CLIMATE CHANGE AND TROPICAL FORESTS IN INDIA

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ABSTRACT. India has 64 Mha under forests, of which 72% are tropical moist deciduous, dry deciduous, and wet evergreen forest. Projected changes in temperature, rainfall, and soil moisture are considered at regional level for India under two scenarios, the first involving greenhouse gas forcing, and the second, sulphate aerosols. Under the former model, a general increase in temperature and rainfall in all regions is indicated. This could potentially result in increased productivity, and shift forest type boundaries along attitudinal and rainfall gradients, with species migrating from lower to higher elevations and the drier forest types being transformed to moister types. The aerosol model, however, indicates a more modest increase in temperature and a decrease in precipitation in central and northern India, which would considerably stress the forests in these regions.

Although India seems to have stabilized the area under forest since 1980, anthropogenic stresses such as livestock pressure, biomass demand for fuelwood and timber, and the fragmented nature of forests will all affect forest response to changing climate. Thus, forest area is unlikely to expand even if climatically suitable, and will probably decrease in parts of northeast India due to extensive shifting cultivation and deforestation. A number of general adaptation measures to climate change are listed.

Key words: Climate Change, India, Tropical forest, Impacts and adaptation

1. Introduction

Climate change, resulting from increase in greenhouse gases such as CO_2 and methane, and other anthropogenic emissions into the atmosphere, can be expected to have significant impacts on forest ecology (including biodiversity), forest distribution, and productivity (Krischbaum *et al.* 1996). The projected impacts of climate change on forests also have implications for forest product flows and trade and forest management (Solomon *et. al.* 1996). In this context, it is important to make assessments of likely impacts of climate change on forests in different countries and regions to allow respective governments and communities to adapt to these impacts. Such assessments are all the more important in tropical countries in which the local communities depend significantly on forests for their livelihoods,

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and where rates of deforestation are high. Indeed, the issue of climate change impacts on forests may be less relevant if the anthropogenic impacts can be expected to be of much greater magnitude (Solomon *et al.* 1996).

In this paper, we summarize existing information on forest types and their distribution in India, and projected changes in climatic parameters such as temperature, rainfall, and soil moisture which are relevant to forest ecology, before making a cautious evaluation of climatic change impacts on tropical forests of the country. This assessment is made possible by the climate model output for the tropics by Hulme and Viner (1995), and the Indian sub-continent by Lal et al., (1995). We also examine the anthropogenic stresses on forests and recent changes in forest cover to evaluate the extent to which these factors are likely to override climate change impacts. Finally, we consider potential adaptation strategies and forest management policies.

2. Forest types and area

India has a geographical area of 328 Mha, of which 64 Mha are under forest (>10% tree cover). The altitudinal distribution of geographic and forest area (FSI, 1988) shows that 78% of geographic and 66% of forest area is at altitudes less than 600 m asl. Only 37% and 20% of geographic area is under forests in the altitudinal range of 600-1800, and 1800-4000 m asl, respectively.

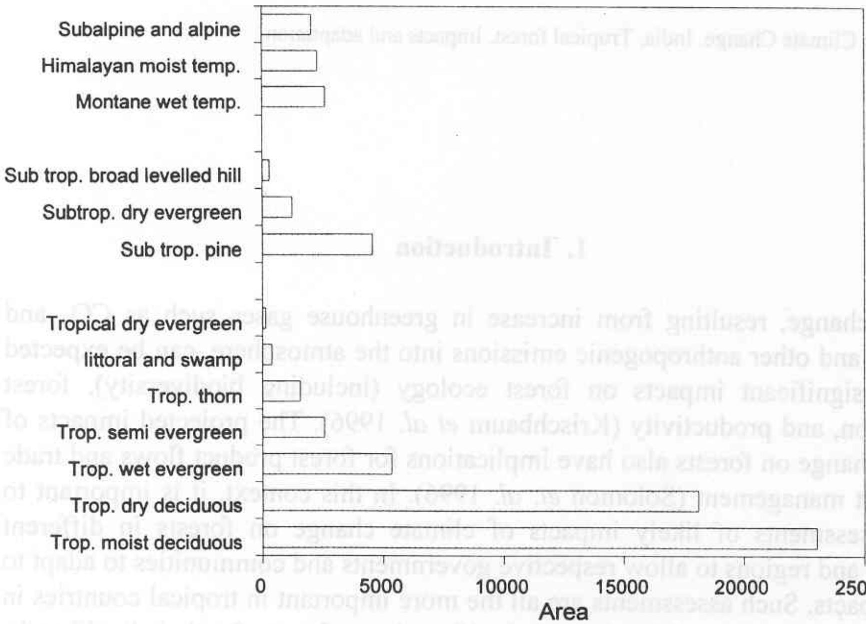

Figure 1. Area under different forests types in India (in '000 ha) from FSI (1988).

