UNITED STATES
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Data report

Indicator 26. Total forest ecosystem biomass and carbon pool, and, if appropriate, by forest type, age class, and successional changes

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I. Analysis

A. Indicator interpretation

1.Rationale from the Montreal Process Technical Advisory Committee (TAC)

This indicator measures the national carbon pool provided by forest ecosystems. Globally, forest ecosystems are one of the largest reservoirs of both biomass and carbon. Reports on trends in this indicator are important for determining national strategies in forest management as a means to help stabilise global climate. Stabilisation of global climate is, in turn, important to national strategies regarding sustainable forest management, as climate change can significantly disturb the ecological balances that have produced the kind and distribution of forest we have today. Global changes in climate could result in the reduction of area available for forests, and/or the reduced productivity of these forests in some countries, an increase in the extent of forests or their productivity in other countries, and a loss of forest biodiversity globally.

2. Clarification of the indicator and additions to rationale

Forests provide the primary vehicle to sequester (store) carbon from the atmosphere, because plants use carbon dioxide in the photosynthesis process. During this process, the carbon becomes part of the plant mass. Thus, managing forests to sequester carbon reduces the net amount of carbon dioxide accumulating in the atmosphere. Less carbon dioxide in the atmosphere might help reduce the possibility of human-induced climate change.

Reducing greenhouse gases through quantification, monitoring, and management is the goal of the United Nations Framework Convention on Climate Change. The scientific basis of the convention relies heavily on information from the Intergovernmental Panel on Climate Change (IPCC). IPCC has published guidelines (IPCC, 1997) for estimating greenhouse gas inventories, including removals and emissions for land use change and forestry. The Technical Advisory Committee for the Montreal Process (TAC) expects Indicator 26 to conform to the IPCC guidelines. The guidelines allow for appropriate country-specific values to be used in developing national greenhouse gas inventories. The primary intent is to provide a calculation and reporting framework to accommodate users with different levels of data but still provide comparable results. As a result, the estimates presented for this indicator conform to the IPCC guidelines.

Carbon can also be viewed as a measure of productivity. Forests that are considered productive show a greater increase in carbon per year than those of lower productivity. Productive soils may contain a high percentage of organic matter, and thus a high percentage of carbon. Soils that are wet or in cold climates may also contain a high percentage of carbon but be relatively unproductive.

B. Data used in quantifying this indicator

Carbon in biomass of forests has not been surveyed directly. However, converting forest inventory data to carbon with a biometrical approach using factors and models is accepted as a standard method (IPCC, 1997; Barford and others, 2001). Forest inventory data for the United States are collected by the USDA Forest Service's Forest Inventory and Analysis (FIA) Program. Volume, area, and other forest characteristics were compiled by Smith and others (2001) for 1953, 1963, 1977, 1987, and 1997. Each inventory year is assumed to begin on the first calendar day of that year. Detailed data are available in databases for 1997: the FIABD (Miles and others 2001) and RPA (USDA Forest Service 2001) for 1997. FIA data currently available for Hawaii and Alaska are older and based on a less detailed survey.

Detailed information is available for nearly two-thirds of the forest-land area in the U.S. for area classified as timberland. Timberland is forest land that is not administratively withdrawn from harvest and is productive. Any forest land, regardless of productivity, that is administratively withdrawn from harvest is called reserved forest. Volume or biomass has not been surveyed on the remaining one-third of forest land, called other forest land. Approximately half of the area of other forest land is in Alaska, with most of the remainder in the western United States. Other forest land is defined as forests of low productivity; these tend to be low in carbon, and unmanaged. Consequently, they are assumed to not contribute substantially to this indicator.

Carbon estimates for other forest land were based on a percentage of carbon per hectare (ha) by forest type for timberland.

All carbon pools, except for soil carbon, are estimated using FIA or imputed inventory data, along with inventory-to-carbon relationships, that were developed with information from ecological studies. Live tree volumes are transformed using equations in Smith and others (2003) to estimate above- and belowground carbon in live and standing dead trees. Forest type, forest areas, and age data are used with equations in Smith and Heath (2002) to estimate carbon in the forest floor. Carbon in understory vegetation is estimated using equations based on information given in Birdsey (1996). Soil organic carbon is based on a map derived from the STATSGO database (USDA Soil Conservation Service 1991). These estimates are based on samples of soil organic carbon measured in the field. The soil carbon map was overlaid on the U.S. forest type map from Zhu and Evans (1994), and soil carbon/ha by forest type was calculated. For this indicator, soil carbon density (carbon/ha) is assumed to remain constant over time. Down dead wood was estimated as a function of region, forest type, and live volume based on decay rates and estimates of logging residue. See Heath and others (2003) for additional information.

