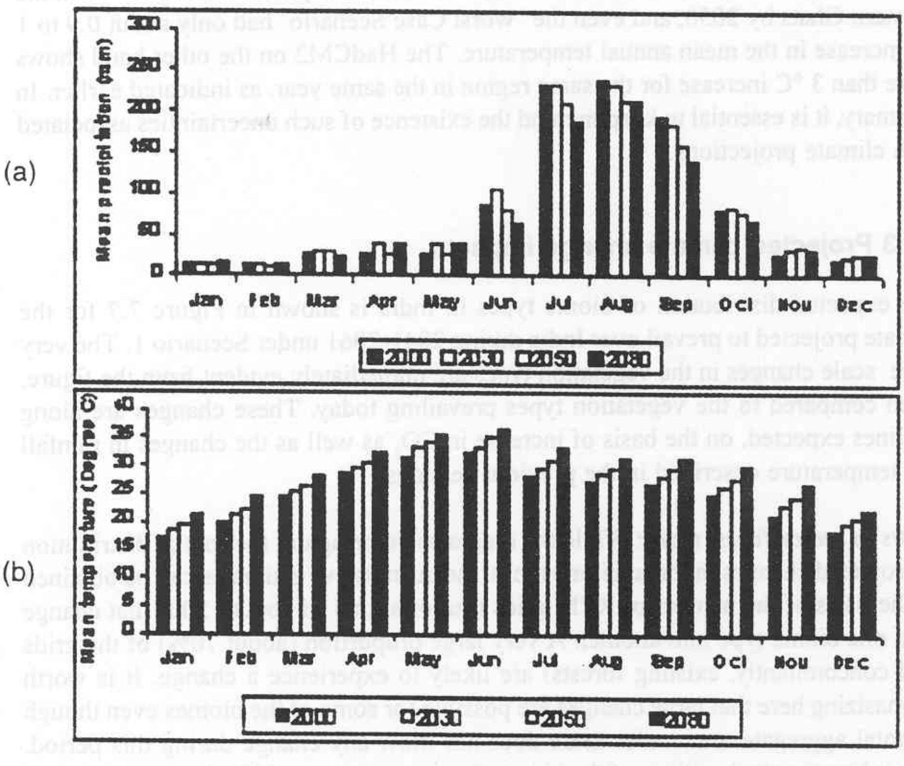

Fig. 7.6 HadCM2 based projections of monthly (a) mean precipitation and (b) temperature

As mentioned earlier, we have based our analysis primarily on the HadCM2 model, and on the scenario corresponding to a 1% compounded annual increase in CO_2 concentration. This led to about 3.4 °C increase in the average annual temperature over the Indian region by 2050. However, when effects of aerosols/sulfates were included in the same scenario, HadCM2 showed a smaller increase, of 1.89°, for the same region for the same year. The other, milder scenario with a 0.5% annual increase of CO_2 showed an increase of 2.31° without sulfates and 2.02 with sulfates. Thus, all the three remaining scenarios are likely to lead to less severe changes in vegetation and in the shifts of forest boundaries than obtained in the present analysis. It is even more difficult to draw any inference based on the changes in precipitation, since there does not seem to be any direct correlation between the changes in temperature and those in the precipitation (see http://ipcc-ddc.cru.uea.ac.uk/cru_data/examine/hadcm2/HadCM2 changes.html for more details); for the Indian region, all the four cases show a small overall decrease in the rainfall. It is possible that this is an artifact of tshe coarse grid of the GCM, since the HadRM2 with a finer grid does show a slight increase in the rainfall expected over the Indian region by 2050.

Further, HadCM2 is one of several GCMs. There is variation in projections of climate parameters (such as temperature and precipitation) among GCMs (though all GCMs project warming and changes in precipitation patterns across all regions). Thus, our previous investigations (Ravindranath et al., 1997) described earlier in section 3.2.2 corresponded to a most likely increase of only about 0.3 to 0.7 °C in the Western Ghats by 2050, and even the 'Worst Case Scenario' had only about 0.9 to 1 °C increase in the mean annual temperature. The HadCM2 on the other hand shows more than 3 °C increase for the same region in the same year, as indicated earlier. In summary, it is essential to keep in mind the existence of such uncertainties associated with climate projections.