The forests of India are broadly classified into 14 major types (FSI, 1988), based on climate and altitude. The area under each type is given in Figure 1. Of these, the tropical forests occupy 51 Mha, or 80% of the forested area. In particular, the tropical moist deciduous and dry deciduous forests are extensive and account for 64% of the total forest area. Tropical, wet evergreen forest is also significant, with 8% of the total forest area.

3. Potential Impacts of Climate Change on Vegetation

Climate change is expected to make impacts on boundaries of forest types and areas, primary productivity, species populations and migration, occurrence of pests and disease, and forest regeneration. There are two models which have been used to assess the impacts of climate change on vegetation on a global scale: (i) The BIOME model (Prentice et al., 1992) is an equilibrium model which defines a set of plant functional types characterized by minimal sets of climate thresholds. Solomon et al., (1993), using BIOME and different future climate scenarios under doubling of CO_2, projects the area under tropical forests to expand in the range of 11% to 16%, depending on the climate model used; (ii) the IMAGE model (IMAGE 2.0, Alcamo, 1994) goes further by incorporating the BIOME vegetation classification into a model of interacting human population, land-use, vegetation, and climate. Its application is most useful where land-use changes are important. Using IMAGE, Zuidema et al., (1994) projected the area under tropical forests to decline by 24% by 2020, and 48% by 2050, compared to the 1990 area.

When annual forest productivity is considered, according to one study (Melillo *et al.* 1995) the annual growth is likely to increase in all zones due to fertilization effect from increasing atmosphere CO_2, and increase in water use efficiency. Conversely, forests may also suffer growth losses from effects of increasing climate stress on growth, from increased stress-induced mortality and other factors (Solomon and Leemans, 1990).

Paleo-vegetation and climate data are one means of understanding how natural vegetation is likely to respond to future climate change. There have been several studies of the desert environment in northwest India (cf. Swain et al., 1983; Singh et al., 1990). There have been however, few paleo-vegetation studies, however, in the tropical forest regions of the sub-continent, and rigorous data needed to analyze climate change impacts are as yet not available.

Pollen analytical studies in the Western Ghats (Vasanthy, 1988 and Caratini et al., 1991), and stable carbon isotope analysis of peats dated up to about 20000 yr BP (Sukumar et al., 1993; 1995) are the main sources of information. Caratini et al., (1991) found evidence for savannization of tropical moist forests in North Kanara of Western Ghats at 3500 yr BP, although it is not clear if this was due to a naturally drier climate or to clearing of forests. A study in the montane region of the Western Ghats by Sukumar et al., (1993, 1995) indicated shifts in the extent of grassland and forest in response to climate change. In particular, grasslands of C4 photosynthetic type dominated during the Last Glacial Maximum (LGM) about 18000 yr BP, characterized by lower atmospheric CO_2 (ca. 200 ppm), lower temperatures, and possibly weaker monsoon (Sukumar et al., 1993, 1995; Robinson, 1994). With increasing CO_2 and temperature, and a stronger monsoon, C3 vegetation (possibly forest and C3 herbs and grasses) expanded to the Holocene Optimum at approximately 10000-6000 yr BP. This was followed by a drier climate, with shift toward C4 vegetation during 6000-3500 yr BP, possibly as a result of lower CO_2 levels and temperature.

4. Projected Changes in Climate Over India and Impacts on Forests

Any assessment of the potential impacts of climate change on forests requires a climate change model and a vegetation change model. While the former projections can be obtained from the several General Circulation Models in use currently, the latter--which links climate with vegetation such as BIOME and IMAGE--have limitations when applied to India. Due to inadequate climatic data sets for the Western Ghats in southern India, BIOME fails to adequately discriminate between the diverse natural vegetation types here (also see Prentice et al., 1992). IMAGE makes unrealistic projections of forest cover change in the country (see below). We are thus constrained to make qualitative statements about climate change impacts on forest types in India for the present.

