RESULTS
4.0 RESULTS

4.1 CHANGES IN FOREST AREA IN INDIA AND ITS TEMPORAL VARIATION

The estimates of major components of carbon pools and fluxes and the factors which determine them, were made for Indian forest ecosystem. These estimates are presented in the following sections:

(a) Temporal variation in forest area since 1950 (section 4.1) based on government statistics and land records. It covers deforestation, area under encroachment as well as afforestation.

(b) State-level changes in forest area and its density classes as obtained from remote sensing surveys since 1975.

(c) Surveys of ecological studies of Indian forest.

(d) Harvest of wood and fuel wood.

(e) Forest area by types

(f) Growing stock

(g) Harvest of minor products from forests like bamboo, tendu leaves, essential oil, lač, tassar etc.

4.1.1 Total forest area

The total forest area statistics for India since 1950-51 as obtained from various sources is plotted in Figure 4.1 and given in Appendix A.1. The sources of these data are Forest
Department Records, Land Utilization Statistics of Ministry of Agriculture, FAO (Food and Agriculture Organization of United Nations) and remote sensing (RS) based inventories by NRSA (National Remote Sensing Agency) and Forest Survey of India (FSI). The differences in definition and/or methodology used to obtain these estimates have been described in Section 2.3 (review of literature). It may be observed that not only there are large differences in forest areas reported by these sources for any particular year, but the temporal behavior is also not consistent. The highest forest area is as reported by Forest Department, and lowest as per remote sensing surveys.

The forest area statistics from land utilization records shows increasing forest area. This is not due to increase in forest area, but increase in the total reporting area for Land utilization statistics. However between 1980-81 and 1987-88 the recorded forest area decreased from 674.16 thousand sq. km to 670.02 thousand sq. km, while there has been an increase in the reporting area from 3041.7 thousand sq. km to 3048.4 thousand sq. km. The estimates by FAO are closely following the recorded forest area. In the overall pattern of increase, some periods of decrease in forest area are also evident. These are between 1964-65 and 1965-66 (decrease of 8900 sq. km), between 1969-67 and 1972-73 (decrease of 6100 sq. km) and continuously since 1981-82.

The area under forest department has generally fluctuat-
ed between 730 and 750 thousand sq. km except for 1960-61 where it dropped to 689.6 thousand sq. km and 1988-89 where it has increased to 770.08 thousand sq. km. However, this cannot be equated to area under forests.

The last source is based on remote sensing technique. This method is expected to be most objective, as it is based on actual existence of tree cover, and reliable. However the estimates by NRSA (1983) pertaining to period 1972-75 and 1980-82 had some limitations as discussed in Section 2.4 of review of literature. The three estimates by FSI (FSI, 1987, 1989, 1991) show a decrease from 642.04 thousand sq. km in 1981-83 to 639.18 in 1987-89. But this series is not exactly comparable and requires some corrections as have been described in Section 3.1 (Materials and Methods).

4.1.2 Forest area lost to non-forest use since 1951

The forest area which was under forest department, which has been put to other non-forest land uses for the two periods, i.e., 1951 to 1976 and 1951 to 1983, is presented in Appendix A.2. A total of 41375 sq. km of forest land was lost between 1951-52 and 1976 and an additional 2076 sq. km was lost between 1976 and 1983. The total forest land diverted to other use implies a yearly deforestation rate of 141267 ha/yr in the period 1951-52 to 1976 and 8,861 ha/yr for the period between 1976 and 1983. The highest area was lost in Madhya Pradesh (18962 sq. km). Eight
TOTAL FOREST AREA IN INDIA

FIGURE 4.1

- LUS
- FOR DEP
- FAO
- FSI
- NRSA
states which lost between 1000-3200 sq. km of forest land in this period are Andhra Pradesh, Gujarat, Karnataka, Kerala, Maharashtra, Orissa, Uttar Pradesh and West Bengal. Six states which lost a forest area between 500-1000 sq. km in this period are Assam, Bihar, Jammu & Kashmir, Rajasthan, Tamil Nadu and Tripura. After the year 1980, 46852 ha of forest lands were approved for diversion to non forest use.

4.1.2.1 Forest area under encroachment

Forest area under encroachment in 1982 in India was 67.9 thousand sq. km. and is given in the Appendix A.11. The highest forest area under encroachment was 24.6 thousand sq.km. observed in Madhya pradesh with Assam was the second highest with 13.1 thousand sq.km. Eleven states having forest area between 112.16 - 761.16 sq.km. under encroachment were Meghalaya, Karnataka, West Bengal, Uttar pradesh, Himchal pradesh, Gujarat, Tamil Nadu, Rajasthan, Mharatra, Arunachal pradesh. While other twelve states were between 0.03 - 99.44 sq.km. are Chandigarh, Manipur, Haryana, Dadra and Nagar Haveli, Nagaland, Tripura, Andaman and Nicobar island, Punjab, Jammu and Kashmir, Goa, Daman and Diu, Orissa, and Bihar. The existence of such a large forest area under non-forest use implies that deforestation rates computed in Section 4.1.2 represent a minimal deforestation rate.
4.1.3 Positive human intervention

4.1.3.1 Area under plantations

The total area under plantations under Social forestry was 27564.8 sq.km., under Production forestry was 19026.30 sq.km. while under farm forestry was 7170 sq.km. during 1951-1986. This is shown in Table 4.1 and plotted in Figure 4.2 and 4.3.

Table 4.1 AFFORESTATION CARRIED OUT SINCE 1951

<table>
<thead>
<tr>
<th>Period</th>
<th>area planted in sq km</th>
<th>social forestry</th>
<th>production forestry</th>
<th>farm forestry cum fuelwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951-56</td>
<td>90.7</td>
<td>258.7</td>
<td></td>
<td>730</td>
</tr>
<tr>
<td>1956-61</td>
<td>883.3</td>
<td>1147.6</td>
<td></td>
<td>730</td>
</tr>
<tr>
<td>1961-66</td>
<td>1561.8</td>
<td>2261.4</td>
<td></td>
<td>730</td>
</tr>
<tr>
<td>1966-69</td>
<td>766.8</td>
<td>2276.2</td>
<td></td>
<td>730</td>
</tr>
<tr>
<td>1969-74</td>
<td>1141.6</td>
<td>3667.9</td>
<td></td>
<td>730</td>
</tr>
<tr>
<td>1974-79</td>
<td>3404.0</td>
<td>4577.0</td>
<td></td>
<td>1410</td>
</tr>
<tr>
<td>1979-80</td>
<td>726.3</td>
<td>709.1</td>
<td></td>
<td>420</td>
</tr>
<tr>
<td>1980-85</td>
<td>9930.0</td>
<td>4128.3</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>1985-86</td>
<td>9060.0</td>
<td>*</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>total</td>
<td>27564.8</td>
<td>19026.30</td>
<td></td>
<td>7170</td>
</tr>
</tbody>
</table>

*: included in social forestry.

4.1.3.2 Social forestry

During successive five year plans, provisions were made for growing forests near villages and roadside. It could be seen that the progress was not uniform in the various states.
AGE VS AREA UNDER S & P FORESTRY

000 sq.km

FIGURiI-4.2

*
FIGURE 4.3

COMMULATIVE AREA UNDER S & P FORESTRY
('000 sq.km)


- SOCIAL FORESTRY
- PRODUCTION FORESTRY
During fifth plan area planted was over 50,000 ha. in states like Gujarat, Karnataka, Rajasthan and Tamilnadu. During the annual plan (1979-80) the variations narrowed down and are given in Table 4.1. Under the social forestry programme only quick growing trees like Babul, Siris, Teak, Shisam, Eucalyptus, Subabul, Populus spp., Saru, etc. are planted.

