Climate change and forests in India

R.K. CHATURVEDI, R. TIWARI and N.H. RAVINDRANATH

Centre for Ecological Science, Indian Institute of Science, Bangalore 560012, India

Email: ravi@ces.iisc.ernet.in

SUMMARY

Forests play a critical role in addressing climate change concerns in the broader context of global change and sustainable development Forests are linked to climate change in three ways i) Forests are a source of greenhouse gas (GHG) emissions; ii) Forests offer mitigation opportunities to stabilise GHG concentrations; iii) Forests are impacted by climate change This paper reviews studies related to climate change and forests in India: first, the studies estimating carbon inventory for the Indian land use change and forestry sector (LUCF), then the different models and mitigation potential estimates for the LUCF sector in India Finally it reviews the studies on the impact of climate change on forest ecosystems in India, identifying the implications for net primary productivity and bio-diversity. The paper highlights data modelling and research gaps relevant to the GHG inventory, mitigation potential and vulnerability and impact assessments for the forest sector in India

Keywords: climate change, forestry, inventory, mitigation potential, impact assessment, India

Changement de climat et forêts en Inde

R.K. CHATURVEDI, R. TIWARI ET N.H. RAVINDRANATH

Les forêts jouent un rôle critique dans la recherche de solutions aux problèmes du changement climatique dans le contexte plus large du changement à l'échelle globale et du développement durable Les forêts sont liées au changement climatique de trois manières: 1) les forêts sont une source d'émission de gas serre (GHG), 2) les forêts offrent des opportunités d'atténuation pour stabiliser les concentrations de GHG, 3) les forêts connaissent l'impact du changement climatique. Cet article examine les études ayant trait au changement climatique et aux forêts de l'Inde. Il commence par les études estimant l'inventaire carbone pour le changement d'usage du terrain en Inde et pour le secteur de la foresterie (LUCF), pour se porter ensuite sur les différents modèles et les estimations de potentiel d'atténuation pour le secteur LUCF en Inde. Il examine finalement les études sur l'impact du changement climatique sur les ecosystèmes forestiers en Inde, en identifiant les implications pour la productivité primaire nette et la biodiversité. Cet article souligne les données, la modélisation et les lacunes dans la recherche ayant trait à l'inventaire de GHG, le potentiel d'atténuation et les évaluations d'impact et de vulnérabilité du secteur forestier en Inde.

El cambio climático y los bosques de la India

R.K. CHATURVEDI, R. TIWARI Y N.H. RAVINDRANATH

Dentro del contexto de cambio global y desarrollo sostenible, los bosques desempeñan un papel fundamental en la lucha para combatir los efectos del cambio climático Los bosques están relacionados con el cambio climático de tres formas: i) Los bosques son una fuente de emisiones de gases invernaderos; ii) Los bosques ofrecen oportunidades para mitigar el cambio climático mediante la estabilización de las concentraciones de estos gases; iii) Los bosques sufren el impacto del cambio climático Este artículo analiza los estudios relacionados con el cambio climático y los bosques en la India: en primer lugar, resume los estudios que calculan el inventario de carbono del sector del cambio del uso de la tierra y de manejo forestal (LUCF), y luego examina los modelos diferentes y cálculos de mitigación potencial en el sector de LUCF de la India Para concluir, el artículo analiza los estudios sobre el impacto del cambio climático en los ecosistemas forestales de la India, e identifica las implicaciones para la productividad primaria neta y la biodiversidad Se señalan áreas en las que los datos la modelación y la investigación existentes son insuficientes para el inventario de gases invernaderos, los esfuerzos de mitigación y las evaluaciones de vulnerabilidad e impacto en el sector forestal de la India

INTRODUCTION

The phenomenon of global warming is largely attributable to large-scale anthropogenic emission of greenhouse gases into the atmosphere especially since the industrial revolution, which began in the 19th century. From 1850 to 1998, approximately 405±60 GtC (gigatonnes of carbon) were emitted as carbon dioxide (CO_2) into the atmosphere from fossil fuel burning and cement production About 33 percent was emitted as a result of land use change, predominantly from tropical deforestation (IPCC 2000). Forestry or forest management is broadly included under land use, land use change and forestry (LULUCF) sector in the United Nations Framework Convention on Climate Change (UNFCCC) It includes all activities relevant to forests, pasture and rangelands, croplands and wetlands After the fossil fuel sector, the focus of attention of the Climate Convention and scientific literature is largely on the forestry sector, for the following reasons:

- Since 1750 it is estimated that about one-third of anthropogenic CO_2 emissions have come from land use change, predominantly from tropical deforestation (IPCC 2007a);
- Forestry provides a large mitigation potential (Nabuurs *et al* 2007);
- Forestry provides low-cost mitigation opportunities in developing countries (Sathaye and Ravindranath 1998);
- Mitigation activities have the potential to attract industrialised countries to invest in developing countries, transfer technology and upgrade institutional capacity for forest conservation, reforestation, bioenergy and other forestry-related activities

A few carbon inventory estimates are available for Indian forests (Ravindranath *et al* 1997, Chhabra and Dadhwal 2004, ADB 1999, Haripriya 2003, MoEF 2004); mitigation potential estimates too are available for Indian forests (Ravindranath *et al.* 2007a, Ravindranath *et al.* 2007b, Sudha *et al* 2007, Murthy *et al* 2006, Ravindranath 2001, Sathaye *et al* 2006, and Ravindranath and Somashekar 1995) However, impact and vulnerability studies are limited (Ravindranath *et al* 1996, Ravindranath *et al* 1998, Ravindranath *et al* 2006). Pandey (2002) reviewed the studies on causes and consequences of global climate change and its impact on nature and society Ravindranath *et al* (in press) recently assessed the past and projected afforestation and reforestation activities in India and their implications for forest carbon stocks and inventory Given the importance of assessment of forest carbon inventory, the mitigation potential and likely impacts of climate change, a comprehensive review of the forestry studies related to climate change is needed, and this paper aims to fulfil that requirement In this review the following issues are addressed with reference to climate change, forests and India, where the relevant published literature is reviewed