Assessments of regional changes in climate parameters are more important than the global mean changes; further, seasonal changes are of consequence as compared to the mean annual changes. We now consider two possible scenarios of climate change in India-- one based on greenhouse gas increase and the other also incorporating sulphate aerosols-- and speculate on their possible impacts on forests in the country. We considered two scenarios because the simulated climate projections are substantially different over the northern part of the country.

4.1. SCENARIO 1: CLIMATE CHANGE UNDER GREENHOUSE GAS FORCING

The climate parameters used in this scenario are largely based on projections made by Hulme and Viner (1995) for the 2060s. The method used by them has three components: (a) an observed climatology based on Legates and Willmott (1990) at an original resolution of 0.5 latitude/longitude which has been reduced to 2.5 latitude by 3.75 longitude; (b) a simple upwelling-diffusion energy balance Model for the Assessment of Greenhouse Gas Induced Climate Change (or MAGICC, Wigley, 1994); and (c) a coupled ocean-atmosphere General Circulation Model of the Hadley Center (U.K. Meteorological Office (Murphy, 1995; Murphy and Mitchell, 1995). The scenario construction is flexible enough to handle uncertainty, both in future greenhouse gas emissions and also in the value of climate sensitivity.

The projections of Hulme and Viner (1995) are given in Table I. The parameters considered are changes in temperature, rainfall, length of dry season, soil moisture, and interannual variation in rainfall. We consider the projections for southern, central, northwestern, and northeastern zones of India.

Table I

Projected changes in climate parameters for the 2060s derived from maps prepared by Hulme and Viner (1995) for different regions of India (South, North, Central and Northeast India)

i) Changes in Temperature (over 1990)

	South	North	Central	Northeast
December-February (winter)	2.0 to 2.5°C	3.0 to 3.5°C	3.0 to 3.5°C	2.5 to 3.0°C
March-May (Summer)	3.0 to 3.5°C	3.0 to 3.5°C	3.0 to 3.5°C	2.5 to 3.0°C
July-November (Monsoon)	0.5 to 1.0°C	3.0 to 3.5°C	3.0 to 3.5°C	2.0 to 2.5°C

ii) Changes in Rainfall (compared to 1990)

	South	North	Central	Northeast
June-August (Southwest monsoon)	10 to 30%	10 to 30%	50 to 70%	10 to 30%
September-November (Northeast monsoon)	50 to 70%	10 to 30%	50 to 70%	-30 to 10%

iii) Changes in Soil Moisture (compared to 1990)

	South	Central	Northeast
December-February			-5 to 25%
March-May	15 to 25%		-5 to 25%
June-August	15 to 25%	15 to 25%	15 to 25%

Temperature

The southern peninsular India is projected to experience relatively moderate increases of 2.0-2.5 °C in winter (DJF), 3.0-3.5 °C during early summer (MAM), and 0.5-1.0 °C during the summer monsoon (JJA) season. Central and northern India may experience warming in the region of 3.0-3.5 °C during all seasons.

Rainfall

The Indian subcontinent is dominated by southwest (June to September) and northeast (October to December) monsoonal rains. According to projections for the Southwest monsoon season, rainfall will generally increase in the southern (10-30%), central (50-70%), and northeast (10-30%) regions. During the Northeast monsoon season, rainfall is projected to increase by 50-70% in southern India, where this is of significance. Projected increases in other parts of the country are probably not of much consequence during this period. Thus, the rainfall is generally expected to increase in the Southwest as well as Northeast monsoons, though at varying intensities.

Length of dry season

The dry season length (defined as number of months with less than either 50 or 100 mm rainfall) is generally expected to decline over central India, but increase in parts of southern India. In other regions there is no significant change.

Soil moisture

Soil moisture is crucial for a range of ecological processes such as seed germination, natural regeneration, growth rates of plants, and decomposition rates. Soil moisture is projected to increase marginally by 15-25% over parts of southern and central India. This increase is confined to the monsoon months of June through November. During the rest of the year there is either no change in soil moisture, or a marginal decline, even though rainfall is expected to increase by 30-50%. This could possibly be due to the increase in temperature leading to enhanced evapotranspiration.

Interannual variability (IAV)

Changes in IAV of rainfall are important for a wide range of biological and hydrological processes. The IAV for the Indian subcontinent is projected to decline in some regions and experience no change in others.