4.1.3.3 Farm forestry

Between 1951 to 1974, only 73 thousand ha area was planted under farm forestry. But in the last two decades farm forestry has been introduced in a big way which is shown in Table 4.1. Neem, Eucalyptus, Teak, Peltoforum, Casia, etc., are major species grown under the farm forestry.

4.2 STATE-WISE DESCRIPTION OF CHANGES IN FOREST AREA AND ITS DENSITY CLASSES AS OBSERVED FROM REMOTELY SENSED DATA

4.2.1 Changes during 1972-75 and 1980-82

4.2.1.1 Total forest area

The total forest area increased in Sikkim and Andamans and Nicobar Islands, did not change in case of Chandigarh and Pondicherry and decreased in all other states and Union territories during this period. The total decreased area was
110.6 thousand sq.km. which was mean change while 68 thousand sq.km. was minimum change (Table 4.3). The highest decrease of 18.3 thousand sq. km. was observed in Madhya Pradesh with Maharashtra lying in second place with a 10.3 thousand sq. km. decrease. In case of six other states the deforestation exceed 5 thousand sq. km. these were Andhra Pradesh, Himachal Pradesh, Jammu & Kashmir, Orissa, Rajasthan and Arunachal Pradesh. Similarly the six states, union territories in which deforestation was less than 1 thousand sq. km. were Goa, Diu, & Daman, Haryana, Nagaland, Punjab, Dadra & Nagar Haveli and Delhi.

These are summarised in Table 4.2 and Figure 4.4

Table 4.2: CORRECTED TOTAL AND DENSITY-CLASS FOREST AREA IN INDIA AS OBTAINED FROM RS BASED SURVEY. (area in sq. km.)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Year</th>
<th>Total forest</th>
<th>closed forest</th>
<th>open forest</th>
<th>mangrove forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1972-75</td>
<td>555180.00</td>
<td>464226.00</td>
<td>87673.00</td>
<td>3281.00</td>
</tr>
<tr>
<td></td>
<td>(a)</td>
<td>565403.55</td>
<td>406400.17</td>
<td>155722.39</td>
<td>3281.30</td>
</tr>
<tr>
<td>2</td>
<td>1980-82</td>
<td>463479.00</td>
<td>360229.00</td>
<td>100592.00</td>
<td>2649.30</td>
</tr>
<tr>
<td></td>
<td>(a)</td>
<td>463470.00</td>
<td>308767.71</td>
<td>152053.29</td>
<td>2649.30</td>
</tr>
<tr>
<td></td>
<td>(b)</td>
<td>642041.00</td>
<td>361412.00</td>
<td>276583.00</td>
<td>4046.50</td>
</tr>
<tr>
<td>3</td>
<td>1981-83</td>
<td>640530.00</td>
<td>361036.00</td>
<td>275598.80</td>
<td>3895.20</td>
</tr>
<tr>
<td></td>
<td>(a)</td>
<td>3895.20</td>
<td>257409.00</td>
<td>4255.00</td>
<td>4244.00</td>
</tr>
<tr>
<td></td>
<td>(b)</td>
<td>3895.20</td>
<td>257409.00</td>
<td>4255.00</td>
<td>4244.00</td>
</tr>
<tr>
<td>4</td>
<td>1985-87</td>
<td>639182.00</td>
<td>385008.00</td>
<td>249930.00</td>
<td>4244.00</td>
</tr>
<tr>
<td></td>
<td>(a)</td>
<td>639182.00</td>
<td>385008.00</td>
<td>249930.00</td>
<td>4244.00</td>
</tr>
<tr>
<td></td>
<td>(b)</td>
<td>639182.30</td>
<td>385008.00</td>
<td>249930.30</td>
<td>4244.00</td>
</tr>
</tbody>
</table>

(a): original values
(b): corrected values

4.2.1.2 Density classes

In case of Andaman & Nicobar Islands, the increase in
RS BASED FOREST AREA & DENSITY ESTIMATES BY FSI

'000 sq.km

DENSE FOREST  OPEN FOREST  MANGROVE FOREST

1981-83
1985-87
1987-89
total forest area was associated with increase in both dense and open forests, while in case of Sikkim, the dense forest area increased by 725 sq. km and open forest area decreased by 103 sq. km. The decreased in dense forest area was associated with increase in open forest area for Assam, Bihar, Karnataka, Manipur, Meghalaya, Nagaland, Uttar Pradesh, West Bengal and Arunachal Pradesh. However in all these cases, the increase in open forest area was smaller than decrease in dense forest area, thus producing an overall loss in total forest area. The largest group of states and union territories was characterized by a decrease in both dense and open forests and it includes Andhra Pradesh, Goa, Diu & Daman, Gujarat, Haryana, Himachal Pradesh, Jammu & Kashmir, Kerala, Madhya Pradesh, Maharashtra, Mizoram, Orissa, Punjab, Tamil Nadu and Dadra & Nagar Haveli. Generally the decrease in dense forest category exceeded the decrease in open forest category except for Goa, Diu & Daman and Haryana.

4.2.1.3 Mangrove forests

The area under mangrove forests decreased by 919 sq. km in this period. More than 70 percent of this was contributed by deforestation in West Bengal and Andaman & Nicobar Islands. In case of Tamil Nadu, the mangrove forest area increased by 52 sq. km.
4.2.2 Changes between 1981-83 and 1985-87

4.2.2.1 Total forest area

During this period, the total forest area of India decreased by 1902 sq. km. (Table 4.3). When the disaggregated data of different states and union territories is considered, this total decrease is brought about by a decrease of 30513 sq. km. in 14 states/UT and an increase of 8910 sq. km. in 12 states/UT. Among the states which figured prominently in decreased forest area were Orissa (6026 sq. km.), Andhra Pradesh (2283 sq. km.), Bihar (1814 sq. km.) and Maharashtra (1453 sq. km.). All these states were significant losers of forest area in the preceding period also. Amongst the states where the forest area increased were Madhya Pradesh (5442 sq. km.), Arunachal Pradesh (4870 sq. km.), Uttar Pradesh (2401 sq. km.). Change in forest area between 1981-83 and 1985-87 plotted in Figure 4.5.

4.2.2.2 Density classes of forest

The changes in total area dense and open categories of forests indicates that area under the former increased by 16957.7 sq. km. while that under the latter decreased by 19126.7 sq. km.
When the state-wise data on changes in area under dense and open categories is compared, it is seen that in 24 out of 30 cases, the increase in one associated with a decrease in the other. Amongst the states having large decrease in total forest area three types of behaviour could be distinguished. Orissa and West Bengal showed decrease in both the categories with larger decrease in open category. Andhra Pradesh, Jammu & Kashmir, Meghalaya, Assam and Tamil Nadu had lower dense forest area but higher area under open forest category. In case of Bihar, Maharashtra, Mizoram and Tripura, a larger decrease in open forest category was the major factor in the decreased total forest area.

The increase in forest area was also result of various combinations, similar to above. Thus in cases of Madhya Pradesh and Uttar Pradesh an increase in open forest category. In case of Arunachal Pradesh, the larger increase can be seen in open forest category.