C. How should the data be interpreted relative to the rationale from the TAC?

This indicator reports trends in carbon pools by forest type, age class, and successional stage, periodically from the first year inventory data were collected using a modern design, 1953, to 1997. Detailed results are presented for unreserved timberland for 1997, the most recent year for which a compiled database is available. Forest carbon pools for Alaska and Hawaii are presented for 1987 only due to limited historical data. Carbon is presented in units of megagrams per hectare (Mg/ha) or megatonnes (Mt), carbon equivalent. A megatonne equals one million metric tons; a megagram equals one million grams, which equals a metric ton.

1. Overview

Total carbon in forests of the conterminous U.S. is 50,554 Mt. About 46 percent is in coniferous forests, 48 percent is in broadleaved forests, 4.5 percent is in mixed forests (oak-pine forest type), with a minor portion in nonstocked and chaparral forests (Fig. 26.1). Plantations contain only about 6 percent of the total forest carbon. Slightly more than half of the carbon is in the soil, 40 percent is aboveground, and an estimated 8 percent belowground in roots. Aboveground carbon includes carbon in all aboveground portions of live trees, understory vegetation, standing and down dead wood, and forest floor. Roots comprise belowground carbon. Soil carbon is estimated to a depth of one meter. According to 1987 estimates (Birdsey 1992), carbon in forest land of Alaska and Hawaii totals 14,019 Mt on 52,953 thousand hectares (Fig. 26.2). Thus, forest land of the conterminous U.S. contains about 80 percent of the carbon in all U.S. forests.

Carbon pools from 1953 to 1997 are presented in Figure 26.3 for non-soil components of forest land of the conterminous United States. Carbon increased by almost 46 percent over the period, from 16,613 to 24,292 Mt. Most of the increase resulted from increases in vegetation, particularly live trees. For this analysis, soil carbon changed if area of forest type or total forest area changed. Land use change effects on soil carbon density are not included. Preliminary analysis suggests that the land use change effects are larger than the effects of forest type changes; therefore, the estimates should be interpreted cautiously.

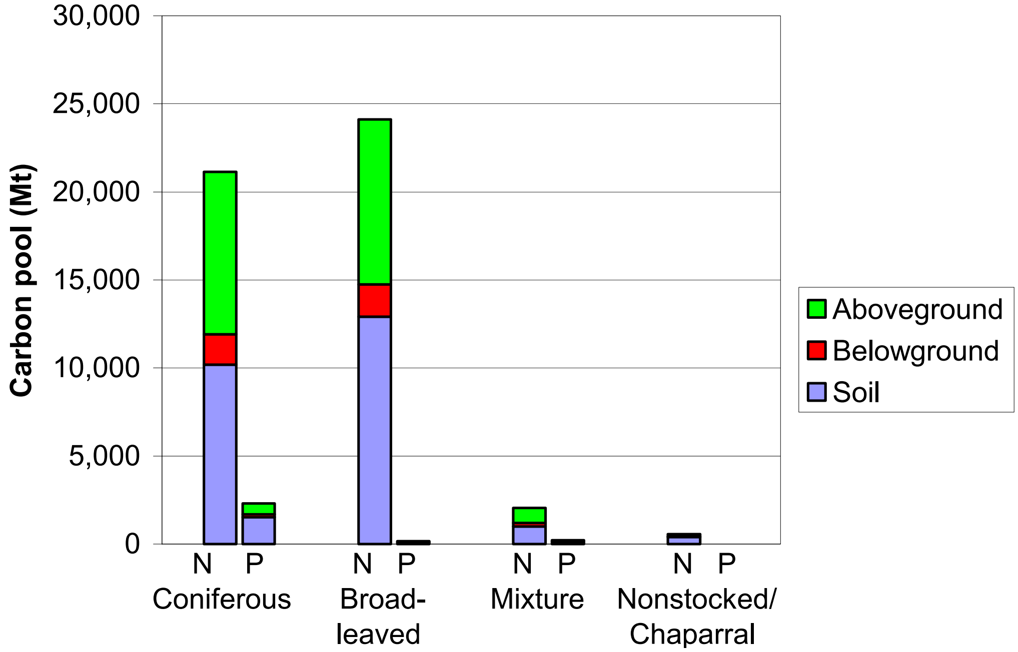

Figure 26.1— Forest carbon pool (Mt) by broad forest types and regeneration status (N=natural regeneration, P=plantation) for all forest land of the conterminous United States, 1997. Aboveground carbon pools are aboveground live vegetation, standing and down dead tree mass, and forest floor. Belowground pools are live and dead coarse roots. Soil is soil organic carbon to a depth of 1 meter, including the soil order Histosol.