4.2. POTENTIAL IMPACTS OF CLIMATE CHANGE ON FORESTS UNDER SCENARIO 1

We now consider the potential impact of climate change on forests in India by illustrative examples from different regions of the country.

The forests in southern India are mainly in two distinctive belts, one along the Western Ghats and the other along the Eastern Ghats. The former tract is biologically more diverse and has been much more extensively studied than the latter. The Western Ghats rise to over 2000 m asl, and their complex topography contributes to a wide spectrum of tropical vegetation types, from wet evergreen forest along the western slopes receiving high rainfall (typically> 2000 mm/annum) and montane stunted evergreen forest and grassland (at altitudes >1800 m asl), through semi-evergreen, moist deciduous, deciduous, and dry thorn forest in areas of lower rainfall to the east of the ghats.

Increased temperatures of 2.0-3.5 °C during winter and summer would potentially stress vegetation through increased evapotranspiration. The increased rainfall, however, coupled with elevated CO_2 increasing water use efficiency, could compensate for this loss. In the balance, the marginal increase in soil moisture projected for this region could result in increased productivity in all forest types. Further, a shift in vegetation type boundaries could be expected along a west-east gradient (with moist forest types expanding farther east) and along an altitudinal gradient (with species adapted to the warmer, lower elevations migrating to higher altitudes). An increase in dry season length could also place forest types such as dry and moist deciduous forests at increased risk of dry season fires.

The montane regions of the Western Ghats featuring a mixture of stunted evergreen forest and grasslands with sharp ecotones are a sensitive indicator of past climate change (Sukumar et al., 1993; 1995). With an increase in temperature and reduction in incidence of frost, the montane forests dominated by Lauraceae and Rubiaceae could potentially expand into the grasslands. It is more likely, however, that anthropogenic disturbances such as fires and the raising of plantations of Australian wattle (*Acacia* spp.) and eucalypts (*Eucalyptus* spp.) in recent decades would set the stage for a further spread of these exotic plants (of C3 photosynthetic type)--especially the weed-like wattles--into the grasslands in the absence of management to restore the grasslands.

The central Indian forests in states such as Madhya Pradesh and Maharashtra are mostly moist deciduous and dry deciduous forests. Increase in rainfall and soil moisture during the Southwest monsoon could potentially transform these to moister vegetation types. Sal (*Shorea robusta*) forest, characteristic of the moister belt, could replace teak (*Tectona grandis*) forest in the drier belt.

The forests of northwest India are mostly dry deciduous and dry thorn forests. No change in soil moisture storage is indicated for this region. Thus, there may be no scope for any significant changes in forest type or productivity.

Northeast India again has a wide spectrum of tropical and subtropical forests and grasslands associated with the flood plains of rivers. The climate change scenario for northeast India is not very clear. There seems to be much greater variability in the various climatic parameters over even a small area. This region already experiences very heavy rainfall, and any small changes in rainfall may not be of much consequence for vegetation. The projected increase in temperature, however, in all the seasons, is likely to result in shifts of lower altitude tropical and sub-tropical forests to higher altitude temperate forest regions, resulting in contraction or die-off of some temperate vegetation types.

4.3. SCENARIO 2: GREENHOUSE GAS AND SULPHATE AEROSOL FORCING OF CLIMATE

The Intergovernmental Panel on Climate Change had recognized that sulphate aerosols would exert a strong negative radiative forcing on climate (IPCC, 1994). The numerous uncertainties, including atmospheric lifetime of sulphate aerosols and large regional differences, have made it difficult, however, to model climate incorporating this factor. A recent experiment run at the Max Planck Institute using the European Community Hamburg (ECHAM version 3) coupled ocean-atmosphere model (Lal et al., 1995), incorporating data on sulphate aerosols from Langner and Rodhe (1991), provides the only detailed projections for the Indian subcontinent, and this forms the basis for this scenario. Simulated outputs are available for only temperature and rainfall, and the implications of these results for forest change in the country are briefly summarized.

The aerosol model (CO_2 + sulphate) also simulates an overall warming (<1.0 °C) over the Indian subcontinent between the 1980s and 2040s, but at a significantly lower rate than simulated by the CO_2-only model. There are also substantial regional differences in temperature changes. During winter, the southern, central and northwestern regions are projected to experience 1.0-2.5 °C warming, while a cooling of up to 2.0 °C is simulated for northeastern India. The warming simulated over most parts of the subcontinent during the monsoon season is about 1.0 °C, and a cooling of about 0.5 °C over north-central India.