7.6.3 Projected climate change impacts

The expected distribution of biome types in India is shown in Figure 7.7 for the climate projected to prevail over India during 2041-2061 under Scenario 1. The very large scale changes in the vegetation types are immediately evident from the figure, when compared to the vegetation types prevailing today. These changes are along the lines expected, on the basis of increase in CO_2 as well as the changes in rainfall and temperature described in the previous sections.

Shifts in major forest types: While the diagrams do bring out the spatial distribution of projected changes in forest biome types, the quantitative estimates can be obtained on the basis of the number of RCM grids (out of a total of about 1500) that change from one biome type into another. A very large proportion (about 70%) of the grids (and concomitantly, existing forests) are likely to experience a change. It is worth emphasizing here that large changes are possible for some of the biomes even though the total aggregate area under these does not show any change during this period. This is because the locations of the biome show conspicuous shifts due to the marked changes in the climatic conditions.

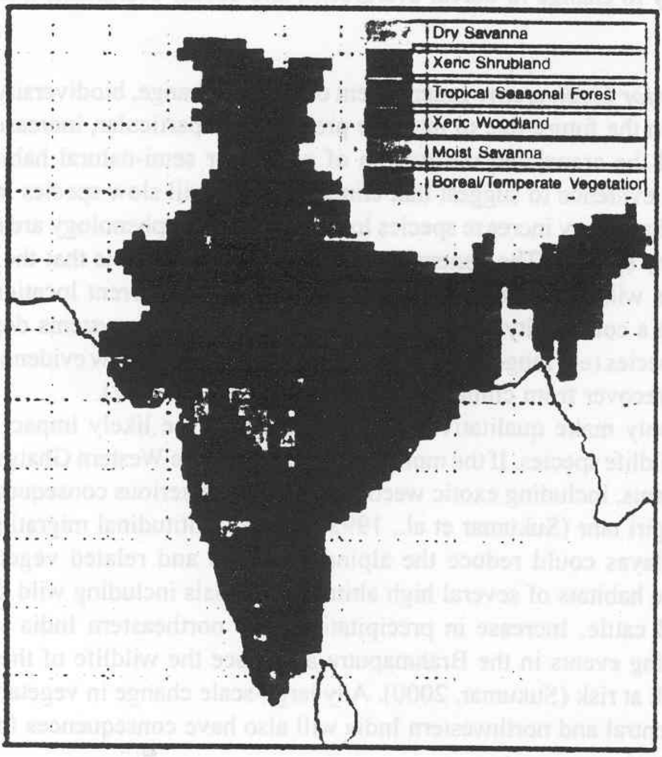

Fig. 7.7 Vegetation map for year 2050, GHG run of HadRM2 (see color plates)

The biome type most seriously impacted is the Dry Savanna. About 62% of it, mainly lying in the northern/central parts of India, is likely to be converted into Xeric Woodland (Dry Thorn Forest), while another 24%, mainly in the northwestern parts, is likely to change to Xeric Shrubland. In general, increased CO_2 is expected to lead to an increase in the net primary productivity (as will be discussed later). This has an effect of converting grassland into woodlands and woodlands into forests. Thus, in the region with a relatively large temperature increase, dry and moist savannas are likely to be replaced by xeric vegetation, while in the areas with a lower temperature increase and enhanced rainfall, the moist savannas seem to be transformed into Seasonal Tropical Forests. However, the northern part of the country has largely been transformed into agriculture and thus the Savannas occupy only a small geographical area.