Aboveground tree biomass for forest land of the conterminous U.S. in 1997 is presented by forest type in Table 26.1. Estimated total biomass of aboveground live and dead trees is estimated at 28,505 Mt dry weight biomass on 250,036 thousand hectares of forest land. The redwood forest type contains the largest biomass density at 265.8 Mg/ha, while nonstocked forests in the Eastern U.S. contain the least biomass, 8.2 Mg/ha. Soil carbon density by forest type is also presented in Table 26.1 by forest type. For this indicator, soil carbon density is assumed to remain constant over time.

For context, estimated global carbon stocks in the 1990's in vegetation and soil carbon pools to a depth of 1 m totaled 2,477,000 Mt on the total land area of 15,120 million ha according to the IPCC (Watson and others 2000). Of this, forests (tropical, boreal, and temperate) contained nearly 46% of the carbon stocks on 4,170 million ha. Temperate forests contained an estimated 159,000 Mt carbon on 1,040 million ha (IPCC 2000). Compared to these estimates, U.S. forests comprise 7 percent of the world's forest area, and 6 percent of the carbon in global forests.

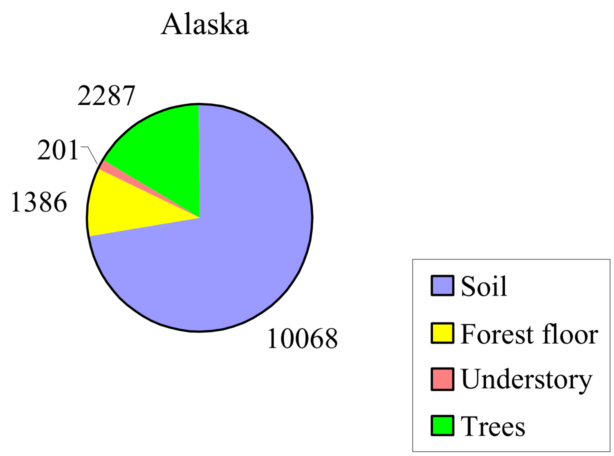

Figure 26.2—Forest carbon pools (Mt) of Alaska and Hawaii, 1987 (Birdsey 1992).

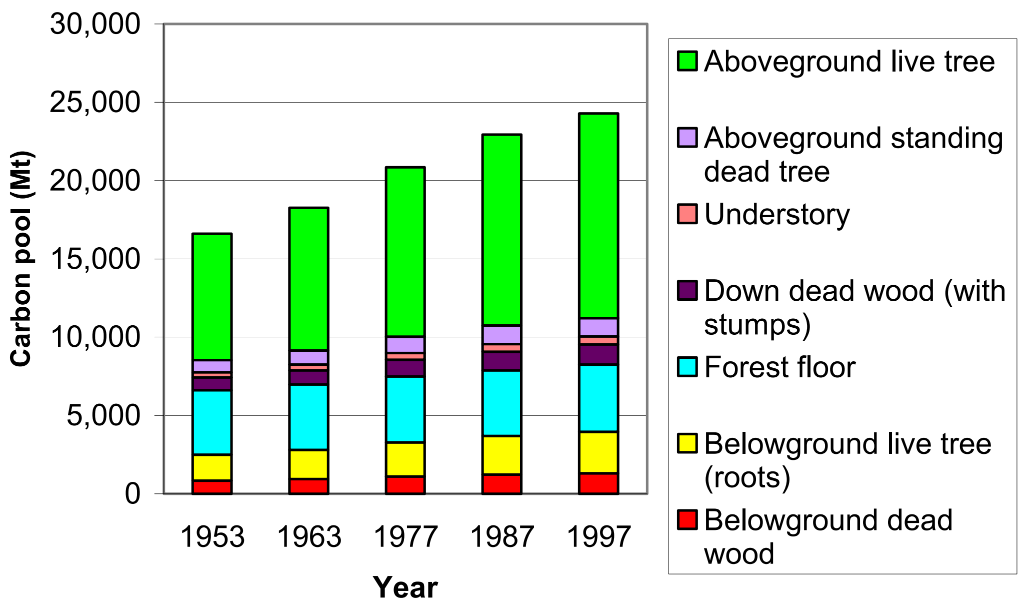

Figure 26.3—Forest ecosystem non-soil carbon pools (Mt) for all forest land of the conterminous United States, 1953-1997.