The major consequence of this simulated temperature change scenario is on precipitation patterns. With a reduction of the land-ocean thermal contrast, the strength of the Indian summer monsoon is expected to actually decline, with significantly reduced precipitation in parts of the country. While peninsular India may still show increased rainfall of up to 2 mm/day at the extreme south, a gradual decrease in this figure is simulated as one proceeds northward, with a deficit in rainfall (as compared to the 1980s) above 20 °N latitude. Northern India may experience up to a 1.0 mm/day decrease, while in central India this may be as high as 2 mm/day. We do not have these results at present in terms of percentage change, but a 1mm/day change during the summer monsoon implies an approximate shift of 10%, as compared to the 1980s. There is no significant change projected for winter precipitation, which, is not of much consequence for most parts of the country, except the extreme south.

As compared to the Hulme and Viner scenario, the potential impacts of CO_2 and aerosol forcing of climate on natural forests can be very different. There are no major changes indicated for the forests of southern India, but a very different picture might emerge for central and northern India. With a slight increase in temperature and a decrease of 20% or more in summer rainfall, the forests of central India would face considerable soil moisture stress. In such an event there would be increased mortality of trees and shifts from moister to drier forest types. The drier teak (*Tectona grandis*) dominated forests could replace sal (*Shorea robusta*) forests. Similar trends, though of lower magnitude, are indicated for the entire northern India, including the forests of the Himalayan slopes and foothills, and those of the northeastern states. In conclusion, the forests of central and northern India could undergo significant changes due to climate change impacts and anthropogenic pressures as described in the previous scenario.

4.4. SUMMARY OF CLIMATE CHANGE IMPACTS ON FORESTS

Both the direct impacts of increased atmospheric CO_2 and the impacts of changing temperature, rainfall,and soil moisture have to be considered. The CO_2 fertilization effect may have its greatest positive effect on tropical forests on net primary productivity. Overall, the increased rainfall and soil moisture over the Indian subcontinent,as projected in the Hulme and Viner scenario, coupled with increasing CO_2, could stimulate productivity in the tropical forests and thereby result in higher levels of (alpha) diversity. The opposite would be true if the aerosol model projections of Lal and co-workers were to unfold over central and northern India.

In any case, an increased turnover of forest species is indicated. This could, however, potentially result in species extinctions and decline in large-scale biodiversity (Phillips and Gentry, 1994). Much depends on the rate of change of climate and the time available for species and populations to adapt to this change, and for vegetation boundaries to shift. Models of transient response (as opposed to static or equilibrium models) of vegetation to climate change are needed to understand plausible trends in the coming decades.

Realizing the need for and importance of studies on impacts of climate change and adaptation at regional level, two regional studies have been completed in India. A study of the Western Ghat region concluded that for Nilgiris, the projected changes under the "most likely" scenario were an increase in area under evergreen forests due to increased precipitation and an increase in dry thorn forest due to increased temperature. In addition there was a noticeable decline in dry deciduous forest and a modest decrease in montane forest/grassland. In Uttara Kannada part of the Western Ghats, the projections indicate a shift from the drier vegetation types towards moister types (Ravindranath et al 1997). A similar study in Himachal Pradesh in Northern India based on the output of BIOME model for assessing the impacts of climate change on the temperate and sub-tropical forest vegetation has shown that there would be significant changes in the cover and location of different forest types. The extent to which the biomes shift, shrink or expand would also depend on their sensitivity to climate change. The study concluded that if the present trends (arising out of anthropogenic pressures) continue, the negative repercussions of climate change are likely to be severe (Deshingkar *et al* 1997).

5. Anthropogenic Stresses on Forests

India has a human population of 846 million (1991) and a population density of 258 persons/km^2. Rural and indigenous communities depend on forests for a range of products and livelihoods. Thus, there are intense anthropogenic pressures on forests. From 1951 to 1980, about 4.3 Mha of forest was officially diverted to non-forest use, mainly for agriculture (62%) and river valley (hydro-electric and irrigation) projects (12%) (FSI, 1988).

