Forest conservation, afforestation and reforestation in India: Implications for forest carbon stocks

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This article presents an assessment of the implications of past and current forest conservation and regeneration policies and programmes for forest carbon sink in India. The area under forests, including part of the area afforested, is increasing and currently 67.83 mha of area is under forest cover. Assuming that the current trend continues, the area under forest cover is projected to reach 72 mha by 2030. Estimates of carbon stock in Indian forests in both soil and vegetation range from 8.58 to 9.57 GtC. The carbon stock in existing forests is projected to be nearly stable over the next 25 year period at 8.79 GtC. However, if the current rate of afforestation and reforestation is assumed to continue, the carbon stock could increase from 8.79 GtC in 2006 to 9.75 GtC by 2030 – an increase of 11%. The estimates made in this study assume that the current trend will continue and do not include forest degradation and loss of carbon stocks due to biomass extraction, fire, grazing and other disturbances.

Keywords: Afforestation, carbon stocks, conservation, reforestation.

INDIA is a large developing country known for its diverse forest ecosystems and is also a mega-biodiversity country. Forest ecosystems in India are critical for biodiversity, watershed protection, and livelihoods of indigenous and rural communities. The National Communication of the Government of India to the UNFCCC has reported[1] that the forest sector is a marginal source of CO_2 emissions. India has formulated and implemented a number of policies and programmes aimed at forest and biodiversity conservation, afforestation and reforestation. Further, India has a goal[2] to bring one-third of the geographic area under forest and tree cover by 2012. All forest policies and programmes have implications for carbon sink and forest management. This article presents an assessment of the implications of past and current forest conservation and regeneration policies and programmes for forest carbon sink in India. It also estimates the carbon stocks under current trend scenario for the existing forests as well as new area brought under afforestation and reforestation for the period 2006–30.

We have primarily relied on published data from the Ministry of Environment and Forests (MOEF), Government of India (GOI); Food and Agricultural Organization of United Nations (FAO), and Forest Survey of India (FSI). We have used the Comprehensive Mitigation Analysis Process (COMAP) model for projecting carbon stock estimates. The article is based only on past trends from 1980 to 2005 and uses the assumption – 'if the current trend continues'. We feel that such an assumption is well justified because, despite the increase in population and industrialization during 1980–2005, forest area in India not only remained stable but has marginally increased. This is due to favourable policies and initiatives pursued by GOI. We expect that India will not only keep pursuing aggressive policies of afforestation and forest conservation, but also go a step forward. A case in point is the Prime Minister's recently announced '6 mha greening programme'. If the assumptions of continuation of current rates of afforestation, forest conservation policies and no significant degradation of forest carbon stocks are changed, the future carbon stocks projected will also change.

Area under forests

According to FSI, 'all lands, more than one hectare in area, with a tree canopy density of more than 10 per cent are defined as Forest'. The total forest cover in India according to the latest[3] State of Forest Report 2003 is 67.83 mha and this constitutes 20.64% of the geographic area. The distribution of area under very dense, dense and open forest is given in Table 1. Dense forest dominates, accounting for about half of the total forest cover. Tree cover (which includes forests of less than 1 ha) is 9.99 mha (3.04%). The total area under forest and tree cover is 77.82 mha, which is 23.68% of the geographic area (Table 1).

FAO[4] defines forests as 'Land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10%, or trees able to reach these thresholds *in situ*'. And other woodlands as 'Land not classified as "Forest", spanning more than 0.5 ha; with trees higher than 5 m

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and a canopy cover of 5–10 per cent, or trees able to reach these thresholds *in situ*; or with a combined cover of shrubs, bushes and trees above 10 per cent. Both of these categories do not include the land that is predominantly under agricultural or urban land use'. According to FAO, the area under forests and other wooded land in India has increased from 63.93 mha in 1990 to 67.70 mha in 2005. Thus FAO estimates do not significantly differ from FSI estimates.

