CARBON EMISSIONS AND SEQUESTRATION IN FORESTS:

CASE STUDIES FROM SEVEN DEVELOPING COUNTRIES

VOLUME 3: INDIA AND CHINA

N.H. Ravindranath, B.S. Somashekhar, and M. Gadgil

Center for Ecological Sciences and ASTRA
Indian Institute of Science
Bangalore, India

Xu Deying

Research Institute of Forestry
Chinese Academy of Forestry
Beijing, China

Series Editors: Willy Makundi and Jayant Sathaye

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Energy Analysis Program
Lawrence Berkeley Laboratory

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Energy and Environment Division
Lawrence Berkeley Laboratory
Berkeley, CA, USA

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PREFACE

In January 1990, scientists and policymakers from around the world convened for a meeting of the Intergovernmental Panel on Climate Change (IPCC) in São Paulo, Brazil, to continue the ongoing discussions on emissions of greenhouse gases and global climate change. As part of the effort to further understand the sources of carbon dioxide (CO_2) and other major greenhouse gases, LBL and the University of Sao Paulo, with support from the U.S. Environmental Protection Agency, organized a workshop on tropical forestry and global climate change which was attended by the IPCC conference participants. Discussions at the workshop led to the establishment of the Tropical Forestry and Global Climate Change Research Network (F-7). The countries taking part in the F-7 Network -- Brazil, China, India, Indonesia, Malaysia, Mexico, Nigeria and Thailand -- possess among the largest tracts of the Earth's tropical forests and together experience the bulk of tropical deforestation.

The following research objectives were identified as the F-7 Network's priorities:

1. To improve and expand the body of knowledge about the extent of tropical deforestation through the use of available tools, including remote-sensing imagery, detailed biomass measurements and existing models.

2. To explore the dynamics of forest land use within the context of individual country's social and economic structures.

3. To identify alternative response options aimed at stemming deforestation and promoting sustainable land-use practices while maintaining each country's economic well-being. Meeting this objective includes carrying out an assessment of the economic costs of implementing various mitigative policies.

One of the strategies of this project was to rely on the work of indigenous researchers and institutions from each of the participating countries. This approach allowed for the integration of more precise, on-site information, some of which had not been previously published, into the more general and universally available base of knowledge. The Lawrence Berkeley Laboratory (LBL), which employed a similar approach to carry out a study on carbon emissions from energy use in developing countries (LDCs) (see Sathaye and Ketoff 1991), coordinated the work of the researchers and provided scientific and institutional support for the F-7 participants. The U.S. Environmental Protection Agency (EPA) financed the Network's work.

The information contained in this report represents the results of the first phase of the F-7 project, which had the explicit aim of providing quantitative data on forestry-related carbon emissions in the F-7 countries. This report contains the results of the first phase of the research effort. The next stage of the process will involve an assessment of response options in the forestry sector and the economics of undertaking these measures.

The following scientists and institutions participated in the research:

Country	Expert	Institution
Brazil	Philip Fearnside	Departmento de Ecologia Instituto Nacional de Pesquisas de Amazonia Manaus-Amazonia
China	Xu Deying	Research Institute of Forestry Chinese Academy of Forestry Beijing
India	N.H. Ravindranath B.S. Somashekhar Madhav Gadgil	Centre for Ecological Sciences Indian Institute of Science Bangalore
Indonesia	Edy Brotoisworo	Institute of Ecology Padjadjaran University Bandung
Malaysia	Roslan Ismail Ismariah Ahmad Faizah Fakhruddin	Forest Research Institute Kepong Kuala Lumpur
Mexico	Omar Masera Cerutti María de Jesús Ordóñez Rodolfo Dirzo Minjarez	Centro de Ecología Universidad Nacional Autonoma de México Mexico City
Thailand	Somthawin Patanavanich Ladawan Atipanumpai	Thailand Development Research Institute Faculty of Forestry, Kasetsart University Bangkok
USA	Willy Makundi Jayant Sathaye	Energy and Environment Division Lawrence Berkeley Laboratory

The opinions expressed in this work are those of the authors and do not necessarily reflect those of the affiliated institutions or of the respective governments.

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PART 1: INDIA

CARBON FLOWS IN INDIAN FORESTS

N.H. Ravindranath, B.S. Somashekhar and
Madhav Gadgil

Centre for Ecological Sciences and ASTRA
Indian Institute of Science
Bangalore 560012
INDIA

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ABSTRACT

India's forests play a vital role in the global carbon cycle and make numerous contributions to the country's economic and environmental well-being. The forests offer an opportunity for sequestering carbon dioxide emitted from various anthropogenic activities. To date, however, little progress has been made towards quantifying the carbon emissions associated with the use of forests in India. This study attempts to estimate the carbon emissions and seqestration in these forests. Drawing from a series of satellite images from the 1980s and other recent research, this paper provides a detailed overview of India's forest sector, including the classification of forest lands, as well as extent, rates and causes of deforestation for the base year. Based on the above and other available data, this paper provides estimates of carbon storage, uptake and emissions in Indian forests for 1986 and presents two possible visions of emission profile in the year 2011. The study finds that while Indian forests generated about 64 million tonnes of carbon in the base year, the corresponding uptake from growing forests (plantations and secondary forests) was estimated at 69 million tonnes. The business-as-usual projection for 2011 forecasts that forestry emissions will increase by 56 percent over the 1986 level. The more optimistic picture of 2011 limits the increase in emissions to 10 percent of the base year value. The more favorable of the two long-term scenarios would increase carbon uptake threefold between 1986 and 2011 through the implementation of a series of measures which offer local, national and global benefits.

1. INTRODUCTION

Deforestation in the tropics has contributed to the rise in atmospheric concentration of carbon dioxide (CO_2). On the other hand, carbon sequestration by growing forests has been shown to bea cost-effective option for mitigating global climatic change (Andrasko 1990). In addition, bio-energy culled from forests and tree plantations can provide a renewable energy source to replace fossil fuels (Hall *et al.* 1991). Thus, developing a sustainable reliance on forest resources can help to avert the build up of greenhouse gases associated with the intensive use of oil, coal and other carbon-intensive energy sources. In developing countries like India, forests are important for a variety of other reasons, including: conserving biological diversity, sustainence of watersheds and meeting the diverse biomass needs of local communities.

There may not be any conflict regarding the role of forestry in achieving global, national and local objectives. In the context of global warming there is a need to clearly understand the contribution of the forestry sector to emissions of greenhouse gases, particularly CO_2, and to evaluate its potential role in coping with global warming. Several recent studies have attempted to estimate global carbon emissions from forests (Houghton 1991; Hao *et al.* 1990; Myers 1989), and the estimated annual carbon release lies between 1.5 - 3.6 gigatonnes of carbon (GtC). These uncertainties result from the difficulties associated with obtaining accurate data on rates of deforestation, the modes and purpose of forest conversion, the extent of forest degradation, carbon content in both standing biomass and soil in different forest types, the rate at which the carbon is released into the atmosphere and the extent and rate of rea-absorption by growing vegetation.

As the climate change debate advances, policy makers require more accurate information on emissions and sequestration in the forestry sector. For this reason, there is a need to study the carbon flow in forests at the country level as a necessary step in arriving at more reliable global estimates. This study aims at understanding the carbon flow in Indian forests and at evaluating their contribution to the atmospheric CO_2 build-up. It will also attempt to identify the factors that influence the carbon flow and to consider some policy options which can be implemented in the forestry sector for both local and global benefits. Specifically, the study aims at addressing the following:

1. To identify the area under different forest types and estimate both the standing and detrital biomass, and the total carbon storage in each forest type.

2. To estimate the extent and rate of deforestation and forest degradation, and to understand the local population's dependence on forests for meeting various biomass needs. This information will facilitate estimates of the levels of carbon release associated with various conversions;

3. To estimate the net carbon emissions from the forestry sector;

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6. To analyze some forestry strategies for promoting benefits to the environment and local communities.

The methodology is mainly based on the COPATH model developed by Makundi *et al.* (1991). However, several additions and modifications are incorporated into the model so as to be able to handle aspects unique to Indian forestry. Carbon flows in the Indian forest sector were estimated for the 1986 reference year.

2. LAND-USE PATTERNS IN INDIA

India, with a population of 843 million, has a geographic area of 328.8 million hectares (ha). As shown in Table 1 below, nearly half of the land area is under agricultural crops. Forests account for 22.8 percent of the land area. The share under various categories of use other than forests and crop lands account for 15.3 percent, or 50.3 million ha, of the total land area (Table 1). Most of this land is highly degraded and has a poor vegetation cover. About 15 percent of the land area is either barren and wasteland or is unclassified in terms of land use.

Table 1. Land-use patterns in India

Land Use	Area (10^6 ha)	percent of total area
Agriculture/area cropped	154.70	47.0
Forests (area officially recorded as forests)	75.18	22.9
Permanent pastures and other grazing land	12.15	3.7
Land under cultivable tree crop and groves	3.91	1.2
Cultivable wasteland	16.64	5.1
Land under other non-agricultural uses	17.53	5.3
Barren and wasteland	24.60	7.5
Area for which no records exist	24.09	7.3
Total	328.80	100.0

Source: Ministry of Environment and Forests, 1987

2.1. Forested area

Estimates of forested area in India have been highly contested in the past. However, with access to satellite imagery data, current estimates appear more certain (Table 2) (Ministry of

Table 2. Area under forests statewide (1981-83 and 1985-87) in 10^3 ha.

State/ Union territories	1987 Assessment based on imagery 1981-83	1989 Assessment based on imagery 1985-87	1989 Assessment Dense forest (Crown cover above 40%)	1989 Assessment Open forest (Crown cover 10% to 40%)	Mean net area deforested per year, 1982-86
Andhra Pradesh	5019.4	4791.1	2553.5	2197.1	57.075
Arunachal Pradesh	6050.0	6876.3	5427.2	1449.1	-
Assan	2638.5	2605.8	1668.8	937.0	8.200
Bihar	2874.8	2693.4	1341.2	1352.2	45.350
Goa (including Daman & Diu)	128.5	130.0	97.5	32.2	-
Gujart	1357.0	1167.0	525.9	599.9	47.500
Haryana	64.4	56.3	13.0	43.3	2.025
Hinachal Pradesh	1288.2	1337.7	710.0	627.7	-
Jammu & Kashmir	2088.0	2042.4	1082.4	960.0	11.400
Karnataka	3226.4	3210.0	2474.9	735.1	4.100
Kerala	1040.0	1014.7	831.2	183.7	6.325
Madhya Pradesh	12774.9	13319.1	9144.8	4174.3	-
Maharashtra	4741.6	4405.8	2617.7	1776.7	83.950
Manipur	1767.9	1788.5	506.0	1282.5	-
Meghalaya	1651.1	1569.0	342.7	1226.3	20.525
Mizoram	1909.2	1817.8	388.3	1429.5	22.850
Nagaland	1435.1	1435.6	463.2	972.4	-
Orissa	5316.3	4713.7	2756.1	1938.4	150.650
Punjab	76.6	116.1	9.7	106.4	-
Rajasthan	1247.8	1296.6	290.2	1006.4	-
Sikkim	283.9	312.4	241.0	71.4	-
Tamilnadu	1838.0	1771.5	975.9	790.9	16.625
Tripura	574.3	532.5	121.4	411.1	10.450
Uttara Pradesh	3144.3	3384.4	2263.2	1121.2	-
West Bengal	881.1	839.4	333.2	295.3	10.425
Andanan & Nicobar	760.3	762.4	651.8	13.3	0.800
Other territories	265.0	23.5	16.2	7.5	-
TOTAL	**64203.9**	**64013.0**	**37847.0**	**25740.9**	**498.250**

Source: Ministry of Environment and Forests, 1989.

