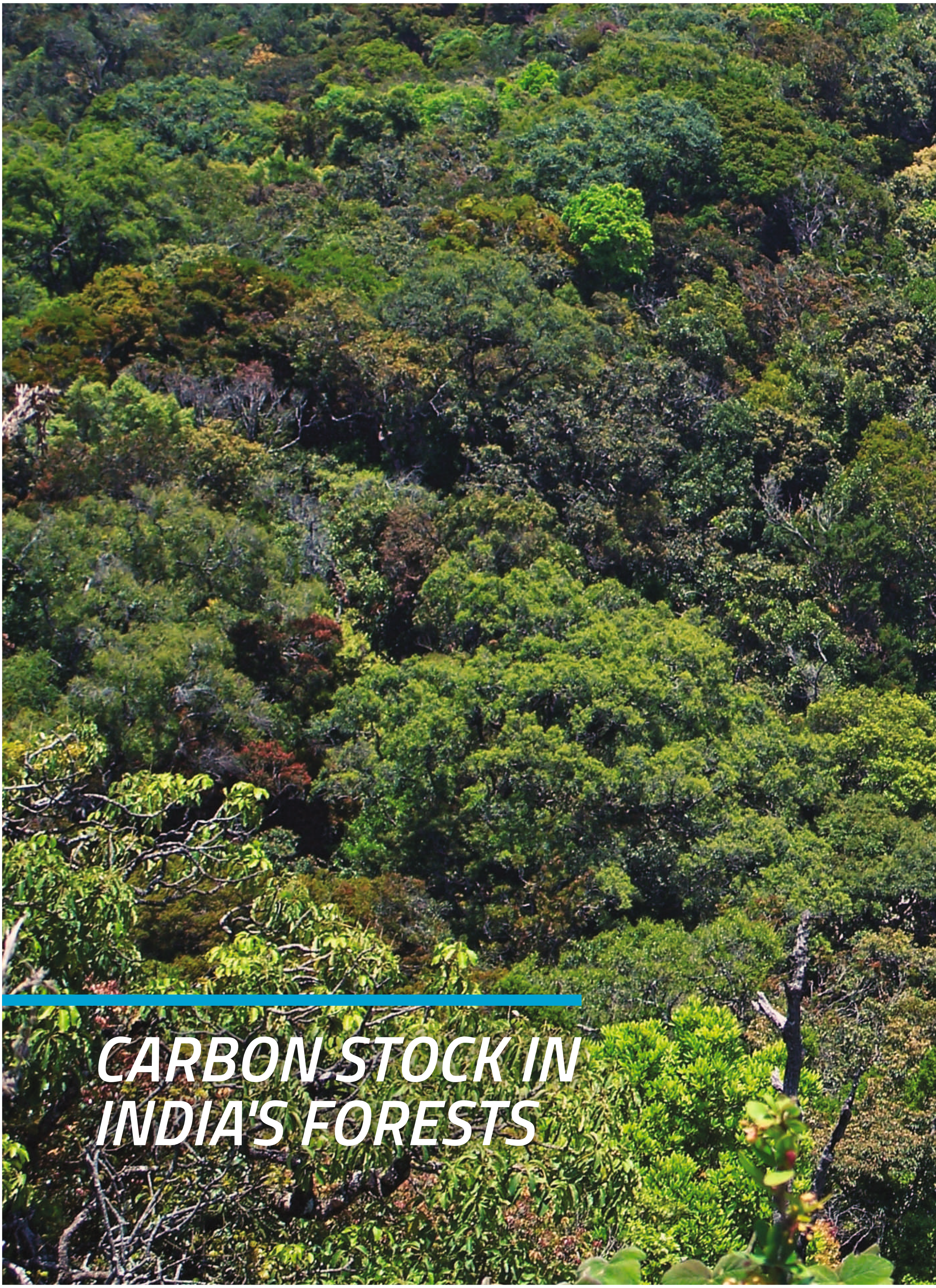

CARBON STOCK IN INDIA'S FORESTS

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CARBON STOCK IN INDIA'S FORESTS

8.1

Introduction

Climate change has emerged as the leading environmental issue in the recent past. The resulting variability of climate change poses serious threat to the environment and the quality of human life all over the world. It is for this reason, the parties to the United Nations Framework Convention on Climate Change (UNFCCC) have undertaken a comprehensive exercise to address the issues of climate change adaptation and mitigation. Forests play an important role in mitigation and adaptation of climate change. Forests sequester and store more carbon than any other terrestrial ecosystem and are an important natural 'brake' on climate change. Carbon sequestration by forests has attracted much interest as a mitigation approach, as it has been considered a relatively inexpensive means of addressing climate change immediately. In India, varied climate regimes and topography, large geographical area, long coastline and the existence of oceanic islands have endowed it with a diversity of natural biomes-from deserts to alpine meadows, tropical rain forests to temperate pine forests, mangroves to coral reefs and from marshland to high altitude lakes.

Forests and climate change are intimately intertwined. Forests regulate the climate, rain, groundwater and soil of the Earth. Forests are both sources and sinks of carbon. A growing forest captures carbon from the atmosphere and a mature forest is a store house of carbon. The world's forests and forest soils currently store more than one trillion tons of carbon – twice the amount found floating free in the atmosphere. According to Global Forest Resource Assessment Report, 2010 of FAO (FAO, 2010), the total forest carbon stock of the world is 652 Giga tonnes (161.8 t/ha). Out of this the forest biomass contains 289 Giga tonnes (71.6 t/ha); the 'dead organic matter' contains 72 Giga tonnes (17.8 t/ha); and forest soil organic carbon contains 293 Giga tonnes (72.3 t/ha) of carbon.

According to Fifth Assessment Report of Intergovernmental Panel on Climate Change, annual greenhouse gas emission flux from land use and land use change activities accounted for approximately 4.3-5.5 $GtCO_2eq$/yr, or about 9-11% of total anthropogenic greenhouse gas emissions (IPCC, 2014). The contribution of Agriculture, Forestry and Other land Use (AFOLU) sector to anthropogenic emissions is around one quarter of the global anthropogenic total.

To tackle the issue of climate change, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) agreed to undertake common actions. At the Third Conference of Parties (COP 3), held in Kyoto in 1997, Parties adopted the Kyoto Protocol. Under the Protocol, industrialized Parties or “Annex I countries” committed themselves to reducing their GHG emissions by an average of 5.2% below 1990 levels by 2012. The Protocol came into force in February 2005. At UNFCCC COP 11 in Montreal in 2005 the Coalition for Rainforest Nations-a group of Parties spearheaded by Papua New Guinea and Costa Rica-tabled a motion to include the reduction of emissions from deforestation and forest degradation in the provisions of the UNFCCC.