Of particular interest are cases of Gujarat and Himachal Pradesh where a small decrease (70 sq. km.) and no change in total forest area, respectively are associated with very large decrease in dense category and nearly similar increase in open category. These suggests forest degradation due to human pressure.

4.2.2.3 Mangrove forest

The total area under mangrove forests increased by 268.3
'000 sq.km

CHANGE IN FOREST AREA (1981/83 - 1985/87)
(FSI/RS)

FIGURE 4.
sq. km. The area under mangroves decreased in Andhra Pradesh, Maharashtra and Orissa and increase in the remaining states. The largest increase was observed in Andaman & Nicobar Islands (285.9 sq. km).

4.2.3 Changes between 1985-87 and 1987-89

4.2.3.1 Total forest area

The total forest area increased by 562.2 sq. km (Table 4.3) in this period. When state-wise results are seen, of 5968 sq. km, predominantly brought about by increase in total forest area in Karnataka, Meghalaya and Mizoram. A gross decrease of 458 sq. km is observed in 6 states, most of it is contributed by Arunachal Pradesh (245 sq. km), Assam (81 sq. km) and Nagaland (78 sq. km). Figure 4.6.

4.2.3.2 Forest density classes

The density class changes for India in this period were a net increase of 7014.3 sq. km in dense category and a net decrease of 6533.8 sq. km in open category. Except for Mizoram where the forest area under both dense and open classes increased and Pondicherry which did not register any change in forest class, in all the cases the changes in open and dense classes were in opposite direction. Thus state-wise increase in dense class of more than 160 sq. km was observed in 13 states.
FIGURE 4.6

CHANGE IN FOREST AREA (1985/87 - 1987/89)

(FSI/RS)

-3 -2 -1 0 1 2 3 4

'000 sq.km

MANGROVE FOREST
OPEN FOREST
DENSE FOREST
(Gujarat, Haryana, Himachal Pradesh, Jammu & Kashmir, Karnataka, Madhya Pradesh, Manipur, Mizoram, Punjab, Rajasthan, Tripura, Uttar Pradesh, and West Bengal). Similarly the 4 states showed a decrease in dense class by more than 100 sq. km (Andhra Pradesh, Meghalaya, Nagaland, Orissa).

In contrast, in case of open category, 12 states showed decrease by more than 100 sq. km and only 5 states and increase in forest area.
Table 4.3: SUMMARY OF FOREST AREA CHANGES IN INDIA FROM VARIOUS SOURCES.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>PERIOD</th>
<th>TOTAL CHANGE (sq. km.)</th>
<th>ANNUAL CHANGE (sq. km./yr)</th>
<th>REMARKS</th>
<th>[REF.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>1951/52-75/76</td>
<td>-41357</td>
<td>-1723.2</td>
<td>Recorded CFC, 1988</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Forest area</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>1975/76-82/83</td>
<td>-2072</td>
<td>-296.0</td>
<td>&quot;</td>
<td>CFC, 1984</td>
</tr>
<tr>
<td>3.</td>
<td>1972/75-81/83</td>
<td>-110671.55*</td>
<td>-13020.18</td>
<td>RS</td>
<td>NRSA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>68018.40#</td>
<td>-9069.12</td>
<td>RS</td>
<td>NRSA</td>
</tr>
</tbody>
</table>

*: Mean change, #: Minimum change; RS: Remote Sensing Based.
4.3 SUMMARY OF RESULTS ON STUDY OF CHANGES IN LANDUSE IN INDIA BY FLINT AND RICHARDS (1991)

Although the recent data does not match due to deforestation from Indian forest, Flint and Richards (1991) have carried out one of the most detailed study on phytomass C changes in land for the northern India for the period of hundred years. The total phytomass C pool decreased from 2736 Mt C in 1880 to 1505 Mt C in 1980 which are given in below table.

<table>
<thead>
<tr>
<th>Particulars</th>
<th>1880</th>
<th>1920</th>
<th>1950</th>
<th>1980</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total land area</td>
<td>319703</td>
<td>319703</td>
<td>319703</td>
<td>319703</td>
</tr>
<tr>
<td>Total forest cover</td>
<td>102682</td>
<td>94793</td>
<td>82537</td>
<td>64591</td>
</tr>
<tr>
<td>Forest/woodland</td>
<td>65071</td>
<td>58971</td>
<td>51352</td>
<td>39227</td>
</tr>
<tr>
<td>Carbon stock of vegetation x 10^6t</td>
<td>2736</td>
<td>2423</td>
<td>2054</td>
<td>1504</td>
</tr>
</tbody>
</table>

4.4 SURVEY OF ECOLOGICAL STUDIES OF INDIAN FORESTS

4.4.1 Phytomass

Estimation of phytomass is a prerequisite to understanding of ecosystem properties, functioning and role of forests in carbon cycle. A large number of biomass studies have been carried out in India. Here we ensemble data on biomass from different studies, and obtain average values for different forest types (Appendix A.17). The forest were classified in to five major groups, namely deciduous forest, evergreen forest, subtropical forest, montane forest, and mangrove and
swamp forest.

The range and mean of biomass grouped according to forest types is given in Table 4.4. Values for biomass for deciduous forest types that occur about 300 and 350 m elevations in different regions in India. In case of tree biomass, the estimated range for deciduous forest is 234.7 - 711 (t/ha) and mean value is 518.1 (t/ha), for above ground biomass estimated range is 21.1 - 562 (t/ha) and mean is 245.7 and for below ground estimated range is 98 - 149 (t/ha). For evergreen forest types above ground biomass range is between 402.2 - 584.5 (t/ha) and mean value is 548.05 (t/ha).

Montane temperate forest occur between 1350-2200 m elevation in India. For tree biomass estimated range is between 112.8-782 (t/ha), below ground estimated range is between 34 - 142 (t/ha) and total forest estimated range is between 115.2-787 (t/ha). As enough observation on biomass for different forest types in India are not available, these cannot be used for obtaining a second estimate of forest C pool. However, the means are within the range given by Ajtay et al., (1979).
Table 4.4: Mean values of biomass (t/ha)

<table>
<thead>
<tr>
<th></th>
<th>Natural forest</th>
<th>Range</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous forest</td>
<td>n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree biomass</td>
<td>4</td>
<td>234.7 - 711</td>
<td>518.1</td>
</tr>
<tr>
<td>Above ground biomass</td>
<td>5</td>
<td>21.1 - 562</td>
<td>245.7</td>
</tr>
<tr>
<td>Below ground biomass</td>
<td>3</td>
<td>98 - 149</td>
<td>93.7</td>
</tr>
<tr>
<td>Evergreen forest</td>
<td>n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree biomass</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Above ground biomass</td>
<td>4</td>
<td>402.2 - 584.5</td>
<td>548.05</td>
</tr>
<tr>
<td>Below ground biomass</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Montane temperate forest</td>
<td>n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree biomass</td>
<td>13</td>
<td>112.8 - 782</td>
<td>346.7</td>
</tr>
<tr>
<td>Above ground biomass</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Below ground biomass</td>
<td>6</td>
<td>34 - 142</td>
<td>82.8</td>
</tr>
<tr>
<td>Total forest</td>
<td>12</td>
<td>115.2 - 787</td>
<td>348.05</td>
</tr>
</tbody>
</table>

4.4.2 Litterfall

The mean total and leaf litterfall from trees for 7 forest categories, which are based on observations from 64 and 75 sites, respectively, are given in Table 4.5. The means vary from 8.5 to 4.3 t/ha/yr for total litterfall and 6.9 - 3.4 t/ha/yr for leaf litterfall. The overall range is similar to that obtained by Vogt et al. (1986), which was 9.44 to 2.44 t/ha/yr for the global data set covering full range of forest types. However, because of different classification schemes adopted, class-wise comparison are not valid. Littoral and Swamp forest and tropical moist deciduous forest had the highest total as well as leaf litterfall, while tropical dry deciduous had lowest total and leaf litterfall. In a com-
parison of functioning in four contrasting forest types in India, Singh et al. (1992) also report that dry deciduous forest had lower litterfall than other types. This could be due to lower net primary productivity in semi-arid region of the country having dry deciduous forests or could also reflect heavy human pressure on dry deciduous forests as many forest sites for which litterfall observations were available were under open forest category. The mean contribution of leaf litterfall to total litterfall varies between a narrow range of 0.75 to 0.82 for the seven forest types.