Table 26.1— Biomass of aboveground live and dead trees (Megagram, Mg=metric ton), soil organic carbon (Megatonne, Mt=million metric ton), and forest area (thousand hectares) by forest type for all forest land of the conterminous United States, 1997.

Forest type	Biomass of aboveground live and dead trees (dry wt.)		Soil organic carbon (1 m)	Forest area
	Mg/ha	*Mt*	*Mg C/ha*	*Thousand ha*
White-red-jack	125.8	603	196.1	4,795
Spruce-fir	97.9	693	192.9	7,079
Longleaf-slash	70.1	375	136.3	5,351
Loblolly-shortleaf	81.6	1,738	91.7	21,293
Oak-pine	95.3	1,312	82.3	13,766
Oak-hickory	127.8	6,770	85.0	52,972
Oak-gum-cypress	142.9	1,751	152.2	12,256
Elm-ash-cottonwood	112.6	619	118.1	5,498
Maple-beech-birch	138.2	3,137	139.5	22,694
Aspen-birch	93.1	678	237.0	7,278
Other Eastern types	9.4	18	99.6	1,953
Nonstocked (Eastern U.S.)	8.2	17	99.6	2,074
Douglas-fir	175.5	2,974	89.6	16,947
Ponderosa pine	105.7	1,431	70.4	13,534
Western white pine	102.5	25	68.3	239
Fir-spruce	168.7	1,998	137.5	11,845
Hemlock-Sitka spruce	229.3	822	157.1	3,586
Larch	156.1	80	65.6	516
Lodgepole pine	100.9	711	62.7	7,043
Redwood	265.8	99	85.8	371
Other hardwoods	119.6	1,365	79.5	11,410
Other forest types	87.7	399	90.1	4,544
Pinyon-juniper	39.5	790	56.3	19,999
Chaparral	34.2	72	58.7	2,099
Nonstocked (Western U.S.)	32.4	29	90.1	895
Total	114.0	28,506	105.0	250,036

2. Regional trends

Trend data for non-soil forest carbon are presented from 1953 to 1997 by forest type in Figures 26.4 and 26.5, respectively, for the Eastern United States in Figure 26.4 and the West, excluding Alaska and Hawaii. Soil carbon is not included in these figures because land use effects are not yet included in the soil carbon estimates. Oak-hickory forests contain more carbon than any other type because they have a reasonably high carbon density and occupy the largest area (Table 26.1). The maple-beech-birch type increased over the period and has the second highest carbon in a forest type. Among forest types in the West, Douglas-fir contains the most carbon. The lower amount for Douglas-fir in 1977 resulted from the lower amount of area recorded in surveys conducted that year. From 1953 to 1997, carbon increased in the fir-spruce type and decreased in ponderosa pine. Carbon in nonstocked forests in both the East and West decreased, because the area of forests in nonstocked status declined.