- Area under forests, changes in area under forests;
- Forest conservation in India and afforestation and reforestation;
- Greenhouse gas and CO_2 emissions inventory for the Indian forest sector;
- Mitigation potential of forest sector and cost-effectiveness;
- Impact of climate change on forest ecosystems and biodiversity and adaptation; and
- Research priorities on greenhouse gas inventory, mitigation potential assessment, climate impacts and adaptation issues, relevant to climate change and forests, as well as other natural ecosystems

STATE OF FORESTS IN INDIA

Area under forests and changes in India

Forest is generally described as a tract of land having a plant community largely consisting of trees and other woody vegetation However, there is no universally accepted technical definition of forest The Food and Agriculture Organization (FAO) defines forest as land having a tree canopy cover of more than 10 percent over an area of more than 0.5 ha with forest as the principal land use. In the past, the meaning of area under forest has been highly contested However, with access to satellite imagery data from FSI (Forest Survey of India), improved estimates of forest area are periodically available.

According to the FSI, "all lands, more than one hectare in area, with a tree canopy density of more than 10 percent is defined as forest" The total forest cover of India according to the latest *State of Forest Report* 2003 is 67 83 million hectares (ha), and this constitutes 20 64 percent of the geographic area Dense forests dominate by accounting for about half of the total forest cover. The tree cover (which includes forests of less than one hectare) is 9.99 million ha (3.04 percent). The total area under forest and tree cover is 77 82 million ha, which is 23 68 percent of the geographic area (FSI 2003).

FSI has been periodically estimating the forest cover in India since 1987 using remote sensing techniques. The forest cover reported for the year 1987 was 64.08 million ha compared to 67.83 million ha for the year 2003 (FSI 1987, FSI 2003). This indicates an increase in forest cover of 3 75 million ha over a period of 15 years It can be observed from *Figure 1* that the forest cover in India has nearly stabilised and further it has been increasing marginally over the years (http://envfor nic in). In 2001 and 2003 assessments, the FSI has included the tree cover, in addition to forest cover The area under tree cover reported is also marginally increasing (*Figure 1*)

Afforestation and reforestation programmes and area

India has been implementing an aggressive afforestation programme since 1980 under the social forestry programme.

FIGURE 1 *Forest cover trends in India*

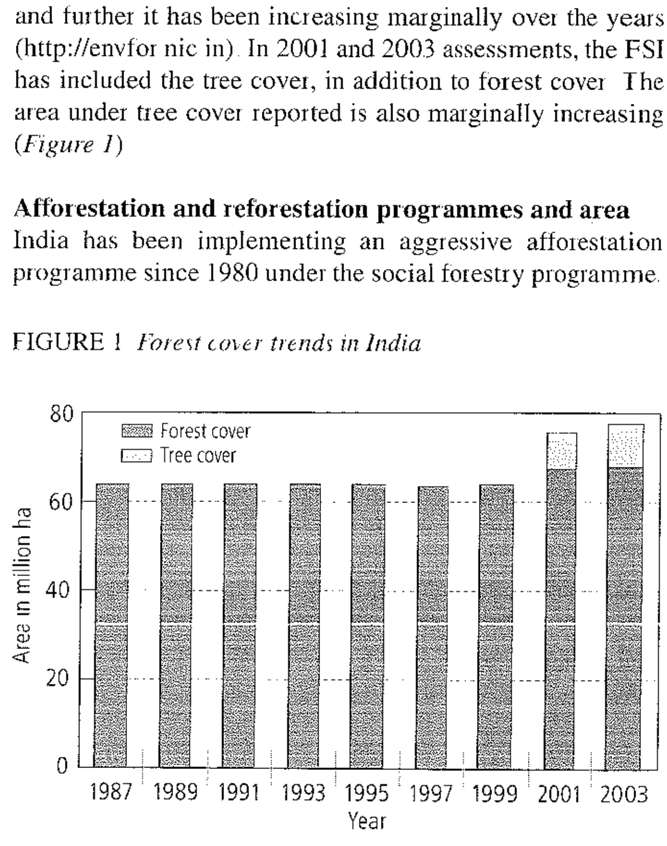
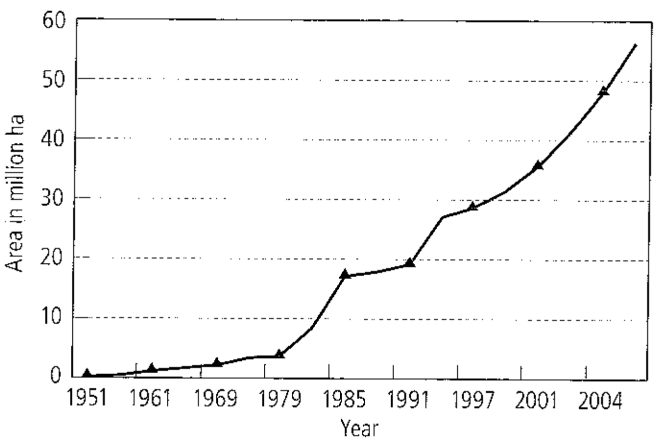


Figure 2 presents the progress of afforestation in India for the period 1951 to 2005 (http://envfor.nic.in). The cumulative area afforested during the period 1980 to 2005 is about 34 million ha at an average annual rate of 1.32 million ha. This includes community woodlots, farm forestry, avenue plantations and agro-forestry. Afforestation and reforestation in India is being carried out under various programmes, namely:

- Social forestry initiated in the early 1980s;
- Joint forest management (JFM) Programme initiated in 1990;
- Afforestation under National Afforestation and Eco-Development Board (NAEB); programmes since 1992;
- Private farmer and industry-initiated plantation forestry or farm forestry.