Trends in area under forest and tree cover

The FSI has been periodically estimating the forest cover in India since 1987, using remote sensing techniques. The forest cover reported[5] for 1987 was 64.08 mha and according to the latest assessment[3] for 2003, the forest cover is 67.83 mha. This indicates an increase in forest cover of 3.75 mha over a period of 15 years (Figure 1). It can be observed from Figure 1 that the forest cover in India has nearly stabilized and has been increasing marginally over the years[3,5–12]. FSI has included the tree cover in the 2001 and 2003 assessments[3,6], in addition to forest cover. The area under tree cover reported is also found to be marginally increasing (Figure 1).

Afforestation and reforestation programmes

India has been implementing an aggressive afforestation programme. The country initiated large-scale afforestation under the social forestry programme starting in the early 1980s. Figure 2 shows the progress of afforestation in India for the period 1951–2005. It can be seen from Figure 2 that the cumulative area afforested in India during the period 1980–2005 is about 34 mha, at an average annual rate[2] of 1.32 mha[2]. This includes community woodlots, farm forestry, avenue plantations and agro-forestry. Afforestation and reforestation in India are being carried out under various programmes, namely social forestry initiated in the early 1980s, Joint Forest Management Programme initiated in 1990, afforestation under National Afforestation and Eco-development Board (NAEB) programmes since 1992, and private farmer and industry-initiated plantation forestry.

Table 1. Status of forest cover in India[3,4]

Tree crown class	Area (mha)	Per cent geographic area
Very dense forest (>70%)	5.13	1.56
Dense forest (40–70%)	33.93	10.32
Open forest (10–40%)	28.78	8.76
Mangroves	0.45	0.14
Total forest cover	67.83	20.64
Tree cover	9.99	3.04
Total	77.82	23.68
Forest cover according to FAO	67.7	–

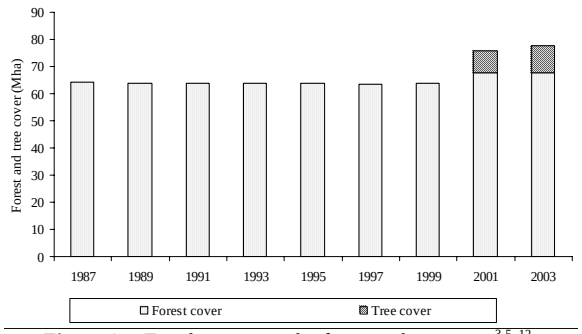

Figure 1. Trends in area under forest and tree cover[3,5–12].

Future trends in area under forests and afforestation

The projections for area under forest as well as area afforested are based on current trends or what is generally termed the 'current trend scenario'. The current trend scenario is based on the past, current and short-term afforestation plans. The projections exclude the tree cover component as reported in 2001 and 2003 by the FSI.

Projections for area under forest cover based on current trend scenario

The forest cover is projected up to 2030, based on the past and current trends, as reported by the periodic re-

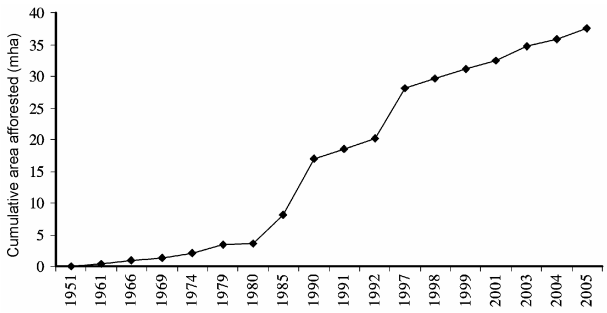

Figure 2. Cumulative area afforested[2] during 1951–2005.

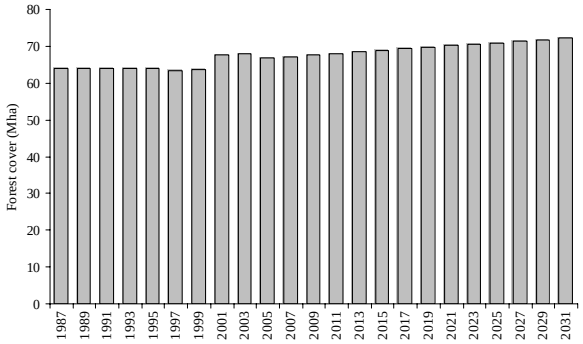

Figure 3. Projected trend in forest cover under the current trend scenario[3,5–12].

ports of the FSI. It can be observed from Figure 3 that the forest cover will continue to increase all the way up to 2030. The forest cover is projected to reach 72.19 mha by 2030, assuming that the current trend scenario will continue.