At UNFCCC COP 13, held in Bali in December 2007, the Parties agreed on the Bali Action Plan, which provides a 'roadmap' for negotiations towards a post-2012 climate arrangement. Among other things, the Parties agreed to the establishment of a climate change adaptation fund and a simplification of CDM rules for afforestation and reforestation projects. They also passed a resolution on reducing emissions from deforestation and forest degradation. The Bali Action Plan proposes that sustainable forest management and reducing emissions from deforestation and forest degradation be considered in the negotiation process for a post-2012 climate arrangement.

At COP 15 held at Cancun in 2016, methodological guidelines were discussed for REDD+. The five activities namely Reducing emissions from deforestation; Reducing emissions from forest degradation; Conservation of forest carbon stocks, Sustainable management of forest and Enhancement of forest carbon stocks were added for REDD+. The COP-16 in its milestone decision on REDD+ encourages developing countries to develop a “National Forest Reference Emission Level (REL) and/or National Forest Reference Level (RL) or, if appropriate, as an interim measure, sub-national REL and/or RL, in accordance with the national circumstances”. REL and RL serve as benchmark for assessing performance of implementation of REDD+ in a country.

8.2

General concepts and approaches in forest carbon accounting

The 'Good Practices Guidance' (GPG) developed by Intergovernmental Panel on Climate Change (IPCC) is universally accepted source book for concepts, definitions, various pools, methods, default values, various required equations etc for preparing account of forest carbon stocks (FCS).The GPG uses the term “Categories” to refer specific sources of emissions/ removals of greenhouse gases. The 2003 revision of GPG for LULUCF has six categories of land viz Forest land, Cropland, Grassland, Wetlands, Settlements and Other lands. Each land-use category is further subdivided. The forest land is divided into three sub categories namely Forest land remaining Forest land, land converted to forest land and forest land converted to other land.

According to GPG, the calculation of GHG inventories require information on extent (in case of LULUCF, areal) of an emission/removal category termed as 'Activity data' and emission or removal of GHG per unit of area (removal of CO_2 per ha of added forest area) termed as 'Emission factors'. The main aim is to estimate these factors for the reporting unit. Once these are estimated then the emission or removal, can be ascertained through the change in carbon stocks using stock difference method.

Three different approaches are given in the GPG to present the activity data (the change in area of different land categories). Approach 1 identifies the total area for each land category; it only provides “net” area. Approach 2 identifies the land conversions between categories by tracking and provides tabular information about land-use conversion. Approach 3 involves, in addition, the spatial tracking of land-use conversion.

The total carbon which is stocked in the forests is divided into several pools and the emission factors are derived from assessments of the changes in carbon stocks in these carbon pools. These factors are developed using estimates which are used at different levels; global, national and sub-national and based on the 'Tier levels' (Table 8.1) which are independent of the approach being followed.

Table 8.1 Three IPCC tiers and data requirements

Tier	*Data needs/examples of appropriate biomass data*
Tier 1	*IPCC default factors: Default MAI (for degradation) and/or forest bio-mass stock (for deforestation) values for broad continental forest types - default values given for all vegetation-based pools.*
Tier 2	*Country specific data for key factors: MAI and/or forest biomass values from existing forest inventories and/or ecological studies. Default val-ues provided for all non tree pools. Newly-collected forest biomass data is required.*
Tier 3	*Detailed national inventory of key C stocks, repeated measurements of key stocks through time or modeling: Repeated measurement of trees from permanent plots and/or calibrated process models. Can use default data for other pools stratified by in-county regions and forest type, or estimates from process module.*

In general, moving to higher tiers improves the accuracy of the inventory and reduces uncertainty, but the complexity and resources needed for conducting inventories also increases with higher tiers.

Tier 1 employs the basic method and default emission factors provided in the IPCC Guidelines (Workbook). Tier 1 methodologies generally use activity data that are spatially coarse, such as nationally or globally available estimates of deforestation rates, agricultural production statistics, and global land cover maps.

Tier 2 applies emission factors and activity data which are defined by the country. Tier 2 can also apply stock change methodologies based on country-specific data. Country-defined emission factors/activity data are more appropriate for the climatic regions and land use systems in that country.

At Tier 3, higher order methods including models and inventory measurement systems are used in which measurements are repeated over time and supported by high-resolution activity data and disaggregated at sub-national level. Such systems may use Remote Sensing and GIS tools for tracking land-use change over time.

In forest ecosystem, enormous carbon is stored which is classified in five pools by GPG. The living portion of biomass carbon is classified in two pools: the 'above ground biomass' (AGB) and 'below ground biomass' which are stores of significant amount of carbon. The 'dead organic matter' (DOM) is also classified into two pools: 'dead wood' and 'litter'. The fifth pool is 'Soil organic matter' (SOM) which contains substantial amount of organic carbon.

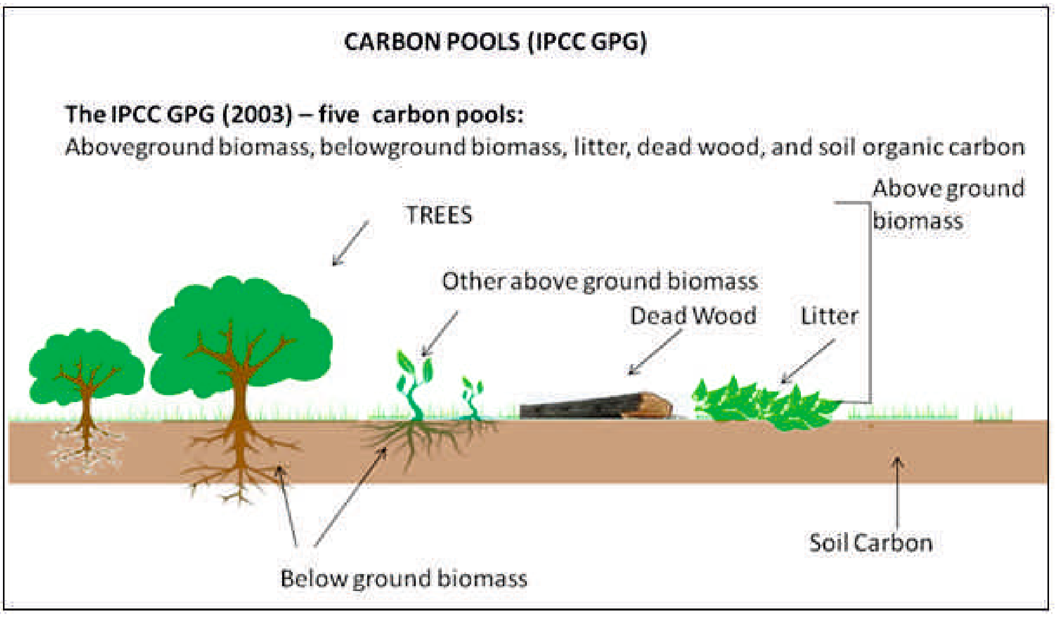


Figure 8.1: Carbon Pools (IPCC GPG)

Table 8.2 Different forest Carbon Pools

	Pools	Description
Living Biomass	Above ground biomass (AGB)	All living biomass above the soil including stem, stump, branches, bark, seeds and foliage.
	Below ground biomass (BGB)	All living biomass of live roots. Fine roots of less than 2mm diameter (country specific) are often excluded because these often cannot be distinguished empiri-cally from soil organic matter or litter.
Dead Organic Matter	Dead wood	Includes all non living woody biomass not contained in the litter, either standing or lying on the ground. Dead wood also includes dead roots and stumps larger than or equal to 10cm in diameter or any other diameter used by the country.
	Litter	Includes all non-living biomass with a diameter less than a minimum diameter chosen by the country (for FSI 5 cm), lying dead, in various states of decomposi-tion above the mineral or organic soil.
Soil	Soil organic matter (SOM)	Includes organic carbon in mineral and organic soils (including peat) to a specific depth chosen by the country (for FSI 30 cm) and applied consistently through the time series.