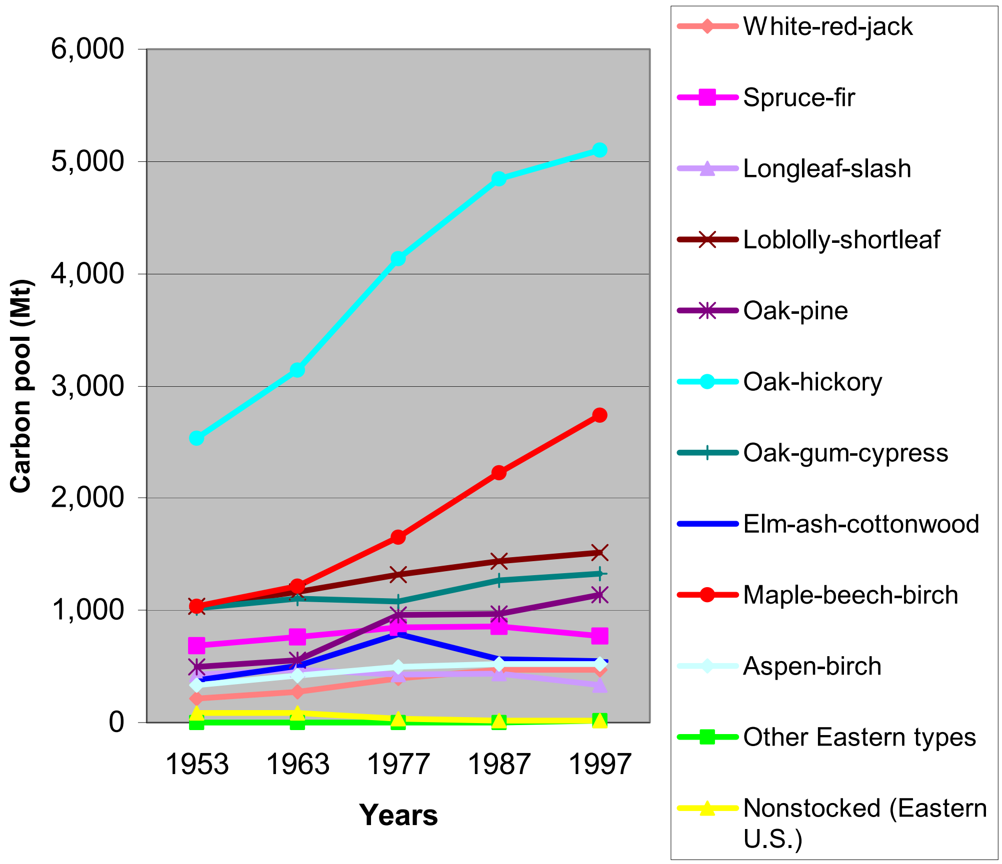

Figure 26.4—Total forest ecosystem non-soil carbon pools (Mt), by forest type for all forest land in the Eastern United States, 1953-1997.

From 1953 to 1997, forest carbon increased in most of the regions of the conterminous U.S. (Fig. 26.6). The exceptions were the Pacific Northwest and Pacific Southwest regions, both of which feature relatively stable carbon pools. The Rocky Mountain region contains the most carbon, because it has the largest forest-land area, followed by the South Central and Northeast (NE). The North Central (NC) and NE regions gained the most carbon over the period, with NC gaining 1,840 Mt versus 1,820 Mt for NE. Soil carbon is not included because the interpretation of the results is confounded by transfer of carbon from the atmosphere to forests and a transfer of carbon already sequestered from one sector to another (e.g., agriculture to forest).

