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Carbon in U.S. Forests and Wood Products, 1987-1997: State-by-State Estimates

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Abstract

Estimated changes in carbon stocks are reported for the forests and wood products of the 50 U.S. States. Carbon stocks on forest land and in harvested wood products increased between 1987 and 1997 at an annual rate of 190 million metric tons. Most of this increase was in biomass, followed closely by wood products and landfills. Changes in land use since 1987 caused a small decrease in carbon stocks, but this loss was offset by large gains on existing forest land. The East had the greatest gain in carbon stocks with smaller gains estimated for the West. Most of the individual states showed increases in ecosystem and wood-products carbon. Observed changes were attributed to distinct regional and local factors, e.g., timber production, land-use change, and natural disturbance. The information in this report can be the basis for determining the potential gain or loss of forest carbon resulting from management and policy decisions.

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Introduction

In this publication we report estimated changes in carbon stocks for the forests and wood products of the 50 U.S. States. A first approximation of carbon status and trends for the forestry sector, these estimates were developed to assist states in compiling greenhouse-gas inventories for submission (on a voluntary basis) to the U.S. Environmental Protection Agency (EPA). These initial estimates are designed to raise awareness of accounting issues, identify common sources of information and methods, and quantify the approximate contribution of the forestry sector to a state's status in emitting or sequestering greenhouse gases. Individual states should view these estimates as a starting point for developing their own estimates. It is important to carefully consider the forestry situation in each state by consulting with local experts who are familiar with the most currently available data. Because we used the same methodology and national databases for every state, more recent data than are included in this report may be available, and the available data for a particular state may support use of different estimation methodology.

Summary statistics by region and state are presented in this report. All of the tables and figures as well as additional statistics can be accessed at: http://www.fs.fed.us/ne/global.

Estimation Process and Accounting Methods

The methods used for this report are similar to those of Birdsey and Heath (1995). These methods were the basis for reporting greenhouse-gas emissions for the forest sector in annual EPA reports through 1998 (Environ. Prot. Agency 2000). Since the beginning of this project, improved methods have been developed for estimating carbon pools and flows in the forest sector. These are reflected in recent greenhouse-gas inventories (Environ. Prot. Agency 2001), but are not included here.

Estimates are based on forest-inventory data collected for each state by the USDA Forest Service's Forest Inventory and Analysis units. Until recently, U.S. forest lands were inventoried periodically, i.e., each state was inventoried every 5 to 15 years. Every 5 years, the most recent state forest statistics are aggregated for a national assessment of forest conditions and trends. These reports include summaries of state-level forest statistics. For this study, the primary sources of forest-inventory information were inventory statistics for 1987 and 1997 (Waddell et al. 1989; Smith et al. 2001). These reports are accompanied by supporting statistical databases that were used to develop the inventory base for estimating carbon by forest-ecosystem component.

The inventory data used in this study can be accessed at: http://fia.fs.fed.us. This web site also contains relevant information on forest-inventory methodology, definitions of terminology, and state-level data for recent inventory years.

In some cases, definitional or procedural changes in collecting the underlying inventory data may cause apparent shifts in carbon stocks. For example, the definitions of forest land or forest type were not applied consistently for some National Forest lands in the West. Reported changes in stocks may be the consequence of such inconsistencies rather than a reflection of actual change in the forest resource. The most apparent inconsistencies are listed in Appendix 3.

We used the "stock change" approach to estimate changes in carbon stocks (also known as carbon flux) for forest-ecosystem components. This entails estimating the total stock of carbon at two points in time, taking the difference between the two estimates, and converting the difference to an annual rate of change. Other approaches entail direct estimation of the annual or periodic carbon flux, or its principal components: growth, decay, harvest, and mortality. We chose the stock-change approach because it is consistent with the comprehensive inventory data that are available for two points in time: 1987 and 1997.