Environment and Forests 1990).[1] According to a recent assessment (1985-87), 64.01 million ha, or 19.5 percent of India's geographic area, is under forests with over 10 percent crown cover. The total area under dense forest (with over 40 percent crown cover) is only 37.8 million ha, or 11.5 percent of India's geographic area. The forested area includes natural forests, forest plantations and plantation crops, like rubber and fruit trees. Forests and plantation areas with less than 10 percent crown cover do not fall under the definition of "forests" used in this study.

2.2. Forest types

Indian forests have been classified into four major groups based on climate and location (Ministry of Environment and Forests 1987): tropical forests; montane subtropical forests; montane temperate forests; and alpine forests. Each of these major groups is further classified into different forest types based on vegetation type. The area under each forest type is given in Table 3. Tropical moist deciduous and tropical dry deciduous forests dominate, accounting for 36 and 28.2 percent of the total forest area respectively.

2.3. Deforested area

The most commonly quoted figure for the area deforested annually in India is 0.4 million ha (Myers 1989). It is not clear how this figure was estimated or whether it takes into account the area brought under afforestation each year. In this study we used satellite imagery taken at two different periods four years apart to provide estimates of the changes in the forested area (including the area brought under tree plantations) (Table 2). The total area under forests declined by 190,900 ha during the four-year period. Thus, the annual loss of forest area net of afforestation and reforestation is 47,725 ha as compared to the 0.4 million ha quoted in the literature (Myers, 1989). The year of reference for the estimates in this study is 1986, (the mid-year of the 1985-87 imagery assessment). The following procedure was adopted for estimating the extent of the deforested area.

All the states where there was a decline in area under forest between the years 1982 and 1986 are considered. The net decline in forest area was estimated and then divided by four to obtain the mean annual area deforested in each state.

Net area deforested in a year =

$$\sum_{i-1}^{27} (A82_i - A86_i)/4$$

Only for those states where A 82_i > A 86_i.
A 82_i = Area under forest in 1982 assessment in State "i"
A 86_i = Area under forest in 1986 assessment of State "i"
i = 1 to 27 states and union territories.

The sum of the area in all such states is considered as the net area deforested during the reference year 1986. The area brought under forest plantations is included as forest area.

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[1] The satellite assessment carried out during 1981-83 and 1985-87 was the basis for the estimates of changes in the forest area.

Table 3. Area under different forest types, aread deforested by forest type, conversion of deforested area for different purpses and maximum releasable carbon, 1986

Sl. No.	Forest Type	Area occupied (10³ ha)	Area deforested (10³ ha)	Conversion rate (% of the total deforested area)				Maximum releasable carbon from the vegetation in deforested areas (MtC)
				Agri.	Pasture	Clear cut	Sel.cut	
1.	Tropical wet evergreen	5289	7.48	44.8	24.72	19.88	10.57	1.00
2.	Tropical semi evergreen	2576	16.77	44.4	22.3	22.4	10.9	1.77
3.	Tropical moist deciduous	23054	240.45	68.0	16.3	12.0	3.7	20.57
4.	Littoral and swamp	384	5.35	89.5	6.2	3.3	1.0	0.25
5.	Tropical dry deciduous	18083	172.49	67.8	18.1	11.0	3.1	3.43
6.	Tropical thorn	1573	25.81	29.9	46.0	21.0	3.1	0.20
7.	Tropical dry evergreen	134	1.36	31.4	14.5	52.2	1.9	0.01
8.	Subtropical broad leaved hill	268	2.57	80.5	8.7	9.1	1.7	0.05
9.	Subtropical pine	4567	3.27	34.4	28.7	29.2	7.7	0.15
10.	Subtropical dry evergreen	1201	13.68	8.5	85.4	6.0	-	0.32
11.	Montane wet temperate	2582	.89	49.9	13.7	19.6	16.8	0.05
12.	Himalayan moist temperate	2243	6.09	20.8	52.8	22.6	3.8	0.72
13.	Himalayan dry temperate	30	.17	-	100.0	-	-	0.00
14.	Subalpine and alpine	2028	1.87	26.3	57.2	10.7	5.8	0.56
	TOTAL	64013	498.25	62.8	21.3	12.2	3.7	28.59

Source: Assembled from Ministry of Environment and Forest , State of Forest Report 1987 & 1989.

The net area deforested in each state and the total marginal deforestation is given in the last column of Table 2. Thus, the net area deforested in the reference year is estimated to be 498,250 ha. Because this area only covers the states where forest cover declined between the two assessments, this estimate may under-estimate deforestation of primary forests. However, the states where the forest area increased between 1982 and 1986 were included in the estimation of carbon uptake.

2.4. Conversion of deforested area for different purposes

Details on the conversion of deforested areas for different uses disaggregated for individual states are available for the period 1951-75 (Central Forestry Commission 1981). Using this state-level data, it is possible to obtain details on the different purposes for which each forest type is being converted. The same proportions of total deforested area diverted for different purposes between 1951 and 1975 (Table 4) are used for the reference year of this study. In this study, forest conversions fall into four broad categories: agriculture, pasture, clear cutting and selective cutting. The transformation of forested areas to river valley projects and roads is considered clear cutting, conversion to crop lands is designated as agriculture, conversion for industrial lands is selective cutting and conversion to other purposes is considered as conversion to pasture.

By considering the rates of conversion of deforested area to different purposes at the state level and the area under different forest types in that state, the proportion of deforested area diverted to each of the four purposes is calculated for each forest type at the national level for application in the COPATH model. The proportions are given in Table 3. At the national level, conversion to agriculture dominated all other conversion purposes, accounting for 62.6 percent of the area deforested, followed by pasture and clear cutting.

3. BIOMASS DEMANDS ON INDIAN FORESTS

The biomass demands on forests are considered under three headings: combustion, long-term use and short-term use. It is very difficult to estimate the quantity of different types of biomass removed from different forest types as well as the contribution of the deforested area in meeting various biomass demands. Thus, the current consumption levels as given in Tables 5 and 6 are used to estimate and forecast the demand for woodfuel and biomass for short- and long-term.

3.1. Combustion (firewood)

Firewood is the dominant source of fuel for cooking in rural areas (95 percent of households depend on biomass in the form of firewood, crop residue and/or dung) and is a less important energy source in urban areas (used in about 16 percent of households in urban areas; Reddy and Reddy 1983). According to the (Ministry of Environment and Forests 1987), the total firewood consumption in 1987 was 157 million tonnes (mt), or 286 kilograms (kgs)/annum per capita. This figure does not include crop residues and dung. The different sources of firewood are forests, village trees, shrubs and weeds (e.g., *Prosopis juliflora*) and plantation tree crops (e.g., coconut, arecanut tea and rubber). The combustion of fuelwood leads to the release of CO_2. Firewood in the form of twigs and branches, if harvested in a sustainable way, will not make any net CO_2 contribution. However, if trees and branches are felled for fuel purposes in a non-sustainable way and burnt, there are net emissions of CO_2.

Table 4. Diversion of forest area for various purposes

Causes	Conversion taken in the present study	Area lost during 1951-75 (10³ ha)	% of area lost to total (%)	Area lost/year between 1981-83 & 1985-87 (10³ ha)	% lost to the total forest area (%)
Agriculture	Agriculture	2520	0.625	313.02	0.4875
River valley projects and roads	Clear Cutting	479 57	0.119 0.014	60.61	0.0944
Industries	Selective cutting	168	0.042	18.53	0.0289
Miscellaneous purposes	Pasture	803	0.199	106.08	0.1652
Total		4028	1.000	498.24	0.7750

Note: Since statewide details of deforestation for various purposes were available only for the years 1951-75 (Central Forestry Commission 1981) the same proportions have been used as the basis for allocating the area deforested for various purposes in different states during 1981-83 and 1985-87.

Table 5. Firewood, crop residues and dung as fuel (10⁶ tonnes)

Year	Fuelwood	Crop residue	Dung
1953-54[a]	86.3	26.4	46.4
1960-61[a]	99.6	30.6	64.5
1965-66[a]	109.3	33.6	59.9
1970-71[a]	117.9	36.3	64.6
1975-76[a]	133.1	41.0	73.0
1986[b]	157	-	-
2011[c]	190.8	-	-

Sources: a. Department of Environment, Forests and Wildlife 1986
b. Forest Survey of India 1988
c. Projected Figure

Note: Projected population for 2011 is 1287.18 million, calculated using a decimal growth rate of 23.50 between 1981-91 (74.3% rural and 25.7% urban). Entire rural and 16.1% (Reddy and Reddy 1989) of urban people are dependent on fuelwood. Using a demand of 286 kgs. wood/capita/year (obtained by dividing 157 mt by the size of the population using firewood) and a 33 percent savings due to improved efficiency, a value of per capita wood requirement of 189 kgs/year is considered.

Table 6. Long-term and short-term use category demand (10^4 m³)

Description	1986[a]	2011[b] projections
For long-term use:		
Plywood and veneer	1.71	
Fibreboard, Particle and chipboard	0.23	
Sports goods	0.03	
Railway sleepers	0.50	
Agricultural implements bullock carts and temporary rural constructions	5.43	
Furniture and panels	0.36	
Housing	2.50	
Long-term total	13.76	25.85
For short-term use:		
Pulp and paper	6.57	
Matches	0.44	
Packaging	6.81	
Short-term total	13.82	25.96
Total	27.58	51.81

Sources: a. Forestry Survey of India 1988.
b. Timber demand: Population and demand ratio of 1981 was calculated. This ratio was multiplied with the projected population of 2011 to estimate the projected consumption assuming current rate of growth in demand.