FIGURE 2 *Cumulative area afforested from 1951 to 2005*



Source: Ravindranath *et al* 2007

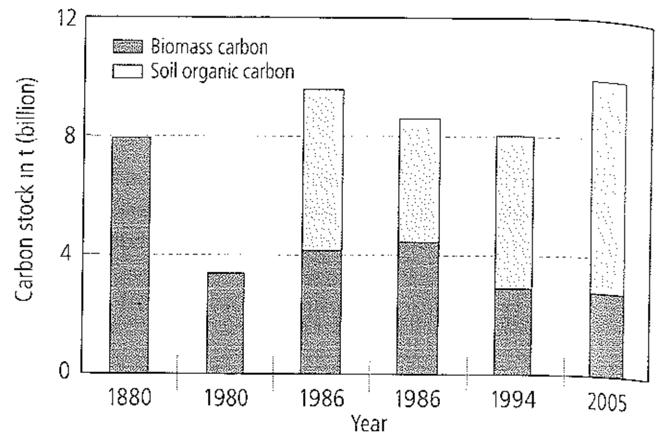
GREENHOUSE GAS EMISSIONS FROM FOREST SECTOR

Very few studies have estimated the GHG emissions or changes in carbon stocks in Indian forests (Richards and Flint 1994, Ravindranath *et al.* (1997), Haripriya (2003), ADB 1999, MOEF 2004). Estimates from these studies are not comparable as they vary in methodology, carbon pools included, sources of data, year of inventory and assumptions.

Carbon inventory in Indian forests

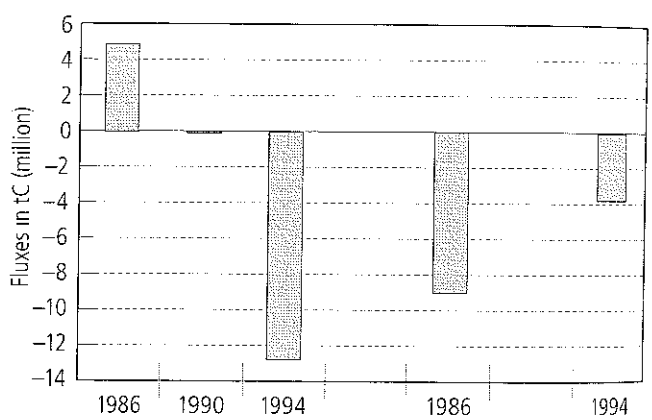
Richards and Flint (1994) pioneered the estimation of carbon stocks and changes over the course of a century (1880–1980) for south and southeast Asian forests, using data obtained at the local and regional level for each country from official agricultural and economic statistics, historical, geographic and demographic texts, reports, articles and other available sources. Biomass stock for Indian forests was estimated to be 7 940 mt (million metric tonnes) for the year 1880, which is estimated to have decreased to 3 426 mt in 1980. *Figures 3* and *4* depict the stocks and fluxes of carbon from Indian forests as estimated by different studies.

FIGURE 3 *Estimates of carbon stocks in Indian forests*



Sources: *For 1880*: Richard and Flint 1994. *For 1980*: column 2: Richard and Flint 1994. *For 1986*: column 3: Ravindranath et al. 1997, column 4: Chhabra and Dadhwal 2004. *For 1994*: Haripriya 2003. *For 2005*: FAO 2005

FIGURE 4 *Estimates of carbon fluxes in mtC (million tonnes of carbon) from Indian forests*



Sources: *For 1986*: column 1: Ravindranath et al. 1997, column 5: Chhabra and Dadhwal 2004. *For 1990*: ALGAS (ADB) 1999. *For 1994*: column 3: Haripriya 2003, column 7: NATCOM 2004

Ravindranath *et al* (1997) using the COPATH model computed the total carbon stock and flux in Indian forests for 1986. They estimated total carbon stored in Indian forests at 9 585 mtC. Gross estimates of emission from deforestation and committed emissions from deforestation in the preceding years were calculated using data on deforestation and biomass extraction statistics. Gross emissions were computed to be 64 mtC. Carbon sequestration from the area brought under afforestation and reforestation and the existing forest area under forest succession were estimated by employing data on net primary productivity (NPP), to calculate the annual carbon accumulation in the given year. Thus gross carbon uptake was estimated to be 68.8 mtC. The study concluded that carbon uptake in Indian forests nearly offsets the gross carbon emissions, leading to no net emissions of carbon from the Indian forest sector.

Haripriya (2003) estimated the carbon budget of Indian forests employing a simulation model The model included forest product pool in addition to live biomass, dead biomass and soil carbon All these pools were assigned a carbon retention curve including the forest product pool Carbon stored in forest ecosystems in India was calculated by summing over all the area and net carbon remaining in each carbon pool. A stock of 2 933 mtC was estimated for biomass pool, 5 109 mtC for forest soils and 3 5 mtC in forest products Total carbon stock was estimated to be 8 206 mtC Results of the carbon budget model indicated that the Indian forest sector acted as a net source of 12 8 mtC during the year 1993–1994

Chhabra *et al.* (2004) estimated the cumulative net carbon flux from Indian forests between the period 1880–1996 due to land use change, using a book-keeping approach. The mean annual net carbon flux was estimated to be a net emission of 9.0 mtC/yr

Estimates using IPCC methods

The Asian least-cost greenhouse abatement strategy study(ADB 1999) estimated the inventory using the revised 1996 guidelines of the Intergovernmental Panel on Climate Change (IPCC) The net flux of carbon in biomass was estimated by first calculating the net annual increment in woody biomass stock followed by calculation of the total release of carbon from commercial and traditional extraction of biomass from woody forest biomass Using the IPCC methodology, the net CO_2 emissions from the land use change and forestry sector was estimated to be 0.4 mt for the year 1990 (*see Table 1*) Thus, the study concludes that in India, carbon emissions from land use change and forest sector are nearly offset by carbon uptake in forests, regenerating forests and plantations.