Projected afforestation rates based on current trends

The long-term average annual rate of afforestation over the period 1980–2005 is 1.32 mha. Assuming the average rate[2] of 1.32 mha for the period 2006–30, the total area that would be afforested is 33 mha. The cumulative area afforested would be 70.5 mha by 2030 (Figure 4). This includes short- and long-rotation plantation forestry as well as natural regeneration. It is important to note that some of the afforested area, particularly short-rotation plantations, is likely to be periodically harvested and replanted or left for coppice regrowth.

Carbon stocks in forests

The forest sector could be a source or a sink of carbon. Forest carbon stock includes biomass and soil carbon pools. Biomass carbon can be further disaggregated into aboveground and belowground biomass and dead organic matter. Change in forest carbon stock between two time periods is an indicator of the net emissions of CO_2 from the sector. Carbon stocks are estimated and projected for the period 2005–30.

Methodology

The COMAP model[13] is a set of versatile models with the ability to analyse the mitigation potential as well as cost-effectiveness of diverse activities such as forest conservation (e.g. Protected Areas and halting forest conversion), natural regeneration (with no logging) and afforestation/reforestation through plantation forestry, including short- as well as long-rotation forestry (with logging or harvesting).

Assessment of mitigation activities using the COMAP model would involve consideration of the following:

- Land availability for different mitigation activities during different years.
- Wood product demand and supply to ensure that socio-economic demands are met with and real additional mitigation is feasible.
- Developing a baseline or current trend scenario to enable estimation of incremental carbon mitigation.
- Developing a mitigation scenario incorporating the extent of area to be covered for meeting different goals.

Data required for assessing different activities: The data required for assessing the mitigation potential of afforestation and reforestation include land area-related information, baseline carbon density (tC/ha) in above-ground vegetation and soil, rotation period, above-ground woody biomass accumulation rate (tC/ha/yr), soil carbon enhancement rate (tC/ha/yr), and cost and benefit flows. Input data were obtained from the literature[14,15].

Outputs of the COMAP model: These include mitigation potential estimates per ha and aggregate tonnes of carbon benefit, annual carbon stocks, carbon stocks for a given year such as 2008 and 2012 and cumulative over a period, and cost-effectiveness parameters.

Carbon stock estimates

Estimates for the forest carbon stocks, including biomass and soil carbon from previous studies are given in Figure 5. According to an earlier estimate by Richards and Flint[16],

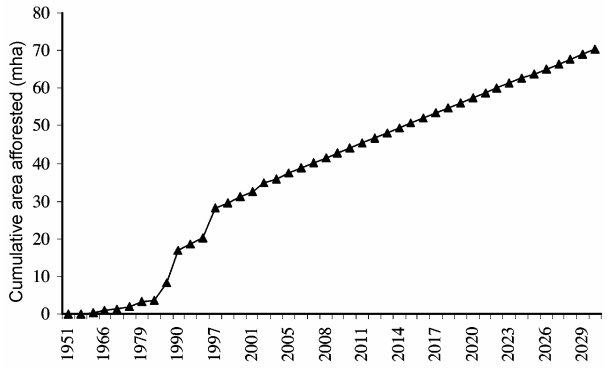

Figure 4. Projected afforestation under the current trend scenario.

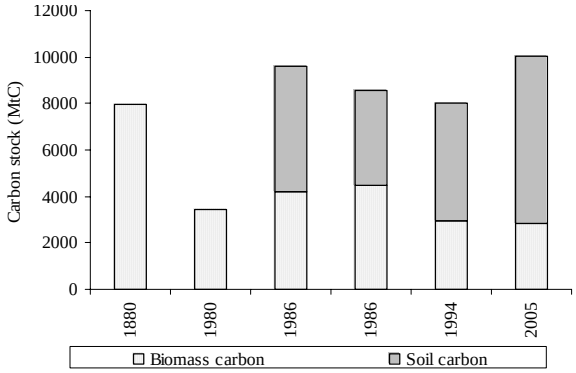

Figure 5. Trends in carbon stock estimates for Indian forests[15–19].