The other biome type to be affected is the moist savanna located in the northeast and some of the parts of the southern India. This is likely to be converted into Tropical Seasonal Forest (about 56%), mostly in the northeast and Xeric woodland (Dry Thorn Forest) (about 32%) mostly in south India, depending on the change in the quantum of rainfall. The Tropical seasonal forest, especially in the northeast, is likely to change into Tropical Rain Forest due to a large increase in rainfall expected to take place in that region.

The changes expected in the colder regions are also along similar lines, with the tundras likely to change to boreal evergreens, and boreal evergreens into temperate conifers.

Implications for biodiversity: Independent of climate change, biodiversity is forecast to decrease in the future due to multiple pressures, in particular, increased land use intensity and the associated destruction of natural or semi-natural habitats. While there is little evidence to suggest that climate change will slow species losses, there is evidence that it may increase species losses. Changes in phenology are expected to occur in many species. The general impact of climate change is that the habitats of many species will move poleward or upward from their current locations. Species that make up a community are unlikely to shift together. Ecosystems dominated by long-lived species (eg. long-lived trees) will often be slow to show evidence of change and slow to recover from climate-related stresses (IPCC, 2002).

We can only make qualitative observations about the likely impact of climate change on wildlife species. If the montane grasslands of the Western Ghats are invaded by woody plants, including exotic weeds, this will have serious consequences for the endemic Nilgiri tahr (Sukumar et al., 1995). Upward altitudinal migration of plants in the Himalayas could reduce the alpine meadows and related vegetation, thus impacting the habitats of several high altitude mammals including wild sheep, goat, antelope and cattle. Increase in precipitation over northeastern India will lead to severe flooding events in the Brahmaputra and place the wildlife of the Kaziranga National Park at risk (Sukumar, 2000). Any large-scale change in vegetation to drier types over central and northwestern India will also have consequences for the fauna of these regions.

Implications for NPP, growing stock (biomass) and regeneration: At the global level, net biome productivity appears to be increasing. Modeling studies, inventory data and inverse analyses provide evidence that over the past few decades, terrestrial ecosystems have been accumulating carbon. Several effects contribute to this. Plants are responding to changes in land use and land management practices (eg. reforestation and regrowth on abandoned land), increasing anthropogenic deposition of nitrogen, atmospheric concentrations of CO_2, and possibly climate warming. Where a significant ecosystem disruption occurs (eg. loss of dominant species or losses of a high proportion of species, thus much of the redundancy), there may be losses in net ecosystem productivity during the transition (IPCC, 2002).

The mean net primary productivity (grams of carbon per square meter per year) was about 338 in the control run, with a maximum value around 1049. By 2050, as per the BIOME model, these values are likely to show a considerable increase. The mean value reaches about 435 (more than 25% increase) while the maximum reaches about 1400 (more than 30% increase). In fact, more than 75% of the grids show an increase in NPP. As expected, the grids showing a decrease in NPP lie in the northwestern region where a deficit in rainfall, and a large increase in temperature are expected. However, this region has a rather low value of NPP (about 230), and the projected decrease is also rather small (about 13%).

7.6.4 Vulnerability of forest ecosystems in India and socioeconomic impacts

Thus, even in the relatively short span of about 50 years, most of the forest biomes in India seem to be highly vulnerable to the change in climate. As estimated earlier, about 70% of the locations are expected to experience a change in the prevailing biome type. In other words, about 70% of the vegetation is likely to find itself less optimally adapted to its existing location, making it more vulnerable to the adverse climatic conditions as well as to the biotic stresses, which it is subjected to from time to time. As a result, during the process of take over of one biome type by another, large-scale mortality might be expected.

The actual negative impact may be more than what is initially expected from the above description. This is because different species respond differently to the changes in climate. So even in the region where there is no shift in the biome type, changes in the composition of the assemblages are certainly very likely. Thus, one expects that a few species may show a steep decline in populations and perhaps local extinctions. This, in turn, will affect the other taxa dependent on the different species (i.e., a 'domino' effect) because of the interdependent nature of the many plant-animal-microbe communities that are known to exist in forest ecosystems. This could eventually lead to major changes in the biodiversity.

