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ORIGINAL ARTICLE

Forest policies and programs affecting vulnerability and adaptation to climate change

Shamama Afreen · Nitasha Sharma · Rajiv K. Chaturvedi · Ranjith Gopalakrishnan · N. H. Ravindranath

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Abstract Due to large scale afforestation programs and forest conservation legislations, India's total forest area seems to have stabilized or even increased. In spite of such efforts, forest fragmentation and degradation continues, with forests being subject to increased pressure due to anthropogenic factors. Such fragmentation and degradation is leading to the forest cover to change from very dense to moderately dense and open forest and 253 km^2 of very dense forest has been converted to moderately dense forest, open forest, scrub and non-forest (during 2005–2007). Similarly, there has been a degradation of 4,120 km^2 of moderately dense forest to open forest, scrub and non-forest resulting in a net loss of 936 km^2 of moderately dense forest. Additionally, 4,335 km^2 of open forest have degraded to scrub and non-forest. Coupled with pressure due to anthropogenic factors, climate change is likely to be an added stress on forests. Forest sector programs and policies are major factors that determine the status of forests and potentially resilience to projected impacts of climate change. An attempt is made to review the forest policies and programs and their implications for the status of forests and for vulnerability of forests to projected climate change. The study concludes that forest conservation and development policies and programs need to be oriented to incorporate climate change impacts, vulnerability and adaptation.

Keywords Forest policies · Pressures on land · Forest status · Climate change impacts · Vulnerability reduction · India

1 Introduction

Forest area in India seems to have stabilized in the recent decades (Ravindranath et al. 2008). Forests in India face significant pressures in the form of forest fires, livestock grazing, timber and fuelwood extraction, shifting cultivation, invasive species, pests,

S. Afreen (✉) · N. Sharma · R. Gopalakrishnan · N. H. Ravindranath
Center for Sustainable Technologies, Indian Institute of Science, Malleswaram, Bangalore 560 012, India
e-mail: afr.ali@gmail.com

R. K. Chaturvedi
Center for Ecological Sciences, Indian Institute of Science, Bangalore 560 012, India

unsustainable extraction of forest products by forest dependent communities and diversion of forest lands to other uses. According to Ravindranath et al. (2006), forests in India are likely to be adversely impacted by climate change. Further, disturbed forests are likely to be more vulnerable to climate change than undisturbed forests (Thompson et al. 2009). The status of forests (area, biodiversity, biomass stock, regeneration, and growth rate) is determined to a large extent by forest policies, regulations, programs and management practices. Ravindranath et al. (2003) highlighted the need for studying and identifying forest policies, programs and silvicultural practices that contribute to vulnerability of forests to climate change. Such studies would enable policy makers and implementers to identify and promote policies that increase the resilience of forests to climate change.

The specific objectives of the study are;

1. to review the status of forests in India and current pressures on forests,
2. to present the forest conservation, afforestation and development programs and policies,
3. to analyze the forest policies and programs in determining the vulnerability of forests to projected climate change, and
4. to identify and suggest programs and policies that reduce the vulnerability or enhance the resilience of forests to projected climate change impacts.

2 Status of forests in India

2.1 India's changing forest cover

According to the Forest Survey of India (FSI) forest cover encompasses all lands, including orchards, bamboo and palm of more than one hectare in area, with a tree canopy density of more than 10%, irrespective of ownership and legal status. The total geographic area of India is 3,287,263 km^2, out of which the total forest cover as per 2007 assessment of the FSI is 690,899 km^2, constituting 21% of the geographic area of India. Forest cover of India has been classified into three density classes: very dense forest (tree canopy density over 70%), moderately dense forest (40–70%), and open forest (10–40%). Of the total area under forest, 83,510 km^2 (12.1%) is very dense forest, 319,012 km^2 (46.2%) is moderately dense forest, while 288,377 km^2 (41.7%) is open forest cover (FSI 2009).

The State of Forest Report (SFR) 2009 indicates that there is an increase in total forest cover as compared to SFR 2007 (FSI 2009). However, during the period 2001 to 2005 area under dense forest declined, while the area under open forests increased, indicating potential degradation of forests (Table 1; Fig. 1). However, this trend changed during the period 2007–09 with area under dense forests increasing and area under open forests decreasing. The 2009 SFR (FSI 2009) shows that 127 km^2 of very dense forest has been converted to moderately dense forest, 45 km^2 to open forest, 5 km^2 to scrub and 76 km^2 to non-forest. Similarly, there has been a degradation of 1,948 km^2 of moderately dense forest to open forest, 42 km^2 to scrub and 2,130 km^2 to non-forest resulting in a net loss of 936 km^2 of moderately dense forest. Additionally, 186 km^2 of open forest have degraded to scrub while 4,149 km^2 have degraded to non-forest.

2.1.1 Forest types in India

Table 2 gives an estimate of the areas under different forest types in India according to classifications by Champion and Seth (1968), FSI and others (Table 2).

Table 1 Forest cover (km^2) according to FSI assessments

Forest type	Year of assessment						
	1987 (1985–87)	1997 (1995–97)	1999 (1997–99)	2001 (1999–2001)	2003 (2001–03)	2005 (2003–05)	2009 (2007–09)
Dense	3,61,412[a]	3,67,260	3,77,358	4,16,809[c]	3,90,564[c]	3,87,216[c]	4,02,522[c]
Open	2,80,629[b]	2,66,137[b]	2,59,935[b]	2,58,729[c]	2,87,769[c]	2,89,872[c]	2,88,377[c]
Total	6,42,041	6,33,397	6,37,293	6,75,538	6,78,333	6,77,088	6,90,899

Source: FSI (1987, 1997, 1999, 2001, 2003, 2005, 2009)

[a] Contains coffee plantations

[b] Contains mangrove forests

[c] Contain mangrove cover of corresponding density class

According to Champion and Seth (1968), forests in India have been classified into six major groups which are further categorized into 16 types, with tropical moist deciduous and tropical dry deciduous forests dominating, accounting for 36% and 28% of the total forest area respectively. FSI (2001) has stratified forests into 22 strata, with "Miscellaneous forest" accounting for 63.48% of total forest area, where no single species dominates. Sal (*Shorea robusta*), Teak (*Tectona grandis*) and Pines are the dominant forest plantations.

2.1.2 Forest biodiversity

India, one of the 12 mega biodiversity countries of the world, has diverse fauna and flora that accounts for about 8% of the world's biodiversity (MoEF 2006). These range from xerophytic in Rajasthan, evergreen in the North–East and the Ghat areas, mangroves of coastal areas, conifers of the hills and the dry deciduous forests of central India to alpine pastures in the higher altitudes of the Himalaya. The varied natural habitats of India have given rise to ten biodiversity rich zoogeographic zones (MoEF 2006).

The plant wealth of India, about 45,000 species, accounts for 12% of the global plant repository (Bahuguna and Upadhyay 2002). Of the world's 34 terrestrial biodiversity hotspots, three are spread over the Indian region, namely, Himalaya, Western Ghats-Sri Lanka and

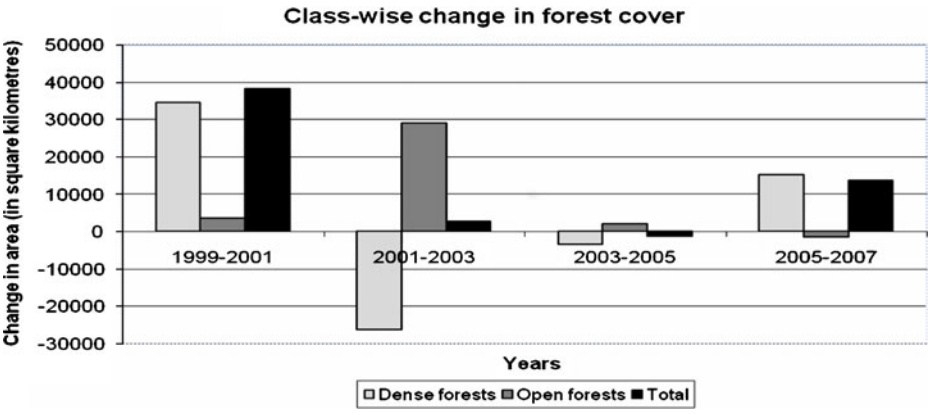

Fig. 1 Changes in forest cover according to tree crown density classes (Source: The State of Forest Report of respective years)