The latest estimate of the greenhouse gas inventory was made by the Ministry of Environment and Forests as part of India's initial national communication to the UNFCCC (MOEF 2004). The CO_2 emissions were estimated using the 1996 revised IPCC guidelines Net uptake from woody biomass stock was estimated to be 14 2 mt of CO_2. The CO_2 released from *on-site* and *off-site* burning during conversion of forestland to grassland was estimated to be 17 mt of CO_2. Total carbon uptake in managed lands that were abandoned and subjected to regeneration was estimated to be 9 mt of CO_2. Emissions from agriculturally impacted soils were estimated to be 19 78 mt of CO_2 Thus, according to the latest inventory for the base year 1994, India's net emissions from land use change and forestry sector is estimated to be 14.2 mt of CO_2 or 3 9 mtC.

Uncertainty of estimates

The uncertainty in carbon stock and changes in the land use sector has been estimated to be up to 70 percent by the latest national communication reports (http://unfccc int/national_reports/items/1408 php) As a consequence, assessing the reliability and accuracy of the estimated carbon stocks and changes becomes a critical requirement GPG (IPCC 2003) states that "the definition of good practice requires that inventories should be accurate in the sense that they are systematically neither overestimated nor underestimated as far as can be judged, and uncertainties are reduced as far as practicable". It further states that "there is no predetermined level of precision; uncertainty is assessed to help prioritise efforts to improve the accuracy of inventories in future and guide decisions on methodological choices" Given the complexity, lack of data and methodological limitations, uncertainty of GHG inventory estimates is likely to be high Most of the studies except India's national communication (NATCOM) to UNFCCC (MoEF 2004), do not perform uncertainty analysis of their estimates

NATCOM has largely used Tier 2 approach for GHG inventory estimation for the LUCF sector, which is based on input data estimates for activity data as well as emission/sequestration factors, derived from national sources rather than IPCC default values Data from national sources were compiled to reduce the uncertainty, based on field ecological studies, to measure parameters such as soil organic carbon density in different land use systems, growing stock, biomass growth rate in abandoned regenerating lands, etc. Uncertainty was assessed using the range and standard deviation for different parameters It was estimated to be high for several parameters such as annual growth rate in biomass, soil carbon density and growing stock (Sudha *et al* 2003)

TABLE 1 *GHG emissions (for 1994) from land use change and forestry sector (gigatonnes)*

Greenhouse gas source and sink categories (gigagrams per year)	CO_2 emissions	CO_2 removals	CH_4 emissions	N_2O emissions	CO_2 eq emissions*
Changes in forest and other woody biomass stock		14 252			(14 252)
Forest and grassland conversion	17 987				17 987
Trace gases from biomass burning			6.5	0.04	150
Uptake from abandonment of managed lands		9 281			(9 281)
Emissions and removals from soils	19 688				19 688
Land use, land use change and forestry	37 675	23 533	6.5	0.04	14 292

*Converted by using global warming potential (GWP) indexed multipliers of 21 and 310 for converting CH_4 and N_2O respectively to CO_2 equivalents; values in parenthesis are negative values

Source: MoEF (2004)

Research gaps and needs

Estimation of CO_2 emissions or stocks made for Indian forest sector are based on different methods and consideration of different pools, for different years and different sources of data Thus the estimates are not comparable. The estimates of CO_2 emissions or carbon stocks are limited by lack of availability of "activity data" (i e., data on forest area changes or transition from one land use to another) and "emission or sequestration factors" (i.e , data on stocks and changes in different carbon pools over time for different forest types or agro-ecological zones [AEZ]). In India no periodic forest inventory is conducted, leading to a lack of two point measurement of carbon stocks; and because of lack of emission and sequestration factors for different forest and plantation types, uncertainty of the estimates of CO_2 emission or removals in LUCF sector is high There is a need to generate forest and plantation specific data co-efficients, models and emission and sequestration factors, to meet the obligation to periodically report the GHG inventory to the UNFCCC (IPCC 2000).

MITIGATION OPTIONS AND POTENTIAL IN FOREST SECTOR

According to the working group III report of the fourth assessment report (IPCC 2007b), the options available to reduce emissions by sources and/or increase removals by sinks in the forest sector are grouped into four general categories.

- Maintaining or increasing the forest area through the avoidance of deforestation and degradation and through afforestation/reforestation;
- Maintaining or increasing the stand-level carbon density (tonnes of C per ha) through the avoidance of forest degradation and through planting, site preparation, tree improvement, fertilisation, uneven-aged stand management, or other silvicultural techniques that contribute to sustainable forest management;
- Maintaining or increasing the landscape-level carbon density using forest conservation, longer forest rotations, fuel management, protection against fire and insects;
- Increasing carbon stock in wood products and enhancing product substitution using forest-derived biomass to substitute products with high fossil fuel requirements and increasing the use of biomass-derived energy as a substitute for fossil fuels.

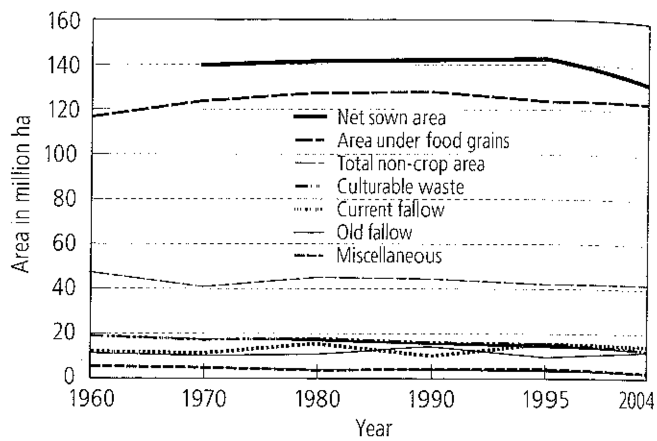
These activities are broadly termed as mitigation activities, and it is interesting to assess what proportion of emissions may be reduced or how much additional quantity of carbon may be sequestered within a given project boundary, a region or at the global scale

However, estimates for the mitigation potential of avoided deforestation are not available for Indian forests Most of studies reviewed in this paper make estimates of the mitigation potential of afforestation & reforestation (A&R) and forest management activities.