To measure changes in carbon stock, GPG recommends two methods: the Gain-Loss method (activity/process based approach) and the Stock-Difference method (inventory based approach). The Gain-Loss method is a process-based approach which estimates the net balance of additions to and removals from a carbon stock. The annual carbon stock change in a given pool is the difference between the annual gain and the annual loss of carbon for that pool. Not all transfers involve emissions or removals, since any transfer from one pool to another is a loss from the donor pool but a gain of equal amount for the receiving pool. The Stock-Difference method is a stock-based approach. It is used where carbon stocks in relevant pools are measured at two points of time to assess carbon stock changes.

As per GPG, principles of forest carbon account namely Accurate and Precise, Comparable, Complete, Conservative, Consistent, Relevance and transparent as given in GPG should be satisfied.

8.3

FSI initiatives in forest carbon estimation

Growing stock obtained through forest inventories forms the basis for calculation of carbon. FSI has been conducting forest inventory since its inception. FSI inventoried a large part of the country during 1965 to 2001 with some areas inventoried twice. Since 2002, the forest inventory is being carried out at national level. Due to a long history of inventories, FSI has a huge repository of data on forest growing stock. FSI made the first tentative estimate of woody growing stock of the country's forests in 1995 using its forest inventory data collected during 1965 to 1990, thematic maps and forest cover information (SFR, 1995). This information was used by different institutions and scientists for estimating forest carbon stock during early 2000.

FSI has been the major contributor on forest biomass estimation and carbon stock change (during 1984 and 1994) in India's Initial National Communication (INC) submitted to UNFCCC in 2004. In INC (also referred as NATCOM -I) process, FSI estimated forest carbon of only woody growing stock. The growing stock (volume) data was first converted into biomass by using species wise specific gravity of the wood. Thereafter, biomass expansion factors were used to convert woody biomass to total above ground biomass which included all other factors like small wood and foliage of trees, shrub, herbs etc. Similarly, below ground biomass was computed using default root-shoot ratio from GPG. The total biomass so obtained was then converted into carbon using conversion factor ('tier 1 approach').

For Second National Communication (SNC) to UNFCCC, FSI conducted 'Greenhouse gas inventory in Forest Land Remaining Forest Land & Land Converted into Forest Land for the period 1994 to 2004' under 'Land Use, Land-Use Change and Forestry (LULUCF)'. GHG fluxes in the LULUCF sector are generally estimated as net changes in carbon stocks over time. The use of carbon stock changes to estimate CO_2 emissions and removals is based on the fact that changes in ecosystem carbon stocks are predominantly through CO_2 exchanges between the land surface and the atmosphere. The increase in total carbon stocks over time are equated with a net removal of CO_2 from the atmosphere and decreases in total carbon stocks (less transfer to other pools such as harvested wood products) are equated with net emissions of CO_2. FSI estimated carbon stock for 1994 and 2004 in respect of Forest Land Remaining Forest Land & Land Converted into Forest Land.

In addition to the above work, FSI published a separate report on 'Carbon stock in India's Forest' in 2011. A separate chapter on 'Carbon stock' was given in ISFR 2011. Since then, the information on total carbon stock and change with respect to previous assessment is a part of successive ISFRs. Considering the importance of carbon stock, a separate chapter has been given in the present report giving total carbon stock in 2017, change with respect to 2015 ISFR, state wise and major forest types group wise carbon stock along with per hectare figure under different carbon pools.

8.4

Methodology used by FSI in estimating carbon stock

The calculation of carbon stock requires information on extent of area of an emission/removal category termed as 'Activity Data' and emission or removal of GHG per unit area termed as 'Emission Factor' as per the GPG developed by IPCC. The methodology used by FSI for activity data and emission factors has been described in the following paragraphs.

8.4.1

Methodology for estimating activity data

Three different methodologies are advocated in GPG and are being used by different countries to assess the extent of area (activity data) under 'Forest land remaining forest' and 'Non-forest land converted to forest'. These methodologies are: Wall-to-wall mapping using remote sensing data; Mapping of sampled areas using remote sensing data and; Using field survey methods. For activity data, FSI used remotely sensed (RS) data and adhere to the guidelines of GPG with respect to RS data. A hybrid approach combining automated digital classification techniques with visual interpretation was used. This technique is generally used as it is simple, robust and cost effective.

8.4.2

Stratification of Forest area

Stratification gains precision by dividing a heterogeneous population into relatively homogeneous sub-population based on certain stratification variables. Since, carbon stored in the vegetation is largely depends upon canopy density and forest type; these two were considered as stratification variables.

8.4.3

Forest Type Mapping

Forest type wise extent of forest cover is useful information for characterizing forests in terms of floristic composition and ecological value. FSI mapped forest types of India, according to Champion & Seth classification (1968) on 1:50,000 scale. Using the forest type maps, distribution of forest cover in different forest types has been determined for the country. Canopy density wise spatial information was available from the 'forest cover mapping'. This was supplemented with the forest type wise information generated under the national forest type mapping project carried out by FSI. This gave three canopy density classes and 17 type groups including plantation– thus yielding fifty one classes in all. Using this classification, area statistics (activity data) were generated through GIS technique.

8.4.4

Methodology for estimating emission factors

To measure exchange of GHGs between forest eco-system and the atmosphere which is eventually change in carbon stocks over time, FSI has used Stock-Difference method (inventory based approach or periodic accounting) for estimating various emissions factors as recommended by GPG. The emission factors have been estimated partly by using the NFI data collected during 2002-2008 and partly by conducting a special study between 2008-10. The same factors have been used for estimation of carbon stock for 2017. The methodology followed in deriving these factors are given below:

8.4.4.1

Above Ground Biomass (AGB) of trees having dbh 10 cm and above and bamboo

Under the national forest inventory programme, FSI has been conducting a national forest inventory since 2002 following a multistage sampling approach. As per the design, data from about 21,000 sample plots (size 0.1 ha) had been collected between years 2002-2008. At each sample plot, all trees of diameter 10 cm and above were measured. The woody volume of trees for each sample plot was calculated using volume equations developed by FSI for various species. The volume equation provides above ground woody volume i.e. above ground volume, which includes volume of main stem measured upto 10 cm diameter and volume of all branches having diameter 5 cm or more. Data of specific gravity and percentage carbon content of most of the tree species have been obtained from different published literature. For few species, percentage carbon content was ascertained by experimentation and for remaining an average of all other species was used. Standard formulae were used to calculate biomass and carbon content of each tree.