It is difficult to estimate what proportion of the 157 mt of firewood comes from forests and, further, how much of the total is harvested in a non-sustainable manner. This study assumes that firewood comes from a number of sources including: clear felling for development projects, etc., the culling of wood resources from existing forests and shifting cultivation. For details on the calculations see Appendix I.

3.2. Short-term use

Wood used in pulp, paper, packaging, the match industry, etc. is considered as short-term use. The demand was officially estimated to be 13.82 million cubic meters (m³) for the reference year (Ministry of Environment and Forests 1987). The sources for obtaining timber for short-term uses are forests and tree plantations.

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3.3. Long-term use

Long-term use consists of timber use for housing, agricultural implements, plywood, mining pit props, railway sleepers, etc. The total long-term use assumed for the reference year (based on Ministry of Environment and Forest 1987) was 13.76 million m^3. The sources of timber for long-term use are forests (particularly as a source of timber for various structural materials, plywood and mining pit props), tree plantations and trees in village ecosystems (which are not considered forests).

3.4. Standing biomass in forests

Data on standing biomass for different forest types was obtained from the literature (references and values given in Appendix II). The maximum estimates of standing biomass recorded for each forest type is used in this study, under the assumption that it has 100 percent crown cover.

the State of Forest Report 1989 gives the crown cover of forests in each state. Tiwwari and Singh (1987) have provided estimates of biomass under five different levels of crown cover for some forest types. This information was extrapolated to cover other forest types. Using the data on standing forest biomass under full crown cover and the estimated mean crown cover for each forest type, the total standing biomass was calculated for each forest type (Table 7). The total standing biomass in Indian forests is estimated to be 8357.9 mt with a mean per ha standing biomass of 130.5 t.

4. HISTORICAL AND CURRENT TRENDS IN CARBON FLUX

4.1. Carbon storage

Carbon storage in the vegetation and soil is given in Table 8. The average carbon content of the biomass is estimated to be 50 percent. The estimates of carbon storage in forest soil are based on the soil organic carbon content in the soils of different forest types as stated in the literature (references and values are given in Appendix III).

The total carbon stored in Indian forests is estimated to be 9578 mt, of which vegetation and soil account for 43.6 and 56.4 percent respectively.

4.2. Carbon uptake in forests

In order to calculate the net carbon release, the carbon uptake and the carbon storage in forests, perennial plantation crops (like rubber, apple, tea, coffee, coconut) and tree plantations (like *Eucalyptus*, *Casuarina equisetifolia*) must be considered.

Table 7. Production and Standing Biomass in Forests, 1986.

Forest Type	Area occupied (10³ ha)	Standing Biomass[a,b] (t/ha)	Average crown cover[a] (%)	Total standing biomass (10⁶ t)
1. Tropical wet evergreen	5289.3	607.7		1496.55
2. Tropical semi evergreen	2575.7	468.0	0.4782	576.46
3. Tropical moist deciduous	23054.7	409.3	0.4259	4018.56
4. Littoral and swamp	383.4	213.8	0.4426	36.30
5. Tropical dry deciduous	18083.3	93.8	0.4313	731.51
6. Tropical thorn	1573.0	40.0	0.3989	25.10
7. Tropical dry evergreen	134.2	40.0	0.4156	2.23
8. Subtropical broad leaved hill	267.8	108.7	0.3818	11.11
9. Subtropical pine	4567.5	210.8	0.4581	441.10
10. Subtropical dry evergreen	1201.0	159.7	0.2901	55.63
11. Montane wet temperate	2581.9	237.67	0.4875	299.15
12. Himalayan moist temperate	2242.8	562.2	0.4263	537.50
13. Himalayan dry temperate	30.5	169.1	0.4079	2.10
14. Subalpine and alpine	2027.7	127.4	0.4822	124.56
TOTAL	64013.0	--	--	8357.90

Notes: a. Average crown cover and standing biomass was calculated using data on standing biomass under lower canopy from Tiwari and Singh (1987).
b. See Appendix II for references on standing biomass.

Table 8. Carbon flows: current and future scenarios (million tons)

Carbon Flux	1986	2011 (at current rates)	2011 (at favorable rates)
CARBON STORAGE:			
Forest			
- vegetation	4178.95	4178.95	4178.95
- soil	5399.33	5399.33	5399.33
Plantation	—	850.50	1181.25
Perennials	—	75.00	3000.00
Natural regeneration	—	—	1096.87
Total	9578.28	10503.78	14856.40
CARBON RELEASE			
Shifting cultivation	1.56	1.560	1.560
Combustion	31.97	61.660	31.850
Past long-term use	1.38	4.610	4.610
Past short-term use	3.10	5.908	5.908
Current short-term use	2.84	2.954	2.954
Release from soil	3.91	3.910	3.990
Biomass decomposition (surface and underground)	18.82	18.820	18.820
Total	63.58	99.422	69.692
CARBON UPTAKE			
Forest	68.87	68.870	68.870
Natural regeneration	—	0.225	9.375
Afforestation (short rotation forestry)	—	27.000	37.500
Reforestation	—	—	75.000
Total	68.87	96.095	190.745

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Only in mature or climax forests is all the gross primary productivity of biomass and living tissue either used up in respiration or returned to the soil as litter. Therefore, there is no net addition to the standing biomass in these forests. At all other stages of succession, there is a net addition to the standing biomass (carbon accumulation). Large tracts of forests in India have been subjected to anthropogenic factors over the centuries; thus, the nation's forests are at various stages of succession. For example, the 64.01 million ha of forest considered in the study include a cumulative area of 11.4 million ha afforested between 1952 to 1986 (Ministry of Environment and Forests 1989) and several plantation crops like rubber coffe and tea.

The net annual accumulation for the reference year is calculated using data on the net primary productivity (NPP), or mean annual increment (MAI), and standing biomass from various studies (See Appendix IV for References). Only the accumulation of biomass in the main trunk and large branches is considered for calculating carbon uptake. Productivity in the form of leaf litter and micro-wood litter is not considered, as it is likely to end up decomposing. The net accumulation of woody biomass considered in the study lies in the range of 3.28 to 8.84 t/ha/year. Based on the above figures, the net accumulation of carbon in Indian forests is estimated to be 68.87 mt for the year 1986 (Table 8).

4.3. Carbon emissions

Carbon emissions from forests stem from deforested areas as well as from unrecorded depletion plus degradation in existing forest areas. The carbon emission values are given in Table 9. The total carbon emissions from all the natural and anthropogenic factors affecting the forest are estimated to be 63.58 mt. The following section disaggregates this total according to four major sources.

4.3.1. Carbon emissions from clear-felled forests

This study assumes that the firewood component of annual removal from forests comes from deforested areas (Ministry of Environment and Forests 1987). Thus, 13.5 mt of carbon is estimated to be released from combustion in clear felled areas. In the case of carbon release from long-term use, this work assumes that timber dedicated to long-term purposes has a life span of 30 years. Based on this assessment, the carbon estimate for the reference year includes releases from the timber used for long-term products 30 years prior to the reference year. Due to this inclusion, the emissions in the reference year will not equal the stored carbon in the deforested vegetation For this reason, there is no balance between the total biomass from felled areas (28.59 mt, see Table 3) and the total carbon released from deforested areas (27.65 mt, see Table 9). Regarding short-term use, the quantity of wood or timber used is expected to last for only three years. Accordingly, the biomass used for short-term purposes three years prior to the base year is assumed to release carbon in the base year; in addition, one-third of the carbon devoted to short-term products in the reference year is assumed to be released during that same year. Releases of carbon from soil was calculated based on Ayanaba *et al.* (1976), while biomass decomposition was calculated based on values by FRI (1970).

1 - 13

Table 9. Carbon emissions from forests, 1986

End use	From clear felled area for					From the NPP in the forest	From degradation of existing stock	From shifting cultivation	Total
	Agriculture	Pasture	Clear cutting	Selective cutting	Total				
1. Combustion	8.15	2.92	2.03	0.40	13.50	10.75	7.72	1.56	33.53
2. Past LT use	—	—	1.38	—	1.38	—	—	—	1.38
3. Past ST use	—	—	1.30	0.25	3.10	—	—	—	3.10
4. Current ST	—	—	1.30	0.25	1.55	—	1.29	—	2.84
Root decomposition	—	—	0.26	0.05	0.21	—	—	—	0.21
Soil	2.41	0.83	0.50	0.17	3.91	—	—	—	3.91
Other surface decomposition	—	—	—	—	4.00	10.75	3.86	—	18.61
Total	10.56	3.75	6.67	1.12	27.65	21.50	12.87	1.56	63.58

Note: LT = Long term, ST = Short term, NPP = Net Primary Productivity

The total carbon released from various conversions (like combustion, short- and long-term use and decomposition) is estimated to be 27.65 mt. (Table 9).

4.3.2. Carbon emissions from current year's production

Total NPP was obtained from biomass studies for different forest types (Appendix IV). Out of the total net primary productivity of 137.7 mt of carbon, 69 percent assumably accumulates in bole and big branches for long-term storage. Of the remaining current year's production, 50 percent is considered to be used as fuelwood and the remaining 50 percent is assumed to be left for decomposition.

The total carbon released from the reference year's production in forests for combustion and decomposition is estimated to be 21.5 mt. (Tabble 9).

4.3.3. Carbon emissions from forest degradation and illegal removal

In addition to the carbon released from deforestation or clear felling, the degradation of existing forests also contributes to the release of carbon. Degradation can result from grazing, fires, diseases and pest attacks, illegal removal of timber and over-harvesting for fuelwood. Several studies site evidence of these activities (Brown et al. 1991; Flint and Richards 1991). The analysis carried out by Flint and Richards (1991) for southern Asia (including northern parts of India) indicates a degradation ratio (the ratio of biomass lost to area lost relative to the initial biomass) of 1.54 for the period 1950-80. One interpretation according to Houghton (1991) is that for every tonne of carbon released into the atmosphere through deforestation, an additional 0.54 t of carbon is released from degradation of the standing forests. Thus, out of the total carbon emission of 27.65 mt from deforestation, the amount emitted due to degradation factors is 15.0 mt. Out of this total, about half is assumed to be used as fuelwood (7.72 mt), and the balance is equally divided between decomposition (3.86 mt) and short term use (3.86 mt).

The carbon released due to degradation and unaccounted for removal is estimated to be 12.87 mt for the reference year.

4.3.4. Carbon emissions from shifting cultivation

About 0.99 million ha are annually subjected to shifting cultivation (Ministry of Environment and Forests 1987). The fallow period is continually shortened. Considering the shortened fallow periods, net carbon emissions are estimated at 1.56 mt (Table 9). This total accounts for new accumulation in areas left fallow and degradation or burning of new areas.