We report changes in carbon stocks between 1987 and 1997 to be consistent with the reported dates of the forest-inventory statistics and supporting databases. The dates of the original inventory data used in the compilations of forest-inventory statistics for 1987 and 1997 are included in Appendix 3. The compilations for 1987 and 1997 include data from inventories conducted up to those dates, with little updating or projecting of the original statistics to account for the differences between data collection and reporting dates. Therefore, for most states, the changes we report represent trends from a period earlier than 1987 to 1997.

Ecosystem carbon is divided into biomass, forest floor, and soil. Harvested carbon is treated separately. Biomass includes all aboveground and belowground portions of all live and dead trees and understory vegetation, including the merchantable stem, limbs, tops, cull sections, stump, foliage, bark and rootbark, and coarse roots (larger than 2 mm). The forest floor includes all dead organic matter above the mineral soil horizons except standing dead trees: litter, humus, and other woody debris. The soil component includes all organic carbon in mineral horizons to a depth of 1 m (excluding coarse roots). Harvested carbon includes carbon removed from the forest for wood products and

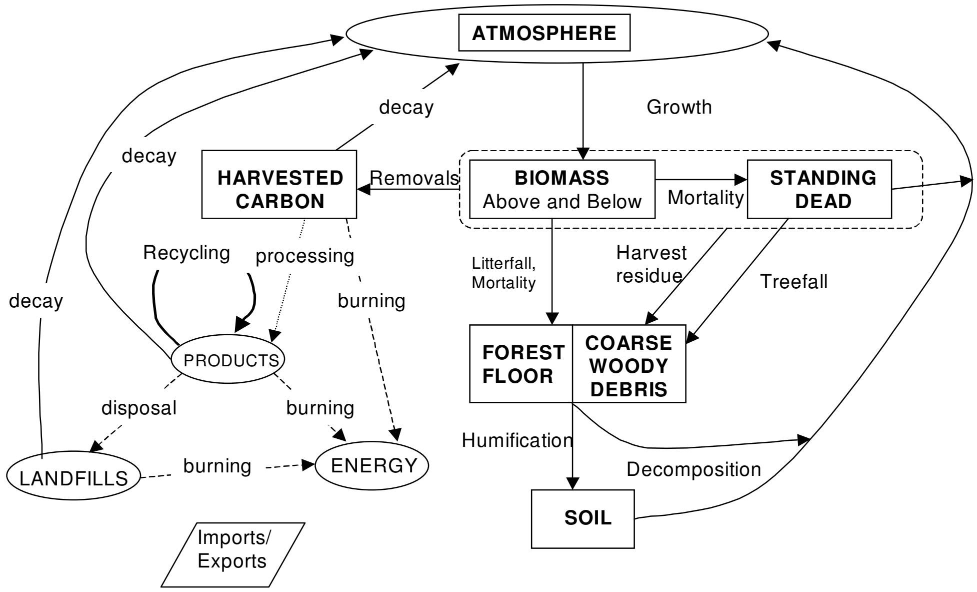

Figure 1.—Comprehensive accounting for carbon pools and flows in the forest sector (energy consumption not shown; from Heath et al. 2002).

fuelwood. Each of the component pools is related through transfers of carbon (Fig. 1).

Using data from forest inventories and intensive-site ecosystem studies, estimates of average carbon storage by age or volume classes of forest stands (analogous to a forest yield table) are made for each ecosystem component, and stratified by forest classes defined by region, forest type, productivity class, and land-use history. Carbon in biomass is estimated by applying derived factors that convert estimates of forest volume to carbon. Equations are used to estimate carbon storage in the forest floor, soil, and understory vegetation for each forest class (see Birdsey 1996). Derived equations are applied to estimates of growing-stock inventory and increment, harvested area and volumes, and timberland area obtained from the forest-inventory databases.