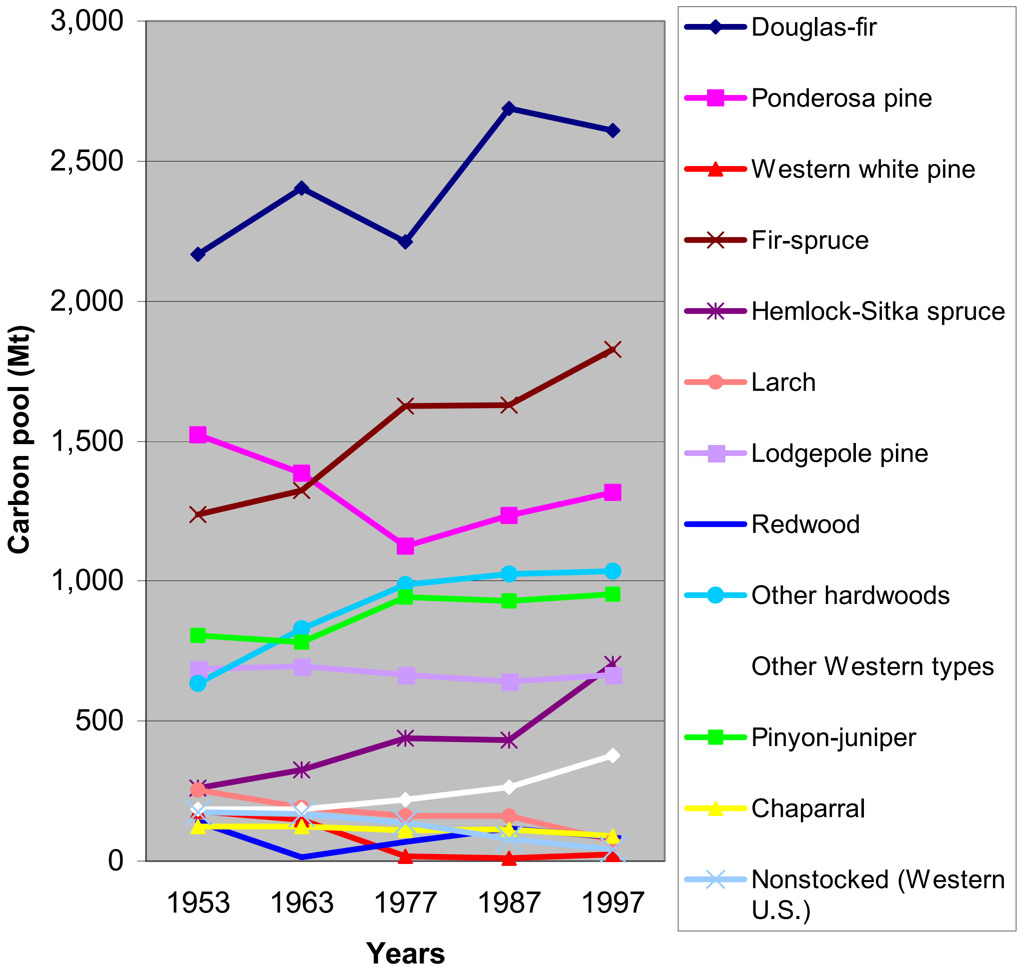

Figure 26.5— Total forest ecosystem non-soil carbon pools (Mt), by forest types for all forest land in the Western United States, (excludes Alaska and Hawaii), 1953-1997.

Data on unreserved timberland of the conterminous U.S. are sufficiently detailed that forest carbon pools can be estimated by age class (Fig. 26.7) and successional stage (Fig. 26.8). Unreserved timberland contains about 85 percent of the forest carbon in the conterminous United States. Almost 50 percent of forest carbon is in stands less than 60 years old, and about 80 percent is in stands less than 100 years old. About six percent of the carbon on unreserved timberland is in uneven-aged forests. However, due to the methods used in collecting and compiling the data, uneven-aged forests may be underrepresented in the data as compared to the true estimate. Stand-size class is used to estimate the successional stage of forests. More than 55 percent of forest carbon of unreserved timberland in the conterminous U.S. is in sawtimber stands (Fig. 26.8).

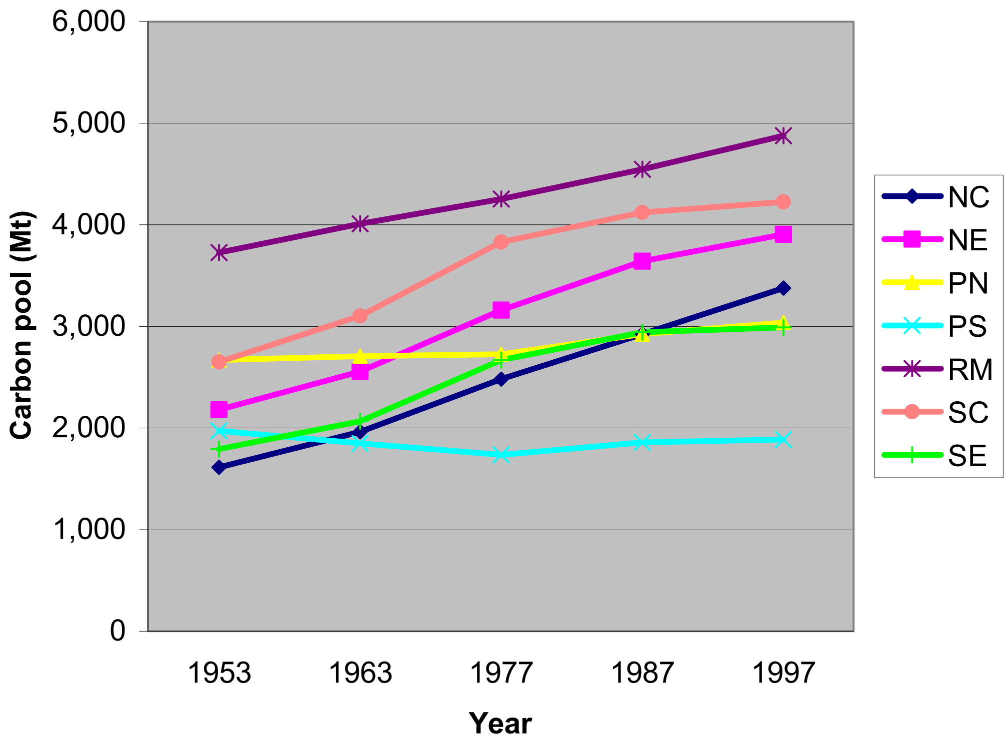

Figure 26.6—Total non-soil forest ecosystem carbon pools (Mt) by region for all forest land in the conterminous United States, 1953-1997 (NC=North Central, NE=Northeast, PN=Pacific Northwest, PS=Pacific Southwest, RM=Rocky Mountain, SC=South Central, SE=Southeast. Regions are the same as in Smith and others (2001), with the exception of the States of ND, eastern SD, NE, and KS, which are compiled with the NC region.