Land availability for mitigation activities

The major land use systems in India include cropland fallow land, forestland, grassland and wasteland (*Figure 5*). The wastelands include degraded grasslands, forests and several other categories Wastelands in India are classified into 28 categories by the National Remote Sensing Agency (NRSA 2005). The Planning Commission (1992) reported the area available for biomass production to be 130 million ha Different estimates range from 41 to 66 million ha (MoA 1992, Sudha and Ravindranath 1999, Ravindranath *et al* 2001, NRSA 1995, NRSA 2005) (*Table 2*)

FIGURE 5 *Trends in degraded land availability in India*



One of the most recent estimates was made by Ravindranath *et al* (2007b). This is based on the wasteland data as provided by NRSA. Among 28 categories provided by NRSA (2005), eight were excluded (e g , barren rocky and saline soils) as they were not suitable for forestry activities and some of the remaining categories were merged The resulting nine land categories totalling 37 9 million ha were considered as suitable for A&R activities, which include land with scrub (16 2 million ha), degraded forest scrub-dominated (12 2 million ha), and land without scrub (3 9 million ha).

Models used for mitigation assessments

A number of models are available for the assessment of the mitigation potential, of land use change and forestry sector (Sathaye and Meyers 1995, Sathaye *et al* 2005, Schelhas *et al* 2004, Edmonds and Reilly 1985, Darius *et al* 1999, Plantinga *et al* 1999) However, COMAP (comprehensive mitigation assessment process) and GCOMAP generalised comprehensive mitigation assessment process) are so far the only models that have been employed to estimate the mitigation potential in India.

Mitigation potential estimates

The mitigation potential estimate depends on mitigation activity (forest conservation afforestation and agro-forestry), species (mono-culture, mixed species, short- and long- rotation), biomass growth rates and area In India

TABLE 2 *Potential land available for biomass production for energy*

Study/source	Land categories	Land available in million ha	Total area in million ha
Planning Commission (1992)	Degraded forest	36.00	130.00
	Degraded non-forest	94.00	
Chambers *et al.* (1989)	Cultivated land	13.00	84.00
	Strips and boundaries	2.00	
	Uncultivated, degraded land	33.00	
	Degraded forest land	36.00	
Kapoor (1992)	Agricultural land	45.00	106.00
	Forest land	28.00	
	Pasture land	7.00	
	Fallow land (long and short)	25.00	
	Urban land	1.00	
Ministry of Agriculture (1992)	Forest land with <10% tree crown cover	11.00	66.00
	Grazing land	12.00	
	Tree groves	3.00	
	Culturable land	15.00	
	Old fallow	11.00	
	Current fallow	14.00	
Sudha and Ravindranath (1999)	Cultivable land under agro-ecological zones	26.10	42.60
	Land not suitable for cultivation	13.60	
	Pasture land	2.90	
Ravindranath *et al.* (2001)	Short rotation (SR)	38.20	63.20
	Long rotation (LR)	14.00	
	Forest regeneration	11.00	
NRSA (1995)	Forest degraded land	16.27	65.45
	Wasteland	38.11	
	Other category	11.07	
NRSA* (2005)	-	-	41.00

*NRSA, National Remote Sensing Agency. Hyderabad, India

attempts have been made to estimate the mitigation potential at all the three levels (i.e., national, regional as well as project scales).

Mitigation potential estimates at national level: The first comprehensive mitigation potential assessment at national level was made by Ravindranath and Somashekar (1995) using the COMAP model. The annual mitigation potential was shown to be in the range of 23 to 175 mtC by the year 2050, requiring an annual investment of US$2.1 billion at 1994 prices over a 6-year period (US$1= INR 31: 1994 value).

Comparison of mitigation potential in developing countries by Sathaye and Ravindranath (1998) for 13 developing countries gave an estimate of 32 gtC (gigatonnes of carbon). The technical potential is estimated to be highest for China (9.7 gtC) followed by India (8.7 GtC). These estimates show that IPCC third assessment estimates were conservative and the actual mitigation potential of LUCF sector activities is much higher than the known global level estimates given in IPCC reports (Ravindranath and Sathaye 1998). Further, the study suggests that India has a large mitigation potential among the developing countries, second only to China.

Ravindranath *et al.* (2001) developed and analysed a sustainable forestry scenario aimed at meeting the projected biomass demands, halting deforestation and regenerating degraded forests for estimating the additional mitigation potential and cost-effectiveness for India. Similarly, the mitigation potential of a commercial forestry scenario aimed at meeting the biomass demands from forestry activities on private land was assessed. The study reported that the sustainable forestry scenario could lead to an additional carbon (C) stock of 237 mtC during 2000 to 2012, while the commercial forestry scenario, apart from meeting all the incremental biomass demands, could potentially lead to an additional carbon stock of 78 mtC during 2000 to 2012.

A study by Ravindranath *et al.* (2007a) estimated the incremental mitigation potential at between 258 and 260 mtC by the year 2035, depending on the specific land classification system (i.e., AEZ (agro-ecological zones) and GTAP (Global Trade Analysis Project), used for the analysis, while considering wastelands as potential land available for mitigation activity If the long fallow and marginal agricultural land is also included (10 percent of the total agricultural land) then the incremental mitigation potential is projected to be between 425 to 520 MtC by the same year. *Table 3* provides a comparison of different mitigation potential estimates made for Indian LULUCF sector by different studies

forestry projects [Bazpur]) in Uttaranchal At Belaghat after 30 years the net mitigation potential on degraded *Vanpanchayat* land of 1 589 ha was estimated to be 197 242 tC which increased to 479 905 tC after 80 years At Bazpur block total mitigation potential was estimated to be 73.4 mt for the year 2035 through farm forestry on 2 667 ha of private croplands.

Comparison of regional baseline estimates to project-specific baseline

A case study of Kolar district of Karnataka showed that the means from the two samples (i e., regional as well project specific baseline) were highly correlated. Thus, it can be safely assumed that the regional baseline may be applied to determine a project specific baseline to reduce transaction costs for projects (Sudha *et al* 2007).