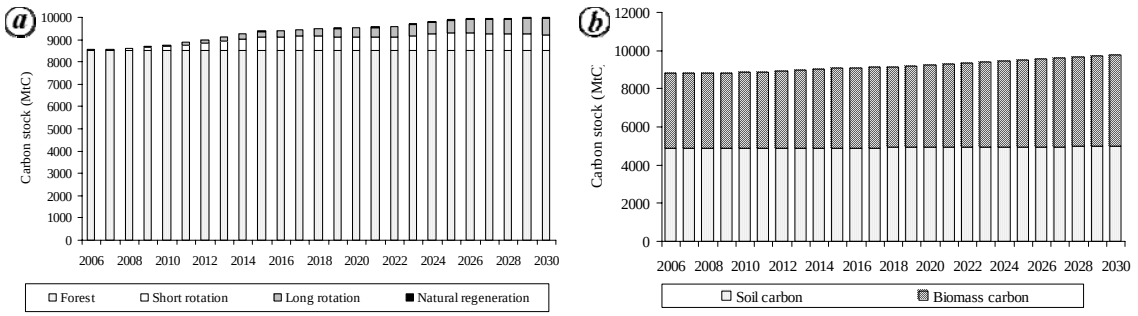

Figure 6. Projected forest carbon stocks. ***a***, Under the current trend scenario for existing forests and area afforested (short- and long-rotation and natural regeneration). ***b***, According to biomass and soil carbon.

the biomass carbon stock in Indian forests was 7.94 MtC during 1880. This study does not provide soil carbon estimates. Further estimates by the same authors for 1980 showed that forest biomass carbon stock had declined by nearly half over a period of 100 years. Estimates[17–19] of forest carbon stock, including biomass and soil carbon for the year 1986, are in the range 8.58–9.57 GtC. According to a latest estimate by FAO[4], total forest carbon stock in India is 10.01 GtC. Thus, the carbon stocks in Indian forests have not declined, and in fact seem to have increased, over a period of 20 years (1986–2005). Forest soil carbon accounts for over 50% of the total forest carbon stock.

Carbon stock projections under current trend scenario

Carbon stock projections for the existing forests as well as new area brought under afforestation and reforestation for the current trend scenario are made for the period 2006–30. The carbon stock projections are made using the COMAP model. The forest cover data were obtained from the projections made using the FSI area trends (Figure 3) and afforestation rates were obtained from the past trends (average annual rate of 1.32 mha). The biomass and soil carbon stock and growth rates were obtained from published literature[14,15]. The afforestation rate of 1.32 mha/annum was allocated to short- and long-rotation and natural regeneration at 63.7, 32.2 and 4.1% respectively, based on the previous years' trend[12].

The carbon stock projections for the period 2006–30 are given in Figure 6. The carbon stock in the existing forests is projected to be nearly stable over the 25-year period at 8.79 GtC (Figure 6 *a*). When afforestation and reforestation is included, the carbon stock is projected to increase from 8.79 GtC in 2006 to 9.75 GtC by 2030, about 11% increase (Figure 6 *a*). It is important to note that COMAP model accounts for harvests and the resulting emissions. Thus, Indian forests will be a net sink over the next 25 years. Figure 6 *b* shows the dominance of soil carbon in the total forest carbon stock.

Factors contributing to stabilization of carbon stocks in Indian forests

India is one of the few countries where deforestation rate has been reduced and regulated and forest cover nearly stabilized, unlike most other tropical countries. Further, the projections of carbon stocks for the period 2006–30 showed that the carbon stock will increase. Thus, it is important to understand the likely factors contributing to the observed and projected stabilization of forest cover as well as forest carbon stocks in India. The factors include legislations, forest conservation and afforestation programmes, and community awareness and participation.

Forest Conservation Act, 1980

This Act is one of the most effective legislations contributing to reduction in deforestation. This was enacted to reduce indiscriminate diversion of forest land for non-forestry purposes, and to help regulate and control the recorded forest land-use changes.