4.4. Net carbon releases

At the global level, deforestation is estimated to contribute 1.5-3.6 Gt of carbon annually (Houghton 1990). It is not clear whether the carbon sequestered in the existing forests and in the new forest plantations each year is considered in the various global estimates. For example,

Myers (1989) considers a deforestation rate of 0.4 million ha annually for India and, correspondingly, 41 mt of carbon is estimated to be released to the atmosphere; Myers' estimate does not account for sequestered carbon. Ahuja (1990) has made an estimate of the net carbon emissions, based on values of global flux of 0.7 pentagrams (pg) of carbon (Lashof and Tirpak 1989) and the assumption that India's share in global deforestation is 20.2 tetragrams (tg)/year. Because Indian forestry is considered as an ecosystem, what is of consequence to climate change is the net carbon release after accounting for both annual emissions from deforestation and forest degradation and total long-term sequestration (or the annual accumulation resulting from net primary productivity in bole and large branches) in forests and tree plantations.

When the net carbon flow in the Indian forest ecosystem is considered (carbon uptake - carbon release), a marginal net carbon sequestration of 5.29 mt results for the reference year (Table 8). This figure, however, does not include carbon emitted in the base year due to deforestation-related activities in previous years.

4.5. Explanation for no net carbon releases

India has witnessed a surge in efforts aimed at protecting forest resources and afforesting exploited forest regions over the past two decades. As a result, carbon uptake from India's forestry sector has increased. Based on an analysis of these trends, this study estimates that the contribution of Indian forests to the atmospheric build up of CO_2 is far less than previously estimated; in fact, Indian forests may sequester more carbon than they emit. The following factors have all served to reduce net emissions by the forestry sector:

(i)   The Forest Conservation Act of 1980 prescribes that no land should be alienated from the control of state forest departments without the consent of the central government. In the Indian context, obtaining permission from the central government is a very difficult task, as is reflected in the official statistics which indicate an essential halt to the process of deforestation.

(ii)   Beginning with the Fifth Five-Year Plan of 1975-80, it became compulsory for all major development projects to carefully prepare an environmental impact statement and to provide for compensatory afforestation in the event of the loss of any forest cover.

(iii)   Beginning in the late 1970s, the high levels of subsidies enjoyed by the forest-based industries have been gradually reduced, thereby helping to motivate the industries to use forest resources more carefully.

(iv)   Since the 1970s, Indian farmers have been encouraged to produce tree crops. In addition, many industries and farmers have developed healthy links with one another in order to fulfill the needs of forest-based industries.

(v)   Local tribes and villages increasingly have been given an economic stake in the well-being of local forest resources. The first example of this trend were the Village Forest

Protection Committees of West Bengal. The response has been most encouraging. Other states like Haryana and Gujarat have initiated measures to create community-based management systems at the village level for involving the local people in sustainable use and restoration of the local forest resources.

(vi)   Over the past two decades, many state governments have decentralized their political decision-making (e.g., West Bengal in the late 1970s and Karnataka in the mid-1980s). As a result, village and district level political authorities have been established that are far more motivated to ensure the prudent use of local resources -- including forest resources. Other states are expected to follow suit in decentralizing power, thus creating more favorable conditions for better management of forest resources. Further, the National Wastelands Development Board, created in 1985, has taken novel initiatives in decentralizing integrated planning in the use of natural resources and is spearheading efforts to restore the vegetation cover on vast stretches of degraded lands by meaningfully involving the local people.

(vii)   India has launched a very large afforestation program. The area afforested in recent years is given below (Ministry of Environment and Forests 1989a).

Year	Area Afforested
1985-86	1.51 million ha
1986-87	1.76 million ha
1987-88	1.77 million ha
1988-89	2.12 million ha

The above data indicates that large areas have been brought under tree vegetation. These new forest areas were priorly deforested or degraded community lands, or degraded private lands. Studies of plantations raised by the forest department as well as farmers have shown a productivity in the range of 1.3 to 8.3 t/ha/yr (Ravindranath et al., 1992). This substantial biomass productivity has contributed significantly to the increased uptake by growing forests in India.

(viii)   Above all, the strong environmental movements in different parts of the country, with the very active support of the mass media, have contributed significantly to reducing large-scale legal and illegal conversions of forest land.

(ix)   Biomass fuel conservation programs like biogas utilization and the use of efficient stoves are being implemented in all the states. Such programs lead to diminished levels of biomass-related deforestation.

(x)   A large section of the forest with less than 40 percent crown cover is under successional and is therefore actively sequestering carbon, albeit at a reduced rate than plantations.

5. FUTURE SCENARIOS OF CARBON FLOW

To provide an estimate of the possible levels of carbon emissions in the future, this section presents two medium-term scenarios for the year 2011. The carbon flux values for the scenarios are given in Table 8.

5.1. Assumptions

Scenario I: In this scenario, current rates of deforestation, afforestation, firewood consumption, productivity, long-term and short-term timber uses, etc. are maintained from 1986-2011. The area under plantations and perennials (coffee, tea, rubber, etc.) continues to increase at current rates.

Scenario II: This more favourable scenario assumes the following changes:

- Short-term forestry (firewood and soft wood) increases by 2.5 million ha/year.
- Long-term forestry rises by 2 million ha/year.
- Area to be brought under natural regeneration expands by 1 million ha/year.
- Productivity of plantations rises by 3 t of carbon/ha/year.
- Productivity of land under natural regeneration grows by 0.75 t of carbon/ha/year.
- Number of biogas plants for cooking increases by 0.5 million/year.
- All houses gain access to efficient cook stoves (at a savings of 33 percent in fuel use).
- The area under forests remains unchanged, but the area under perennials (like rubber, coconut, tea, coffee) and forest plantations increases at current rates.

5.2. Results

Scenario I: The business-as-usual scenario for the year 2011 shows that with an increase in population there would be a relative increase in demand for biomass from forests and plantations. If the current proportion of demand for firewood and timber being met from the forests is assumed for 2011, Indian forests would produce 99.42 mt of carbon that year. Thus, the business-as-usual scenario is not environmentally sound given a large increase in the population.

Such a scenario is not likely to be realized as a result of several factors:

(i) Biomass fuel conservation programs are being implemented rigorously.

(ii) The area afforested annually is likely to go up from the assumed rate of 1.8 million ha. Even farmers are likely to shift from marginal cropping to tree cropping.

(iii) There is likely to be a shift from wood to other materials, like steel, plastics and reinforced cement concrete, for structural purposes and packaging.

(iv)   The increased participation of communities in the management of forests and community plantations should lead to sustainable harvests.

Scenario II: The favorable assumptions made for this scenario do not appear unrealistic. All the assumptions are plausible. Under this scenario, Indian forests sequester 121.05 mt of carbon. This scenario highlights the great contribution the forestry sector can potentially make at both the local and global level.

6. CONCLUSION: FORESTRY FOR GLOBAL AND LOCAL BENEFITS

This study estimates that forest land conversions in India generated 63.58 million tonnes of carbon emissions in 1986. Agriculture accounted for the largest share of all emissions from clear-felled areas, followed by clear cutting. According to the estimate, carbon uptakes for forest lands reached 68.87 million tonnes of carbon that year

One long-term scenarios indicates that if carbon releases were to continue to grow at current rates for the 25 years following the base year, carbon releases would rise by 56 percent of the 1986 value. In contrast, a more optimistic scenario for the same time span suggests that India would witness a far smaller increase in emissions by 2011, equalling only 10 percent of the base year value. The most striking difference between the two long-term scenarios is the variation in carbon uptake for 2011. In the favorable scenario, carbon uptake is almost three times higher in 2011 than in 1986 and just under twice as high as in the business-as-usual scenario for 2011.

This study seeks to illustrate the extent of the activities underway that have served to increase carbon uptake and stem previously high rates of deforestation. As a result of these efforts, carbon uptake appears to have risen to levels high enough to offset emissions resulting from current deforestation. If this finding is accurate, India may not be adding to the build up of CO_2 in the global atmosphere.

The favorable scenario (II) shows the large potential for increasing carbon sequestration. The primary goals of pursuing these options in India would be to promote biological diversity, watershed development and sustainable biomass use. Carbon sequestration with its global benefits would be a very important outcome of any good forest strategy. It is possible to promote a forestry strategy which provides local as well as global benefits. Such a strategy would involve the following important factors:

1.   All the wood required for commercial purposes (mainly for short-term use) should be met from privately owned degraded crop lands. Appropriate incentives have to be provided to farmers to encourage them to shift from marginal-cropping to tree-farming on such degraded crop lands.

2.   The subsistence biomass needs of tribal and rural populations could be met from a network of community lands near their habitats in a sustainable way.

3. The reserve forest lands (including the degraded forest areas) should be brought under a regime of production restricted to non-wood forest products for employment and income generation to tribal and rural communities.

4. The local communities must be empowered with the ability to sustainably manage the common lands as well as the reserved forests.

5. Biomass fuel conservation programs must be implemented more vigorously. Biomass fuel conservation could lead to a significant net reduction in the release of greenhouse gases.

6. The potential for developing bio-energy technologies and options for power generation at the decentralized level to meet village energy needs in a sustainable way should be explored. The substitution of fossil-fuel based energy with bio-energy systems would lead to a net reduction in greenhouse gases (Hall *et al.* 1991).

All of these strategies have a strong bias towards assuring local benefits and would lead to increased storage of carbon in the existing forests and to new sequestration of carbon in currently degraded areas. As a result, a significant amount of carbon would be sequestered for global benefits. The economic, social and political implications of such a strategy have to be analyzed carefully.

APPENDIX I: SOURCES OF FIREWOOD

1. From deforestation

This study assumes that all the recorded production of firewood (27 mt) came from the official estimates of deforested area (Ministry of Environment and Forests, 1988); the remaining 130 mt of firewood came from other sources. Of the total recorded fuelwood produced, 17.7 mt came from the area deforested for agriculture, while 5.3 mt, 3.4 mt and 0.6 mt came from the areas deforested for pasture, clear cutting and selective cutting respectively.

2. From the net primary productivity (NPP) of woody biomass in the forest

Biomass accumulated annually in the forest through NPP is 137.7 mt. Studies (Rai, 1981; Rana 1985; Sharma *et al.* 1990) have shown that about 48-74 percent of the NPP accumulates in the bole. Thus, about 94.7 mt remain in the bole fraction and about 43 mt are available in the form of small twigs and branches. Out of the latter share, only 50 percent (21.5 mt) is considered extractable firewood; the remaining micro-litter is likely to end up decomposing (Table 9).