The northwestern region of the country seems to be more vulnerable to climate change, since it is likely to experience the effect of two negative influences: a large temperature increase together with a decrease in precipitation. The vulnerability of the northeastern region stems from a very different cause. The major increase in precipitation expected in this region is likely to shift the vegetation towards the wetter, more evergreen vegetation. Since these are rather slow growing, the replacement will take much longer, and increased mortality in the existing vegetation may lead to a decrease in the standing stock.

Uncertainty of projected impacts: GCMs are more robust in projecting global mean temperatures compared to their ability for making predictions at regional levels. Further, the RCMs are still evolving. The uncertainty involved in projections of temperature and particularly, precipitation at the regional level is high. The vegetation response model BIOME3 is an equilibrium model and does not project the transient phase responses. Also, the database on soil, water and plant physiological parameters as input to vegetation models such as BIOME3 is poor. Thus, the findings of the present analysis should be viewed with caution. We have been able to obtain preliminary estimates of the likely impacts based on scenarios other than the one examined here in detail. When the CO_2 increase is assumed to be only 0.5% per year instead of 1%, the changes in vegetations are rather modest; in fact, only about 36% of the grids show shifts in vegetation type compared to the figure of 70% obtained here based on the RCM projections. Using GCM projections, which take into account sulfates/aerosols, also show changes that are smaller in magnitude; about 64% grids are seen to be affected instead of 70% for a 1% compounded increase of CO_2. The types of changes in vegetation, however, are rather similar in all these situations. Thus, though there is some uncertainty on the magnitudes of the projections of change and though these may also vary with the GCMs and RCMs used, the direction of change is unlikely to be different.

Socio-economic impacts: In India, nearly 200,000 villages are situated in or on the fringe of the forests. Further about 200 million people depend on forests for their livelihood directly or indirectly. Forest ecosystems in India are already subjected to socio-economic pressures leading to forest degradation and loss, with adverse impacts on the livelihoods of forest dependent communities. Climate change will be an additional pressure on forests affecting biodiversity as well as biomass production. According to the assessment of projected climate change impacts on forests made in this study, significant changes in the forest boundary of different forest biomes as well as biodiversity are projected. However, during the transient phase, large-scale forest dieback may occur. This may affect the production and supply of non-timber forest products to the forest dependent communities, affecting their livelihoods. In the transient phase, there could be increased supply of timber, due to forest dieback, depressing timber prices.

7.7 Forest Policies and Programmes – Vulnerability of Forest Ecosystems

7.7.1 Broad forest policies and programmes implemented in India

Forest policies in any country determine the status of forests; rates of deforestation and afforestation, levels of fragmentation, conservation and protection, and rates of timber and non-timber extraction. Vulnerability of forest ecosystems to climate change depends on the status of forests; biodiversity, fragmentation, afforestation practices, rates of extraction of timber etc. For example, forest fragmentation may enhance vulnerability and decrease adaptation capacity of forest ecosystems to climate change, whereas biodiversity conservation may reduce vulnerability. In this section, first, the major forest policies and programmes are briefly presented and second, the policies and programmes that enhance or reduce vulnerability of forest ecosystems are discussed.

Forest policy of 1894: The first, and major, forest policy in India was formulated in 1894. It was drawn up after the Forest Department had demarcated, surveyed and mapped the forest area of India. The goals of the policy were: (a) to lay down certain general principles of forest management, (b) to formulate a forest policy that would serve agricultural interests more directly, (c) to maintain forests primarily for preservation of the climatic and physical conditions, and (d) to fulfill the needs of the people.

The forests were classified to reflect these objectives, and according to their primary functions, into: forests where preservation was essential on climatic and physical grounds, forest for extraction of valuable timber for commercial purposes, and forests for use by the community and as pasturelands. This exercise resulted in the demarcation of 78 Mha of forests into 92% as forests, 5% as community forests and 2% for private ownership. Further, forest classification was based on the quality of forests; 47% as Reserve forest, 30% as Protected forest and 22% as unclassified forests.