The estimated total carbon flux for each forest category separately for total and leaf litterfall as well as total estimate for India are also given in Table 4.5. The total litterfall C-flux in India is estimated as $188\pm24$ MtC/yr of which $152\pm13$ MtC/yr is leaf litterfall. This value may be taken to be valid for 1980-82 period on which the FSI assessment of 1987 (FSI, 1987) is based. There are no equivalent estimates available for India to compare with these estimates. Some comparison can be done by using the global average litterfall C fluxes provided by Ajtay et al., (1979) which were used by Dadhwal and Nayak (1993) in making a preliminary estimate of Indian C cycle. Out of the estimated total terrestrial litterfall flux in India of 811.6 - 991.2 MtC/yr by Dadhwal and Nayak (1993), the contribution from forest was 363.1-421.7 MtC/yr (see Section 4.5). Ajtay et al. (1979) adopted the definition of litter-
fall (Rodin and Bazilevich, 1967) as 'the organic matter incorporated in all plant elements of the above-ground and underground parts of the community that die annually, and in plants or parts of plants that die in the course of ageing or natural thinning'. According to Vogt et al. (1986), while belowground litterfall studies are not available in all the forests, in temperate forests, this values can equal or exceed aboveground litterfall. Thus, the differences between two estimates (ratio of 1.99-2.21) could arise simply because of

Table 4.5. Mean litterfall, forest area and estimated total and forest-wise litter-fall C-flux in India.

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>Area '000ha</th>
<th>Mean litterfall t/ha/yr</th>
<th>Mean C-flux Mt C /yr</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Litterfall</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-evergreen</td>
<td>7767.3</td>
<td>6.44 (±0.82)</td>
<td>22.5 (± 2.88)</td>
</tr>
<tr>
<td>T-moist deciduous</td>
<td>23679.4</td>
<td>8.39 (±1.06)</td>
<td>89.4 (±11.32)</td>
</tr>
<tr>
<td>Littoral &amp; Swamp</td>
<td>404.6</td>
<td>8.51 (±0.94)</td>
<td>1.5 (± 0.17)</td>
</tr>
<tr>
<td>T-dry deciduous</td>
<td>20011.1</td>
<td>4.33 (±0.72)</td>
<td>39.6 (± 6.55)</td>
</tr>
<tr>
<td>T-dry evergreen</td>
<td>140.4</td>
<td>7.52 (±1.55)</td>
<td>6.5 (± 0.10)</td>
</tr>
<tr>
<td>ST-Montane</td>
<td>5769.6</td>
<td>7.13 (±0.71)</td>
<td>18.5 (± 1.84)</td>
</tr>
<tr>
<td>Montane Temperate</td>
<td>6431.7</td>
<td>5.52 (±0.49)</td>
<td>16.0 (± 1.40)</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td>188.0 (±24.27)</td>
</tr>
<tr>
<td><strong>Leaf Litterfall</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-evergreen</td>
<td>7767.3</td>
<td>4.95 (±0.51)</td>
<td>17.3 (± 1.79)</td>
</tr>
<tr>
<td>T-moist deciduous</td>
<td>23679.4</td>
<td>6.86 (±0.45)</td>
<td>73.1 (± 4.75)</td>
</tr>
<tr>
<td>Littoral &amp; Swamp</td>
<td>404.6</td>
<td>6.49 (±1.13)</td>
<td>1.2 (± 0.21)</td>
</tr>
<tr>
<td>T-dry deciduous</td>
<td>20011.1</td>
<td>3.44 (±0.40)</td>
<td>31.4 (± 3.65)</td>
</tr>
<tr>
<td>T-dry evergreen</td>
<td>140.4</td>
<td>5.78 (±1.46)</td>
<td>0.4 (± 0.10)</td>
</tr>
<tr>
<td>ST-Montane</td>
<td>5769.6</td>
<td>5.87 (±0.67)</td>
<td>15.2 (± 1.74)</td>
</tr>
<tr>
<td>Montane Temperate</td>
<td>6431.7</td>
<td>4.52 (±0.31)</td>
<td>13.1 (± 0.90)</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td>151.7 (±13.12)</td>
</tr>
</tbody>
</table>

T: Tropical; ST: Sub-tropical; *: standard error in parentheses
total (Dadhwal and Nayak, 1993) and aboveground (present study) litterfall estimated in the two studies and an additional term of nontree component which also needs to be considered in total forest litterfall.

4.5 FOREST TYPE AREA AND GLOBAL AVERAGES BASED CARBON CYCLE

The approach commonly used for estimating the major pools and fluxes of carbon in forests at global level is to multiply the estimated areas of forest types with average/representative carbon densities or flow rates. One of the most widely used source for carbon cycle averages is Ajtay et al., (1979). Along with the RS-based estimate of forest area for 1981-83, the Forest Survey of India (FSI, 1987) also reported the area under 16 forest types of Champion and Seth (1968). As the forest type categories in the two sources do not match, a low and a high estimate can be computed to taken into account all overlapping categories. The results for three major carbon pools (living phytomass, litter and soil organic carbon) and two important fluxes (net primary production, litter fall) are summarized in Table 4.6 and 4.7 for high and low estimates, respectively. The two most dominant forest types in India are tropical moist deciduous and tropical dry deciduous forests, which correspond to tropical seasonal forests of Ajtay et al., (1979). The results indicate that NPP lies between 4.65-5.44x10^{14}gCa^{-1}, while the litterfall could range from 3.63-4.22x10^{14}gCa^{-1}. The living phytomass and soil organic carbon are the two dominant pools,
with estimated sizes lying between 77.3-96.0x10^{14} g C and 59.9-62.2x10^{14} g C, respectively. Because of high turnover rates, the litter pool remains very small and was estimated to lie in the range 3.9-4.1x10^{14} g C, which is roughly of the same order as litterfall.