3. From the degradation of existing stock

At a degradation ratio of 1.54, the biomass that would come from degraded sources is estimated to be 30.88 mt out of which 15.44 mt (50%) is available as firewood and the remaining part may end up partly for short-term or long-term use and partly for decomposition (Table 9).

4. From shifting cultivation

From an annual area of 0.99 million ha under shifting cultivation, an amount of wood equivalent to 3.12 mt is assumed to be burnt (Table 9).

Altogether firewood from forests totals 67.6 mt. The rest of the firewood (89.94 m.t.) may come from (i) trees in the village ecosystems, (ii) shrubs like *Prosopis juliflora*, *Lantana camera* and *Cassia auriculata*, and (iii) plantation crops like tea, coffee, rubber and coconut.

APPENDIX II: MAXIMUM STANDING BIOMASS OF DIFFERENT FOREST TYPES

	Forest type	Standing biomass (t/ha)	Reference
1.	Trop. wet evergreen	607.7	Rai 1981
2.	Trop. semi evergreen	468.0	Swamy 1989
3.	Trop. moist deciduous	409.3	Swamy 1989
4.	Littoral & swamp	213.8	Singh 1989
5.	Trop. dry deciduous	93.8	Singh 1990
6.	Trop. thorn[1]	40.0	---
7.	Trop. dry evergreen[2]	40.0	---
8.	Sub trop. broad-leaved hill	108.7	Toky & Ramakrishnan 1982
9.	Sub trop. pine	210.8	Chaturvedi & Singh 1984
10.	Sub trop dry evergreen[3]	159.7	---
11.	Montane wet temp.	237.67	Yadava 1986
12.	Himalayan moist temp.	562.2	Rana 1985
13.	Himalayan dry temp[4]	169.1	---
14-16.	Subalpine & alpine	127.4	Yoda 1968

Notes: 1. Tropical thorn forests were assumed to have 40 percent crown cover of tropical dry deciduous forests as they appear along side the tropical dry deciduous forests; 40 percent of the standing biomass of deciduous forests vere assumed to be the standing biomass of tropical thorn forests, which is 37.52 t/ha further rounded off to 40 t/ha.

2. Same as tropical thorn forests.

3. Since it occurs between subtropical pine and tropical dry deciduous forests a mid value between the standing biomass values of these two forests types is taken.

4. Since it occurs between subtropical pine and sub alpine forests, a mid value between the standing biomass values of these two forest types is taken.

APPENDIX III: SOIL CARBON IN DIFFERENT FOREST TYPES

Forest Type		Soil carbon (t/ha)	Reference
1. Tropical wet evergreen		125.19	Singh 1968
		140.4	Rajamannar & Krishna moorthy 1978
	Mean	132.79	
2. Tropical semievergreen		152.9	Singh 1968
		190.6	Swamy 1989
	Mean	171.75	
3. Tropical moist deciduous		40.17	Das 1975
		42.12	Rajamannar & Krishna moorthy 1978
		67.08	Banerjee et al. 1986
		79.17	Jha et al. 1979
	Mean	57.135	
4. Littoral & swamp		26.52	
		29.25	Sahoo et al. 1989
		34.90	
	Mean	30.22	
5. Tropical dry deciduous		51.87	Kumar et al. 1987
		54.21	Sachan et al. 1980
		61.16	Singh et al. 1990
		64.74	Singhal & Sharma 1983
	Mean	57.99	
6. Tropical thorn		44.0	(1)
7. Tropical dry evergreen		33.0	(2)

Notes: 1. Since no studies were available it was assumed that soil carbon in this forest type would be equivalent to 75% of soil carbon of tropical dry deciduous forests.

2. Since no studies were available, it was assumed that soil in this forest would contain carbon equivalent to 75% of soil carbon of tropical thorn forest.

Forest Type		Soil carbon (t/ha)	Reference
8. Subtropical broad-leaved hill		94.37	Mandal *et al.* 1990
		111.93	Banerjee *et al.* 1986
		119.70	Mandal *et al.* 1990
	Mean	108.66	
9. Subtropical pine		73.9	Singh *et al.* 1990
		85.0	Sachan *et al.* 1981
		88.14	---
		114.66	Nair & Chamuah 1988
	Mean	90.425	
10. Subtropical dry evergreen		33.0	(1)
11. Montane wet temperate		170.0	Singh 1990
		206.7	Banerjee 1986
	Mean	188.35	
12. Himalayan moist		132.6	Banerjee & Badola 1980
		132.6	Sachan *et al.* 1981
		144.3	Rawat & Kumar 1989
		152.1	Dhar & Jha 1983
	Mean	140.4	
13. Himalayan dry temperate		71.4	Singh & Gupta 1990
		78.0	Negi & Ghosh 1980
	Mean	74.7	
14-16. Sub alpine and alpine		255.0	Das *et al.* 1988
		259.7	Datta *et al.* 1989
		259.7	Gangopadhyaya 1990
	Mean	258.13	

Notes: 1. Since no studies were available, it was assumed that soil carbon content would be similar to a value equivalent to 75 percent of that of tropical dry evergreen forests.

APPENDIX IV: NET PRIMARY PRODUCTIVITY (NPP) in t/ha/yr.

Forest Type	Description of Forest type	Standing Biomass	NPP of Stem, branch & twiggs	NPP as % of St. Biomass	Reference	% of Forest Cover
1.	Tropical wet Evergreen	607.7	7.806	1.28	Rai, 1981	8
3.	Tropical moist deciduous	588.9	8.59	1.46	Rana, 1985	36
5	Tropical dry deciduous	115.5	3.28	2.84	Sharma *et al.*, 1990	28
9	Sub tropical pine	198.96	4.12	2.07	Rana, 1985	7
12	Himalayan moist temperate	432.8	8.98	2.07	Rana, 1985	3

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PART 2: CHINA

FOREST-RELATED CO$_2$ EMISSIONS IN CHINA: CURRENT ESTIMATES AND LONG-TERM FORECAST

Xu Deying

Research Institute of Forestry
Chinese Academy of Forestry
Beijing, China

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ABSTRACT

Despite its extensive forested areas, China has largely been omitted from discussions of deforestation and global climate change, because most of her forests are non-tropical. However, the social-economic factors which drive deforestation in the tropical regions are also active in China. In an effort to study the role of Chinese forests in global climate change, this paper presents information on the current state of China's forests, identifying the types of forests in China, describing the country's forest management policies and calculating recent rates of deforestation and afforestation. This study estimates that China's forests emitted 73.7 million tonnes of carbon in 1988. However, carbon uptake from forests was far higher that year, leading to a net uptake of 32.7 million tonnes. Six long-term scenarios for forest-related CO_2 flux in China are presented in intervals up to the year 2050. Each scenario is based on different assumptions about certain key parameters (e.g., annual increases in afforested area, etc.) affecting China's forestry sector. The final section identifies opportunities for improving and expanding upon this research, which include refining the conversion factors and estimating emissions of methane and nitrous oxides associated with forest activities.

1. INTRODUCTION

China has a huge population and relatively limited forested areas. As of 1990, China's population totalled 1.13 billion persons -- a figure which currently is increasing at a rate of 1.47 percent per year. The land area covers 9.6 million square kilometers (km^2), 13 percent of which is occupied by forests. Of the remaining area, arable lands account for 10 percent, grassland for 33 percent, watershed area for 2 percent, semi-arid land for 31 percent and other areas, such as cities, roads, coral reefs, etc., for the remaining 11 percent (National Statistics Bureau 1989).

On a national level, the forests play a crucial role in satisfying the country's demand for wood and other forest products. Chinese demand for wood has witnessed rapid growth due to the pressures of economic development and a rising population. The annual consumption of wood between 1984 and 1988 exceeded the net forest growth by about 20 million cubic meters (m^2). In order to meet this increasing demand, China initiated a large-scale afforestation program in the middle of the century. As of 1990, China had approximately 30.7 million hectares (ha) of planted forests, the largest area of planted forests for any country in the world. But as mentioned above, despite the impressive afforestation efforts, the consumption of forest resources has continued to out-pace forest growth.

From an international perspective, changes in China's forest cover are important because of their impact on the levels of CO_2 emitted into the atmosphere. Hence, forest-related activities taking place on the national scale have implications for the global environment.

This paper provides an overview on the current state of China's forests, identifying the types of forests in China, who controls them and recent rates of deforestation and afforestation. It then provides estimates of current forest-related CO_2 emissions in China and presents six long-term scenarios for CO_2 in China through the year 2050.
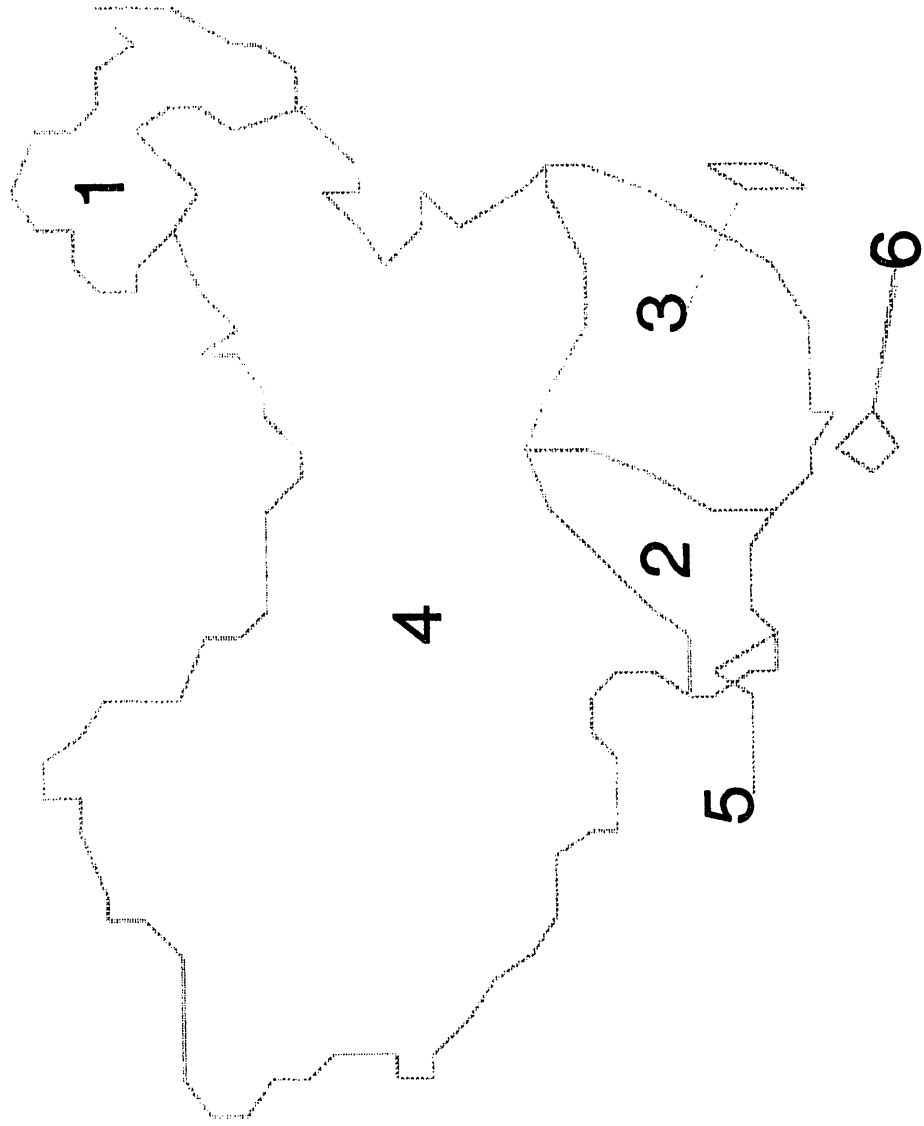
2. FOREST ZONES[1]