TABLE 3 *Comparison of estimates of Indian forestry mitigation potential across aggregate national and disaggregated AEZ-based estimates, using different methods*

Mitigation options	Ravindranath *et al.* 2007		Ravindranath *et al.* 2007		Sathaye *et al.* 2006	Ravindranath *et al.* 2001
Specifications	@ US$100, for 30 year (2005–2035), WL* scenario, two land classification systems		@ $US100, for 30 year (2005–2035), WL*+LF*+MC* scenario, two land classification systems		@ $US100, for 30 year (2000–2030),	For 30-year period
	GTAP*	Indian AEZ*	GTAP	Indian AEZ		
Short rotation	51	34	75	67	348	25
Long rotation	129	150	95	179	505	75
Natural regeneration	80	75	254	273	NA	215
Total	260	258	424	520	853	315

*AEZ, agro-ecological zone; GTAP global trade analysis project; WL, wasteland; LF, long fallow; MC, marginal cropland

Mitigation potential estimates at regional level

Setting a baseline for carbon stock changes for forest and land use sector mitigation projects is an essential step in assessing the additionality or the mitigation potential of a project. Sudha *et al.* (2007), as part of the exercise of creating regional baseline for the forestry projects in the dry zone of southern Karnataka, developed a regional baseline for the two agro-climatic zones, namely, the eastern dry zone and the central dry zone comprising the districts of Tumkur, Chitradurga and Kolar. The baseline carbon stock was estimated at 38.97 t/ha for the wasteland categories and 34.63 tC/ha for the fallow land categories. However, they have not estimated the mitigation potential at regional level

Mitigation potential estimates at project level

Ravindranath *et al* (2007b), estimated project specific baseline and mitigation potential for community and farm forestry in the Kolar district of Karnataka. The mean project specific baseline was estimated to be 39.95 tC/ha for the wasteland categories and 33.64 tC/ha for the fallow land categories. The overall mitigation potential in Kolar for a total area of 14 000 ha under different mitigation options is found to be 278 380 tC at a rate of 20 tC/ha for the period 2005–2035.

Hooda *et al* (2007) estimated the mitigation potential for two case studies (i.e., community [Belaghat] and farm

Cost-effectiveness of the mitigation options

Several studies provide estimates of the cost-effectiveness of the mitigation projects (Kadekodi and Ravindranath 1997, Ravindranath *et al.* 2001, Ravindranath *et al* 2007) Ravindranath *et al.* (2001) analysed the cost-effectiveness of forestry mitigation options The cost of afforestation in most parts of India is within a narrow range, so this may well be generalised for India The cost-effectiveness parameters were analysed using 6 percent and 12 percent discount rates The values are shown in *Table 4*.

The mitigation costs on a life cycle cost basis for the mitigation activities are given in *Figure 6* for four activities as reported by Ravindranath *et al* (2001), taking into account a 12 percent discount rate The life cycle cost was estimated to be lowest for forest protection, followed by forest regeneration, long-rotation forestry and short-rotation forestry

Transaction costs of mitigation projects

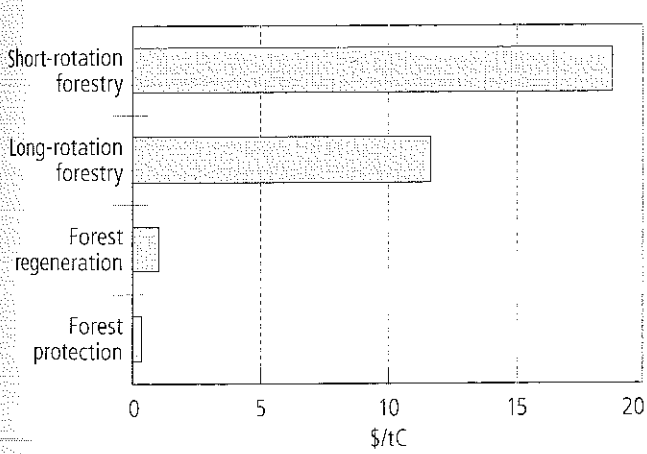
Forestry mitigation projects will involve baseline development, preparation of mitigation scenarios,

TABLE 4 *Cost-effectiveness and mitigation potential of forestry activities in India*

	Short rotation		Long rotation		Forest regeneration		Forest protection	
Discount rate (%)	6.00	12 00	6 00	12.00	6.00	12.00	6.00	12.00
Investment cost (US$/ha)	328.00	303 00	746.00	695 00	38 00	35 00	45 00	45 00
Lifecycle cost (US$/ha)	530.00	415 00	1079.00	877.00	279 00	164.00	93 00	68 00
NPV of Benefits (US$/ha)	645.00	55 00	787 00	-584 00	444.00	0 12	-1777 00	-867.73
Investment cost (US$/tC)*	15 00	13.77	9.94	9 26	0.23	0 21	0 26	0 26
Lifecycle cost (US$/tC)	24 00	18 86	14 38	11.69	1.70	0 99	0.53	0 39
Rotation period (year)	8 00		30 00				–	–
SOC increment (tC/ha/yr)	0.30		0 30		0 70			
MAI (t/ha/yr)	6 60		3 00		2 00			
Products expected	Industrial wood, fuelwood		Sawnwood		NTFP**, fuelwood		NTFP**	
Product life (years)	1–3		40					

1US$ = INR 42 (year 2000 value)
*Investment cost for the first rotation at 2000 prices
**Non-timber forest products
Source: Ravindranath *et al* (2001)

FIGURE 6 *Mitigation cost (life-cycle cost $US/tC)*



Source: Ravindranath *et al* 2001

estimation of changes in stocks of five carbon pools with and without the mitigation project activities Further, after the implementation of the project there is a need to periodically monitor the carbon stocks and changes for all the selected carbon pools, which may involve large transaction costs (Ravindranath and Ostwald, 2007) Case studies in the Western Ghats forestry programme showed that less than 10 percent of the project budget may be adequate for periodic and intensive monitoring of carbon stocks and changes in forests or plantations of large projects (Ravindranath and Bhat 1997) A recent study by (Ravindranath *et al* 2007) estimated the transaction cost for baseline and project scenario development at less than INR 5/tC. No study has provided a complete estimate of transaction costs of mitigation projects in the forest sector.