In order to estimate biospheric pools from ecosystem areas, representative ecosystem specific global values of C pools and fluxes from Ajtay et al., (1979) were used (Table 4.8). The ecosystem area estimates were based on a number of sources including recent RS-based forest inventory. The areal extent of ecosystem and the source on which they were based was indicated in Dadhwal and Nayak (1993) (Section 3.6). In the terrestrial C cycle, the total area of India, 19.5 % forest area was contributed. From the total phytomass, 87.5 - 92.4 % of forest phytomass was contributed, while forest litter was about 42.8 - 73.09 % contributed from the total litter. From the total soil C, total litterfall and total NPP, 22.9 - 25.5 % forest soil C, 43.42 - 44.8 % litterfall and 35.09 - 35.5 % forest NPP contributed, respectively.
Table 4.6: IMPORTANT POOLS AND FLUXES OF CARBON FOR INDIAN FOREST ECOSYSTEM (HIGH ESTIMATE) USING 1981-83 FOREST TYPE AREA AND GLOBAL AVERAGES OF AJTAY ET AL., (1979)

<table>
<thead>
<tr>
<th>Forest type.</th>
<th>AREA $10^9$ sq.m.</th>
<th>NPP $10^{15}$gC</th>
<th>Liv.PhytoM $10^9$gC</th>
<th>Litter $10^9$gC</th>
<th>Litter fall $10^9$gC</th>
<th>Soil carbon $10^9$gC</th>
</tr>
</thead>
<tbody>
<tr>
<td>TWE</td>
<td>Tropical humid.</td>
<td>51.25</td>
<td>53.04</td>
<td>968.61</td>
<td>42.66</td>
<td>16.66</td>
</tr>
<tr>
<td>TWSE</td>
<td>Tropical humid.</td>
<td>26.42</td>
<td>27.35</td>
<td>499.41</td>
<td>22.00</td>
<td>8.59</td>
</tr>
<tr>
<td>TMD</td>
<td>Tropical seasonal</td>
<td>236.79</td>
<td>170.49</td>
<td>2663.93</td>
<td>138.52</td>
<td>100.64</td>
</tr>
<tr>
<td>TDDF</td>
<td>Tropical seasonal</td>
<td>183.62</td>
<td>132.31</td>
<td>2065.73</td>
<td>107.42</td>
<td>78.04</td>
</tr>
<tr>
<td>Lit&amp;S</td>
<td>Mangrove</td>
<td>4.05</td>
<td>1.82</td>
<td>54.62</td>
<td>1.09</td>
<td>20.23</td>
</tr>
<tr>
<td>MWT</td>
<td>Temp.deciduous</td>
<td>23.37</td>
<td>13.67</td>
<td>294.40</td>
<td>8.94</td>
<td>35.05</td>
</tr>
<tr>
<td>HWT</td>
<td>Temp.deciduous</td>
<td>22.01</td>
<td>12.88</td>
<td>277.35</td>
<td>8.42</td>
<td>33.02</td>
</tr>
<tr>
<td>STP</td>
<td>Temp.evergreen</td>
<td>42.38</td>
<td>27.93</td>
<td>558.59</td>
<td>15.83</td>
<td>62.07</td>
</tr>
<tr>
<td>HDT</td>
<td>Temp.deciduous</td>
<td>0.31</td>
<td>0.18</td>
<td>3.93</td>
<td>0.12</td>
<td>0.47</td>
</tr>
<tr>
<td>TTF</td>
<td>Dry savanna</td>
<td>16.49</td>
<td>9.65</td>
<td>111.31</td>
<td>5.94</td>
<td>2.89</td>
</tr>
<tr>
<td>TDE</td>
<td>Tropical seasonal</td>
<td>1.40</td>
<td>1.01</td>
<td>15.80</td>
<td>0.82</td>
<td>0.60</td>
</tr>
<tr>
<td>STBLHF</td>
<td>Tropical seasonal</td>
<td>2.54</td>
<td>2.88</td>
<td>52.56</td>
<td>2.32</td>
<td>0.90</td>
</tr>
<tr>
<td>STDE</td>
<td>Tropical seasonal</td>
<td>12.54</td>
<td>9.03</td>
<td>141.05</td>
<td>7.33</td>
<td>5.33</td>
</tr>
<tr>
<td>Sub-alp Low arctic</td>
<td>18.63</td>
<td>2.93</td>
<td>19.28</td>
<td>1.68</td>
<td>46.57</td>
<td>372.56</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>642.04</td>
<td>465.23</td>
<td>7726.57</td>
<td>363.09</td>
<td>411.06</td>
</tr>
</tbody>
</table>

CS68: Champion & Seth, 1968
TWE = Tropical W. evergreen; TDE = Tropical dry evergreen
TWSE = Tropical W. Semi evergreen; STBLHF = Sub-tropical Hill Forest
TMD = Tropical moist deciduous; ASTDE = Sub-tropical dry evergreen
TDDF = Tropical dry deciduous; Sub-alP= Sub-alpine & alpine
Lit&S= Littoral & Swamps; MWT = Montane wet temp.; HWT = Himalayan wet temp.
STP = Sub-tropical wet Pine; HDT = Himalayan dry temp.
TTF = Tropical thorn forest
<table>
<thead>
<tr>
<th>Forest type</th>
<th>AREA (10^9 sq.m.)</th>
<th>NPP</th>
<th>Liv.Phym</th>
<th>Litter</th>
<th>Soil Litter</th>
<th>Soil carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>TWSE</td>
<td>Tropical humid.</td>
<td>26.42</td>
<td>27.35</td>
<td>499.41</td>
<td>22.00</td>
<td>8.59</td>
</tr>
<tr>
<td>TMD</td>
<td>Tropical seasonal</td>
<td>236.79</td>
<td>245.08</td>
<td>4475.33</td>
<td>197.13</td>
<td>76.96</td>
</tr>
<tr>
<td>TDDF</td>
<td>Tropical seasonal</td>
<td>183.62</td>
<td>132.31</td>
<td>2065.73</td>
<td>107.42</td>
<td>78.04</td>
</tr>
<tr>
<td>Lit&amp;S</td>
<td>Mangrove</td>
<td>4.05</td>
<td>1.82</td>
<td>54.62</td>
<td>1.09</td>
<td>20.23</td>
</tr>
<tr>
<td>MWT</td>
<td>Temp.deciduous</td>
<td>23.37</td>
<td>15.77</td>
<td>315.43</td>
<td>8.94</td>
<td>35.05</td>
</tr>
<tr>
<td>HWT</td>
<td>Temp.deciduous</td>
<td>22.01</td>
<td>14.86</td>
<td>297.16</td>
<td>8.42</td>
<td>33.02</td>
</tr>
<tr>
<td>STP</td>
<td>Temp.evergreen</td>
<td>42.38</td>
<td>27.93</td>
<td>558.59</td>
<td>15.83</td>
<td>62.07</td>
</tr>
<tr>
<td>HDT</td>
<td>Temp.deciduous</td>
<td>0.31</td>
<td>0.21</td>
<td>4.19</td>
<td>0.12</td>
<td>0.47</td>
</tr>
<tr>
<td>TTF</td>
<td>Dry savanna</td>
<td>16.49</td>
<td>9.65</td>
<td>111.31</td>
<td>5.94</td>
<td>2.89</td>
</tr>
<tr>
<td>TDE</td>
<td>Tropical seasonal</td>
<td>1.40</td>
<td>1.01</td>
<td>15.80</td>
<td>0.82</td>
<td>0.60</td>
</tr>
<tr>
<td>STBLHF</td>
<td>Tropical seasonal</td>
<td>2.78</td>
<td>2.88</td>
<td>52.56</td>
<td>2.32</td>
<td>0.90</td>
</tr>
<tr>
<td>STDE</td>
<td>Tropical seasonal</td>
<td>12.54</td>
<td>9.03</td>
<td>141.05</td>
<td>7.33</td>
<td>5.33</td>
</tr>
<tr>
<td>Sub-alp</td>
<td>Low arctic</td>
<td>18.63</td>
<td>2.93</td>
<td>19.28</td>
<td>1.68</td>
<td>46.57</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>642.04</td>
<td>543.87</td>
<td>9597.07</td>
<td>421.7</td>
<td>387.38</td>
</tr>
</tbody>
</table>