National forest policy of 1952: The Forest Policy of 1952 was initiated to allow exclusive state control over forests and its management. The policy aimed to increase government control over forest resources and develop forests to meet the timber needs of industry and defense. It declared that village communities should not be permitted to exercise their traditional rights over the forests at the expense of national interest. The policy recognized the need for:

(a) balanced and complementary land use, under which the forests would produce the most and deteriorate the least,
(b) establishment of tree lands wherever possible, for the amelioration of physical and climatic conditions and promoting the general wellbeing of the people,
(c) increasing supplies of fodder and small wood for making agricultural implements,
(d) sustained supply of timber and other forest produce required for defence, communication and industry, and
(e) getting the maximum revenue in perpetuity, while fulfilling the needs enumerated above.

Social forestry phase (post 1980): The National Commission on Agriculture (NCA), 1976, suggested the setting up of a corporation to manage forests and to attract monetary assistance from various government and non-government sources. As a result, autonomous forest corporations were started and large-scale plantation activities began. The NCA report also suggested initiation of the social forestry programme on non-forestry lands such as village commons, government wastelands and farmlands to reduce pressure on forests.

Social Forestry is India's as well as one of the world's largest afforestation programmes and has covered more than 28 Mha. The survival rate of seedlings in plantations at the national level was 77%. Productivity recorded in farm forestry is 4.2 t/ha/year and in Forest Department plantations, 2.6 t/ha/year (Seebauer, 1992).

Forest conservation act, 1980: The Forest Conservation Act of 1980 was enacted to regulate, reduce or ban indiscriminate diversion of forestland for non-forestry purposes and. to regulate and control forestland use change. Forest conversion is banned or regulated under the Act, effectively reducing deforestation. All forest conversion to non-forestry purposes has to be cleared by the Central Government as per this Act. If conversion is approved, then raising of compensatory plantations is mandatory.

Wildlife act, 1972: The Wildlife (Protection) Act was passed in 1972 and subsequently revised in 2002. The goals of the Act are: to ensure protection of wild animals and to declare forests and habitats of wild animals as sanctuaries and national parks. The Wildlife (Protection) Amendment Bill, 2002, proposes to enhance penalties for violation of the provisions of the Act. It also proposes to create two new categories of Protected Areas, viz., 'Conservation Reserve' and 'Community Reserve'. There are

89 National Parks and 500 Wildlife Sanctuaries in India, covering an area of 156,640 sq. km. Conversion of forestland and extraction of timber and non-timber products is highly regulated in the National Parks and Wildlife Sanctuaries.

Protected area (PA) and biosphere reserves: Protected Areas have been established for conservation of biodiversity (both flora and fauna). In India, PAs cover about 14.8 Mha, accounting for 14% of the forest area. The formation of Protected Areas has reduced developmental and commercial pressure on forests. Biosphere Reserves have been established with emphasis on conservation of biodiversity, its sustainable use, with communities as an integral part of the reserves. Thirteen Biosphere Reserves have been declared so far in India.

The forest policy of 1988: The forest policies hitherto emphasized the importance of protecting forests, which are places of high faunal and floral diversity and national heritage sites. However, the success of several experiments in West Bengal and Haryana on participatory forestry encouraged the government to include local people in forest management (Poffenberger and Singh, 1996; Ravindranath et. al., 1997; Saxena, 1997).

The basic objectives of the National Forest Policy, 1988 are:

- Maintenance of environmental stability through preservation and, where necessary, restoration of the ecological balance that has been adversely disturbed by serious depletion of forests
- Conservation of the natural heritage by preserving the remaining natural forests with the vast variety of flora and fauna, which represents remarkable biological diversity and genetic resources
- Substantial increase of forest/tree cover through massive afforestation and social forestry programmes, especially on denuded, degraded and unproductive lands
- Meeting of the requirements of fuelwood, fodder, minor forest produce and small timber of the rural and tribal population
- Increasing the productivity of forests to meet essential national needs
- Encouragement of efficient utilization of forest produce and maximization of wood substitution.
- Recognition of the rights of forest dependent communities.