This has led to dire predictions about the future of forests in the country, a subject of intense debate and controversy (Myers, 1991; WRI, 1992; Zuidema et al., 1994). Using the IMAGE model, Zuidema et al., (1994) project, for instance, that India and south Asia would lose much of its forest cover by 2005. If such a scenario were to unfold, it is irrelevant to consider climate change impacts on natural forests. Therefore, we consider how such anthropogenic pressures are likely to affect forests, especially in the light of changes recorded since 1980.

5.1. LAND FOR FOOD PRODUCTION

According to IPCC (1991), the land required for food production in developing countries will increase by 50% by 2025 as a result of population growth. Even though the population of India has nearly doubled during the past 30 years, the total area under food crops has nearly stabilized to around 123 Mha since 1970 (Ravindranath and Hall, 1995). Even the total area under crop production has stabilized approximately 140 Mha during 1982 to 1990 (Figure 2). Further, given the relatively low productivity of food crops (less than 1.5 t/ha/year), there is significant potential to double or triple food production without increasing the area under crops. Compared to other tropical countries, reserve forest (primary forest) lands in India are unlikely to be converted for food production on a significant scale.

Shifting cultivation is likely, however, to further reduce forest cover in some states. The forests of Orissa state in central India are subject to the highest rates of shifting cultivation, with a minimum of 2.6 Mha, or 44% of the forest area being under cultivation at some time (FSI, 1987). In the northeastern region, the major proportion of tropical and subtropical forests in hill states such as Meghalaya, Tripura, Manipur, and Mizoram are not government-controlled reserve forests but under private or village ownership. This varies from about 55% in Mizoram to about 90% in Manipur, Nagaland, and Meghalaya. These forests are also subject to extensive clearing for slash-and-burn shifting cultivation. Thus, 20-30% of the forests are under shifting cultivation in these states (FSI, 1987). With a shortening of rotation periods, these lands will increasingly remain under cultivation or early forest successional stages. Overall, this is likely to override any climate-related change in the coming decades in such regions.

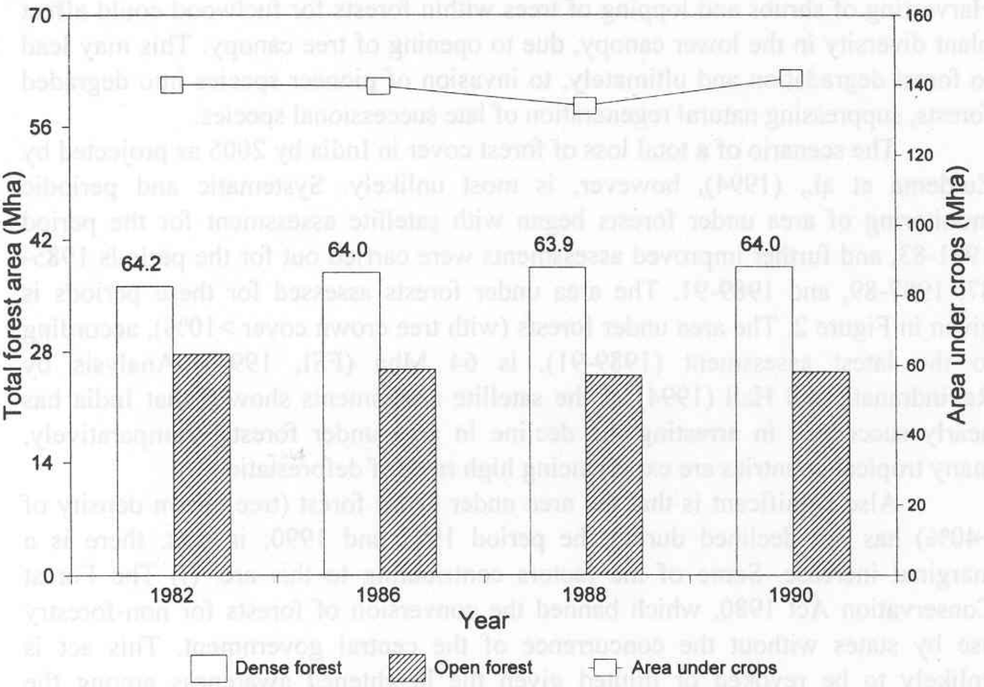

Figure 2. Area under crops and changes in area under forests for different tree crown classes for the four assessment periods (from 1982 to 1990), taking the mid-period of assessment; based on Indian National Remote Sensing Agency's periodic assessment, published by Forest Survey of India (and compiled by Ravindranath and Hall, 1994). Total area under forests is given above the bars.