**Notes:**
- CS68: Champion & Seth (1968)
Table 4.8 FOREST C CYCLE PARAMETERS DERIVED FROM AREA UNDER TYPE AND GLOBAL AVERAGES OF AJTAY et al.,

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Units</th>
<th>Forest only</th>
<th>Total for India</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$10^3 m^2$</td>
<td>642.0</td>
<td>3287.8</td>
</tr>
<tr>
<td>2</td>
<td>$10^{12}$ gC</td>
<td>7726.6 - 9597.1</td>
<td>8360 - 10930</td>
</tr>
<tr>
<td>3</td>
<td>$10^{12}$ gC</td>
<td>387.4 - 411.1</td>
<td>530 - 960</td>
</tr>
<tr>
<td>4</td>
<td>$10^{12}$ gC</td>
<td>5987.7 - 6223.5</td>
<td>23450 - 27140</td>
</tr>
<tr>
<td>5</td>
<td>$10^{12}$ gC$^{-1}$</td>
<td>363.1 - 421.2</td>
<td>810 - 970</td>
</tr>
<tr>
<td>6</td>
<td>$10^{12}$ gC$^{-1}$</td>
<td>465.2 - 543.9</td>
<td>1310 - 1550</td>
</tr>
</tbody>
</table>

* : Dadhwal and Nayak (1993)

4.6 ESTIMATED FOREST CARBON POOL (1981-83) USING GROWING STOCK DATA.

Using the new expansion factors relating commercial growing stock to biomass (Brown et al., 1989, Hall and Uhlig, 1991), the estimate of India's growing stock (Lal, 1989) in (Appendix A.8) and the conversion procedure (Materials and Methods, Section 3.7), a wood volume based estimated of carbon pool was made. The expansion factors which depend on degree of disturbance in a forest, were estimated separately for each state for both a low and a high estimate.

This procedure gives an estimated carbon pool of forest lying between 2972.3 and 3445.8 Mt of C. The state-wise breaks up of carbon pool is shown in Figure 4.7. Madhya Pradesh followed by Arunachal Pradesh have the largest forest carbon pools.
STATE WIDE FOREST PHytOMASS C POOLS
(Based on Growing Stock Data)

Mt C

200
150
100
50
0

CARBON t/ha  =  2 LOW  /  =  3 LOW  ♦  =  2 HIGH  ▲  =  3 HIGH
4.7 Changes in forest carbon pool due to changes in forest area between 1981-1989

The changes in forest area, separately for each state, were used along with carbon pool/ha of the respective state as per procedure described in Materials and Methods (Section 3.8) to determine what effect the forest area changes have on total carbon pool size which shows in Table 4.9. This analysis was carried out using RS based inventories by FSI for three time periods (viz., 1981-83, 1985-87, 1987-89) thus providing for changes in two time periods 81/83-85/87 and 85/87-87/89.

In this case four estimates were made, corresponding to dense/open forest carbon stock ratio of 2 and 3 for each low and high carbon stock estimate.

4.7.1 Changes between 1981-83 and 1985-87

The total forest carbon pool in 1985-87 was higher than that at 1981-83. The increase was dependent on the model used and was 22.68x10^{12}gC for low biomass estimate and dense/open forest biomass ratio (DOBR) of 2 use of 3 gave a figure of 35.06x10^{12}gC, however the largest difference of 40.84x10^{12}gC occurred in high biomass estimate and DOBR of 3.
Table 4.9: ESTIMATE OF CHANGES IN FOREST VEGETATION CARBON POOL BETWEEN 1981 AND 1989

<table>
<thead>
<tr>
<th>Study area &amp; Model used</th>
<th>Changes in forest vegetation on carbon pool</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1981-83 and 1985-87 and 1987-89</td>
</tr>
<tr>
<td><strong>INDIA</strong></td>
<td></td>
</tr>
<tr>
<td>Low estimate + D/O* ratio 2</td>
<td>22.68</td>
</tr>
<tr>
<td>Low estimate + D/O ratio 3</td>
<td>35.06</td>
</tr>
<tr>
<td>High estimate + D/O ratio 2</td>
<td>26.32</td>
</tr>
<tr>
<td>High estimate + D/O ratio 3</td>
<td>40.84</td>
</tr>
<tr>
<td><strong>Himachal Pradesh</strong></td>
<td></td>
</tr>
<tr>
<td>Low estimate + D/O* ratio 2</td>
<td>-17.75</td>
</tr>
<tr>
<td>Low estimate + D/O ratio 3</td>
<td>-24.74</td>
</tr>
<tr>
<td>High estimate + D/O ratio 2</td>
<td>-20.49</td>
</tr>
<tr>
<td>High estimate + D/O ratio 3</td>
<td>-28.57</td>
</tr>
<tr>
<td><strong>Madhya Pradesh</strong></td>
<td></td>
</tr>
<tr>
<td>Low estimate + D/O* ratio 2</td>
<td>46.22</td>
</tr>
<tr>
<td>Low estimate + D/O ratio 3</td>
<td>60.54</td>
</tr>
<tr>
<td>High estimate + D/O ratio 2</td>
<td>53.64</td>
</tr>
<tr>
<td>High estimate + D/O ratio 3</td>
<td>70.25</td>
</tr>
</tbody>
</table>

*: Dense/open forest biomass ratio.
The individual states showed large variation in their behaviour. These differences are illustrated in Figure 4.8. In this period gains above 10x10^12 gC were noticed for four states, namely, Karnataka, Madhya Pradesh, Uttar Pradesh and Arunachal Pradesh. The states having similar behaviour for loss in phytomass C-pools were Andhra Pradesh, Assam, Himachal Pradesh, Jammu & Kashmir, Meghalaya and Orissa.

4.7.2 Changes between 1985-87 and 1987-89.

The total forest carbon pool in 1987-89 was higher than that at 1985-87. This increase was also dependent on the model used and was 31.98 x 10^12 gC for low biomass estimate and dense/open forest biomass ratio (DOBR) of 2 use of 3 gave a figure of 45.44 x 10^12 gC, however the largest difference of 52.71 x 10^12 gC occurred in high biomass estimate and DOBR of 3.

These difference changes have shown in Figure 4.9. In this period gains above 18 x 10^12 gC were noticed for only in Himachal Pradesh. While there is no loss in biomass C.

4.8 FOREST PRODUCTS

4.8.1 Industrial wood

The production of industrial wood in India is plotted in Figure 4.10. The industrial round wood extraction from forests as per FAO statistics (Appendix A.12) shows that annual recorded
wood extraction has increased more than 12-fold from 0.656 MtC in 1946 to 8.086 MtC in 1986. The total wood removal in the four decade (1946 - 1985) is 128.137 MtC. Which shows in Figure 4.11.

The wood removal are used for making medium / long term storage product in human ecosystem in the form of building materials, furnitures, railway sleepers, electric and telegraph poles etc. Using a simple model of 50 % transfer to storage pool and half life of 15 or 25 years, gave the following results.

(i) Cumulative removal (1946-85) is 128.137 MtC.
(ii) Pool size in 1985 is 32.733 and 39.446 MtC for 15 and 25 year half life, respectively.
(iii) Increase in storage pool in human ecosystem is between 0.82 and 0.98 MtC per year.