JFM resolution of 1990: The afforestation programme under social forestry was dominated by monocultures of exotic species such as *Acacia auriculiformis, A. mangium*, Eucalyptus, Casuarina, *etc.*, with minimal participation of the local community and with the Forest Department wholly implementing the programme. One of the major criticisms of the social forestry programme was that it did not meet its objectives such as meeting diverse biomass needs and participation of local communities. The programme was helpful to the farmers who were market oriented (such as in Gujarat, Punjab and Haryana) but less helpful to meet the subsistence biomass needs, such as firewood, fodder and NTFP (Ravindranath et al., 1997), of the rural poor and tribal communities. Therefore, the natural forests continued to get degraded. Thus, efforts were initiated to enhance forest cover through a participatory process where people protect forests and derive benefits.

The policy aims at recognition of the rights of organized communities over a clearly defined degraded patch of the forest. Communities are eligible to receive benefits for the responsibility of protection and conservation of specific forest patches. State level resolutions have legitimized JFM activities at all levels - from the state Forest Departments to the village communities.

Under the JFM programme, 14.6 Mha of degraded forest and non-forest has been revegetated largely through protection, promotion of natural regeneration and in some states through plantation forestry, through 74,000 village forest management committees. The JFM programme is proposed to be extended to most villages in and around the forests during the 10th plan period of 2002 to 2007.

Thus, India has formulated and implemented a large number of legislations, and forest conservation and reforestation programmes. These programmes have not been rigorously monitored and evaluated for their performance and impacts. However, these programmes have contributed towards; a) stabilization of the area under forests with marginal rates of deforestation, even though forest degradation may be continuing, b) producing fuelwood and industrial wood, thereby reducing pressure on the forests, and iii) involvement of local communities in protection and management of forests, even though there is inadequate empowerment of community institutions.

7.7.2 Forest policies, programmes and practices that enhance vulnerability to climate change

Some of the policies, programmes and practices that potentially contribute to enhancing the vulnerability of forest ecosystems to climate change are as follows:

- Forest fragmentation leading to loss of biodiversity and hampering migration of species
- Forest degradation leading to loss of biodiversity, affecting forest regeneration
- Dominance of monoculture species under afforestation which increases vulnerability to fire, pests, etc.
- Absence of fire protection and management practices, enhancing vulnerability to fire
- Non-sustainable extraction of timber, fuelwood and NTFPs leading to degradation of forests, fragmentation of forests and affecting shift of forest boundaries and regeneration of plant species
- Inadequate fuelwood conservation programmes which increase pressure on forests, leading to degradation
- Inadequate and less-effective implementation of the different conservation programmes leading to forest degradation.

There is a need for research studies to identify and assess the implications of policies and programmes to vulnerability of forest ecosystems.

7.7.3 Forest policies, programmes and practices reducing forest vulnerability

India has implemented a large number of forest conservation and development programmes that have the potential to reduce the vulnerability of forest ecosystems to impacts of climate change.

- The Forest Conservation Act, Wild Life Act, Protected Areas and other policies contribute to forest and biodiversity conservation and reduction of forest fragmentation
- The large afforestation programme has reduced pressure on forests for timber, industrial wood and fuelwood, leading to conservation of biodiversity and reduction of forest degradation
- The involvement of local communities in forest protection and regeneration and creation of long-term stake in forest health, through JFM

The impacts of these measures in quantitative terms are, however, not clear.