Table 2 Area under different forest types (in Mha) (Source: Chaturvedi Rajiv et al. 2010)

Studies using forest classification according to Champion and Seth (1968)			Studies using FSI strata classification		
Forest type/Strata	Ravindranath et al. 1997	ALGAS 1999	Forest type/Strata	NATCOM 2004	Haripriya 2003
Tropical Moist evergreen	5.2	4.5	Fir	0.38	0.4
Tropical semi evergreen	2.5	1.9	Blue-Pine	0.4	0.42
Tropical moist deciduous	23	23.3	Deodar	0.14	0.13
Tropical dry deciduous	18	29.4	Chir-Pine	1.3	1.2
Littoral and swamp	0.3	0.7	Mixed conifers	1.62	1.6
Tropical thorn	1.5	5.2	Hardwood & conifers	0.5	0.5
Tropical dry evergreen	0.1	0.1	Up-lands hardwoods	1.44	2.02
Sub tropical broadleaf hill	0.2	0.3	Teak	6.12	6.07
Sub tropical pine	4.5	3.7	Sal	7.53	8.07
Sub tropical dry evergreen	1.2	0.2	Bamboo	1.02	0.9
Montane moist temperate	2.5	1.6	Depterocarpus	0.006	0.005
Himalayan moist temperate	2.2	2.6	Khasi pine	0.14	0.17
Himalayan dry temperate temperate	0.03	0.2	Khair forest	0.2	0.19
Sub alpine and alpine	2.02	3.3	Alpine pastures	0.006	0.006
			Miscellaneous forest	40.73	40.82
			W.G (evergreen forest)	0.37	0.39
			W.G (semi-evergreen)	0.28	0.28
			Deciduous	0.23	0.24
			Others	0.162	0.161
Total	64.01	64		63.33	63.99

Indo-Burma. These are highly species-rich regions housing a large number of endemic species, many threatened and some already extinct (www.biodiversityhotspots.org). It is important to assess the likely impacts of climate change on these biodiversity rich hotspots.

2.1.3 Carbon stocks

According to an assessment (Ravindranath et al. 2008) forest carbon stocks in India have been increasing and are estimated to be 8.79 GtC during 2006 and projected to increase to 9.75 GtC during 2030, excluding removals of wood. Further, according to Kishwan et al. (2009) the forest carbon stocks increased from 6.24 GtC in 1995 to 6.62 GtC during 2005. Forest policies aimed at conservation of forests and afforestation have contributed positively to carbon stock changes in forests.

3 Pressures on forests In India

Among the different land-uses in India, forestry is the second largest land-use after agriculture. It is estimated that nearly 200,000 villages are located in and around the forests

(FSI 1999). An estimated 275 million people living in rural areas of India depend directly on forests for at least part of their livelihoods (World Bank 2006). India's forests are facing increasing pressure and stress due to several factors and the availability of non-timber forest products (NTFP), utilized by the rural population residing in the vicinity of forests, is getting further depleted due to over exploitation and expanding human population (MoEF 2003). Based on the forest cover values (in km^2) of different states and Union Territories, given in the State of Forest Report 2007 (FSI 2009), the net change in forest area over a 2 year period has been shown to be 728 km^2. This is calculated using the sum of the area of the states which show an increase in forest cover (1,494 km^2) and the sum of the area of states which show a decrease in forest cover (−766 km^2). This means 38,300 ha of forests have been converted annually during 2005 and 2007. Understanding the existing pressures on forests and their management is crucial for planning appropriate actions so that the detrimental effects caused by these pressures on forest ecosystems are not aggravated in the face of climate change. These pressures may not only increase the vulnerability of forest ecosystems but also that of the forest dependent communities (Mukhopadhyay 2009).

3.1 Shifting cultivation

In India, shifting cultivation is practiced on the hill slopes of eastern and north–eastern parts with 85% of the total cultivation in northeast India (Singh and Singh 1992). Intensified shifting cultivation is impacting forests leading to degradation of forests, especially in the North–Eastern states. Increase in the population of shifting cultivators and the declining productivity of forest soils have resulted in reducing shifting cultivation cycle from 25–30 to 2 years to 3 years, leaving no time for the land fertility to be restored (Patro and Panda 1994). Decrease in forest area due to shifting cultivation accounted for 23% of the total deforestation in India, with an annual loss of 0.93 Mt C yr^{-1} (Manhas et al. 2006). Frequent shifting from one land use to the other under shifting cultivation affects the ecology of these regions, thereby leading to: decline in the area under natural forests, fragmentation of habitats, local disappearance of native species, invasion by exotic weeds and other plants and reduction in soil fertility and soil erosion. Degraded and fragmented forests are highly vulnerable to climate change. Fragmented forests are likely to demonstrate less resilience and resistance to climate change than intact forests (Singh 2008).

3.2 Demand for fuelwood, timber and non-timber forest products

Apart from fuelwood and timber, forests in India provide forage and a wide range of food products, oilseeds, medicinal herbs and aromatics known as non-timber forest products.

Fuelwood is the dominant forest product extracted. At the national level, the Planning Commission had set up a study group on Fuelwood and Fodder which estimated the demand for fuelwood at about 306, 343 and 384 million tonnes, respectively for 1990, 1996 and 2001 (GoI 1979). The FSI (1996) estimated the fuelwood consumption at 201 million tonnes whereas Ravindranath and Hall (1995) reported varying estimates of the fuelwood consumption from 227 to 298 million tonnes. There are no estimates of extraction of fuelwood from forests, though Forest Survey of India (FSI 2001) states that fuelwood demand is largely met from forests leading to degradation. The consumption of wood products in India is calculated by the assumption that consumption = production + import−export. According to the Forest Department, production of timber is the material produced in the forest after felling of trees. But all such production does not reach the sale depots (markets). There are no reliable figures on the quantity of material obtained

from the forests and that removed illegally and therefore, the illicit removals of timber and fuelwood are not accounted in the country's production.

Timber removal from forests also contributes to degradation as well as deforestation. During the last 5 years to 6 years, several large scale timber extraction cases have been reported from many states including from protected areas. The Buxa Tiger Reserve, in West Bengal, lost about 10 km^2 of forest cover in 1998–1999 alone, as a result of extraction of timber. Many important Protected Areas like Rajaji National Park in Uttarakhand, Nagarhole National Park in Karnataka, Palamou or Betla Tiger Reserve in Jharkhand and many other forest areas in India report similar incidents. Maharashtra state has reported the a large number of cases of illicit felling of trees as well as maximum loss of timber (http://www.indiastat.com/forestandwildlife/13/illegaltrade/127/stats.aspx).

In addition to fuelwood and timber, a large number of NTFPs have been extracted. Many of the NTFPs have been extracted in a non-sustainable way leading to degradation of forests. Though there are no quantitative studies on the extent of extraction of fuelwood, timber and NTFPs, the large scale and increasing dependence on forests for these products would lead to forest degradation, deforestation and fragmentation of forests, potentially increasing the vulnerability of forests to future impacts of climate change.

3.3 Grazing

According to an assessment, grazing adversely affects approximately 78% of forests in India (FSI 1995). Infact, 67% of the National Parks and 83% of the Wildlife Sanctuaries report grazing incidents. Mudumalai Wildlife Sanctuary in southern India is connected to three protected areas in the region, namely Nagarahole and Bandipur National Parks and Wynaad Wildlife Sanctuary through forest corridors between the Western Ghats and Eastern Ghats forests and these corridors are used by large animals such as elephants for migration. Livestock grazing, originating from the villages located in the fringes of the sanctuary is a major biotic interference in these forest corridors, and has adversely affected the forest regeneration and helped proliferation of weed species (Silori and Mishra 2001) such as *Lantana camara*, *Chromolaena odorata, Imperata cylindrica, Parthenium hysterophorus, Cassia tora*, etc.