The estimates of bamboo biomass and carbon stocked in this resource has also been calculated from NFI data. For estimating volume of the bark, the double bark thickness of trees measured during forest inventory and volume equation of trees have been used. Using species-wise, dbh and bark thickness, bark volume equations were developed and were adjusted for 'bark void factor' which were utilized to estimate bark volume. With the help of the specific gravity of bark, the volume was converted into biomass. Using carbon content percent of wood, carbon stored in bark was estimated.

8.4.4.2

Above ground biomass of trees having dbh less than 10 cm

This information was derived by FSI from a special study conducted during 2008-10 for SNC. On the basis of data collected between 2002-08, 20 important tree species were identified for each of 14 strata in NFI. For each of such species, 3 trees of diameters 1- 9 cm (at 1.37 m. height) were felled. From the felled trees, separate biomass was calculated and recorded for wood, twigs and leaves in the prescribed format. Taking the dry biomass of wood/foliage as dependent variable and dbh as independent variable biomass equations were developed for each species. Using the plot level regeneration data from NFI i.e. recruits, un-established, established and all trees having dbh between 5 to 10 cm, biomass and carbon content at plot level is calculated.

8.4.4.3

Above Ground Biomass of shrubs, herbs, climbers and biomass of Dead Organic Matter (DOM: dead wood and litter)

For this purpose, the data of forest inventory conducted during 2002-08 was analysed to ascertain the optimum number of plots required for each combination of forest type and forest density. It revealed that about 15 clusters of 2 sample plots for each combination, would suffice for estimating the biomass/carbon factors for these components if 30% permissible error is considered. This survey was conducted in the districts on randomly selected points which were already inventoried during 2002-2008 and for which forest type and density were known.

For the desired combinations of forest type and forest density, the exact geographical locations (latitude and longitude) of the optimum number of randomly selected sample plots were visited. Using this information, at the centre of sample point, three concentric plots of size 5mx5m, 3mx3m and 1mx1m were laid out at a distance of 30m away from the centre of sample point in North and South direction. In 5mx5m plot, all dead wood above 5 cm diameter were collected, weighed and recorded. In 3mx3m plot, all woody litter i.e. all branches below 5 cm diameter were collected, weighed and recorded. All shrubs & climbers in 3mx3m plots were uprooted, weighed and recorded in the prescribed format. In 1m x 1m plot, all herbs were uprooted, weighed and recorded. Dry biomass was converted to carbon stock.

8.4.4.4

Above Ground Biomass of branches, foliage of trees having dbh greater than or equal to 10 cm

This information was derived by FSI from a special study conducted during 2008-10 for Second National Communication (SNC). As described above, 20 important tree species in each stratum were identified. For each such species other than palm like trees, in each of the diameter class, three normal trees were selected. Its diameter, height, crown length, crown width in two directions, blank in canopy and shape of the crown were recorded.

For the purpose of biomass calculation, one normal tree of each diameter class of each species was selected. In the selected tree, partial destructive method was used to compute biomass of woody branches up to 5 cm dia, twigs and leaves. Biomass of all these parameters was separately recorded in the prescribed formats. Taking the dry biomass of small wood/foliage as dependent variable and dbh as independent variable biomass equations were developed for each species. Using the plot level data of NFI, species wise carbon content, the total biomass and carbon content at plot level was calculated.

8.4.4.5

Organic matter in soil and forest floor

During forest inventory, data on forest floor (non-woody litter and humus) and soil carbon is also collected from each sample plot.. For collecting data on humus and soil carbon, two sub-plots of size 1mx1m are laid out within the main plot. The forest floor from both the plots was first swept and material so collected was weighed and a portion of same was kept for carbon analysis. Further, at the center of these two sub-plots, a pit of 30cm x 30cm x 30cm was dug and a composite sample of soil of 200gm was kept for organic carbon analysis. Samples of soil and humus were got analysed from the standard soil labs and were used for the calculation.

8.4.4.6

Below ground biomass

This is the most difficult pool to measure and generally not measured in forest inventory. It is being included using a relationship (usually a root-to-shoot ratio) to aboveground biomass which have been established by various researchers. GPG also provide default ratios for six major global forest types. FSI has selectively used these defaults to arrive at the carbon number.

8.4.5

Synthesizing Data for National Carbon Estimation

GIS techniques were used to intersect forest type map (2004) and forest cover map (2015 and 2017) resulting in two maps having 51 strata (forest type and canopy density intersections) one corresponding to each year. The real extent of these strata were ascertained using GIS techniques. The geographical location of each sample plot recorded with GPS during field visits have created a GIS compatible point layer of the forest inventory plots. This NFI point layer map was overlaid on the above map having 51 forest type - canopy density strata. The NFI points falling in each stratum were identified. For each stratum, the plot wise information on all the parameters of each carbon pool, were aggregated to have generalized factor for that stratum. Biomass and carbon factors were specifically developed for each stratum like, shrubs, herbs, climbers, dead wood and woody litter. Multiplying activity data with these factors, different parameter wise total carbon for all the 51 strata were arrived at. This information was arranged into five carbon pools. Adding pool wise carbon contents, national carbon estimates were arrived at for the year 2015 and 2017. The difference between pool wise carbon estimates gave the net removal of carbon.

8.5

Results

The national level estimates of carbons stocks for 2015 and 2017 under different carbon pools has been given in Table 8.3.

Table 8.3 Change in carbon stock in forest between 2015 and 2017. (Million tonnes)

Component	Carbon Stock in forest as per ISFR 2015	Carbon stock in forest in 2017	Net change in Carbon stock	Annual increase in Carbon stock
Above Ground Biomass	2220	2238	18	9.00
Below Ground Biomass	695	699	4	2.00
Dead wood	29	30	1	0.50
Litter	131	136	5	2.50
Soil Organic Carbon	3969	3979	10	5.00
Total	**7044**	**7082**	**38**	**19.00**

The carbon stock for 2017 has been estimated to be 7083 million tonnes. There is an increase of 39 million tonnes of carbon stock as compared to the estimates of previous assessment. The annual increase of carbon stock is worked out to be 19.50 million tonnes which is 71.5 million tonnes of CO_2 equivalent. Soil organic carbon is the largest pool of carbon followed by AGB, BGB, Litter and dead wood. On comparing the changes between present and previous assessment, maximum changes has been observed in AGB followed by soil organic carbon, litter and dead wood.