China's vast land area, which reaches from the cold temperate zone to the tropical zone, encompasses many forest types and an abundance of species. Due to the organization of the bio-physical data, this study dis-aggregates China's woodlands into six forest zones. In general, this zonal breakdown corresponds with differences in the types of forests located throughout the country. The zoning allows for the use of forest inventory data drawn from studies conducted at the provincial level. The distribution of the six forest zones is shown in Figure 1, as obtained from the National Statistics Bureau, 1989.

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[1] The figures on forested areas in the following section include Taiwan. The estimates of CO_2 emissions do not include Taiwan or the area beyond the control line of Tibet due to insufficient data. If the Taiwan and Tibet figures are excluded, China's forested area equals 119.5 million hectares and covers 12.4 percent of the national land area. If these two regions are included, the total forest area adds up to 124.6 million hectares which is 12.98 percent of the combined area.

FIG 1: MAP OF P.R.CHINA
FOREST TYPES

2.1. The temperate forest zone (Zone 1, Figure 1)

The temperate forest zone, located in north-eastern China, includes forests located in the cool temperate zone and the temperate zone. The area is characterized by temperatures averaging about 0° C throughout the year and 15-20° C during the growing season. This zone receives about 350-1000 mm. of rainfall annually. Temperate forests covered 35.68 million ha in 1988, comprising 30 percent of the country's total forest area. The main species are larch (*Larix gmelini, Larix olgensis*), pine (*Pinus koraiensis, P. sylvestris var. mongolica*), and birch (*Betula fruticosa and B. ermanii*). While this district still dominates all forest production in China, production in this zone has dropped in recent years because the mature forest area has been declining by about 40,000 ha/yr. The harvested timber volume averaged 87.6 mi. m³/yr during the past five years.

2.2. The west sub-zone of the subtropical forest (Zone 2, Figure 1)

Most of the subtropical areas in the world are dry lands and deserts. In the case of China, however, monsoons from the Pacific and Indian Oceans make its subtropical area a productive forest zone. The subtropical zone is divided into two sub-zones differentiated by floral species distribution. The west sub-zone has an average temperature of 10-20° C and an annual precipitation of 1000-1500 mm. This sub-zone includes provinces in the southwest (i.e., Yunnan, Sichuan, Guizhou, etc.). Although this zone has only 20.2 million ha of forested area, it possesses the largest volume of mature forests (1765 million m³) in the country due to its out-of-the-way location. The main species are pines (*Pinus yunnanensis, Pinus kesya var. langbianensis*) and various species of *Lauraceae* and *Faguceae*.

2.3. The east sub-zone of the subtropical forest (Zone 3, Figure 1)

This zone is located in China's southern district, which encompasses nine provinces to the east of the Sichuan Basin and to the south of the Yangchi River. The average temperature is 10-20° C and has an annual precipitation of 1000-2000 mm. The main tree species are Chinese Fir (*Cunninghamia lanceolata*), pine (*Pinus massoniona*) and abundant species of *Lauraceae* and *Faguceae*. This forest area covers 42.76 million ha, of which 50 percent is occupied by *Pinus massoniana* and 30 percent by *Cunninghamia*. As shown in Table 1, this forest type has become the main source of timber, with a harvested area which is more than 3 times that of the temperate zone, which is the second largest harvested forest type.

2.4. The warm temperate forest zone (Zone 4, Figure 1)

This zone encompasses a vast area, from Liaotong Peninsula in the east to Xing jiang province in the west and from Inner Mongolia in the north to the Yangchi River in the south. It includes plateau provinces, such as Xizhang (Tibet) and Qinghai. This area does not represent one uniform climate zone. It is located in an arid or semi-arid region with an average annual temperature range from 5° to 18° C, and an annual precipitation between 100 mm and 800 mm. Most of the forests are found in mountainous areas, which are characterized by low forest

productivity. The total forest area covers about 19.4 million ha. The main tree species are spruce (*Picea schrenkiana*, etc.) and poplars (*Populus davidiana*, etc.) in mountainous areas and pines (*Pinus tablaeformis*, etc.) and *Faguceae* in lower altitude regions.

2.5. The Xishuangbanna tropical pre-montane moist forest zone (Zone 5, Figure 1)

Xishuangbanna, located in the southern Yunnan Province, receives an average of 2000-3000 mm of rain each year, 80 percent of which falls during the rainy season. The average annual temperature is about 20-25° C. The main tree species are *Vatica xishuangbannanensis* and various species of *Faguceae*, *Dipterocarpaceae* and *Lauraceae*. The whole district stretches across an area of 1.97 million ha, 0.57 million ha of which are forest lands. Shifting cultivation practices have led to severe deforestation in this region, as has been the case in so many other tropical areas of the world. In 1986, however, about 12 percent of the district was transferred to natural reserves, which has managed to mitigate the level of deforestation.

2.6. The Hainan tropical pre-montane moist forest zone (Zone 6, Figure 1)

The forests on Hainan Island do not differ significantly from those in Xishuangbanna. The climate is characterized by even more dramatic seasonal variations due to the impact of typhoons. The mean temperature is 20-25° C, and the precipitation ranges from 1000-3000 mm/yr. The forested area extended over 0.87 million ha of the region's total area of 3.36 million ha in 1988. The main tree species are *Vatica hainannensis* and various species of *Faguceae*, *Dipterocarpaceae*, *Lauraceae* and *Euphobiaceae*. Due to severe deforestation, the forested share of this island diminished from 36 percent in 1949 to 19.8 percent in 1980. Since 1980 afforestation efforts have been expedited, raising the forested share to 25.9% as of 1988.

3. OWNERSHIP AND UTILIZATION OF FORESTS

Currently, there are two major types of forest ownership in China, state-owned and collective-owned forests. The use of forest resources is determined by national policy. Prior to 1988 each year China's Ministry of Forestry outlined a national harvest plan which permitted a certain amount of over-harvesting. In reality, however, the allowable harvest volume for over-harvesting typically surpassed the planned harvest volume three- to four-fold. The Ministry instituted a new policy in 1988 obligating both state-owned and collective-owned forests to abide by national "controlling quotas", which were based on consumption levels from the previous year. These "quotas" are generally smaller than the past consumption levels. Historically the pressure to maintain production levels from the forest estate has stemmed not only from the market for forest products but also from the need to keep forest workers employed. In recent years efforts to conserve forests have been thwarted further due to rising standards of living and the lack of alternative employment opportunities for the forest workers. In the country's tropical areas (Xishuangbanna and Hainan Island), where the government has relatively little control, shifting cultivation has caused severe deforestation. As the population has grown, the area cleared by slash-and-burn methods has expanded. The total forested areas and rates of landuse change by conversion mode and forest type are shown in Table 1.

Table 1.   Forest types in the PRC

Description	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
	Temperate	Subtropical	Subtropical	Temperate	Tropical	Tropical
Forest area (m.ha)	35.68	20.20	41.08	19.4	0.569	0.866
Area changed/yr (m.ha)	-0.039	0.115	0.185	0.290	-0.002	0.096
Area changed/yr (%)	0.11	0.57	0.45	1.49	-0.35	11.09
Area cut/yr (m.ha)	0.686	0.382	2.014	0.159	0.023	0.022
Area planted/yr (m.ha)	0.647	0.498	2.200	0.449	0.020	0.118
Area used for (%):						
- agriculture	0.3	0.31	0.80	0.13	0.49	0.18
- pasture	0	0	0	0	0	0
- clear cutting	1.6	1.35	3.97	0.58	0.49	0.18
- selective cutting	0	0	0	0	0	0
- other	0.1	0.1	0.1	0.1	0.1	0.1
- forest land	0.1	0.1	0.1	0.1	1.0	0.1
Re-conversion into forest from: (%)						
- agriculture	0.35	0.48	1.04	0.45	0	0
- forestation	1.46	1.98	4.32	1.86	3.58	13.55
- burnt sites	0.1	0.1	0.1	0.1	0.1	0.1

Source: Compiled from China Ministry of Forestry Reports, 1989.

China's Ministry of Forestry has maintained reliable records on national levels of timber production and consumption. Figures for 1988 indicate that 32.5 percent of the nation's timber supply was used for fuelwood, followed by 14.2 percent for rural buildings. Consumption of forest resources averaged 344.8 million m^3 per year between 1984 to 1988, while the total stock of forest resources grew by 322.9 million m^3 during the same period. Because the consumption of forest products surpassed the new forest growth, China experienced a forest stock deficit of 21.9 million m^3 in 1988 (see Table 1 in China Ministry of Forestry 1989).