D. Limitations of data provided

The data are compiled from a scientifically-based sample that was designed to provide reliable volume and area data at a predetermined level of precision. For instance, FIA field surveys were designed to provide data on forest area within 3 percent of the true value for every million acres of forest (67 percent confidence limit). Using a modeling approach to transform volumes to carbon adds uncertainty to the models and conversion factors. See Smith and Heath (2000), Smith and Heath (2001), and Heath and Smith (2000) for a discussion of uncertainty in the U.S. forest carbon budget.

Volume data for other forest land are limited, and the uncertainty of modeled estimates, especially the changes in volume over time, is unknown. In particular, data have not been sampled on areas in the Western U.S. on which volume and dead wood mass is thought to have increased relative to 19th century forests due to fire suppression (Houghton and others 1999). Also, long-term land use history is an important variable needed to estimate carbon in forests accurately, particularly soil carbon. Historical statistics on land use have not yet been included in the soil carbon estimates.

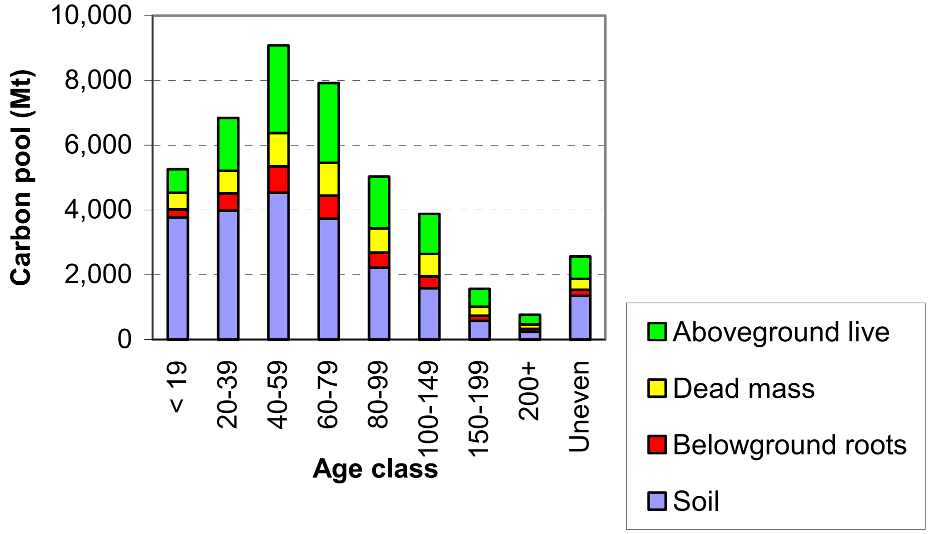

Figure 26.7— Forest ecosystem carbon pools (Mt) on unreserved timberland in the conterminous United States by age-class, 1997, uneven refers to uneven-aged stands.