The state wise carbon stock and per hectare carbon stock under different carbon pools have been given in Table 8.4.

Table 8.4 State wise Carbon Stock in different carbon pools in 000' tonnes with per ha stock in tonnes in parentheses

State	Area in sq km	AGB	BGB	Dead wood	Litter	SOC	Total
Andhra Pradesh	28,147	100,539 (35.72)	38,585 (13.71)	568 (0.20)	4,527 (1.61)	118,471 (42.09)	262,690 (93.33)
Arunachal Pradesh	66,964	243,462 (36.36)	53,378 (7.97)	4,305 (0.64)	16,231 (2.42)	677,163 (101.12)	994,539 (148.52)
Assam	28,105	47,343 (16.85)	10,824 (3.85)	1,093 (0.39)	5,240 (1.86)	112,352 (39.98)	176,852 (62.93)
Bihar	7,299	19,063 (26.12)	6,707 (9.19)	138 (0.19)	625 (0.86)	28,864 (39.55)	55,397 (75.90)
Chhatisgarh	55,547	206,678 (37.21)	68,159 (12.27)	2,588 (0.47)	7,628 (1.37)	275,927 (49.67)	560,980 (100.99)

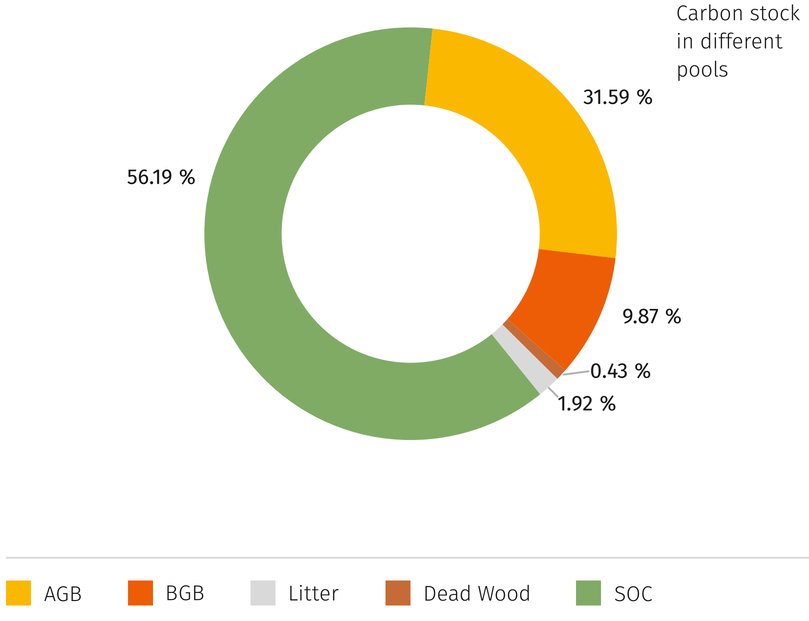
State	Area in sq km	AGB	BGB	Dead wood	Litter	SOC	Total
Delhi	192	230 (11.98)	52 (2.71)	2 (0.10)	11 (0.57)	653 (34.01)	948 (49.38)
Goa	2,229	5,153 (23.12)	1,512 (6.78)	250 (1.12)	417 (1.87)	11,684 (52.42)	19,016 (85.31)
Gujarat	14,757	32,668 (22.14)	11,719 (7.94)	322 (0.22)	993 (0.67)	64,995 (44.04)	110,697 (75.01)
Haryana	1,588	3,736 (23.53)	1,269 (7.99)	20 (0.13)	74 (0.47)	7,312 (46.05)	12,411 (78.15)
Himachal Pradesh	15,100	70,655 (46.79)	18,691 (12.38)	739 (0.49)	2,511 (1.66)	83,186 (55.09)	175,782 (116.41)
Jammu & Kashmir	23,241	112,919 (48.59)	30,083 (12.94)	1,004 (0.43)	3,529 (1.52)	128,391 (55.24)	275,926 (118.72)
Jharkhand	23,553	86,006 (36.52)	33,173 (14.08)	438 (0.19)	1,298 (0.55)	101,967 (43.29)	222,882 (94.63)
Karnataka	37,550	128,098 (34.11)	35,045 (9.33)	2,545 (0.68)	19,745 (5.26)	289,652 (77.14)	475,085 (126.52)
Kerala	20,321	74,166 (36.50)	19,245 (9.47)	1,058 (0.52)	7,436 (3.66)	153,976 (75.77)	255,881 (125.92)
Madhya Pradesh	77,414	266,040 (34.37)	101,516 (13.11)	1,654 (0.21)	7,741 (1.00)	318,713 (41.17)	695,664 (89.86)
Maharashtra	50,682	142,651 (28.15)	48,947 (9.66)	1,986 (0.39)	9,385 (1.85)	290,052 (57.23)	493,021 (97.28)
Manipur	17,346	27,253 (15.71)	8,821 (5.09)	530 (0.31)	3,909 (2.25)	102,578 (59.14)	143,091 (82.49)
Meghalaya	17,146	25,168 (14.68)	6,835 (3.99)	881 (0.51)	5,184 (3.02)	117,772 (68.69)	155,840 (90.89)
Mizoram	18,186	15,359 (8.45)	3,173 (1.74)	633 (0.35)	2,652 (1.46)	73,224 (40.26)	95,041 (52.26)
Nagaland	12,489	16,151 (12.93)	4,150 (3.32)	666 (0.53)	2,432 (1.95)	101,661 (81.40)	125,060 (100.14)
Odisha	51,345	152,525 (29.71)	50,407 (9.82)	2,108 (0.41)	9,087 (1.77)	238,776 (46.50)	452,903 (88.21)
Punjab	1,837	5,095 (27.74)	1,883 (10.25)	26 (0.14)	63 (0.34)	8,971 (48.84)	16,038 (87.31)
Rajasthan	16,572	32,558 (19.65)	12,736 (7.69)	216 (0.13)	721 (0.44)	43,429 (26.21)	89,660 (54.10)
Sikkim	3,344	13,379 (40.01)	3,735 (11.17)	211 (0.63)	585 (1.75)	30,624 (91.58)	48,534 (145.14)
Tamilnadu	26,281	84,067 (31.99)	29,252 (11.13)	1,006 (0.38)	5,579 (2.12)	109,434 (41.64)	229,338 (87.26)
Telangana	20,419	72,498 (35.51)	28,388 (13.90)	333 (0.16)	3,117 (1.53)	80,639 (39.49)	184,975 (90.59)
Tripura	7,726	15,674 (20.29)	3,224 (4.17)	556 (0.72)	1,613 (2.09)	42,341 (54.80)	63,408 (82.07)
Uttar Pradesh	14,679	47,752 (32.53)	14,264 (9.72)	444 (0.30)	1,824 (1.24)	60,850 (41.45)	125,134 (85.25)
Uttarakhand	24,295	105,173 (43.29)	26,961 (11.10)	1,316 (0.54)	5,665 (2.33)	145,549 (59.91)	284,664 (117.17)
West Bengal	16,847	45,382 (26.94)	13,916 (8.26)	434 (0.26)	2,585 (1.53)	100,884 (59.88)	163,201 (96.87)
Andaman & Nicobar Islands	6,742	39,426 (58.48)	11,901 (17.65)	2,048 (3.04)	3,702 (5.49)	57,996 (86.02)	115,073 (170.68)