5.2. HUMAN AND LIVESTOCK POPULATION DENSITY

India is home to 15% of the world's cattle, 10% of the sheep and goats, and 50% of buffaloes, but has only 4% of global land area. Forest degradation caused by livestock grazing pressure is significant in India (Brandon and Ramankutty, 1993). The grazing pressure on forests is about 5 livestock per ha of forest and pasture land. This large livestock grazing pressure will affect the forest regeneration, succession, and potential shift of species driven by climate parameters.

5.3. BIOMASS DEMANDS

Fuelwood is the dominant biomass demand on the forests. The current consumption level has been estimated to be 224 Mt/y (Ravindranath and Hall, 1995) and is projected to increase to 350 Mt/y by 2005. According to the analysis of Ravindranath and Hall (1995), fuelwood use may not be contributing to deforestation in any significant manner, but it does contribute to forest degradation. Harvesting of shrubs and lopping of trees within forests for fuelwood could affect plant diversity in the lower canopy, due to opening of tree canopy. This may lead to forest degradation and ultimately, to invasion of pioneer species into degraded forests, suppressing natural regeneration of late successional species.

The scenario of a total loss of forest cover in India by 2005 as projected by Zuidema et al., (1994), however, is most unlikely. Systematic and periodic monitoring of area under forests began with satellite assessment for the period 1981-83, and further improved assessments were carried out for the periods 1985-87, 1987-89, and 1989-91. The area under forests assessed for these periods is given in Figure 2. The area under forests (with tree crown cover >10%), according to the latest assessment (1989-91), is 64 Mha (FSI, 1994). Analysis by Ravindranath and Hall (1994) of the satellite assessments showed that India has nearly succeeded in arresting the decline in area under forests; comparatively, many tropical countries are experiencing high rates of deforestation.

Also significant is that the area under dense forest (tree crown density of >40%) has not declined during the period 1982 and 1990; in fact, there is a marginal increase. Some of the factors contributing to this are: (i) The Forest Conservation Act 1980, which banned the conversion of forests for non-forestry use by states without the concurrence of the central government. This act is unlikely to be revoked or diluted given the heightened awareness among the communities, policy makers, NGOs, and the media; (ii) A ban on logging introduced in many states during the 1980s may have contributed significantly to forest recovery, increase in canopy cover, and forest conservation; (iii) the protected area network comprising 80 national parks and 441 wildlife sanctuaries (in 1995) covers an area of 14.8 Mha, or 4.5% of the geographical area of the country, where access to resources from the protected areas is becoming increasingly restricted; (iv) the fact that large-scale social forestry program was launched in India during 1980. According to a national study of vegetation status of forests and plantations in India, 'illegal cuttings were not so rampant in primary forests or in plantations, and social forestry measures in India may have arrested further degradation of forests or even that some of the forests have been rehabilitated' (Seebauer, 1992).

The large reforestation (at an annual rate of 1.5 to 2 Mha since 1980) may not have contributed to the forest area (of 64 Mha) assessed by satellites. This is carried out over many years in different locations, largely on farm or village commons or even degraded forest lands, in isolated patches of a fraction of a hectare or a few hectares. Such small, isolated fragments of forest plantations are not considered in the satellite assessment (only >25 ha contiguous patches are used in area estimation), or the plantations may not be old enough in many locations to achieve adequate tree crown cover (of >10%) to be picked by the satellite imagery.

This high rate of reforestation has a positive impact on natural forests by supplying industrial wood, structural timber, and urban demands for poles and fuelwood (Ravindranath and Hall, 1995). The current reforestation program is characterized largely by monocultures of exotic species (such as *Eucalyptus* spp. and *Acacia auriculiformis*). India also has vast degraded lands (estimates vary from 66 to 130 Mha), which offer potential for some of the adaptation measures to the changing climates such as short rotation forestry, anticipatory planting, and mixed forestry. Promotion of natural regeneration as a part of the revegetation program also enables forests to respond to climate change.

5.4. SUMMARY OF ANTHROPOGENIC AND CLIMATE CHANGE IMPACTS

(a) Anthropogenic impacts on forests from demand for biomass will continue to play a major role in determining forest structure and change in some regions in the coming decades.