India has the largest livestock population in the world. The total livestock population of India as per the Livestock Census 2003 is 485 million (GoI 2003) It is estimated that livestock population in India increased from 280 million in 1947 to an estimated 467 million in 1997 while permanent pasture and grazing land has decreased from 70 Mha in 1947 to 38 Mha by 1997 (Purshothaman et al. 2005). All non-crop lands are subjected to grazing. Uncontrolled livestock grazing in forests may lead to:

- loss of species diversity in forest ecosystems and promotion of weeds,
- soil erosion and depletion of major nutrients,
- transfer of plant nutrients from the forest to the agricultural system which may result in a gradual decline in the fertility of forest soils,
- slow regeneration of plant species.
- compaction of topsoil further leading to increased bulk densities, decreased infiltration rates, increased surface runoff; formation of hydromorphic humus (Broersma et al. 2000),
- damage to tree roots that facilitates root rot (Carson 1992) and
- forest area boundary shrinkage and loss of habitats for forest dwelling species.

Uncontrolled grazing, with high livestock grazing densities, leads to overgrazing and forest degradation, potentially increasing the vulnerability of forests to projected climate change.

3.4 Forest fires

The occurrence of forest fires can be attributed to natural factors (e.g. lightning, erupting volcanoes and droughts) and anthropogenic factors (e.g. fires lit for clearing land for shifting cultivation purpose and human negligence). The fires in Indian forests are mostly attributed to anthropogenic activities. The various reasons behind forest fires in India can range from the need for grass for grazing livestock, to facilitating the collection of fuelwood and certain non-timber products, to clearing the forests for shifting cultivation practices, grazing, etc. Livestock grazing alters forest dynamics by removing the biomass and intensive grazing sometimes leads to domination of a single or a few species, changing the species composition of natural vegetation, aggravating degradation of forests and making them fire-prone.

Further, during summer, when there is no rain for months, the forests become littered with dry leaves and twigs, making the forest floor prone to fires. The mountain ranges of Himalayas are the most vulnerable stretches of the world, susceptible to forest fires. Incidences of forest fires, especially in southern India, are also recurrent due to dominance of dry deciduous forests (Somashekhar et al. 2007). Incidences of forest fires, especially in southern India, are also recurrent due to dominance of deciduous forests. Forest fires are a major recurrent management problem in Western Ghats, even though the incidence and extent may vary from year to year, depending primarily on rainfall during the dry fire season. Table 3 shows the state-wise incidence of forest fires and burnt area (in hectares) in India from 2003–2006 for major states.

Forest fires are of two types namely, surface/ground fire and crown fire. The most common type of fire in India is ground fire. The adverse impacts of forest fires in India (Bahuguna and Upadhyay 2002) include:

- loss of valuable timber resources,
- loss of biodiversity and extinction of plants and animals due to habitat destruction,

Table 3 State-wise incidence of forest fires and burnt area (in hectares) in India from 2003–2006 for dominant states

	Number of fire incidents during 2003–06	Burnt area (in hectares) during 2003–06
Andhra Pradesh	428	5,308
Chhattisgarh	778	6,424
Gujarat	2,782	27,617
Himachal Pradesh	1,794	28,880
Karnataka	721	3,382
Kerala	1,885	19,924
Madhya Pradesh	2,535	36,565
Maharashtra	7,823	134,971
Punjab	892	15,147
Tamil Nadu	1,355	6,657
Uttar Pradesh	347	2,754
Uttaranchal	3,325	14,047
Mizoram	161	11,498
Tripura	948	9,460

http://www.indiastat.com/forestandwildlife/13/forests/108/stats.aspx

- loss of natural regeneration and reduction in forest cover and biomass with ground fires severely affecting regeneration of plant and tree species, since the seeds on the forest floor get burnt out and young saplings die,
- loss of carbon sink and emission of CO_2 and non-CO_2 greenhouse gases
- soil erosion,
- increase in population of weeds such as *Chromolaena* and *Lantana* which would have the capacity to regenerate better and flourish using the open areas created by burning of the native vegetation
- loss of livelihood for forest dependent communities in the long run.

At the policy level, there have been a series of centrally sponsored forest fire protection and control schemes since 1985 such as the Modern Forest Fire Control Methods scheme since 1992–93, which promote the adoption of modern techniques and equipment in the prevention and control of forest fires as well as community involvement in forest fire prevention and control (Hiremath 2007).

3.5 Invasive species

The International Union for Conservation of Nature and Natural Resources (IUCN) defines Alien Invasive Species (AIS) as species which become established in natural or semi-natural ecosystems or habitat, an agent of change, and threaten native biological diversity, alter habitats and disrupt natural ecosystem processes. The introduction of AIS can be intentional or accidental. Invasive species cause loss of biodiversity including species extinctions, and changes in hydrology and ecosystem functions. They may cause a change in soil structure, its profile, decomposition, nutrient content of soil, moisture availability, etc. Invasive species are thus a serious hindrance to conservation and sustainable use of biodiversity, with significant adverse impacts on the goods and services provided by ecosystems.

Invasive plant species generally show fitness homeostasis and phenotypic plasticity thereby having tolerance capacity against environmental extremes and greater adaptability in wide range of environmental conditions, zero or very short dormancy period and high reproductive potential. According to a study by ICFRE (Sharma 2008) out of the identified 75 forest invasive species found in different parts of India, 61 are plant species. Some dominant invasive species affecting forest ecosystems in India are: *Lantana camara*, (Beeson and Chatterjee 1939), *Eupatorium odorata, Mikania micrantha*, *Mimosa pudica*, *Parthenium hysterophorus, Chromolaema adenophorum, Chromolaema odoratum, Ageratum conyzoides, Galinsoga parviflora*, etc. It is anticipated that climate change will affect temperature and moisture levels and the growth of pests and invasive species could be aggravated (Singh 2001).

3.6 Land conversion

Besides the above mentioned major pressures on forests, there are other drivers of deforestation such as conversion of forest land for food production (Nabuurs et al. 2007), infrastructure and settlements. In India, studies have shown that since the 1980s, there has been no significant conversion of forest lands for food production (Sudha and Ravindranath 1999). Thus conversion of forest land to agriculture is not a driver of forest loss or degradation in India. Further, Fig. 2 shows that the area under food production has remained stable since 1970 to 2004 while the area under forests has increased.

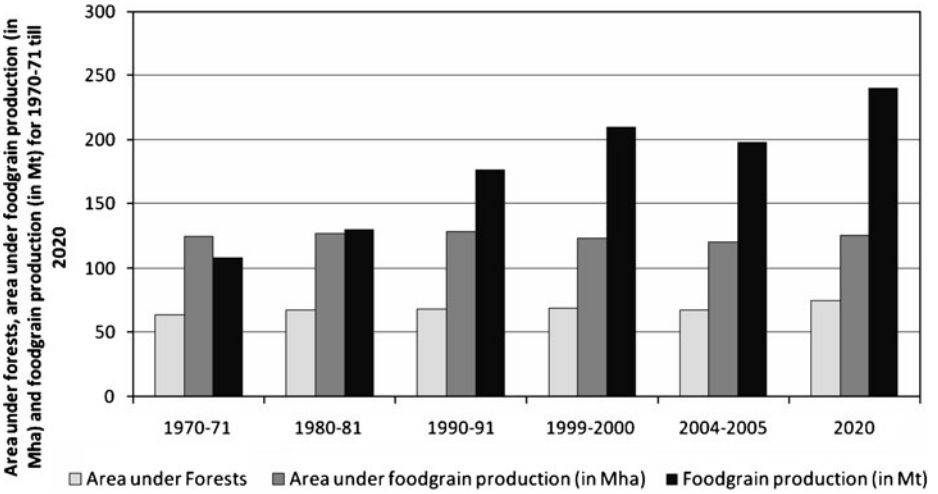

Fig. 2 Area (in Mha) under food production and forest during and food grains production (in Mt). Source: Agricultural Statistics at a Glance (2007). New Delhi: Ministry of Agriculture, Government of India, Paroda and Kumar (2000), Singh (2002), http://nrlp.iwmi.org/PDocs/DReports/Phase_01/08-Future%20of%20Food%20grain%20Production-Anik%20Bhaduri.doc

Conversion of forest land to non-forest uses such as expansion of industries, the Forest Conservation Act 1980 provides for compensatory afforestation. According to the State of Environment Report 2009, measuring the total rate of habitat conversion (defined as change in forest area plus change in woodland area minus net plantation expansion) for the 1990–2005 interval, India gained one per cent in forest and woodland habitat. The amount of forest land area (in hectares) diverted for various purposes varies from 10978.41 in 2006 to 1853.26 in 2009 (Source: http://www.indiastat.com) The compensatory afforestation is not fully implemented and even if afforestation has taken place in some states no attempt is made to promote forest regeneration or restoration keeping in made the biodiversity conservation aspect and instead plantations have been raised.