State	Area in sq km	AGB	BGB	Dead wood	Litter	SOC	Total
Chandigarh	22	61 (27.73)	19 (8.64)	0 (0.00)	2 (0.91)	122 (55.45)	204 (92.73)
Dadra & Nagar Haveli	207	447 (21.59)	106 (5.12)	10 (0.48)	35 (1.69)	827 (39.95)	1,425 (68.84)
Daman & Diu	20	11 (5.50)	2 (1.00)	0 (0.00)	2 (1.00)	76 (38.00)	91 (45.50)
Lakshdweep	27	55 (20.37)	*0 (0.00)	1 (0.37)	5 (1.85)	100 (37.04)	161 (59.63)
Puducherry	54	108 (20.00)	23 (4.26)	1 (0.19)	8 (1.48)	311 (57.59)	451 (83.52)
Total	708,273	2,237,549 (31.59)	698,701 (9.86)	30,130 (0.43)	136,161 (1.92)	3,979,522 (56.19)	7,082,063 (99.99)

* In Lakshadweep, most of the forest cover is of Cocos nucifera for which no suitable ratio for BGB is available.

Arunachal Pradesh has maximum carbon stock of 994.5 million tonnes followed by Madhya Pradesh (695.5 million tonnes), Chhattisgarh (560.9 million tonnes) and Maharashtra (493.0 million tonnes).

Figure 8.2: Carbon stock in different pools



The per hectare carbon stock among different states/UTs indicates that Andaman Nicobar is contributing maximum per hectare carbon stock of 170.68 tonnes, followed by Arunachal Pradesh (148.52 tonnes), Sikkim (145.14 tonnes) and Karnataka (126.52 tonnes). At national level 32% of carbon stock is in AGB where as about 56% in SOC. In all the NE states it is observed that SOC is more than double the carbon in AGB. In all other major states this ratio is around 1:1.5.

Table 8.5: Forest Type and Density wise Carbon Stock in 000'tonnes in different carbon pools with per ha stock in tonnes in parentheses

Forest Type Stratum	Density	Area in sq km	AGB	BGB	Dead wood	Litter	SOC	Total
Tropical Wet Evergreen Forests	VDF	8,761	57,107 (65.18)	19,754 (22.55)	3,173 (3.62)	4,969 (5.67)	82,619 (94.30)	167,622 (191.33)
	MDF	9,022	38,686 (42.88)	13,155 (14.58)	320 (0.35)	3,381 (3.75)	75,577 (83.77)	131,119 (145.33)
	OF	3,089	4,210 (13.63)	1,549 (5.01)	74 (0.24)	867 (2.81)	22,629 (73.26)	29,329 (94.95)
Tropical Semi-Evergreen Forests	VDF	19,475	111,801 (57.41)	22,995 (11.81)	3,541 (1.82)	9,187 (4.72)	249,478 (128.10)	397,002 (203.85)
	MDF	43,671	129,997 (29.77)	26,738 (6.12)	1,583 (0.36)	14,889 (3.41)	345,448 (79.10)	518,655 (118.76)
	OF	34,893	32,943 (9.44)	6,776 (1.94)	737 (0.21)	7,934 (2.27)	160,382 (45.96)	208,772 (59.83)
Tropical Moist Deciduous Forests	VDF	24,606	91,484 (37.18)	18,816 (7.65)	2,881 (1.17)	6,912 (2.81)	183,781 (74.69)	303,874 (123.50)
	MDF	72,288	183,409 (25.37)	37,723 (5.22)	5,957 (0.82)	24,850 (3.44)	446,233 (61.73)	698,172 (96.58)
	OF	47,853	56,807 (11.87)	11,684 (2.44)	1,914 (0.40)	8,638 (1.81)	241,925 (50.56)	320,968 (67.07)
Littoral and Swamp Forests	VDF	1,924	13,482 (70.07)	4,664 (24.24)	4 (0.02)	224 (1.16)	15,639 (81.28)	34,013 (176.78)
	MDF	2,318	10,093 (43.54)	3,491 (15.06)	5 (0.02)	157 (0.68)	13,253 (57.17)	26,999 (116.48)
	OF	2,398	3,381 (14.10)	1,169 (4.87)	5 (0.02)	94 (0.39)	7,905 (32.96)	12,554 (52.35)
Tropical Dry Deciduous Forests	VDF	23,480	146,704 (62.48)	57,605 (24.53)	1,075 (0.46)	15,231 (6.49)	139,076 (59.23)	359,691 (153.19)
	MDF	122,916	725,220 (59.00)	284,765 (23.17)	1,812 (0.15)	7,568 (0.62)	647,378 (52.67)	1,666,743 (135.60)
	OF	133,111	170,285 (12.79)	66,864 (5.02)	1,750 (0.13)	5,573 (0.42)	399,438 (30.01)	643,910 (48.37)
Tropical Thorn Forests	VDF	330	439 (13.30)	170 (5.15)	12 (0.36)	72 (2.18)	899 (27.24)	1,592 (48.24)
	MDF	3,547	4,168 (11.75)	1,624 (4.58)	89 (0.25)	467 (1.32)	10,701 (30.17)	17,049 (48.07)
	OF	9,521	4,674 (4.91)	1,825 (1.92)	120 (0.13)	724 (0.76)	18,502 (19.43)	25,845 (27.15)
Tropical Dry Evergreen Forests	VDF	141	685 (48.58)	269 (19.08)	17 (1.21)	14 (0.99)	1,255 (89.01)	2,240 (158.87)
	MDF	492	1,640 (33.33)	644 (13.09)	18 (0.37)	94 (1.91)	2,087 (42.42)	4,483 (91.12)
	OF	244	460 (18.85)	181 (7.42)	5 (0.20)	22 (0.90)	856 (35.08)	1,524 (62.46)
Subtropical Broadleaved Hill Forest	VDF	1,948	6,463 (33.18)	2,098 (10.77)	185 (0.95)	368 (1.89)	23,677 (121.55)	32,791 (168.33)
	MDF	8,590	19,512 (22.71)	7,219 (8.40)	314 (0.37)	2,417 (2.81)	72,680 (84.61)	102,142 (118.91)
	OF	8,621	13,648 (15.83)	5,282 (6.13)	173 (0.20)	1,606 (1.86)	59,996 (69.59)	80,705 (93.61)