Relative to the size of the population, China has fairly limited forest resources. The forested area per capita of 0.11 ha and the stock volume per capita of 8 m^3 per capita amount to approximately one-sixth and one-ninth of the world average respectively. Despite relatively low levels of timber consumption per capita, if the 1988 levels of timber harvesting prevail, the country will exhaust its harvestable forest resources within the next 10 years (Deying, 1991).
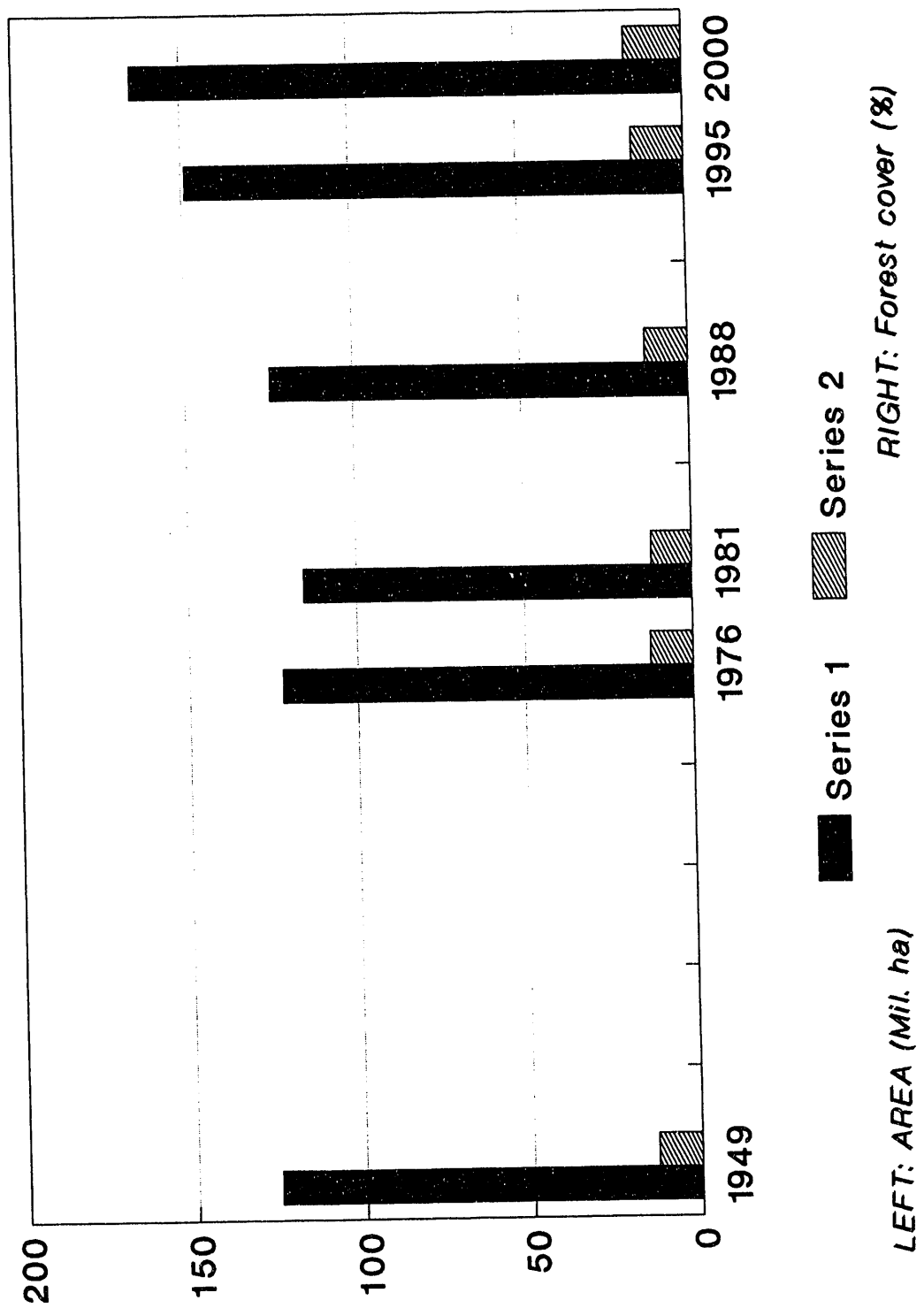
4. REFORESTATION AND AFFORESTATION

The rapid depletion of China's forest resources has been the major galvanizing force behind the nation's large-scale afforestation program. The area of planted forests in China reached 30.66 million ha by 1990, far surpassing the planted forest areas in any other nation in the world. Between 1984 and 1988, China planted 3.932 million ha of forest cover per year; over this same period, China cleared 3.287 million ha of forest land per year. Hence, there was a net annual increase of 0.645 million ha of forested area. The net increase rate accelerated after 1988. The area of newly planted young forests totalled 5.33 million ha in 1989 and 5.53 million ha in 1990. In the latter year, China also designated 3.67 million ha of closed hillsides for facilitating forest development (Gao 1990).

China has initiated a large-scale shelter-belt system in the vast temperate semi-arid zone which covers 42.4 percent of the land area. A total of 6.06 million ha of land has been mosaicked with shelter-forests, raising the share of forest cover from 4 to 5.9 percent in that region. The nation has also begun implementing a shelter-forest system in the upper reaches of the Yangchi River and another afforestation plan in Taihang Mountains.

A nationwide voluntary tree-planting campaign was initiated in 1981. About 300 million people have participated in the campaign and 1700 million trees have been planted each year since its implementation. Over the next 30 years, the Chinese Government is planning to develop 20 million ha of fast-growing timber forests located in south-east China. Eight million ha of fast-growing forests are to be established by the end of the century. Efforts to stem rates of deforestation have included the construction of a large-scale telecommunication system (initiated in 1987) which will allow for faster responses to fires in China's northern forests.

China's goal is to increase its forest area by 40 million ha by the end of the century, thereby raising the share of national land area covered by forests to 17.1 percent. The historical changes in forest cover and the targets for the planned scheme are shown in Figure 2.

FIG. 2: CHANGES IN THE FOREST COVER

LEFT: AREA (Mil. ha)

RIGHT: Forest cover (%)

■ Series 1   ▨ Series 2

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5. MODEL AND PARAMETERS

This study used the COPATH model (Makundi *et al.* 1990) to calculate carbon emissions from forest sources in China . The basic data was drawn from the forestry inventories conducted in China in 1977-81 and 1984-88 (China Ministry of Forestry 1989). Because this data lacked other information required by the model such as wood density, carbon content and conversion rates, other published literature was used to supplement the information taken from the Ministry reports. The data on forest changes were re-adjusted to fit the particular requirements of the COPATH model. In order to separate China's tropical forests from its total forested areas, recently published literature (Liang 1988; Kuang 1985) was used to calculate or estimate forest changes in Xishuangbanna and Hainan Island, China's only tropical zones. The original version of COPATH did not account for the re-conversion of agricultural and waste lands to forests, because this practice is not common in developing countries other than China. Although China converts a large area of land from forests to crop fields each year, it re-converts an even larger area of land from crop fields to forest lands. The COPATH model was revised and specifically adapted to China's particular conditions (Makundi, 1991).

The basic data on forest areas, conversion rates, biomass and wood density are presented in Tables 1-3. The data on forest areas and conversions came from the national inventory (China Ministry of Forestry 1989). There are about 255,000 permanent survey sample plots distributed across the country. The Chinese Ministry of Forestry organizes a nationwide inventory once every five years. The change in forest resources was calculated from the data collected in the last two inventories mentioned above.

Table 2. Biomass in sampled forests

Dominant species	Stem biomass	Total biomass	Total/ aboveground	Aboveground/ stemwood	Remark
Phoebe bournei	65.39	174.4	1.22	1.25	Subtropic
Castanopis fissa	51.0%	100.0%	1.38	1.42	Subtropic
Lithocarpus glaber	36.5%	100.0%	1.51	1.81	Subtropic
Larix gmelini (1)	66.2%	100.0%	1.25	1.21	Temperate
Larix gmelini (2)	177.4	249.7	1.31	1.07	Temperate
Larix gmelini (3)	206.7	251.1	1.10	1.10	Temperate
Larix mastersiana	87.3	135.2	1.19	1.30	Temperate
Picea schrenkiana	183.5	286.9	1.18	1.32	Temperate
Tropical Forest (21 species)	202.9	297.0	1.24	1.18	Tropical
Cunninghamia lanceolata	97.4	150.7	1.19	1.29	Subtropic

Note: Biomass in the unit of Tonnes/ha. Others are in " % ".
Source: Feng *et al.* 1985; Liu *et al.* 1987; Yang 1985; Zhang 1986.

Forest lands are not converted into pasture in China. The amount of land struck by forest fires had to be estimated, since the inventory lacked this data. Some selective cutting occurred in China's tropical regions under the government's harvesting policy; these areas were estimated based on data drawn from some unofficial publications. Biomass data came from selected articles (Feng *et al.* 1985; Liu *et al.* 1987; Yang 1985; Zhang 1986). Destructive sampling was used in the biomass studies, and the biomass ratios were calculated based on the above sources. The data on wood densities were cited from a book published by the Division of Wood Character (1981) (Table 3).

Table 3. Wood density of sampled species (tonnes/m^3)

Tree species	Wood density	Tree species	Wood density
Abies dellzvayi	0.41	*Cupressus funebris*	0.49
Larix gmelini	0.53	*Picea schrenkiana*	0.35
Pinus koraiens⁻	0.35	*Pinus masonianna*	0.45
Pinus tablaeformis	0.42	*Pinus yunnanensis*	0.51
Tsuga dumosa	0.38	*Cassia siamea*	0.59
Cinnamomum camphora	0.44	*Cyclobalanopsis glauca*	0.71
Eucalyptus globulus	0.64	*Dipterocarpus tonkinensis*	0.54
Fagus longipetiolata	0.64	*Hopea mollissima*	0.75
Tectona grandis	0.50		

Source: Division of Wood Character, 1981.

The carbon content of wood was cited from Buring (1984). The soil carbon content was calculated based on limited Chinese literature (Zhang 1986; Ye & Cai 1986; Ma 1990; Soil Survey Group 1981). The amounts of carbon released in the conversion process and during the decomposition period were estimated using data from corresponding forest types in other countries. The biomass left for decomposition in the whole country was estimated from indigenous biomass studies (Feng *et al.* 1985; Yang 1985; Zhang 1986; Li *et al.* 1987). The values of the parameters used are given in Table 4 below.

Table 4.   Values of Main Parameters used in the Model

Parameter	Forest type					
	1	2	3	4	5	6
Carbon content	0.55	0.52	0.52	0.55	0.52	0.52
Dry biomass (ton/ha)	250	270	288	288	300	207
Overbark stemwood (m³/ha)	142	218	96	151	300	280
Wood density (ton/m³)	0.44	0.51	0.38	0.40	0.58	0.60
Ratio of above/stem biomass	1.1	1.3	1.2	1.3	1.4	1.8
Ratio of total/above biomass	1.1	1.2	1.2	1.2	1.4	1.24
Carbon in soil (ton/ha)	155	97	97	97	140	140
Period of long-term use	0.2	0.2	0.2	0.2	0.2	0.2
Period of short-term use	15	15	15	15	15	15
Decomposition period (year)	50	40	40	50	30	30
Annual increment (ton/yr)	2.2	3.03	3.58	1.65	3.03	3.58
Rotation age (year)	60	30	30	60	30	30

Source: See text.