4 Afforestation programs in India

Afforestation is generally perceived as planting of new forests or tree plantations on open lands that have not been recently forested. Converting non-forest land to forests will typically increase the diversity of flora and fauna, except in situations where biologically diverse non-forest ecosystems are replaced by forests that consist of single or a few species (e.g., plantations of monocultures and especially of exotic species). Apart from increasing carbon stocks, afforestation or reforestation has other environmental benefits such as reducing soil erosion, controlling salinization, and protecting watersheds (IPCC 2000).

The earliest plantation in India is reported to be *Tectona grandis*, planted in 1840 in Nilambur, Kerala state (FSI 1999). In 1910, *Eucalyptus* spp. was introduced in the Nilgiri Hills of the present Tamil Nadu state. Planned afforestation programmes started in the late 1950s. Large-scale afforestation was initiated in India in the early 1980s with social forestry, followed by the Joint Forest Management Programme (JFM) in 1990 and National Afforestation and Eco-development Board (NAEB) programme in 1992. Figure 3 shows

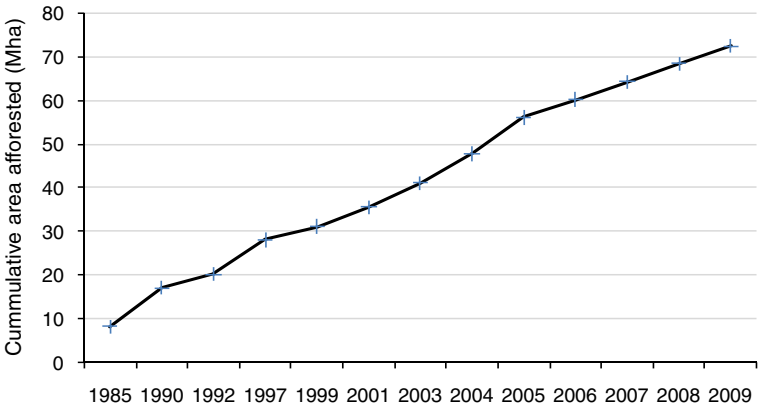

Fig. 3 Cumulative area afforested during 1985–2009 (Source: From Annual Reports of Ministry of Environment and Forests, Government of India)

the progress of afforestation in India for the period 1985–2009 which includes community woodlots, farm forestry, avenue plantations and agro-forestry (Ravindranath et al. 2008; MoEF 2004).

India has announced two new programs namely "National Mission for Greening India" and "Compensatory Afforestation Fund Management and Planning Authority" (CAMPA). Both are large scale programmes, aiming to achieve a goal of bringing one-third of the geographic area of India under forest cover. The National Mission for Greening India will have multiple implications for climate change. Firstly, the large scale afforestation could sequester and create carbon sinks. Secondly, the large afforested plantations, if dominated by monoculture plantations are likely to be become vulnerable to climate change, compared to mixed species forestry, since monocultures are more vulnerable to changes in temperature, fires, pest attacks and diseases. In case of CAMPA, funds collected and accumulated since 2002, by various states in India from private firms and the forest departments whenever forest land has been converted to non-forest use. In 2009 the Supreme Court of India removed the deadlock on utilization of these funds, which are now to be used by the governments for bringing 6 million hectares of degraded forest land under regenerative cover within the next 6 years. Thus large non-forest areas will be afforested under different programmes.

5 Vulnerability of Indian forests to climate change

Forest ecosystems are intrinsically dynamic and are constantly influenced by climatic variations and are capable of adapting to the changes in the environment. However, climate change is expected to occur more rapidly than the rate at which ecosystems can adapt and reestablish themselves. It has been pointed out (Betts et al. 2008) that tropical forests are vulnerable to climate change and its impacts on them could be so severe as to threaten their structure, function and services. The fourth assessment report of IPCC (IPCC 2007) concludes that forest ecosystems could be seriously impacted by future climate change, even with moderate global warming of 1°C to 2°C.

The spatial distribution of forests were assessed using a digital forest map prepared by the FSI. The geographic area of India was divided into 165,000 grids (each of 2.5' by 2.5').

Out of these, 35,899 were classified as "forest grids"—grids dominated by forests. Table 4 (Chaturvedi Rajiv et al. 2010) presents the vulnerability of forests in forest dominated states to climate change. The state that contains the maximum number of forest grids projected to be impacted by climate change is taken to be the most vulnerable, to the long-term climate change. Hence, this table is sorted by "number of forest grids projected to change".

Ravindranath et al. (2006), made an assessment of the impact of projected climate change on forest ecosystems in India, based on climate projections of regional climate model of Hadley Centre (Hadley Center Regional Climate Model—HadRM3) using the A2 and B2 scenarios[1] of Special Report on Emissions Scenario (SRES) and the BIOME 4 vegetation response model. The study found that under the climate projection for the year 2085, 77% and 68% of the forested grids in India are likely to experience shift in forest types under A2 and B2 scenario, respectively. The study also showed that north–eastern region may experience a shift towards wetter forest types whereas northwestern region may experience a shift towards drier forest types in the absence of human interferences. The projected large scale shifts in forest types presents a serious challenge for Indian forestry. Analysis using dynamic global vegetation model IBIS (Integrated Biosphere Simulator) shows that the percent of forested grids expected to undergo vegetation change ranges from 3.5% in North–eastern states to 73% in Chattisgarh (Table 4). This means the future A2 scenario climate is not suitable to existing forest types in most states, except the North–eastern states. Thus the forests in all the major states are vulnerable. Forests could experience die-back and loss of biodiversity. According to the BIOME4 as well as IBIS model projections increasing atmospheric CO_2 concentration could also result in increasing net primary productivity under A2 and B2 scenario. However, these gains in productivity may not be realized as projected by the BIOME4 and IBIS models since in their current form they do not take into consideration nutrient limitations, particularly that of nitrogen in soils.

6 Factors likely to impact forest vulnerability

Excluding the North–eastern states, which as shown earlier, are less vulnerable to the A2 climate scenario, 45% of forested grids in various states are vulnerable to climate change. Thus it is necessary to understand how the forest policies, programs and the current status and management of forests contribute to increasing or reducing the vulnerability of forests to projected climate change.

6.1 Forest fragmentation

Forest fragmentation and edge effects from deforestation have been found to cause pervasive degradation of tropical forests (Gascon et al. 2000; Murcia 1995). Forest fragmentation is the result of projects such as residential and commercial development, road construction, clearing for agriculture or grazing and timber harvesting. Such activities simultaneously reduce forest area, increase forest edge, and divide large contiguous forest areas into smaller non-contiguous patches. Forest fragmentation besides leading to altered

[1] A2 scenario represents a world of increasing population and brisk economic development. B2 scenario represents a world of increasing population (but lesser rate than A2), ecologically friendly policies and intermediate economic development rate.