(b) Large-scale conversion of existing reserve forest land for agriculture is not likely, although further degradation of non-reserve forests due to shifting cultivation in some parts of India will continue. In such locations the anthropogenic impacts will override climate change considerations.

(c) Many forest areas in India are in a highly fragmented state. This fragmentation expands light gaps and leads to changes in vertebrate seed disperser populations, with differential advantages or barriers to regeneration of species, depending on their dispersal vector and distance from seed source. Potential adaptation to climate change impacts of some species could be reduced as a result.

(d) While India could have potentially experienced enhanced rates of deforestation and land conversion during the last 15 years in response to human population pressures as observed in many tropical countries, it has instead largely succeeded in conserving the forests. Satellite assessments since 1980 support this conclusion. The large forestation program has contributed to reducing demand on natural forests for various products.

(e) If the trends of the past 15 years continue, the area under forests, especially reserve forests and protected areas, is unlikely to decline significantly in India, except for the northeastern region, where the ownership and management of forests is different from the rest of India. The projections such as those of Zuidema et al., (1994) of large-scale deforestation during the coming decade is highly unlikely in India.

(f) Thus, we conclude that in India, while anthropogenic impacts on forests will be important, the impact of climate change on natural forests will also be a very relevant and significant issue in the coming decades.

6. Adaptation Measures to Climate Change Impacts on Forests

Due to the uncertainties involved in projections on climate change parameters, particularly at the regional level and the responses of forest vegetation, it is difficult to suggest region-specific or forest type-specific adaptation measures, specifically targeted to mitigate the projected adverse climate changes impacts. It may be possible, however, to suggest many generic `no regret strategies' as well as some `precautionary measures'. It is also possible that accurate climate predictions may not be necessary to develop adaptation measures. The majority of measures (`no regret strategies') necessary to alleviate the current threats to forests would also contribute to enhancing the resilience of forests to any adverse climate changes. Broadly, two kinds of strategies are necessary: first, those which relate to the existing forests, and second, measures concerning reforestation and management.

6.1. ADAPTATION STRATEGIES FOR NATURAL FORESTS

Some of the potential measures are: (i) increasing area under protected forests; (ii) strengthening legislation for forest conservation, (iii) adopting sustainable timber extraction practices; (iv) prevention of forest fragmentation; and (iv) shifting timber supply from natural forests to plantations.

6.2. REFORESTATION AND BIOMASS CONSERVATION MEASURES

Examples of measures are: (i) promotion of natural forest regeneration in currently degraded forest lands; (ii) reforestation in degraded lands to meet the biomass needs; (iii) promotion of mixed species forestry; (iv) conservation of fuelwood, or shifting alternate cooking energy options (such as biogas).

In addition to 'no regret strategies', it is necessary and possible to suggest some 'precautionary measures' given that 'climate parameters are likely to change faster than the natural vegetation adaptation mechanisms' (IPCC, 1990). The first task should be to study the current forestry practices to understand those which will promote forest resilience.

Examples of measures concerning existing forests are: (i) *ex situ* conservation of plant genetic resources; (ii) formation of corridors for assisting natural migration to proceed with minimal anthropogenic pressures, particularly among protected areas. Further, there is a need for studies at a regional level to identify the species and communities which are likely to require assistance to facilitate migration; and (iii) anticipatory planting of species likely to be threatened or likely to migrate.

Examples of measures related to reforestation are: (i) short rotation forestry and shortening of the rotation period which enables quick response to any forest dieback or species extinction; (ii) anticipatory planting and mixed species forestry is an insurance against total loss of vegetation due to pest and disease attack; and (iii) promotion of natural regeneration to enable migrating species to become part of forest succession.

In the face of uncertainty, reforestation strategies should emphasize conservation, diversification and broader deployment of species, seed sources, and families. Planting programs may have to deploy non-local seed sources, imported from lower latitudes or from lower elevations (Ledig and Kitzmiller, 1992). In tropical countries, it is necessary to initiate studies to assess the potential impacts of projected climate changes at regional level to develop adaptation and mitigation strategies.

The reforestation and forest conservation programs in India do not include climate change considerations in planning, policy formulations, and implementation of programs. Due to the uncertainties involved in the models of climate prediction, as well as vegetation response, currently only 'no regret' strategies are likely to be acceptable to forest planners. Thus, any adaptation measure must be compatible with the present goals for the forest sector.

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