Compensatory afforestation

According to Forest Conservation Act, 1980, when after careful consideration forest land is released for any infrastructure projects, it is mandatory for compensatory plantations to be raised on an equivalent non-forested land or equal to double the area on degraded forestland.

Wildlife parks and protected area

In India, 15.6 mha is Protected Area, where all human intervention or extraction is banned.

Afforestation

India has been implementing large-scale afforestation/reforestation since 1980 under social forestry, Joint Forest

Management, silvi-pasture, farm forestry and agro-forestry programmes, covering over 30 mha. This may have reduced pressure on the forests.

National Forest Policy, 1988

It envisages people's participation in the development and protection of forests. The basic objective of this policy is to maintain environmental stability through preservation of forests as a natural heritage.

Joint Forest Management (JFM), 1990

The Forest Policy 1988 set the stage for participatory forest management in India. The JFM programme recognized the rights of the protecting communities over forest lands. The local communities and the Forest Department jointly plan and implement forest regeneration programmes and the communities are rewarded for their efforts in protection and management. The total area covered under the JFM programme is over 15 mha. This has enabled protection of existing forests, regeneration of degraded forests and raising of forest plantations, potentially contributing to conservation of existing forests and carbon stocks.

Significance of stabilization of forest carbon stocks in India

India is one of the few countries in the world, particularly among the tropical countries, where carbon stock in forests has stabilized or is projected to increase. This has implications for reducing the carbon emissions from forest sector, potentially contributing to stabilization of CO_2 concentration in the atmosphere. This Indian achievement is significant due to the following.

High population density and low per capita forest area

India is a large developing country with a population density of 363 persons/km^2. Even more significantly, the forest area per capita is only 0.06 ha, compared to the world average of 0.62 ha/capita and Asian average of 0.15 ha/capita. A comparison of key developing countries and Western European countries[4] is provided in Table 2. Forests and wooded land area per 1000 population in Germany and France is nearly two and five times that of India. Similarly, forest and wooded land in other major developing countries such as Brazil, China and Indonesia are also higher by 3 to 40 times, as compared to India.

Low deforestation rate compared to other developing countries

According to the Global Forest Resources Assessment[4], countries such as India and China are experiencing an increase in forest area since 1990 (Table 3). However, majority of the other tropical countries with large area under forests are experiencing deforestation on a significant scale since 1990 (Table 3). Majority of the countries (42–65%) are experiencing reduction in forest area or net deforestation[4] (Table 4).

High dependence of human population on forests

In India, nearly 196,000 villages are in the forests or on the forest fringes. Fuelwood is a dominant source of cooking energy for the rural population with forests contributing significantly to this. Apart from fuelwood, village communities depend on forests for small timber, bamboo and non-timber forest products.

High livestock density

India accounts for 2.3% of the world's geographic area, but accounts for 15% of the global livestock population. The cattle (cows, bullocks and buffaloes) population density is nearly one per hectare. When sheep and goats are included along with cattle, the livestock population density further increases to 1.5 per hectare. However, if only forest land is considered, the livestock density is 7 per hectare, which is among the highest in the world.

Table 2. Comparison of total forest area and forest area/1000 population[4]

Country	Population (million)	Forest area ('000 ha)	Other wooded land ('000 ha)	Total area under forest and wooded land ('000 ha)	Forest and wooded land (ha/1000 population)
India	1079	67,701	4110	71,811	66
China	1326	197,290	87,615	284,905	215
Brazil	178	477,698	0	477,698	2673
Indonesia	217	88,495	0	88,495	406
Germany	82	11,076	0	11,076	134
United Kingdom	59	2845	20	2865	48
France	59	15,554	1708	17,262	287

Table 3. Comparison of forest area change and deforestation (in '000 ha) in other major developing countries[4]