4.8.2 Fuelwood

Here we have data on production of fuelwood in India from various sources (i) FAO, (ii) GOI, (iii) Kaul and Sharma (1971) and (iv) Operations Research Group (ORG) (Appendix A.13). These are shown in Figure 4.12. The fluxes of total C as well as separately for CO₂, CO, CH₄ (POC) (Particulate organic carbon) and elemental charcoal formation (EC) was obtained from fuelwood data from FAO. Assuming FAO series after 1968 as best estimate. Before 1968 there was very low production of fuelwood.

(Section 3.11)
FIGURE 4.3

CHANGE IN CARBON POOL (1981/83 - 1985/87)
PRODUCTION OF INDUSTRIAL WOOD IN INDIA

Million cu.m


FIGURE-4.10
CONSUMPTION OF FUELWOOD IN INDIA

Million cu.m

KS 90 - KAUL & SHARMA 90

FIGURE-4.12
The estimated total C exposed to burning during 1971-1975, 1976-80, 1981-85 are 49.44, 55.10, 60.88 (MtC respectively. The C released to atmosphere are 49.11-49.24, 54.73-54.88, 60.47-60.63 MtC during 1971-75, 1976-80, and 1981-85 respectively. The estimated CO$_2$ was 20 - 22 Mt C, 22.8 - 24.7 Mt C and 25.3 - 27.3 Mt C during the period 1971-75, 1976-80 and 1981-85, respectively.

Estimated CO was 1.8-3.1 Mt C, 2.0-3.4 Mt C and 2.2-3.8 Mt C to the atmosphere for the period 1971-75, 1976-80 and 1981-85, respectively.

Estimated CH$_4$ was .17 - .32 MtC, .19-.35 Mt C, .21-.39 Mt C for the period 1971-75, 1976-80 and 1981-85 respectively.

Estimated POC (particulate organic carbon) was .37-.52 MtC, .41-.68 Mt C and .45 - 76 Mt C for the period 1971-75, 1976-80 and 1981-85, respectively.

Elemental carbon formed to atmosphere were .10-.17, .11-18 and .12-20 for the period 1971-75, 1976-80 and 1981-85, respectively.

The elemental C formed to atmosphere were 0.20-0.33, 0.22-0.37 and 0.25-0.41 (yearly) in the 1971-75, 1976-80, and 1981-85 respectively. (This refer to Figure 4.13)

4.8.3 Biomass Burning in forests

Biomass burning in forests takes place due to number of factors, namely shifting cultivation, unregulated fires, prescribed burning in natural regeneration areas, protection fires
and in plantations; forest encroachment and forest areas diverted for agriculture. (Kaul, 1991)

With increasing area under shifting agriculture, unregulated fires and plantations, the above ground grass biomass actually burnt has increased from 0.066 - 3.102 Mt of dry wt. Which shows in Table 4.10.

As the area burnt, under natural regeneration, projection fires, encroachments and forest lands diverted for agriculture is assumed to be constant. The above ground biomass actually burnt has also remained static, being to tune of 0.540, 1.128, 0.026, and 0.113 million tonnes, respectively.

4.8.4 Total biomass burnt

The result obtained for individual sources/activities of forest biomass burning, an attempt has been made to arrive at the total quantity of forest biomass actually burnt in the country during 1980s (1985-87). The results are presented in Table 4.11.
<table>
<thead>
<tr>
<th>Year</th>
<th>Shifting cultivation</th>
<th>Unregulated fires</th>
<th>Natural regeneration area</th>
<th>Protection fires</th>
<th>Plantations</th>
<th>Encroachments</th>
<th>Forest area diverted to Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Annual area burnt (Million ha)</td>
<td>Aboveground grass biomass (Million t drywt)</td>
<td>Biomass burnt (Million t)</td>
<td>Annual</td>
<td>Biomass burnt (Million t)</td>
<td>Annual</td>
<td>Biomass burnt (Million t)</td>
</tr>
<tr>
<td>1956</td>
<td>0.542</td>
<td>1.626</td>
<td>0.650</td>
<td>3.60</td>
<td>1.080</td>
<td>0.540</td>
<td>1953</td>
</tr>
<tr>
<td>1960</td>
<td>0.542</td>
<td>1.623</td>
<td>0.649</td>
<td>1963</td>
<td>0.0583</td>
<td>0.175</td>
<td>0.088</td>
</tr>
<tr>
<td>1963</td>
<td>0.596</td>
<td>2.988</td>
<td>1.175</td>
<td>1976</td>
<td>0.4650</td>
<td>1.395</td>
<td>0.593</td>
</tr>
<tr>
<td>1964</td>
<td>0.990</td>
<td>2.970</td>
<td>1.188</td>
<td>1982</td>
<td>0.8810</td>
<td>2.482</td>
<td>0.593</td>
</tr>
</tbody>
</table>
Table 4.11: Total quantity of biomass burnt annually during 1985-1987.

<table>
<thead>
<tr>
<th>Sources/Activities</th>
<th>Biomass burnt annually during 1985-87(M.tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Tree biomass burnt</td>
<td></td>
</tr>
<tr>
<td>Fuelwood</td>
<td>124.740</td>
</tr>
<tr>
<td>Shifting cultivation</td>
<td>9.200</td>
</tr>
<tr>
<td>Unregulated fires</td>
<td>0.009</td>
</tr>
<tr>
<td>Prescribed burning</td>
<td>-</td>
</tr>
<tr>
<td>Encroachments</td>
<td>0.202</td>
</tr>
<tr>
<td>Forest area diverted for agriculture</td>
<td>-</td>
</tr>
<tr>
<td>B Burning of grasses</td>
<td>5.260</td>
</tr>
<tr>
<td>C Burning of litter</td>
<td>12.270</td>
</tr>
<tr>
<td>Total</td>
<td>151.681</td>
</tr>
<tr>
<td>Carbon = 151.681 x 0.45 = 68.26 Mt</td>
<td></td>
</tr>
</tbody>
</table>

Table shows that over 151 million t of forest biomass (dry wt) was burnt annually during the period 1985 -1987, the major contribution of over 88% (over 134 million t) being from tree biomass followed by burning of litter (over 12 million t or 8%) and grasses (5.60 million t or 3.5%)

4.8.5 Minor produce

Air dried weight of various minor products which are listed in the Table 4.12 for two periods 1973-74 to 1975-76 and 1978-79 to 1980-81 were collected from various sources. Obtain carbon content values shown in the below table.
| Year | Products | 73-74 to Ref. 78-79 to Ref. Moisture Dry matter (kt) |
|------|----------|---------------------------------|------------------|------------------|
|      | 75-76    | 80-81                          | content (73-76)  | (78-81)          |
| Bamboo | 4525     | 1 8848.4                       | 4 0.5            | 1934.4           |
|       |          |                                |                 | 3782.6           |
| Tandu lvs. | 320     | 1 300.0                        | 4 1.5            | 138.4            |
|        |          |                                |                 | 132.9            |
| Essential-oil Resins | 4.84    | 1 1.69                        | 4 0.5            | 2.06             |
|        |          |                                |                 | 0.725            |
| Senna lvs & others | 59.9  | + 74.20                       | FAO 0.5         | 25.60            |
|        |          |                                |                 | .31.63           |
| Fibre & floss | 83.6 | 1 355.50                       | 4 0.5            | 35.73            |
|        |          |                                |                 | 151.76           |
| Non edible oil | 74.2 | 1 419.20                       | 4 0.5            | 31.72            |
|        |          |                                |                 | 179.2            |
| Tans & Dyes | -     | - 187.40                       | 4 0.5            | -                |
|        |          |                                |                 | 80.11            |
| Gums & Resins | 64.0 | 1 92.20                       | 4 0.5            | 27.36            |
|        |          |                                |                 | 39.4             |
| Katha & Cutch | 6.01 | 1 -                            | .125 2.3        | 2.3              |
|        |          |                                |                 | -                |
| Lac & Tasar | 41.50  | 1 22.3                        | 4 0.5            | 17.52            |
|        |          |                                |                 | 9.53             |
4.9 FOREST C POOL ASSESSMENT USING FAO DATA