We used a modification of the stock-change approach for wood products because a complete inventory of the volume or mass of carbon in wood products and landfills is not available. We simulated the most dynamic portion of the inventory of carbon retained in wood products and landfills by compiling estimates of wood production from 1952 to 1987 and for 1997, and using a model of carbon retention in various harvest carbon pools (Row and Phelps 1991). The estimate for 1987 was subtracted from the estimate for 1997 to obtain the difference in a compatible way with that for forest-ecosystem components. We used the "production approach" for wood products, that is, all of the accounting is attributed to the land area where the wood is grown regardless of the eventual location and disposition of wood products (Heath et al. 1996). Imported wood is ignored in this approach.

For land-use change, we began with the land base in 1987 and accounted only for land-use change between 1987 and 1997. This approach does not account for long-term effects of prior land-use changes on soil carbon. We counted only the real changes in carbon stocks from land-use change as opposed to apparent changes that can occur due to a change in land classification. For example, if a land area was reclassified from forest to nonforest, we deducted the change in soil carbon caused by the shift but not the remaining soil carbon that was transferred to the new land use. Likewise, for land reclassified from nonforest to forest, we did not include the estimated carbon already on the land prior to reclassification as forest.

The U.S. forest inventory reflects all changes in carbon stocks regardless of cause. Some causes of change in carbon stocks can be identified from the inventory data, particularly human causes such as timber harvesting. But the inventory may not reveal other causes of change, e.g., the effects of increasing atmospheric carbon dioxide or tropospheric ozone on growth rates and tree health. These indirect effects are not easily separated from other factors that affect forest productivity and health; thus, they are implicitly included in the inventory data and our estimates of carbon stocks that are dependent on those data. Analysis of forest-inventory data suggests that the effects of land-use change and land management are more significant than the effects of environmental factors (Casperson et al. 2001).

Details of the methodology and databases used in this report are included in Appendix 1. A summary of the methods used in the most recent annual EPA greenhouse-gas inventory reports along with a comparison of estimates from different reports are included in Appendix 2. State-specific methodology is described and database issues discussed in Appendix 3.

Forest Statistics of the United States

The following is a brief description of recent trends in the forests of the United States. These are the underlying factors that cause the most significant human-induced changes in forest carbon stocks and wood products. These summary statistics are from Smith et al. (2001).

- The area of forest land in the United States totals 747 million acres or 33 percent of the land base. The area of forest land increased by 1 percent between 1987 and 1997

- Nearly 60 percent of U.S. forest land is privately owned. Most of this land is in nonindustrial private ownership. About 33 percent of U.S. forest land is in Federal ownership, and 9 percent is in other public ownership (states, counties, and municipalities).

- Of all forest land, about 504 million acres are classified as timberland, 191 million acres as other forest, and 52 million acres as reserved forest.

- Oak-hickory is the most common forest type in the Eastern United States followed by maple-beech-birch and loblolly-shortleaf pine. A variety of softwood forest types dominates forest land in the West.

- The volume of growing stock has been increasing since 1953 in all regions except the Pacific Coast, where volume has been increasing since 1978. The volume of growing stock in the Nation now totals 836 billion cubic feet.

- Sawtimber-size stands predominate in both the East and West, followed by poletimber and seedling/sapling stands. On average, U.S. forests are relatively mature.

- Removals of timber volume for wood products now totals about 16 billion cubic feet per year. Harvest trends on Federal lands have declined substantially, particularly in the West.

- Net growth (net after mortality is deducted) exceeds harvest by a substantial margin, totaling about 24 billion cubic feet per year. Mortality from all causes is about 6 billion cubic feet per year.

These statistics vary considerably by state. For convenience, the area of forest land for 1987 and 1997, by region, state, and land class is presented in Appendix 4, Tables 1-2. Detailed forest statistics at the state level are available from the sources cited in this report.