Forest Type Stratum	Density	Area in sq km	AGB	BGB	Dead wood	Litter	SOC	Total
Subtropical Pine Forests	VDF	2,069	10,007 (48.37)	2,526 (12.21)	248 (1.20)	298 (1.44)	19,554 (94.51)	32,633 (157.72)
	MDF	9,908	30,154 (30.43)	7,611 (7.68)	363 (0.37)	1,293 (1.31)	62,773 (63.36)	102,194 (103.14)
	OF	7,917	16,678 (21.07)	4,210 (5.32)	159 (0.20)	728 (0.92)	40,761 (51.49)	62,536 (78.99)
Subtropical Dry Evergreen Forest	VDF	7	40 (57.14)	16 (22.86)	1 (1.43)	0 (0.00)	79 (112.86)	136 (194.29)
	MDF	61	245 (40.16)	96 (15.74)	2 (0.33)	3 (0.49)	582 (95.41)	928 (152.13)
	OF	115	347 (30.17)	136 (11.83)	2 (0.17)	4 (0.35)	610 (53.04)	1,099 (95.57)
Montane Wet Temperate Forests	VDF	1,795	7,385 (41.14)	1,864 (10.38)	245 (1.36)	435 (2.42)	16,376 (91.23)	26,305 (146.55)
	MDF	1,759	4,684 (26.63)	1,182 (6.72)	64 (0.36)	341 (1.94)	13,326 (75.76)	19,597 (111.41)
	OF	1,431	1,364 (9.53)	344 (2.40)	29 (0.20)	232 (1.62)	8,245 (57.62)	10,214 (71.38)
Himalayan Moist Temperate Forest	VDF	8,480	61,887 (72.98)	15,622 (18.42)	1,156 (1.36)	2,548 (3.00)	70,853 (83.55)	152,066 (179.32)
	MDF	13,376	74,476 (55.68)	18,799 (14.05)	489 (0.37)	3,393 (2.54)	97,859 (73.16)	195,016 (145.80)
	OF	7,360	19,568 (26.59)	4,940 (6.71)	148 (0.20)	1,466 (1.99)	41,935 (56.98)	68,057 (92.47)
Himalayan Dry Temperate Forests	VDF	1,376	15,403 (111.94)	4,176 (30.35)	165 (1.20)	236 (1.72)	13,469 (97.89)	33,449 (243.09)
	MDF	2,144	12,342 (57.57)	3,346 (15.61)	78 (0.36)	316 (1.47)	14,199 (66.23)	30,281 (141.24)
	OF	1,663	6,313 (37.96)	1,711 (10.29)	33 (0.20)	145 (0.87)	6,914 (41.58)	15,116 (90.90)
Sub-Alpine Forests	VDF	2,991	21,159 (70.74)	5,737 (19.18)	358 (1.20)	558 (1.87)	32,990 (110.30)	60,802 (203.28)
	MDF	5,416	22,514 (41.57)	6,104 (11.27)	198 (0.37)	534 (0.99)	35,477 (65.50)	64,827 (119.70)
	OF	4,517	13,891 (30.75)	3,766 (8.34)	91 (0.20)	291 (0.64)	20,507 (45.40)	38,546 (85.34)
Moist Alpine Scrubs	VDF	208	1,044 (50.19)	283 (13.61)	25 (1.20)	19 (0.91)	1,643 (78.99)	3,014 (144.90)
	MDF	417	1,169 (28.03)	317 (7.60)	15 (0.36)	35 (0.84)	2,915 (69.90)	4,451 (106.74)
	OF	516	879 (17.03)	238 (4.61)	10 (0.19)	34 (0.66)	2,605 (50.48)	3,766 (72.98)
Dry Alpine Scrub	VDF	195	1,588 (81.44)	431 (22.10)	23 (1.18)	23 (1.18)	1,687 (86.51)	3,752 (192.41)
	MDF	444	1,415 (31.87)	384 (8.65)	16 (0.36)	53 (1.19)	3,621 (81.55)	5,489 (123.63)
	OF	986	2,843 (28.83)	771 (7.82)	20 (0.20)	99 (1.00)	2,757 (27.96)	6,490 (65.82)

Forest Type Stratum	Density	Area in sq km	AGB	BGB	Dead wood	Litter	SOC	Total
Plantation/TOF	VDF	372	1,456 (39.14)	300 (8.06)	2 (0.05)	77 (2.07)	3,373 (90.67)	5,208 (140.00)
	MDF	11,949	35,774 (29.94)	7,350 (6.15)	427 (0.36)	2,797 (2.34)	89,464 (74.87)	135,812 (113.66)
	OF	37,562	45,623 (12.15)	9,381 (2.50)	0 (0.00)	3,946 (1.05)	153,537 (40.88)	212,487 (56.57)
	Total	**708,273**	**2,237,546 (31.59)**	**698,701 (9.86)**	**30,131 (0.43)**	**136,162 (1.92)**	**3,979,525 (56.19)**	**7,082,065 (99.99)**

More than 70% of forest cover in India falls in Tropical Semi-Evergreen, Tropical Moist Deciduous and Tropical Dry Deciduous Forest Type. More than 30% areas have this Forest Types fall in the category of Open Forest, which need to be improved in order to achieve NDC targets. Among these forest types Tropical Dry Deciduous and Tropical Moist Dry Deciduous may be taken up. This can also be seen from the above table that the per hectare carbon stock for open forest is 48.37 tonnes where as for moderately dense forest it is 135.6 tonnes per hectare, implying better gain in carbon sequestration rate if Dry Deciduous Open Forest is converted to Dry Deciduous Moderately Dense Forest.