7.8 Adaptation Policies, Programmes and Practices

7.8.1 Why adaptation in forest sector?

The preliminary assessment of the impact of projected climate change, based on BIOME-3 outputs indicates shifts in forest boundaries, replacement of current assemblage of species, leading to forest dieback. The need for adaptation measures to minimize the adverse impacts is strengthened due to the following reasons:

- The impacts are long-term and irreversible; such as loss of biodiversity
- There is inertia and lag period between climate change and impacts
- Long-term planning is necessary for forest conservation, afforestation and silvicultural practices to impact on forest regeneration and biodiversity
- Large forest dependent rural population and potential adverse impacts on their livelihood
- Inadequate technical, institutional and financial capacity to adapt to climate change impacts in the forest departments as well as at the forest dependent community level.

7.8.2 Policies, programmes and practices to promote adaptation

The current state of science has several limitations, particularly in projecting climate change at the regional level and assessing the response of diverse tropical forest vegetation to projected climate parameters. Vegetation models such as BIOME-3 and HYBRID-V.4.2 do not incorporate the adaptation response component. Thus, at the current state of knowledge and the uncertainties involved, only 'no regret' or 'win-win' and a few 'precautionary' adaptation policies, programmes and practices could be considered. Some examples of such measures are listed here.

Forest policies: India has formulated a large number of innovative and progressive forest policies, which have the potential to reduce vulnerability. Some examples of policies, which need effective implementation, are as follows:

- Incorporate climate concern in the long-term forest policy making process
- Incorporate climate concern in the forest 'working plan' process to enable incorporation of silvicultural practices to promote adaptation (Sukumar, et al., 2003, chapter 8 of this book)
- Improve the effective implementation of existing policies/Acts/guidelines such as;
  - Forest Conservation Act, 1980
  - Wildlife Act, 1972 and 2002
  - Enhance coverage and effectiveness of Protected Area
  - Wildlife Conservation programmes such as Project Tiger, Project Elephant etc.
- Link Protected Areas, Wildlife Reserves and Reserve Forests
- Expand area covered under JFM with empowerment and capacity building to enable effective community management of forests
- Enhance support to afforestation and reforestation programmes and increase area covered to increase production of timber and fuelwood to reduce pressure on primary forests
- Effectively implement and expand fuelwood conservation programmes such as fuel-efficient stoves and biogas to reduce pressure on forests

Forestry and silvicultural practices: Current afforestation and silvicultural practices dominated by exotics and monocultures are enhancing the vulnerability of forests. Some of the potential silvicultural practices that could reduce vulnerability and enhance resilience are as follows:

- Promotion of natural regeneration in degraded forest lands and mixed species forestry on degraded non-forest lands
- Anticipatory planting of species along the latitudinal and altitudinal gradient
- In-situ and ex-situ conservation of plant and animal species
- Implementation of fire prevention and management practices
- Adoption of short rotation species and practices
- Adoption of sustainable harvest practices for timber and non-timber products

There is a need for research to identify the silvicultural practices which reduce vulnerability of forest ecosystems to changing climate parameters.

Institution and capacity building to address climate change in forest sector: India has institutions with significant infrastructure and technical capacity. However, these institutions have not focused on climate change research, which includes: modeling, field ecological studies and laboratory experimentation. There is inadequate capacity in the forest departments to address climate change issues. There is a need to create awareness and enhance technical and institutional capacity in the research institutions, forest department and NGOs. Forest dependent communities have poor financial, technical and institutional capacity to adapt to adverse impacts of climate change.

Thus, it is necessary to enhance the capacity of those forest dependent communities who are likely to be vulnerable to projected climate change impacts.

7.9 Research and Monitoring to Increase Understanding of Climate Change Impacts and Adaptation Strategies in Forest Sector

To assist policy-making, particularly in tropical countries such as India, reliable regional projections of climate change and vegetation response are necessary. The regional level AOGCM projections currently have several limitations. A consistent set of high-resolution information of climate change for different regions that can be used as likely climate change scenarios is not yet available. The methodologies to generate such data are still maturing and the limitations, especially for impact applications, are likely to remain till significant modeling developments occur. Also, the information available currently is insufficient and existing climate models lack the spatial details required to make confident projections.