6. CO_2 EMISSIONS

The carbon dioxide emitted and absorbed from forest-related activities were calculated using COPATH (in terms of million tonnes of carbon equivalent). In order to facilitate comparisons with tropical countries, this study presents estimates of emissions solely resulting from tropical forests in China as well as estimates of those from all of the country's forests (tropical and non-tropical). Projections were made for a base year (1988) and a range of different years (1990, 1995, 2000, 2010, 2025 and 2050) to allow for comparisons with other studies (Table 5).

It is interesting to compare the patterns of emissions in different forest zones in the base year. Zone 1, which had the largest harvested area in the country and a smaller reforested area, did not have the greatest level of net emissions of all forest types. Zone 4 had the largest net increase in forested area but not the largest net uptake. This difference can be explained by the relatively low rate of biomass accumulation in zone 4. Although zones 2 and 3 have similar climates, zone 3 had the largest harvested and planted areas, whereas zone 2 had relatively small harvested and planted areas. Nonetheless the net increases in forested area were quite similar for these two zones (0.45 percent and 0.57 percent respectively) (Table 1). In the base year, forested area declined in zone 5, but increased in zone 6 (surpassing the amount cleared by a factor of five) (Table 1). Nonetheless, zone 6 had higher net emissions than zone 5.

The carbon emissions from the use of forest resources in China totalled 74 million tonnes during 1988 (Table 5), and 62 million tonnes will be released in the future as a result of forest use in the base year. However, the COPATH model did not incorporate inherited carbon uptake from growing stock prior to the base-year. In the case of China, the total uptake was estimated by using the growth data for different regions in the country. The annual sequestration from the

Table 5. Base year CO$_2$ emissions and projections (10^3 ton) (Based on scenario 3)

Emissions		1988	1990	1995	2000	2010	2025	2050
					Year			
Country total	Carbon stock	20336085						
	Prompt release	72552	25790	17288	6889	280	1	0
	Annual decomp.	1115	5907	28857	32918	23881	9029	1118
	Annual uptake	-5568	-9424	-59414	-152398	-271045	-49848	-2295
	Net release	68100	22274	-13269	-112590	-246884	-40818	-1177
Forest Type 5	Carbon stock	180650						
(Xishuangbanna)	Prompt release	1855	550	372	152	7	0	0
	Annual decomp.	26	664	3339	4137	2992	233	31
	Annual uptake	-33	-60	-292	-642	-1043	-177	-10
	Net release	1847	1154	6528	3647	1957	-10	21
Forest Type 6	Carbon stock	232067						
(Hainan island)	Prompt release	2216	647	432	170	6	0	0
	Annual decomp.	9	1263	6368	7929	5703	233	11
	Annual uptake	-36	-70	-272	-497	-703	-108	-6
	Net release	2189	1841	6528	7602	5006	124	5

Note: "-" means absorption.

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growing forests was estimated at 112 million tonnes, of which 106.4 was the inherited uptake. If one assumes that the delayed release equals the emissions from historical forest use, then the annual balance flux from China's forest sector is 24 million tonnes of carbon in 1988. Estimates derived using a simpler model[2] indicate that there was a net uptake of 2.5 million tonnes of carbon in 1988. Considering the different methods used in the two models, the difference between these two results is quite small.

Projections of carbon emissions were made based on six different future scenarios for China. Table 6 outlines the parameters used for each of the scenarios. According to the national plan, China's forest area will increase by 40 million ha in the next 10 years. This increase would require the current growth rate of forest areas (0.62 million ha/year) to increase by a factor of 6.2. Scenario 3 assumes that the country is successful in achieving the above rate of increase in forested areas. In this scenario, the average growth rate averages 32 percent per year. In Scenario 2, the national plan achieves only two-thirds of its targeted increase, resulting in a growth rate of 27 percent per year. Scenario 1 assumes the national plan meets half of its set goal, thereby lowering the growth rate to 20 percent per year. Table 6 illustrates the varying assumptions used in Scenarios 4-6.

Table 7 presents total forest-related emissions and tropical forest-related emissions for China for the six different scenarios at various intervals between 1990 and 2050. The national trends are similar in all of the scenarios. In the early time frame, the net emissions do not differ significantly among scenarios. Net emissions decrease during the first few years, reaching their lowest point between 2006 and 2009.

The maximum net absorptions were about 58, 135 and 250 million tonnes of carbon in Scenarios 1, 2 and 3 respectively. Net emissions then increase, leveling out near zero by the year 2030. Increases in agricultural and other land have a minimal impact on the net emission estimates, because afforestation still increases far more rapidly than the forest clearings for agriculture and other purposes.

In the case of tropical forests, the acceleration or deceleration of current deforestation rates would lead to changes in the amount of carbon released. However, the scenarios indicate that emissions from tropical forests will remain stable over the next 60 years.

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[2] An earlier paper by Xu Deying (1990) :*Greenhouse Gas Emissions and China's Forests: A Simple Model*, calculated emissions using simpler model which did not dis-aggregate the forested area by forest type but instead focused on the consumption patterns of forest resources as opposed to taking the COPATH model's integrated approach.

Table 6.   **Scenario parameters**

Element	Scenario					
	1	2	3	4	5	6
Land growth for agriculture	0	0	0	0.01	0.001	0.001
Land growth for fallow	0	0	0	0	0	0
Land growth for afforestation	0.2	0.27	0.32	0.2	0.2	0.32
Land growth for select cutting	0	0	0	0	0	0
Land growth for other land use	0	0	0	0.01	0.001	0.001

Table 7.   **Net CO^2 emissions for different scenarios (10^3 tonnes)**

Scenario	Year					
	1990	1995	2000	2010	2025	2050
1						
Total	22723	4122	-35921	-48136	-2059	-635
Type 5	1155	3479	3914	2647	122	21
Type 6	1842	6565	7764	5427	205	5
2						
Total	22461	-5231	-73219	-124570	-14093	-899
Type 5	1154	3447	3784	2382	82	21
Type 6	1842	7686	7686	5265	181	5
3						
Total	22274	-13269	-112570	-264884	-40818	-1177
Type 5	1154	3419	3647	1957	-10	21
Type 6	1841	6528	7602	5006	125	5
4						
Total	22950	5251	-34967	-48093	-2080	-623
Type 5	1158	3494	3928	2649	123	22
Type 6	1844	6572	7771	5428	206	5
5						
Total	22831	4637	-35500	-48113	-2061	-636
Type 5	1156	3486	3920	2647	122	21
Type 6	1843	6569	7768	5427	206	5
6						
Total	22296	-13158	-112499	-246880	-40820	-1178
Type 5	1154	3420	3648	1957	-10	21
Type 6	1842	6528	7602	5006	125	5

Note: " - " means absorption.

7. ECONOMIC ASPECTS

The model indicates that a long time lag exists between the time of afforestation and that of significant carbon absorption from the newly planted trees. In addition, the impact of different rates of afforestation on carbon emissions appear to be minimal over the long term, unless the rate of deforestation and forest utilization declines substantially.

The cost of establishing, managing and harvesting seven different types of species (Eucalyptus, Poplar, Pawlonia, Cunninghamia, Larch, Pine and Locust) in China was investigated by the Office of Project Loans in 1989. It was found that the cost of establishing the forests ranges from 270 to 440 US$/ha depending on the species and the climatic regions; the average cost is 400 US$/ha. The managerial activities will cost a sum of approximately 350 US$/ha for each rotation. Assuming a carbon uptake potential of about 130 tonnes/ha/rotation, this direct cost would imply an investment of about 5 US$/ton of carbon sequestered. However, if we include the other overhead costs such as constructing forest tracks, roads and other transportation investment, the average cost jumps to 3200 US$/ha per rotation, which means an investment of about 24 US$/ton of carbon sequestered. Some broadleaf and mixed stands may entail even higher costs due to their relatively long rotations. If only the costs of establishing and managing the stands are considered, the total costs for the next 10 years would be 30 billion US$. However, the cost structure under such a large afforestation program is different on account that some of the cost elements will be procured without monetary compensation. Past afforestation schemes in China have involved a large degree of voluntary labour force. Furthermore, the large cost outlay must be balanced by the value of the forest products such as timber and water which would be realized from the program.

8. DISCUSSION AND FUTURE RESEARCH

To obtain a more accurate picture of carbon emissions in China, the COPATH model need to account for both inherited emissions and uptake. The carbon flux from the simple model cited earlier differs significantly from the estimate from COPATH. The difference may rise from two sources: a) the carbon accumulated in the soil of newly planted forests, which was not explicitly incorporated into the COPATH model and/or b) differences in the assumptions about carbon emitted from disturbed soils. Some of the soil carbon data used in the calculations were cited in the literature (Wanru 1986; Xiehua 1990; Zhongje et al. 1986; "A Survey on the Forest Soils at Deqinshan Forestry Experimental Bureau" 1981). However, the data were not detailed enough to provide a full picture of soil carbon content for all the various forest types. There is still insufficient data on carbon emissions from soil disturbance. The simple model assumed that no net emissions resulted from the soil in China. As such, COPATH may have underestimated carbon uptake while the simple model may have underestimated emissions from both past deforestation as well as from soil disturbance.

The existing carbon stock was calculated by multiplying the total forested area by the average stock volume. In carrying out this equation, however, small errors in the conversion factors used for calculating stock volume can lead to major errors in the carbon stock estimates. In addition, the use of different growth rates can lead to a wide range of projections. The use of growth data (from yield studies), for the total volume in a region can minimize the errors. These data are usually available in countri·s where inventories are conducted in regular intervals.

Present carbon emissions are the result of past and present actions (i.e., changes in forested areas, conversion rates, re-conversion rates, wood consumption, decomposition rates for different consumption modes, emission rates of disturbed soils, forest growth rates, etc.). The COPATH model does not account for emissions stemming from past activities. At the same time the uptake by growing forests from past forest use is not include in the model. A more detailed version of COPATH, which incorporates all these actions -- past and present and future -- should be developed so that a complete picture of the carbon flux can be assembled.

Although the model does not impose an upper limit on the harvestable area, in the case of China where the forested area is extremely limited and only about 25 percent of the country's total land area is available for use (Deying, *Forestry Strategies in Mitigating CO_2 Accumulation*, 1991), imposing such a limit in the forecast portion will be necessary. The present afforestation plan, which entails expanding the forested share of the total land area to 17.1 percent by the end of the century seems feasible. While the planned increase in forested area may continue until 2020, it is unlikely to prevail beyond that time due to limitations on available land area.
In the future, estimates of the other greenhouse gases such as methane and nitrous oxide should be incorporated in the COPATH model.

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