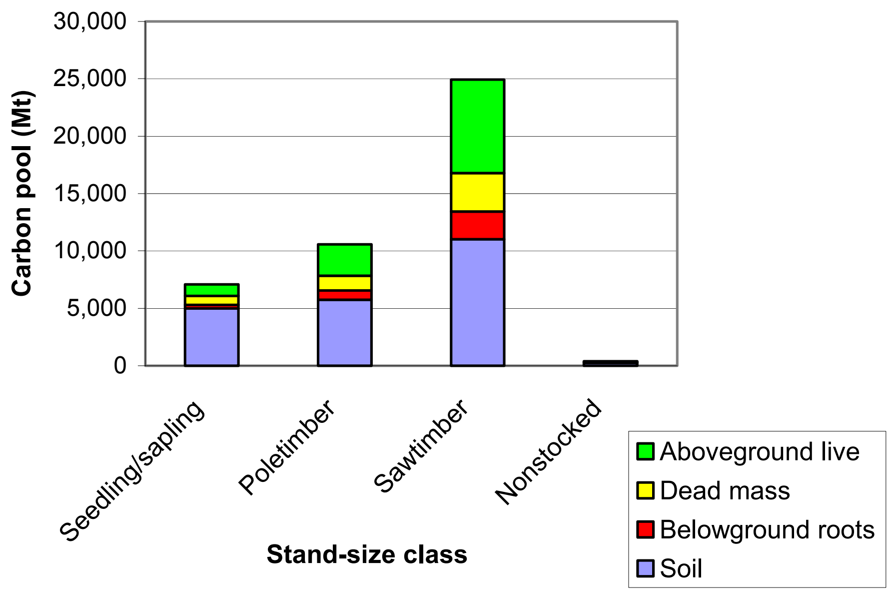

Figure 26.8— Forest ecosystem carbon pools (Mt) on unreserved timberlands in the conterminous United States by successional stage (stand-size class), 1997. Stand-size class is determined by the size of the predominant stocking of all live trees on the plot. Seedling and sapling trees are less than approximately 12.7 cm in DBH. DBH range in sawtimber trees is greater than 22.9 cm for softwoods and 27.9 cm for hardwoods. Poletimber trees are intermediate between seedlings and saplings, and sawtimber.

E. If current data are not adequate to measure the indicator, what options are available for remedy?

The current data and modeling approach are adequate to provide estimates of the indicator. However, additional forest carbon pools will be surveyed in the future on all forest land, resulting in improved accuracy and precision of the estimates. Currently, FIA surveys are being updated to an annualized inventory (Gillespie 1999), with a sample conducted each year in every U.S. state. In addition, other attributes, such as soil carbon, down dead wood, and forest floor carbon, will be sampled in the updated inventory design. These new inventories should be implemented fully by the year 2008.

II. Problems related to scientific, social/political, economic, and institutional concerns

Carbon is an issue related to the entire land base, including croplands, rangelands, and wetlands. FIA surveys the entire land base to estimate area of forests, and focuses on measuring numerous attributes of forested plots. However, official statistics for land areas of major land uses come from the USDA Natural Resource Conservation Service's National Resource Inventory (NRI). The NRI (USDA Natural Resource Conservation Service 2004) is a statistically-based sample of land use and natural resource conditions and trends on U.S. nonfederal lands. The forest-land areas estimated by the NRI do not match FIA-based inventories of forest area and land use change. Thus, to accurately estimate changes in carbon across the land base, one must reconcile the differences between NRI and FIA inventories and include all lands of the United States.

III. Cross-cutting issues/relationships with other indicators

Fundamentally, forest carbon stocks are estimated by multiplying the area of forest land by the carbon density of the forest, the average mass of carbon per area. Aboveground carbon density is related to forest volume or biomass. Thus, the area and biomass used to calculate this indicator should be consistent with estimates of area and forest characteristics for other indicators. The primary related indicators are 2, Extent of area by forest type and by age class or successional stage, and 11, Total growing stock of both merchantable and nonmerchantable tree species on forest land available for timber production. Carbon information summarized by plantation should be consistent with data in Indicator 12, Area and growing stock of plantations of native and exotic species. Information on soil organic carbon should be consistent with Indicator 21, Area and percent of forest land with significantly diminished soil organic matter and/or changes in other soil chemical properties.

Indicator 26 is directly related to the other Criterion 5 indicators, 27 and 28. Indicator 27 is estimated directly by subtracting carbon pools from successive years and dividing the result by the difference between the years to produce annual changes in carbon. Indicator 28 is a measure of the woody material removed from forests as products. To derive the greatest benefit from retaining carbon stocks and/or reducing emissions, both forest and harvested wood components should be considered.

Carbon as a productivity issue overlaps with Criterion 2, Maintenance of productive capacity of forest ecosystems, and Criterion 4, Conservation and maintenance of soil and water resources.

Generally, forests of high productivity will exhibit a greater increase in carbon annually than forests of low productivity.

The ability to understand carbon pools requires knowledge of the carbon cycle, which should be discussed under Indicator 63, Development of scientific understanding of forest ecosystem characteristics and functions. Forest carbon pools should also be a consideration for Indicator 67, Ability to predict impacts on forests of possible climate change. Two other indicators that should be consistent with the information on which Indicator 26 is based are 60, Availability and extent of up-to-date data, statistics and other information important to measuring or describing indicators associated with criteria 1-7, and 61, Scope, frequency and statistical reliability of forest inventories, assessments, monitoring and other relevant information. These two indicators address the legal, institutional, and economic framework for forest conservation and sustainable management and its capacity to measure and monitor changes in these practices.

IV. Suggested guidance on use of the data

FIA data currently available have been collected periodically by state over a number of years that do not necessarily correspond to the years listed in the figures. Thus, the carbon pool reported for a specific year does not strictly correspond to that year; rather, it is the year associated with the compilation of FIA data. Thus, the estimates should be interpreted with caution.

Acknowledgments

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