India has a large diversity of tropical and sub-tropical forest ecosystems subjected to diverse socio-economic pressures. Climate change will be an additional stress on the complex forest ecosystems. There is a need for systematic long-term research, monitoring and modeling programme to study the status of forests, response of forests to changing climate, model future responses and to develop adaptation strategies. Currently, there is little effort to understand climate change and forest response-related aspects in India. Some potential specific research and monitoring programmes include the following:

- Strengthening the forest area monitoring programme according to forest types at finer spatial resolution
- Studies to assess and project socio-economic pressures and drivers contributing to forest degradation and loss
- Field ecological studies to monitor the response of forest vegetation to changing climate at different latitude and altitudinal zones, through long-term permanent research plots
- Field and laboratory studies to develop plant physiological and phenological characteristics of different forest types as input to climate change impact dynamic vegetation models
- Research programmes to achieve indigenization of input parameters for climate change impact models
- Improvement in regional projections of climate parameters; regional climate modeling
- Development of transient ecosystem models that deal with multiple stresses; climate change and socio-economic
- Regional climate model grid level database generation for dynamic vegetation modeling; vegetation characteristics, climate parameters and socio-economic pressures

- Studies to identify forest policies and silvicultural practices that contribute to vulnerability of forest ecosystems and plantations
- Studies to identify forest policies, strategies and silvicultural practices to reduce vulnerability and enhance resilience of forest ecosystems to projected climate change.

7.10 Conclusions

At the global level, significant changes in climate parameters are projected in the next hundred years; global warming (1.4 to 5.4°C), changes in precipitation (increases and decreases regionally), sea level rise (8 to 90 cm) and enhanced extreme climates. Similar projections of climate change are projected at a regional level for India. Preliminary assessments using an equilibrium (BIOME-3) vegetation response model, based on regional climate model projections for India showed: shifts in forest boundary, changes in species-assemblage or forest types, changes in net primary productivity, possible forest dieback in the transient phase, and potential loss or change in biodiversity. These impacts on forests will have adverse socio-economic implications for forest dependent communities and the national economy. The impacts of climate change on forest ecosystems are likely to be long-term and irreversible.

The findings, particularly the magnitudes of change should be viewed with caution, due to the uncertainties associated with the projection of climate parameters among different GCMs and particularly at the regional level as well as the limitations of vegetation response models (such as BIOME3). However, the conclusion that the projected warming and changes in precipitation will have a significant impact on forest ecosystems, forest type boundaries, assemblage of species and biomass productivity is robust.

Thus, there is a need for developing and implementing adaptation strategies to minimize the adverse impacts. Further, there is a need to study and identify the forest policies, programmes and silvicultural practices that contribute to vulnerability of forest ecosystems to climate change. India has formulated and implemented a large number of forest conservation and development policies, programmes and activities. Some policies such as the Forest Conservation Act, large afforestation programmes, and Protected Areas contribute to reducing vulnerability. However, forest fragmentation, monoculture dominated afforestation and non-sustainable biomass extraction practices enhance the vulnerability of forest ecosystems.

India should initiate studies to identify forest strategies, policies, silvicultural practices and institutional arrangements that enhance forest resilience and reduce vulnerability. Due to the limited knowledge and uncertainties involved in regional climate projections and limited dynamic vegetation modeling studies or even the absence of models and input data, India could only focus on planning and implementation of 'win-win' or 'no-regret' strategies such as forest and biodiversity conservation, mixed-species forestry and sustainable extraction of timber and non-timber forest products. India could explore implementation of a few precautionary strategies such as anticipatory planting and linking protected areas and nature reserves.

India should initiate long-term dedicated research, monitoring and modeling programmes to study vegetation responses to climate change, generate regional climate projections, improve dynamic vegetation models and their application and conduct policy analysis to develop adaptation strategies.

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