FAO had carried out a forest inventory using remotely sensed data for the period 1980 (FAO, 1985). Recently a new inventory with the aim of assessing tropical deforestation rates has been computed (FAO, 1993) and this pertains to 1990 time frame. The information provided in this assessment includes total forest area in 1990, the ecological zone wise forest areas for 1990 for Wet, Moist, Dry, Desert and Hill & Montane zone, deforestation rate between 1980 and 1990, afforestation rate between 1980 and 1990 and average standing biomass in the forest. This information was used to (a) Estimate potential forest phytomass C pool and (b) actual phytomass C pools for 1980 and 1990.

4.9.1 Potential phytomass, litter and soil C pool

Using FAO(1993) zone-wise averages and average phytomass, soil and litter pools as estimated for tropical and subtropical forests for the above zones by Palm et al.,(1982), estimates of these pools for 1990 and 1980 were made and are given in Table 4.13. Estimated phytomass C pool for wet zone is 1503.4 and 1418.3 MtC, for moist zone is 1369 and 1299.2 MtC, for dry zone 4143.9 and 3831.3 MtC, for desert is 52.2 and 51.3 MtC, and for hill & montane zone is 1418.6 and 1364.3 MtC for the period 1980 and 1990, respectively. Total phytomass C pool estimated is 8487.1 MtC for the period 1980 and 7964.4 MtC for the period
For Soil C pool, estimated C for the wet zone is 1005.2 and 948.3 MtC, for moist zone 630.7 and 598.6 MtC, for the dry zone 2015.2 and 1863.2 MtC, for desert one 50.9 and 50 MtC and for hill & montane zone 1265.6 and 1217.2 MtC for the period 1980 and 1990, respectively.

For litter C pool, estimated C for wet zone is 26.2 and 24.7 MtC, for moist zone 22.6 and 21.5 MtC, for dry zone 85.1 and 78.7 MtC, for desert 3.8 and 3.7 MtC and for hill & montane zone 29.7 and 28.5 MtC, for the period 1980 and 1990, respectively.

4.9.2 Actual phytomass C pool

Using FAO(1993) zone-wise (wet, moist, dry and hill & montane) averages and average phytomass as estimated for tropical and sub tropical forest and they were adjusted to achieve 98 tDM/ha to Palm et al., (1982). estimates of this phytomass pool for 1980 and 1990 were made and are given in Table 4.14.

Phytomass C pool for wet zone 67.2 t C/ha was estimated. While 587.4 MtC and 554.1 MtC for the period 1980 and 1990, respectively. For moist zone estimated phytomass C is 533.5 and 506.3 MtC for the period 1980 and 1990, respectively. For dry zone phytomass C pool is 1623.5 and 1501 MtC, for desert 21.9 and 21.6 MtC and for hill & montane zone 555.4 and 534.1 MtC, for the
period 1980 and 1990, respectively.

Table 4.13: FOREST C POOLS BASED ON FOREST AREA BY FAO (1993), POTENTIAL PHYTOMASS, SOIL AND LITTER POOLS BY PALM ET. AL. (1982)

<table>
<thead>
<tr>
<th>Forest Zone</th>
<th>Area (Year) '000 ha</th>
<th>Phytomass MtC</th>
<th>Soil MtC</th>
<th>Litter MtC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet</td>
<td>8246 (1990)</td>
<td>1418.3 (127.8)</td>
<td>948.3 (263.9)</td>
<td>24.7 (2.1)</td>
</tr>
<tr>
<td></td>
<td>8741 (1980)</td>
<td>1503.4 (135.5)</td>
<td>1005.2 (279.7)</td>
<td>26.2 (2.2)</td>
</tr>
<tr>
<td>Moist</td>
<td>7042 (1990)</td>
<td>1299.2 (95.1)</td>
<td>598.6 (42.3)</td>
<td>21.5 (2.1)</td>
</tr>
<tr>
<td></td>
<td>7420 (1980)</td>
<td>1369.0 (100.2)</td>
<td>630.7 (44.5)</td>
<td>22.6 (2.2)</td>
</tr>
<tr>
<td>Dry</td>
<td>26242 (1990)</td>
<td>3831.3 (275.5)</td>
<td>1863.2 (314.9)</td>
<td>78.7 (6.6)</td>
</tr>
<tr>
<td></td>
<td>28383 (1980)</td>
<td>4143.9 (298.0)</td>
<td>2015.2 (340.6)</td>
<td>85.1 (7.1)</td>
</tr>
<tr>
<td>Desert</td>
<td>1283 (1990)</td>
<td>51.3 (14.1)</td>
<td>50.0 (13.5)</td>
<td>3.7 (0.8)</td>
</tr>
<tr>
<td></td>
<td>1304 (1980)</td>
<td>52.2 (14.3)</td>
<td>50.9 (13.7)</td>
<td>3.8 (0.8)</td>
</tr>
<tr>
<td>Hill &amp; Montane</td>
<td>8917 (1990)</td>
<td>1364.3 (115.9)</td>
<td>1217.2 (227.4)</td>
<td>28.5 (5.4)</td>
</tr>
<tr>
<td></td>
<td>9272 (1980)</td>
<td>1418.6 (120.5)</td>
<td>1265.6 (236.4)</td>
<td>29.7 (5.6)</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>7964.4 (628.4)</td>
<td>4677.3 (862.0)</td>
<td>157.1 (17)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8487.1 (668.5)</td>
<td>4967.6 (914.9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>* Standard error in parantheses.</td>
</tr>
</tbody>
</table>

Table 14: FAO ASSESSMENTS AND ITS IMPLICATIONS FOR FOREST C CYCLE OF INDIA BASED ON 1980 AND 1990 RS DATA

<table>
<thead>
<tr>
<th>Forest Zone</th>
<th>Area VegDM' t/ha</th>
<th>Tree biomass</th>
<th>Phytomass C pool MtC</th>
<th>Phyto C pool MtC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year/1990</td>
<td>1980</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet</td>
<td>8246</td>
<td>8741</td>
<td>344</td>
<td>109.5</td>
</tr>
<tr>
<td>Moist</td>
<td>7042</td>
<td>7420</td>
<td>369</td>
<td>117.4</td>
</tr>
<tr>
<td>Dry</td>
<td>26242</td>
<td>28383</td>
<td>292</td>
<td>92.9</td>
</tr>
<tr>
<td>Desert</td>
<td>1283</td>
<td>1304</td>
<td>80</td>
<td>25.5</td>
</tr>
<tr>
<td>Hill &amp; Montane</td>
<td>8917</td>
<td>9272</td>
<td>306</td>
<td>97.4</td>
</tr>
<tr>
<td>Total</td>
<td>51729</td>
<td>307.9</td>
<td>98</td>
<td></td>
</tr>
</tbody>
</table>

103