Table 4 Vulnerability of forests of selected states to A2 and B2 scenarios of climate change as projected by IBIS Model (Chaturvedi Rajiv et al. 2010)

State	Number of forested grids	Number of forested grids projected to change under A2 scenario	% forested grids projected to change under A2 scenario	Number of forested grids projected to change under B2 scenario	% forested grids projected to change under B2 scenario
Chhattisgarh	3,130	2,292	73	2,292	73
Madhya Pradesh	4,437	2,183	49	1,807	40.7
Andhra Pradesh	2,588	1,615	62	1,191	46
Karnataka	2,004	1,344	67	904	45
Maharashtra	2,338	1,060	45	827	35
Rajasthan	887	640	72	445	50
Himachal Pradesh	740	400	54	400	54
Tamil Nadu	757	398	52.5	295	38.9
Gujarat	755	334	44	400	52.9
Orissa	2,333	295	12.6	206	8.8
Uttarakhand	1,149	283	24.6	256	22
Jharkhand	988	219	22	219	22
Uttar Pradesh	538	209	38.8	247	45.9
Others	3,103	355	11	672	21.6
North–east states	8,828	312	3.5	312	3.5

microclimates and increased carbon emissions, increases the vulnerability of forests, making them more susceptible to the following detrimental effects:

- ➢ Reduced ability of species to migrate in response to the impacts of climate change (Collingham and Huntley 2000)
- ➢ Increased incidence of wildfires (Alencar et al. 2004).
- ➢ Increased tree mortality and changes in plant and animal species composition (Cushman 2006).
- ➢ Altered plant—animal mutualism and seed dispersion (Cramer et al. 2007).
- ➢ Increased risk of predation (Huhta et al. 2004).
- ➢ Increased access to interior forests and hence increased conversion for agriculture (Kaimowitz and Angelsen 1998).

In India about 200,000 villages (including settlements and agricultural land) are located inside or on the fringe of forests. Thus forest area of about 69 Mha in India is highly fragmented. Fragmentation interspersed with village settlements, farms and roads will hinder migration of species, a vegetation response to climate change, potentially leading to local extinctions.

6.2 Afforestation

India has been implementing a large afforestation program with the aim to cover 33% of geographic area under forests. Afforestation and reforestation programs can affect the resilience of forest ecosystems if species selection is not done prudently. When located in already degraded lands, waste lands and other such areas where the lands is severely degraded and biodiversity is already low, mono-species plantations further decrease biological diversity, degrade soils and render the stand vulnerable to pest, disease and fire

outbreaks. Since mixed forests are more resilient, afforestation programs need to promote multi-species plantations that incorporate native species (Ravindranth 2007). In addition to species selection, other aspects of afforestation programs such as site selection could also impact vulnerability of forests to climate change.

The state forest departments have largely promoted monoculture plantations of *Acacia auriculiformis,* Eucalyptus species, teak, pines, poplar etc. For example, even in the biodiversity rich Western Ghats, forest plantations raised are dominated by *Acacia auriculiformis* (Murthy et al. 2002). It is not clear what proportion of 67 Mha of forest area is under monocultures or single species dominated plantations. Given the large scale nature of afforestation since 1980 (about 1.3 Mha annually), significant proportion of existing forest plantations are vulnerable to climate change.

6.3 Silvicultural practices and fire and pest management

Forest fires are expected to increase in some areas with climate change and decrease in others. Although forest areas in most semiarid regions are predicted to be much drier, and therefore more vulnerable to fire, other areas which may be wetter are less vulnerable to fire (Scholze et al. 2006). However, climate variability is expected to increase across the globe (IPCC 2007) and this will increase periods of drought, making forests more prone to fires. Large wildfires can severely damage forests and watersheds by accelerating runoff and erosion, making burned landscapes prone to invasion by exotic weeds, degrading native plant communities and damaging habitats for terrestrial and aquatic species that are already threatened with extinction (Covington 2003). Forest fires are already severe in India (Table 4). Warming and droughts due to climate change would increase the risk of forest fires. Monoculture plantations raised under afforestation program increase the vulnerability of plantations to fire. Appropriate silvicultural practices may be required to be developed and adopted to increase forest vigor, reduce vulnerability to insects and diseases, reduce tree mortality, decrease fuel loading and susceptibility to forest fires. Silvicultural practices such as appropriate thinning and prescribed burning under controlled conditions can lower the risk of forest fires and decrease vulnerability to impacts of climate change such as droughts. Similarly, treatments such as modifying the composition, structure or age class of the stand so as to manipulate insect/disease habitat can reduce the size of contiguous areas and control outbreaks (Society of American Foresters 2005).

6.4 Forest planning and management

Sustainable Forest Management is a comprehensive approach towards improving the health of forests, increasing their productivity and fulfilling the needs of the communities dependant on them in a sustainable manner. It must be seen as an instrument not only for conserving the biological diversity and increasing productivity but also for averting the adverse effects of climate change.

Forest policies that do not promote participatory management of forests can lead to degradation of forest ecosystems through unsustainable resource extraction and inadequate forest conservation. Community-based forest management programs and the devolution of management responsibilities to local governing units give greater access and control of forest resources by the local people. This in turn encourages them to improve forest protection and reduce pressures on forests. Benefit sharing schemes that bring financial returns can encourage local people to support forest conservation. Governance structures that fail to incorporate sustainable forest management could potentially reduce forest

ecosystem services induced by impacts of climate change, aggravate conflict and non-cooperation over remaining resources and encourage unsustainable resource use, thus affecting the well-being of the communities dependant on them (Osman-Elasha et al. 2009). Forest planning and management should be aimed at minimizing the negative effects of climate change on forests. Management can decrease the vulnerability of forests to climate change related impacts by determining the timing and direction of forest adaptation. Up till now most responses of the forest sector to climate change have been reactive (Roberts et al. 2009). There is a need to encourage proactive adaptation and make climate change adaptation strategies an integral component of forest management plans (Spittlehouse and Stewart 2003).

7 Indian forest policies and vulnerability of forests to climate change

Forest policies are critical in determining the status of forests. The extent of forest cover, biodiversity conservation efforts, afforestation and reforestation rates, conversion of forests for other land uses, levels of fragmentation and rates of timber, fuelwood and non-timber extraction are all directly or indirectly dictated by policies, which in turn could increase or decrease the vulnerability of forests and determine the adaptive capacity of communities to climate change. It is important to assess India's forest policies and programs in order to understand the effect they might have on the resilience of forests and communities and to design appropriate adaptive mechanisms to overcome or cope with minimum damage to the impacts of climate change.

7.1 Forest Conservation Act, 1980

The Forest Conservation Act was enacted in 1980 aimed at halting forest conversion. It was enacted to provide a higher level of protection to forests and to reduce/regulate the indiscriminate conversion of forest land for non-forestry uses. In cases where de-reservation or diversion of forest land for non-forest uses is being approved for infrastructure projects, the Act requires that compensatory afforestation be undertaken over equivalent area in non-forest land or over degraded forestland twice in extent to the area being diverted (Ravindranath et al. 2003).

The impact of the Act is evident from the fact that during 1950–80, the rate of diversion of forest land for non-forestry purposes was 1,50,000 ha per annum and this reduced to about 35,000 ha per annum after enactment of the Act in 1980 (envfor.nic.in/divisions/fp/FP/Annexure%20-3.ppt). Compensatory afforestation is also being undertaken with 380,195 ha having being brought under the programme in 2001 (www.indiastat.com).

The Forest Conservation Act (1980) has been one of the most effective legislations that has contributed significantly to reducing deforestation (Ravindranath et al. 2008). This Act, in addition to the Wild Life Act and the policy on Protected Areas has largely contributed to biodiversity conservation and reduced forest loss, which is very critical for migration of species enabling them to adapt to climate change. The implications of the Forest Conservation Act on the forest ecosystems in India are reduced deforestation, enhanced forest cover, and potentially improved biodiversity conservation since natural forests are less vulnerable to climate change impacts. The Forest Conservation Act, 1980 and its effective implementation is one of the most important policies contributing to reduced vulnerability, though this alone may not be adequate. In the absence of Forest Conservation Act, 1980 a large proportion of forests might have been converted to other uses enhancing fragmentation, degradation and vulnerability of climate change impacts. Even though large

scale forest conversion may have halted, forest degradation and fragmentation may be occurring, actually enhancing the vulnerability.