Changes in Carbon Stocks for U.S. Forests and Forest Products, 1987-97

United States

Estimates were compiled by aggregating individual estimates for each of the 50 U.S. States. Most states are gaining carbon in forests and wood products. The change in carbon stocks for biomass is a good indicator of the overall trend in ecosystem carbon stocks. Using this indicator, 7 states are losing and 43 are gaining carbon in forests (Fig. 2). Generally, forests in the Lake States, Great Plains, and the Northeast are gaining carbon at the fastest rates.

Changes in individual carbon components show different patterns than that for the total of all components (Fig. 2). These differences reflect unique resource characteristics and trends for each state. Biomass is both a large and a dynamic carbon stock, changing in response to management for wood products and natural disturbances. The stock of carbon in the forest floor and coarse woody debris is affected by the same dynamics but the apparent trend is somewhat different than for biomass carbon, reflecting additional impacts of shifts in forest type. Changes in soil carbon, the largest stock of carbon in forests, show another pattern, one that is more responsive to land-use change than to forest management (Fig. 2).

According to our estimates, U.S. forests gained carbon at an annual rate of 190 Mt (million metric tons). Gains in carbon for U.S. forests and wood products were highest for biomass, followed by wood products and soils (Table 1). We have the most confidence in the estimates for biomass and wood products, and the least confidence in the estimates for soils and forest floor/coarse woody debris.