Region	Net annual change in forest area ('000 ha)		Key developing countries	Area under forest ('000 ha)			Net annual change in forest area ('000 ha)	
	1990 to 2000	2000 to 2005		1990	2000	2005	1990–2000	2000–2005
Asia	–792	1003	China	157,141	177,001	197,290	1986	4058
			India	63,939	67,554	67,701	362	29
			Indonesia	116,567	97,852	88,495	–1872	–1871
			Malaysia	22,376	21,591	20,890	–78	–140
			Philippines	10,574	7949	7162	–262	–157
Africa	–4375	–4040	Sudan	76,381	70,491	67,546	–589	–589
			Zambia	49,124	44,676	42,452	–445	–445
			UR Tanzania	41,441	37,318	35,257	–412	–412
			Nigeria	17,234	13,137	11,089	–410	–410
			South Africa	9203	9203	9203	0	0
South America	–3802	–4251	Brazil	520,027	493,213	477,698	–2681	–3103
			Argentina	35,262	33,770	33,021	–149	–150
			Mexico	69,016	65,540	64,238	–348	–260
			Peru	70,156	69,213	68,742	–94	–94
			Columbia	61,439	60,963	60,728	–48	–47

Table 4. Countries with positive, negative and zero or marginal annual rate of change in forest area[4]

Region	Total number of countries	Countries with negative rate of net annual change in forest area (2000–05)	Countries with positive rate of net annual change in forest area (2000–05)	Countries with zero net annual change in forest area (2000–05)	Countries with no significant net annual change in forest area (2000–05)
Asia	48	20	13	12	3
Africa	58	38	8	8	4
South America	15	8	2	3	2 (not available)

Dominance of agrarian economy

Rural areas in India are characterized by large dependence of the population on land resources, particularly cropland and forest land, leading to more human pressure on land.

Implications of Indian forest conservation and development programmes and policies for global change

India is a large developing country with a high population density and low forest area per capita. The livestock population density is among the highest in the world. Further, nearly 70% of the population residing in rural areas depends on forest and other biomass resources for fuelwood, timber and non-timber forest products for its energy needs and livelihood. In such a socio-economic scenario, one would have expected the forest area to decline, leading to large emissions of CO_2 from the forest sector.

The analysis of forest cover, afforestation and reforestation has shown that the forest cover has stabilized in the past 15 years (64–67 mha). Projections under the current trend scenario indicate that the forest cover is likely to increase in the period 2006–30. Further, model-based projections of carbon stocks in the Indian forest sector show a likely increase (from 8.79 GtC in 2005 to 9.75 GtC in 2030). This is a significant achievement for a developing country such as India, despite high human and livestock population density, high dependence of rural communities on forests for biomass resources and low per capita forest area. The factors contributing to the current and projected trends of stable or increasing carbon stocks in the forests are progressive and effective forest conservation legislations, afforestation and reforestation programmes and community participation in forest protection, regeneration and management.

The progressive conservation-oriented forest policies and afforestation programmes are contributing to reduction in CO_2 emissions to the atmosphere, stabilization of carbon stocks in forests and conservation of biodiversity. Thus, the Indian forest sector is projected to keep making positive contributions to global change and sustainable development. This projected estimate and conclusion excludes any potential decline in forest carbon stocks due to forest conversion, forest degradation, biomass extraction, fire, etc.

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ACKNOWLEDGEMENTS. We thank the MOEF, GOI for supporting this project as well as climate change research activities at the Centre for Ecological Sciences, Indian Institute of Science, Bangalore. We also thank Jayant Sathaye and Ken Andrasko for their support in our climate change research over the years.

Received 12 July 2007; revised accepted 22 May 2008

Erratum

Sago starch: An economical substitute for *in vitro* primary screening of starch utilizing microorganisms
R. B. Binky, R. Saikiran, S. Tushar, P. Umesh, J. Yogesh and A. N. Syed
[*Curr. Sci*., 2007, **93**, 459–461]

Line 1, para 2, 2nd column should have been:

1. Successful use of isabgol derived from *Plantago ovata* seeds, gum katira exuded from *Cochlospermum religiosum* bark and guar gum from endosperm of *Cyamopsis tetragonoloba* as gelling agent has been reported for microbial culture media[3,6,7].
2. Nene, Z. L. in ref. 6 should have been Nene, Y. L.

We regret the error.

—Authors