7.2 National Forest Policy, 1988

Although Government of India had a National Forest Policy in 1952, increasing pressures on forests necessitated that the existing strategy on forest conservation be reviewed and the revisions in the policy became imperative. The revised National Forest policy sought to enhance conservation efforts and was adopted in 1988 with the following basic objectives (Ravindranath et al. 2003):

- ➢ Maintaining environmental stability and restoring ecological balance through restoration of depleted forests.
- ➢ Preserving India's remaining natural forests that are home to a vast variety of flora and fauna.
- ➢ Checking soil erosion and denudation in catchment areas of rivers, lakes and reservoirs for soil and water conservation, alleviating floods and droughts and delaying siltation of reservoirs.
- ➢ Undertaking massive afforestation and social forestry programs especially on degraded, denuded and unproductive lands to substantially increase forest cover.
- ➢ Fulfilling rural and tribal population's requirement of fuelwood, fodder, minor forest produce and small timber.
- ➢ Increasing the productivity of forests to meet the growing biomass needs.
- ➢ Encouraging sustainable use of forest produce and maximizing substitution of wood.
- ➢ Large scale involvement of people with emphasis on inclusion of women in achieving forest conservation and sustainable use.

The National Forest Policy is very significant for improving the adaptive capacities of forest dependent communities, especially women. Through a mandate of involving local stakeholders in management of local forest resources, this policy and the subsequent government resolution on Joint Forest Management have contributed to participatory forestry and also enabled local communities to strengthen their coping capacities in the context of uncertainties (Kumar 2008).

The likely implications of the National Forest Policy on forest ecosystems in India are improved biodiversity conservation, improved regeneration of degraded forests, increased availability of fuelwood, fodder and minor forest produce including small timber, thereby reducing pressure on forests, enhanced capacities of forest dependent communities, especially women, to potentially adapt to impacts of climate change. Participation of local communities and meeting their biomass needs sustainably could be critical for reducing vulnerability of forests to climate change. The National Forest Policy is likely to have positive implications for forest resilience. However, poorly implemented activities under the National Forest Policy, such as monoculture plantations and inadequate community participation may contribute to enhancing the vulnerability of forests to climate change.

7.3 The National Wildlife Action Plan, 2002–2016

The National Wildlife Action Plan, 2002 (NWAP) gives primacy to wildlife conservation and recognizes effective ecosystem conservation as the foundation of long term ecological and economic stability. The provisions include strengthening and enhancing the Protected Area Network, effective management of Protected Areas (PAs), conservation of wild and

endangered species and their habitats, restoration of degraded habitats outside PAs and ensuring people's participation in wildlife conservation. It has suggested that the new legal PA categories 'Conservation Reserves' and 'Community Reserves' be formed besides national parks and sanctuaries (MoEF 2010).

Several objectives and provisions of the National Wildlife Action Plan are also significant for enhancing the resilience of the flora, fauna as well as forest dependent communities. Its recommendation that strict conservation zones free of all urban facilities, tourism and public thoroughfare be established is critical for avoiding habitat fragmentation as well as degradation. The action plan recommends that steps be taken to minimize the adverse impacts of human acts like introduction of exotics, monoculture plantations, fires, timber felling, removal of dead wood, contamination from toxics and pollutants—all these measures are likely to increase the resilience of forests to the impacts of climate change. Its strong advice to PAs to adopt a management objective that lays emphasis on promoting natural regeneration ensures perpetuity or return of wild indigenous flora and fauna that are sturdier and less vulnerable to climate change than their exotic counter parts.

The National Wildlife Action Plan further calls for the involvement of local communities and requires that they be made aware of fire control, prevention of over grazing, pests, disease and poaching. In an effort to reduce biotic pressures on PAs and to buffer the impacts of wildlife on humans, crops and livestock, it recommends the involvement of local communities in enhancement of exploitable biomass, including wild foods, fodder and fuelwood in areas outside the PAs. The restoration and management of degraded habitats outside PAs is also an important objective that could provide sufficient habitat for spatial movement of spill-over-species outside PAs and also provide biological resources to local communities, hence reducing their dependence on resources in the PAs. Restoration of such areas would involve a comprehensive approach towards protection, soil and water conservation and planting of local species, all enhancing the resilience of forests to climate change.

The potential implications of the National Wildlife Action Plan on forest ecosystems in India are potentially reduced habitat fragmentation, reduced forest degradation, increased resilience of forests through checks on introduction of exotics and monoculture plantations, through fire management, improved natural regeneration of native species, reduced unsustainable resource extraction and hence reduced pressure on forests, improved adaptive capacity of forest dependent communities and their livelihoods. It is not clear to what extent all these provisions have been implemented. If effectively implemented, these activities will enhance the resilience of forests to potential impacts.

7.4 Protected areas

Networks of ecologically protected areas, linked by large scale conservation initiatives can serve as the "natural infrastructure" essential for helping ecosystems adapt to impacts of climate change and can reduce the risk of extinction of species, even while contributing to sustainable livelihoods. As discussed earlier, natural ecosystems are threatened by many factors that reduce their resilience to climate change by disrupting species migration and altering the patterns of natural ecological processes. In such a scenario, PAs help decrease vulnerability of ecosystems by establishing and managing large scale conservation corridors for species migration and maintaining natural processes. India has an increasing network of PAs that have helped to conserve a significant part of biodiversity. As of 2003 India had 545 PAs of which 23 were more than 100,000 ha in area. Total extent of PAs in all IUCN categories was 15.6 Mha (http://earthtrends.wri.org/). Linking of PAs will contribute to enhancing adaptation by enabling migration of species due to climate change impacts.

7.5 Joint Forest Management Resolution, 1990

Conservation of forests without the involvement of local communities had not been very successful in India (Murali et al. 2002a), prompting the government to rethink its forest management strategy and involve communities in a conservation plan that would help in regeneration of degraded forests and afforestation to meet their subsistence needs (Murali et al. 2002b). The JFM program envisaged a process of management of forests by Forest Departments in partnership with the local people on the basis of mutual trust and jointly defined roles and responsibilities with respect to forest protection and development. The participating communities are granted rights to usufruct and NTFPs and a percentage share of final harvest, in exchange for their efforts to help regenerate depleted forests and wastelands.

Large JFM program covering nearly 15 Mha has not only helped in increasing tree density and canopy cover and promotion of natural regeneration through gap planting (Ravindranath et al. 2004) but also led to protection of existing forests, rehabilitation of degraded forests, establishment of forest plantations and increased moisture retention capacity of the forest soil, all of which decrease the vulnerability of forests to climate change and enhance carbon sequestration (Ravindranath et al. 2008). The JFM program has also been reported to have resulted in reduced illegal extraction of timber and fuelwood in many regions because of the protection measures put in place by the local communities. The village communities have also experienced augmented livelihoods through greater legitimate access to benefits accruing from the forest (Ravindranath et al. 2004). Importantly, through the JFM, the diversity, quality and quantity of forest products usually collected by forest dependent communities has also increased (Ravindranath et al. 2004), potentially reducing the vulnerability of their livelihoods to climate variability and change.

The legislation that can further improve the participation of the communities is the State/ Union Territory Minor Forest Produce (Ownership of Forest Dependent Community) Act, 2005, which endows the ownership rights of minor forest produce to forest dependent communities and recognizes that they be granted the right to process and trade in minor forest produce on a 'share and care basis'. Its recognition of the need for sustainable utilization and long-term conservation of minor forest produce could potentially decrease vulnerability of forests and local livelihoods to climate change. However, JFM and other participatory forestry programs have many limitations with respect to empowerment of local communities, sustainability of their participation and legal rights on the forests and the products. JFM program is on the decline and needs to be revitalized to protect forests and enhance the resilience of forests as well as the communities. Implications of this policy on forest ecosystems of India are promotion of natural regeneration of degraded forests, increased tree density and tree cover, improved supply of fuelwood and fodder, enhanced livelihood opportunities thereby reducing pressure on forests and decreasing vulnerability to climate change. Such diversified livelihood opportunities are important as the vulnerability of communities that depend on a single or few forest products is expected to be higher than communities that have access to a wide range of products, many of which respond differently to climate change (Parkins and MacKendrick 2007).