CDM and LULUCF sector

Afforestation and reforestation are the only forestry activities included under the Clean Development Mechanism (CDM) of the Kyoto Protocol As of December 2007, 10 methodologies have been approved by the Executive Board of the CDM However, only one CDM project has been registered globally Small-scale CDM projects with simplified methodologies are also approved. No project from India was registered until December 2007, though several attempts were made. This is because of the complexities and difficulties in developing the baseline, proving the land eligibility and demonstrating additionality of a CDM project using the approved methodologies. Opportunities to promote CDM projects in forestry include simplifying procedures, developing certainty over future commitments, reducing transaction costs, and building confidence and capacity among potential buyers, investors and project participants (Nabuurs *et al.* 2007). Reducing emissions from deforestation from developing countries has been identified as one of the key approaches to address climate change The Conference of Parties (COP 13) held in December 2007 in Bali, Indonesia, recognised the potential for further actions to reduce emissions from deforestation and forest degradation in developing countries.

Research gaps and needs

Reliable data on the area available for mitigation activities according to different land category at district and AEZ level is critical. There is a need for an understanding of the barriers to land availability for mitigation activities Most of the estimates available in the literature are technical potential values with no consideration of the barriers Thus there is a need for economic and market potential estimates of the mitigation potential.

Mitigation potential estimates in the LULUCF sector are characterised by high uncertainty due to lack of data on stocks and fluxes and rates of growth of different carbon pools. Carbon increment rates in different pools are known to differ from one AEZ to another; however, literature estimates for carbon increment rates are available for only few zones and also rates are not available for all the pools. The estimates of the mitigation potential of forest sector in India are based on single or a few values of C stocks or C-stock growth rates, despite the diverse forest types, ecological and socio-economic conditions. Mitigation potential assessments for projects activities lack data on baseline carbon stocks and rate of change in biomass and soil organic carbon. Lack of reliable data is a barrier in formulation of mitigation projects.

IMPACT AND VULNERABILITY STUDIES

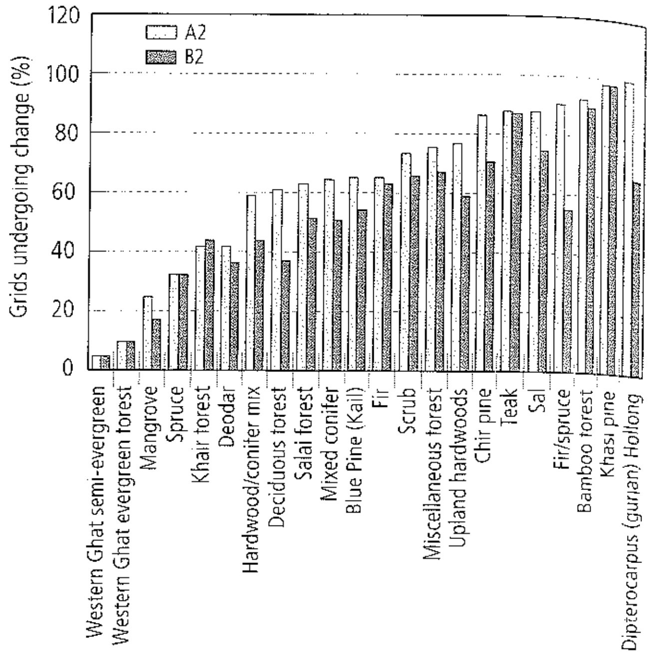
Ecological systems are intrinsically dynamic, are constantly influenced by climatic variations and are capable of adapting to the changes in the environment. However, climate change is expected to occur more rapidly than the rate at which ecosystems can adapt and reestablish themselves. The fourth assessment report of the IPCC (IPCC 2007c) concludes that recent modelling studies indicate that forest ecosystems could be seriously impacted by future climate change, even with moderate global warming of 1–2°C. India is a mega biodiversity country where forests account for about 20 percent of the geographical area. With nearly 200 000 villages classified as forest villages, there is a large dependence of communities on forest resources (Ravindranath *et al.* 2006). Thus it is important to assess the likely impacts of projected climate change on forests and develop and implement adaptation strategies for both biodiversity conservation and improvement in the livelihood of forest-dependent communities.

A number of impact assessment models (Running *et al.* 1991, Coleman *et al.* 1999, Parton *et al.* 1992, Friend *et al.* 1997, Kaplan *et al.* 2003, Neilson 1995, Foley *et al.* 1996) are available. However, only limited studies are available and they too have used only BIOME 3 (Haxeltine *et al.* 1996) and BIOME 4 models (Kaplan *et al.* 2003).

Impact assessment studies

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 (HadRM3) using the A2 and B2 scenarios of the special report on emissions scenarios (SRES) and the BIOME 4 vegetation response model. The study found that under the climate projection for the year 2085, 77 and 68 percent of the forested grids in India, respectively, are likely to experience shift in forest type under A2 and B2 scenario. The northeastern 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 interference.

FIGURE 7 *Percentage of grids under different forest types undergoing change in A2 and B2 GHG scenarios*



Source: Ravindranath *et al.* 2006

Impact on biodiversity

Biodiversity is likely to be impacted under the projected climate scenarios because of the changes or shifts in forest or vegetation types (68–775 percent), forest dieback during the transient phase, and different species responding differently to climate change, even when there is no change in forest type (Ravindranath *et al.* 2006).