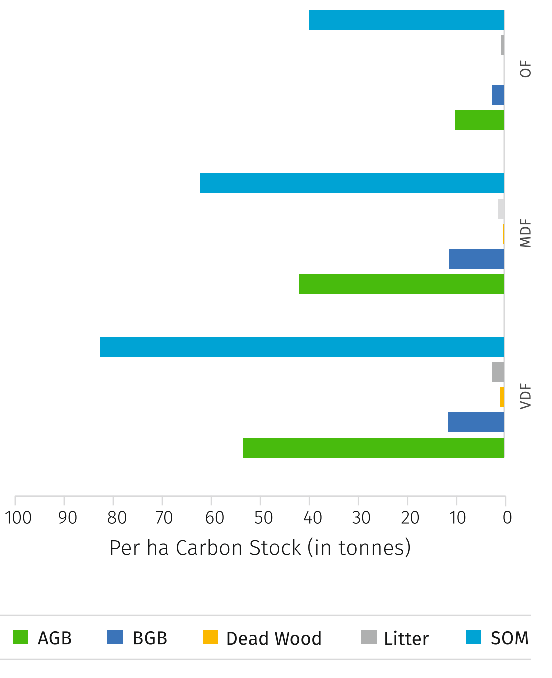


Figure 8.3: Density wise Carbon Stock per hectare in different pools

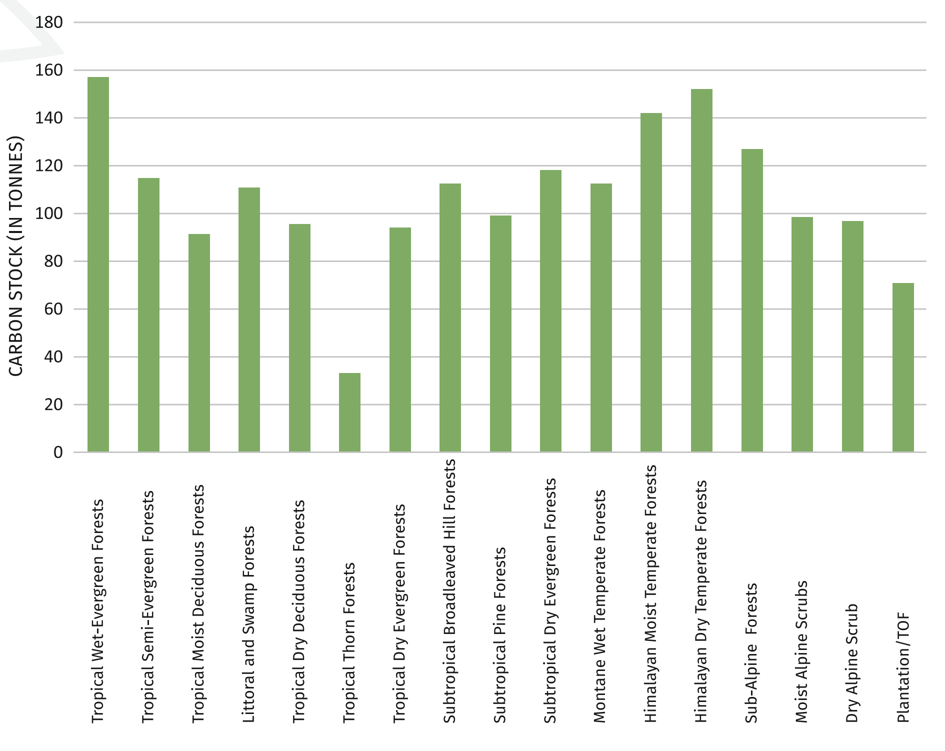
Table 8.6 Forest Type wise Carbon Stock in 000'tonnes in different carbon pools with per ha stock in tonnes in parentheses

Forest Type Stratum	Area in sq km	AGB	BGB	Dead wood	Litter	SOC	Total
Tropical Wet Evergreen Forests	20,872	100,004 (47.91)	34,458 (16.51)	3,567 (1.71)	9,216 (4.42)	180,825 (86.64)	328,070 (157.18)
Tropical Semi-Evergreen Forests	98,039	274,741 (28.02)	56,508 (5.76)	5,861 (0.60)	32,009 (3.26)	755,307 (77.04)	1,124,426 (114.69)
Tropical Moist Deciduous Forests	144,747	331,701 (22.92)	68,224 (4.71)	10,752 (0.74)	40,400 (2.79)	871,939 (60.24)	1,323,016 (91.40)
Littoral and Swamp Forests	6,640	26,955 (40.59)	9,324 (14.04)	14 (0.02)	475 (0.72)	36,796 (55.42)	73,564 (110.79)
Tropical Dry Deciduous Forests	279,506	1,042,208 (37.29)	409,233 (14.64)	4,638 (0.17)	28,372 (1.02)	1,185,892 (42.43)	2,670,343 (95.54)
Tropical Thorn Forests	13,399	9,280 (6.93)	3,619 (2.70)	220 (0.16)	1,263 (0.94)	30,102 (22.47)	44,484 (33.20)

Forest Type Stratum	Area in sq km	AGB	BGB	Dead wood	Litter	SOC	Total
Tropical Dry Evergreen Forests	877	2,785 (31.76)	1,094 (12.47)	40 (0.46)	130 (1.480)	4,198 (47.87)	8,247 (94.04)
Subtropical Broadleaved Hill Forest	19,159	39,623 (20.68)	14,600 (7.62)	672 (0.35)	4,391 (2.29)	156,353 (81.61)	215,639 (112.55)
Subtropical Pine Forests	19,894	56,838 (28.57)	14,347 (7.21)	769 (0.39)	2,320 (1.17)	123,087 (61.87)	197,361 (99.21)
Subtropical Dry Evergreen Forest	183	633 (34.59)	248 (13.55)	5 (0.27)	7 (0.38)	1,271 (69.45)	2,164 (118.25)
Montane Wet Temperate Forests	4,985	13,432 (26.94)	3,391 (6.80)	338 (0.68)	1,008 (2.02)	37,948 (76.12)	56,117 (112.57)
Himalayan Moist Temperate Forest	29,216	155,932 (53.37)	39,361 (13.47)	1,793 (0.61)	7,407 (2.54)	210,647 (72.10)	415,140 (142.09)
Himalayan Dry Temperate Forests	5,183	34,057 (65.71)	9,234 (17.82)	277 (0.53)	696 (1.34)	34,582 (66.72)	78,846 (152.12)
Sub-Alpine Forests	12,923	57,564 (44.54)	15,607 (12.08)	647 (0.50)	1,384 (1.07)	88,973 (68.85)	164,175 (127.04)
Moist Alpine Scrubs	1,141	3,092 (27.10)	838 (7.34)	51 (0.45)	88 (0.77)	7,163 (62.78)	11,232 (98.44)
Dry Alpine Scrub	1,626	5,846 (35.95)	1,585 (9.75)	59 (0.36)	175 (1.08)	8,064 (49.59)	15,729 (96.73)
Plantation/TOF	49,883	82,854 (16.61)	17,031 (3.41)	429 (0.09)	6,820 (1.37)	246,374 (49.39)	353,508 (70.87)
Total	**708,273**	**2,237,545 (31.59)**	**698,702 (9.86)**	**30,132 (0.43)**	**136,161 (1.92)**	**3,979,521 (56.19)**	**7,082,061 (99.99)**

The Table 8.6 reveals that the maximum carbon stock has been stored in tropical dry Deciduous forest (2670 m. tonnes) followed by Tropical Moist Deciduous Forest (1323 m. tonnes) and Tropical Semi Evergreen forest (1124 m. tonnes).

Figure 8.4: Forest Type wise Carbon Stock per hectare



Analyzing per hectare carbon stock in different forest types, it has been found that Tropical Wet Evergreen Forest has maximum per hectare Carbon Stock of 157.18 tonnes followed by Himalayan Dry Temperate Forests (152.12 tonnes), Himalayan Moist Temperate Forest (142.09 tonnes) and Sub-Alpine Forests (127.04 tonnes).