7.6 Compensatory afforestation

The Ministry of Environment and Forests has come up with a new scheme for compensatory afforestation or the *Green Credit Scheme* in case of forest land being diverted for non-forest use, where the user will identify a piece of land, develop a forest and transfer it to the forest department. Also under the Forest Conservation Act, 1980, one has

to pay for compensatory afforestation if an industrial project requires diversion of forest land. *Compensatory Afforestation Fund Management and Planning Authority* (CAMPA) was set up in 2008 with a large budget, adequate to cover 3–5 Mha under forest plantations (PIB 2008). If climate change adaptation components are incorporated, the program could enhance the resilience of forests and plantations to projected climate change.

8 Conclusion

India has very effective forest conservation legislations contributing to reduced deforestation. Further, India has been aggressively working towards increasing its forest cover and large afforestation and reforestation programs like social forestry, JFM, afforestation under the National Afforestation and Eco-development Board, the Green India Mission and CAMPA are being planned or are already being implemented. The cumulative area forested during the period 1980 to 2005, including community woodlots, farm forestry, avenue plantation and agroforestry, is about 34 million hectares at an average rate of 1.32 million hectares per year (Chaturvedi et al. 2008). Such large scale afforestation projects, though important for increasing carbon sinks and mitigating climate change, could have adverse effects if carried out without consideration of potential impacts of climate change and adaptation strategies and practices. The afforestation programs were predominated by monocultures of exotic species which are more vulnerable to pest attack and fires than mixed forests having native species. This study reiterates the opinion put forth by Buck et al. (2009) that actions need to be taken to maintain and increase diversity of species and genes in forests which can help in mitigation of climate change risks. These largely exotic species also do not meet the diverse needs of local communities, to reduce their vulnerability to climate variability and droughts.

Moreover, the lack of community involvement or partial involvement and inadequate empowerment are unlikely to sustain community participation. Such inadequacies of forest policies and programs only serve to alienate communities, fail to increase their adaptive capacity and make forests resilient to the impacts of climate change. In fact, JFM program instead of being strengthened, has nearly been abandoned replaced by new programs, which are less participatory.

In addition to this, policies and programs that pave the way for forest fragmentation, forest degradation, dominant use of monoculture species and unsustainable extraction of timber, fuelwood and NTFP also lead to loss of biodiversity, hinder species migration, prevent forest regeneration and enhance vulnerability to fire and pest attacks. Such policies and programs may also enhance the vulnerability of the forest dependent communities and their livelihoods to potential impacts of climate change. A range of management actions that employ landscape strategies to conserve biodiversity (Brockerhoff et al. 2008) need to be taken to help biodiversity adapt to climate change, enable natural migration of species to more suitable climes, reduce the anticipated effects of increased fire and pest attacks.

Thus there is a need to evaluate all the ongoing and proposed afforestation, Protected Area, wildlife conservation, forest conservation and development programs in the context of the potential impacts of climate change and devise appropriate adaptation and participatory programs to reduce vulnerability of forests to climate change impacts. There is a need for research for an integrated assessment of impacts, vulnerability and adaptation at regional level.

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References

Alencar AA, Solo'rzano LA, Nepstad D (2004) Modeling forest understory fires in an eastern Amazonian landscape. Ecol Appl 14:139–149

ALGAS (1999) Asia least cost greenhouse gas abatement strategy, Asian Development Bank, Global Environment facility, United Nations Environment Programme. Asian Development Bank, Manila, pp 1–260

Bahuguna VK, Upadhyay A (2002) Forest fires in India: policy initiatives for community participation. Int For Rev 4(2):122–127

Beeson CFC, Chatterjee NC (1939) Possibilities of control of Lantana (Lantana aculeata L.) by indigenous insect pests. Indian For Rec (New Series) 6:41–84

Betts RA, Malhi Y, Roberts JT (2008) The future of the Amazon: new perspectives from climate, ecosystem and social sciences. Phil Trans R Soc Lond B 363(1498):1729–1735

Brockerhoff EG, Shaw WB, Hock B, Kimberley M, Paul T, Quinn J, Pawson S (2008) Re-examination of recent loss of indigenous cover in New Zealand and the relative contributions of different land uses. N Z J Ecol 32(1):115–126

Broersma K, Krzic M, Newman RF, Bomke AA (2000), Effects of grazing on soil compaction and water infiltration in forest plantations in the interior of British Columbia, From Science to Management and Back: a Science Forum for Southern Interior Ecosystems of British Columbia. Kamloops, BC: Southern Interior Forest Extension and Research Partnership: 89–92

Buck A, Katila P, Seppälä R (2009) Main conclusions and the way forward. In: Buck A, Katila P, Seppälä R (eds) Adaptation of forests and people to climate change—a global assessment report. Prepared by the Global Forest Expert Panel on Adaptation of Forests to Climate Change. IUFRO World Ser 22:1–224, Helsinki

Carson B (1992) The land, the farmer and the future—a soil fertility management strategy for Nepal. ICIMOD, Occasional Paper No 21. Kathmandu, Nepal: International Centre for Integrated Mountain Development

Champion HG, Seth SK (1968) A revised survey of the forest types of India. Govt of India Publication, New Delhi

Chaturvedi Rajiv K, Ranjith Gopalakrishnan, Mathangi Jayaraman, Bala G, Joshi NV, Sukumar R, Ravindranath NH (2010). Impact of climate Change on Indian forests: A dynamic vegetation modeling approach. In this issue

Chaturvedi RK, Tiwari R, Ravindranath NH (2008) Climate change and forests in India. Int For Rev 10 (2):256–268

Collingham YC, Huntley B (2000) Impacts of habitat fragmentation and patch size upon migration rates. Ecol Appl 10(1):131–144

Covington WW (2003) Testimony, oversight hearing on the crisis on the national forests: containing the threat of wildland fire on the environment and communities. Committee on Resources, Subcommittee on Forests and Forest Health, U.S. House of Representatives, March 7, Washington, DC

Cramer JM, Mesquita RCG, Bruce WG (2007) Forest fragmentation differentially affects seed dispersal of large and small-seeded tropical trees. Biol Conserv 137:415–423

Cushman SA (2006) Effects of habitat loss and fragmentation on Amphibians: a review and prospectus. Biol Conserv 128:231–240

FSI (1987) The state of forest report, Forest Survey of India, Ministry of Environment and Forests, Government of India

FSI (1995) The state of forest report, Forest Survey of India, Ministry of Environment and Forests, Government of India

FSI (1996) Fuel wood, timber and fodder from forest of India, Forest Survey of India, Ministry of Environment and Forests, Government of India

FSI (1997) The state of forest report, Forest Survey of India, Ministry of Environment and Forests, Government of India

FSI (1999) The state of forest report, Forest Survey of India, Ministry of Environment and Forests, Government of India

FSI (2001) The state of forest report, Forest Survey of India, Ministry of Environment and Forests, Government of India

FSI (2003) The state of forest report, Forest Survey of India, Ministry of Environment and Forests, Government of India

FSI (2005) The state of forest report, Forest Survey of India, Ministry of Environment and Forests, Government of India

FSI (2009) The state of forest report, Forest Survey of India, Ministry of Environment and Forests, Government of India

Gascon C, Williamson BG, da Fonseca GAB (2000) Receding forest edges and vanishing reserves. Science 288:1356–1358

Government of India (1979) Report of the working group on energy policy (Planning Commission). Govt. of India, New Delhi

Government of India (2003) 17th Indian livestock census all India summary report, Ministry of Agriculture, Government of India, New Delhi

Haripriya GS (2003) Carbon budget of the Indian forest ecosystem. Clim Change 56:291–319

Hiremath A (2007) Forest fires in India: extent, justification and policy, ATREE, India, Forest Fires in India. Workshop proceedings, Pillar Human Resource Development Centre, Madurai, India

Huhta E, Aho T, Jantti A, Soursa P, Kuitunen M, Nikula A, Hakkarainen H (2004) Forest fragmentation increases nest predation in the Eurasian treecreeper. Conserv Biol 18(1):148–155

IPCC (2000) Land use, land-use change, and forestry. Special report of the intergovernmental panel on climate change. Cambridge University Press, UK