Impact on productivity and biomass production

Increasing atmospheric CO_2 concentration and climate warming could also result in doubling of net primary productivity under A2 scenario and a nearly 70 percent increase under B2 scenario. The NPP under tropical evergreen forest is projected to increase by 1.5 times under the GHG scenarios. The projected rate of increase in NPP is lower for cool conifer forest, cold mixed forest and temperate deciduous forest. Generally the rate of increase is higher for warmer vegetation types (Ravindranath *et al.* 2006). However, the BIOME 4 model does not take into consideration nutrient limitations, particularly those of nitrogen and soils.

CLIMATE CHANGE IMPACTS AND ADAPTATION

Adaptation is adjustment in natural or human systems in response to actual or expected climatic stimuli and their impacts on natural and socio-economic systems. Climate change could cause irreversible damage to unique forest ecosystems and biodiversity, rendering several species extinct, locally and globally. According to a study by Ravindranath *et al.* 2006, forest ecosystems require the longest response time to adapt, say, through migration and regrowth Further, a long gestation period is involved in developing and implementing adaptation strategies in the forest sector Thus there is a need to develop and implement adaptation strategies Currently, there is very little research on adaptation Adaptation is not included in the modelling efforts of impact assessment Adaptation practices may have to be developed and incorporated into afforestation and reforestation programmes Some examples of policies and practices that need to be explored to promote adaptation are (Ravindranath *et al* 2006):

- Incorporate climate concerns into the long-term forest policymaking process and into working plans
- Conserve forests and reduce forest fragmentation
- Expand protected areas and link them wherever possible to facilitate migration
- Promote mixed species forestry to reduce vulnerability
- Undertake anticipatory planting and assist natural migration through transplanting plant species
- Promote in situ and *ex situ* gene pool conservation
- Initiate forest fire management strategies

MITIGATION AND ADAPTATION SYNERGY

Mitigation and adaptation are the two main strategies to address climate change There is a realisation of the need to explore and promote synergy between mitigation and adaptation while addressing climate change A study by Ravindranath (2007c) explores the synergy between mitigation and adaptation by considering forest sector, which on the one hand is projected to be adversely impacted under the projected climate change scenarios and on the other to provide opportunities to mitigate climate change. The study highlights the potential and need for incorporating adaptation strategies and practices into mitigation projects The study concludes that there is a need to ensure that mitigation programmes or projects do not increase the vulnerability of forest ecosystems and plantations Further, several adaptation practices could be incorporated into mitigation projects to reduce vulnerability Mitigation projects could be designed to reduce vulnerability and promote adaptation, for example, forest and biodiversity conservation, protected area management and sustainable forestry

CLIMATE CHANGE AND FOREST RESEARCH NEEDS; MODELLING AND DATA

Climate change and its implications for the Indian forest sector are very critical for reducing the vulnerability of forest ecosystems, developing mitigation strategies and projects, periodic inventory of the greenhouse gases, promoting sustainable management of forests, and sustainable production of timber, industrial wood, fuelwood and biomass feedstock for energy The global circulation models are robust in projecting mean temperature at global level compared to their ability to make projections at regional level The uncertainty involved in projections of precipitation changes is higher at global and particularly at regional level The climate projections particularly the rainfall projections have high uncertainty and vary from model to model The BIOME is an equilibrium model and does not project the transient phase vegetation responses There is therefore a need to improve the reliability of climate projections at regional level as well as the use of dynamic vegetation models Data limitations need to be overcome by initiating studies to develop databases on forest vegetation characteristics and plant functional types, plant physiological parameters, soil and water data and socio-economic dependence and pressures on forest ecosystems The following are the key research priorities for climate change and forests in India.

i) **Dynamic vegetation modelling of climate change impacts on forest ecosystems and biodiversity:** Forest ecosystems are characterised by a large diversity of vegetation types and are subject to human intervention. The studies so far conducted in India are largely based on equilibrium models, which assume that one forest type is replaced by another forest type under changing climate The varying climate tolerances of different plant species and the transient phase response of plant species subjected to climate change are not analysed. It is necessary to adapt the existing dynamic vegetation models and develop diverse tropical forest-type specific dynamic vegetation models and analyse the implications of climate change at species level. The use of dynamic models is characterised by data limitations related to climate parameters, soil characteristics and plant physiological functions for different forest and plantation types (Ravindranath *et al* 1996)

ii) **Adaptation:** Development of adaptation strategies is constrained by the uncertainty in the current projections of climate parameters and impact assessments (Ravindranath *et al.* 1996) Further, there is a need for models where adaptation is incorporated into impact models. The ultimate goal is to develop adaptation strategies and practices to reduce the vulnerability of forests to climate change.

iii) **Climate change and forests—mitigation and adaptation linkage synergy:** So far mitigation and adaptation are considered separately in global negotiations, by IPCC and all the literature. There is a need to explore the presence of synergy and if there is any trade-off between mitigation and adaptation to develop cost-effective strategies so that the adverse effects of climate change are avoided or minimised (Ravindranath 2007c) The forest sector provides an interesting opportunity to analyse and understand the synergy/trade-off between mitigation and adaptation Thus it is necessary to model and study the opportunity to promote mitigation in adaptation programmes and projects and to promote adaptation in mitigation programmes and projects

iv) **Estimation of market mitigation potential of forest sector:** There is a need to make a realistic assessment of economic and market mitigation potential at national and disaggregated level, considering the various barriers to mitigation. Mitigation potential needs to be assessed spatially for different regions in India There is a need to develop a database on growth rates of biomass and soil carbon accumulation rates in different forests and plantation systems in different agro-ecological zones of India These data are required for a realistic assessment of the mitigation potential of forest sector in India as well as for A&R CDM projects.

v) **Impact of climate change on mitigation potential and carbon sinks:** India has a large afforestation programme (over 1 5 million ha annually), and it is important to understand the likely impacts of climate change to ensure sustainable management of forests and flow of timber, industrial wood and non-timber products and conservation of biodiversity. Such an analysis is also required as India is planning to undertake large-scale CDM projects in the forest sector, first to understand the mitigation potential of CDM project activities under climate impacted scenarios and also to develop adaptation strategies to minimise adverse effects.

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