IPCC (2007) Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Kaimowitz D, Angelsen A (1998) Economic models of tropical deforestation—a review. Center for International Forestry Research Bogor, Indonesia

Kishwan J, Pandey R, Dadhwal VK (2009) India's forest and tree cover: contribution as a carbon sink, Technical Paper. Indian Council of Forestry Research and Education, Dehradun

Kumar R (2008) Climate change and India: impacts, policy responses and a framework for EU-India cooperation, policy Department Economic and Scientific Policy, Available via http://www.europarl.europa.eu/activities/committees/studies/download.do?file=19208. Cited on 28th Jan 2010

Manhas RK, Negi JDS, Kumar R, Chauhan PS (2006) Temporal assessment of growing stock, biomass and carbon stock of Indian forests. Clim Change 74:191–221

MoEF (2003) State of the Environment Report 2003, Government of India

MoEF (2004) Ministry of environment and forests, India's Initial National Communication to UNFCCC (NATCOM), New Delhi

MoEF (2006) Report of the National Forest Commission, Government of India

MoEF (2010) National Wildlife Action Plan, 2002–2016, Availbale via http://projecttiger.nic.in/actionplan.asp. Cited on 26th August, 2009

Mukhopadhyay D (2009) Impact of climate change on forest ecosystem and forest fire in India. Climate Change: Global Risks, Challenges and Decisions, IOP Conf. Series: Earth and Environmental. Science 6:382027

Murali KS, Murthy IK, Ravindranath NH (2002a) Joint forest management in India and its ecological impacts. Environ Manag Health 13(5):512–528

Murali KS, Rao RJ, Ravindranath NH (2002b) Evaluation studies of joint forest management in India: a review of analytical processes. Int J Environ Sustain Dev 1(2):184–199

Murcia C (1995) Edge effects in fragmented forests: implications for conservation. Trends Ecol Evol 10:58–62

Murthy IK, Murali KS, Hegde GT, Bhat PR, Ravindranath NH (2002) A comparative analysis of regeneration in natural forests and joint forest management plantations in Uttara Kannada district, Western Ghats. Curr Sci 83(11):1358–1364

Nabuurs GJ, Masera O, Andrasko K, Benitez-Ponce P, Boer R, Dutschke M, Elsiddig E, Ford-Robertson J, Frumhoff P, Karjalainen T, Krankina O, Kurz WA, Matsumoto M, Oyhantcabal W, Ravindranath NH, Sanz Sanchez MJ, Zhang X (2007) Forestry. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds) Climate change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Summary for Policymakers and Technical Summary. Cambridge University Press, Cambridge, pp 67–71

NATCOM (2004) India's first national communication to UNFCCC. Ministry of Environment and Forests, Government of India, New Delhi

Osman-Elasha B, Parrotta J, Adger N, Brockhaus M, Colfer CJP, Sohngen B, Dafalla T, Joyce LA., Nkem J, Robledo C (2009) Future socio-economic impacts and vulnerabilities. In: Buck A, Katila P, Seppälä R (eds) Adaptation of forests and people to climate change—a Global Assessment Report. Prepared by the Global Forest Expert Panel on Adaptation of Forests to Climate Change. IUFRO World Ser 22:1–224

Parkins JR, MacKendrick NA (2007) Assessing community vulnerability: a study of the mountain pine beetle outbreak in British Columbia, Canada. Glob Environ Change 17(3):460–471

Paroda RS, Kumar P (2000) Food production and demand in South Asia. Agric Econ Res Rev 13(1):1–24

Patro SN, Panda GK (1994) Eastern Ghat in Orissa: environment. Resources and Development, Orissa Environment Society

PIB (2008) Increasing forest cover through CAMPA, Thursday, May 22, Available via http://pib.nic.in/release/release.asp?relid=39081, cited on 23rd February, 2010

Purshothaman S, Viswanath S, Swaminathan LP (2005) Managing our grazing lands: Need for a rational grazing policy. Available via http://archived.atree.org/Grazing_policy_05.pdf, cited on 15th December, 2009

Ravindranth NH (2007) Mitigation and adaptation synergy in the forest sector. Mitig Adapt Strateg Glob Change 12:843–853

Ravindranath NH, Hall DO (1995) Biomass energy and environment: a developing country perspective from India. Oxford, New York

Ravindranath NH, Somashekhar BS, Gadgil M (1997) Carbon flows in Indian forests. Clim Change 35:297–320

Ravindranath NH, Joshi NV, Sukumar R, Murthy IK, Suresh HS (2003) Vulnerability and adaptation to climate change in the forest sector. In: Shukla PR, Sharma SK, Ravindranath NH, Garg A, Bhattacharya S (eds) Climate change and India-vulnerability assessment and adaptation. Universities Press (India) Private Limited, Hyderabad, pp 227–265

Ravindranath NH, Sudha P, Malhotra KC, Palit S (2004) Sustaining joint forest management in India. In: Ravindranath NH, Sudha P (eds) Joint forest management in India: spread, performance and impact. Universities Press (India) Private limited, Hyderabad

Ravindranath NH, Joshi NV, Sukumar R, Saxena A (2006) Impact of climate change on forests in India. Curr Sci 90(3):354–361

Ravindranath NH, Chaturvedi RK, Murthy IK (2008) Forest conservation, afforestation and reforestation in India: implications for forest carbon stocks. Curr Sci 95(2):216–222

Roberts G, Parrotta J, Anita Wreford Buck A, Katila P (2009) Current adaptation measures and policies. In: Seppälä R (eds) Adaptation of forests and people to climate change—a global assessment report. Prepared by the Global Forest Expert Panel on Adaptation of Forests to Climate Change. IUFRO World Ser 22:1–224, Helsinki

Scholze M, Knorr W, Arnell NW, Prentice C (2006) A climate-change risk analysis for world ecosystems. Proc Natl Acad Sci 103:13116–13120

Sharma AB (2008) Invasive species are threat to forest cover: ICFRE. available via http://www.financialexpress.com/news/invasive-species-are-threat-to-forest-cover-icfre/282361/

Silori CS, Mishra BK (2001) Assessment of livestock grazing pressure in and around the elephant corridors in Mudumalai Wildlife Sanctuary, south India". Biodivers Conserv 10(12):2181–2195

Singh SP (2001) Biological control of invasive weeds in India. In: Sankaran KV et al (ed) Proceedings of workshop on alien weeds in moist tropical zones: banes and benefits. India, KFRI and UK, pp 11–19

Singh P (2002) Agriculture policy: Vision 2020. Background paper for Committee on Vision 2020 for India, Planning Commission, New Delhi

Singh PP (2008) Exploring biodiversity and climate change benefits of community-based forest management. Glob Environ Change 18:468–478

Singh JS, Singh SP (1992) Forests of Himalaya. Gyanodaya Prakashan, Nainital, pp 1–294

Society of American Foresters (2005) Use of silviculture to achieve and maintain forest health on public lands: A Position of the Society of American Foresters. Available via http://www.eforester.org/fp/documents/silviculture.pdf. Cited on 28th Jan 2010

Somashekhar RK, Nagaraja BC, Urs K (2007) Monitoring of forest fires in Bhadra wildlife sanctuary. J Indian Soc Remote Sens 36:99–104

Spittlehouse DL, Stewart RB (2003) Adaptation to climate change in forest management. BC Journal of Ecosystems and Management 4(1):1–11

Sudha P, Ravindranath NH (1999) Land availability and biomass production potential in India. Biomass Bioenergy 16:207–221

Thompson I, Mackey B, McNulty S, Mosseler A (2009) Forest resilience, biodiversity, and climate change: a synthesis of the biodiversity/resilience/stability relationship in forest ecosystems. Secretariat of the Convention on Biological Diversity, Montreal, Technical Series no. 43:1–67

World Bank (2006) India: unlocking opportunities for forest-dependent people in India. Report Number 34481-IN. World Bank, Washington, D.C., USA. Available via http://siteresources.worldbank.org/INDIAEXTN/Resources/Reports-Publications/366387-1143196617295/Forestry_Report_volume_I.pdf. Cited on 28th Jan 2010