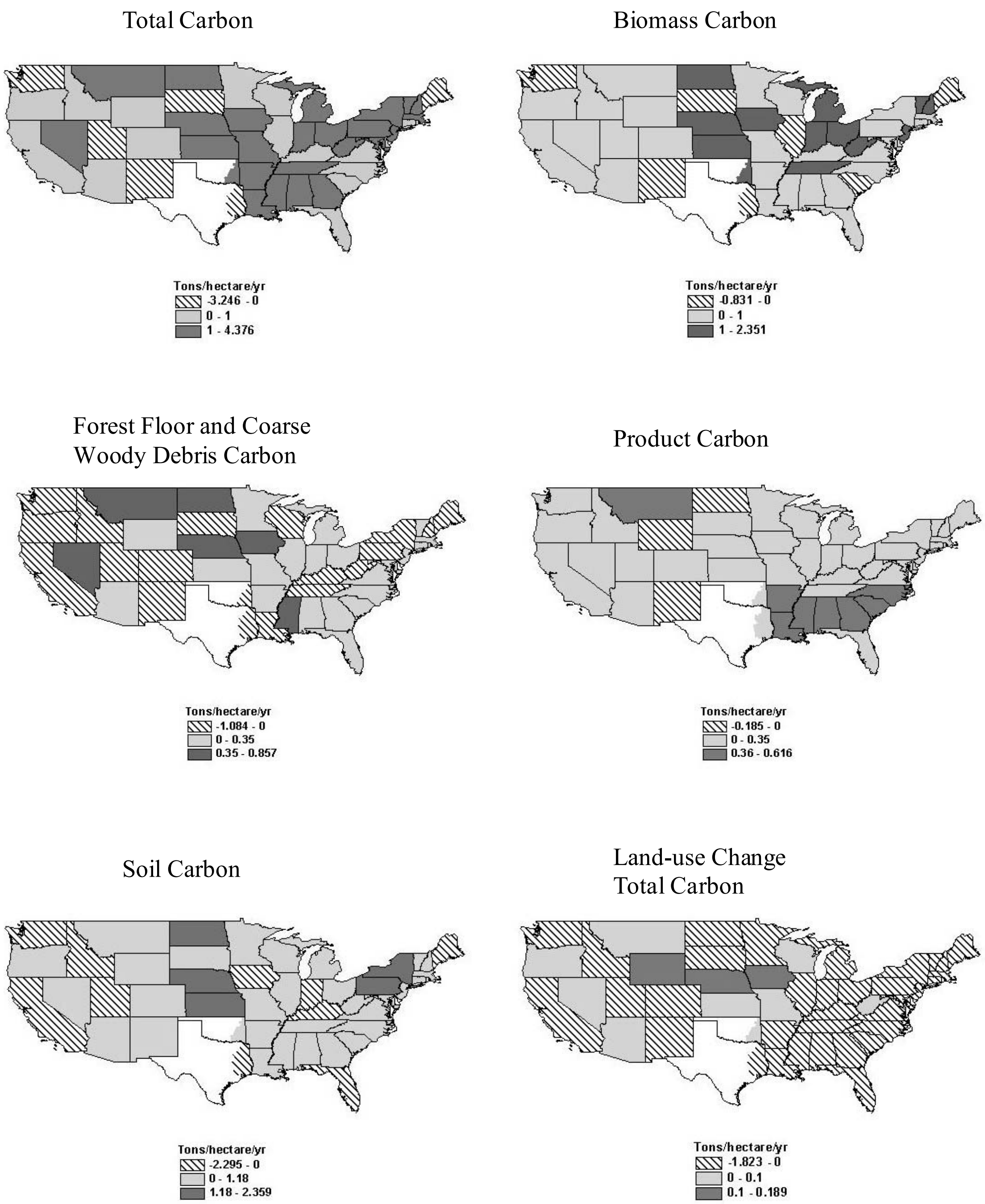

Figure 2.—Rate of change in carbon stocks for forest land, by state and carbon component, 1987-97. Data are not available for west Texas and west Oklahoma, and estimates for Alaska and Hawaii are not included due to scaling difficulties.

There are significant changes in forest carbon among ownership groups. The gains and losses reflect both transfers among ownership groups and actual changes in carbon stocks on the land. Nonindustrial private owners gained the most carbon by a significant margin, followed by National Forests (Table 2). Forest industry and other public ownership groups lost carbon. The loss of carbon on other public forests is attributed primarily to a reclassification of forest land owned in trust for Native Americans into the nonindustrial private group. The loss of carbon on forest industry land can be attributed to a 5-percent shift in the area of forest land to nonindustrial private owners. Increases in carbon on forest land retained by industry nearly offset all of the loss due to ownership change.

Table 1.—Total carbon stock on forest land and in harvested wood products in the United States, and annual change by accounting component, in Mt[1]

Component	1987	1997	Avg. change per year 1987-97
Biomass	15,833.2	16,838.1	100.50
Forest floor/coarse woody debris	9,401.3	9,455.6	5.43
Soils	28,421.6	28,663.5	24.19
Wood products and landfills	2,919.6	3,520.4	60.08
Total	56,575.7	58,477.6	190.19

[1]Million metric tons.

Table 2.—Total carbon stock on forest land and in harvested wood products in the United States, and annual change by owner, in Mt

Owner group	1987	1997	Avg. change per year 1987-97
National forest	11,703.5	12,245.6	54.22
Other public	13,482.4	13,345.5	-13.69
Forest industry	5,696.8	5,559.1	-13.77
Nonindustrial private	25,693.1	27,327.4	163.43
Total	56,575.7	58,477.6	190.19

Table 3.—Change in total carbon stock on forest land and in harvested wood products attributed to land-use change since 1987, United States, in Mt

Component	Total change 1987-97	Avg. change per year 1987-97
Biomass	-104.8	-10.48
Forest floor/coarse woody debris	-77.7	-7.77
Soils	-129.6	-12.96
Wood products and landfills	84.4	8.44
Total	-227.7	-22.77

Land-use changes since 1987 caused a loss of forest carbon (Table 3) even though the overall area of forest land has increased. The reason for this is that carbon is lost more quickly from deforestation than gained from afforestation. If our accounting methods for land-use change began several decades earlier than in 1987, our estimate of the change in carbon attributed to this factor would be closer to zero or positive, since carbon gains on areas afforested prior to 1987 would have compensated for losses of carbon from deforestation after 1987. Note that the effects of land-use change estimated in Table 3 are included in Tables 1-2. By subtracting the estimates in Table 3 from those in Table 1, it is possible to estimate the change in carbon for land that was classified as forest in both 1987 and 1997.

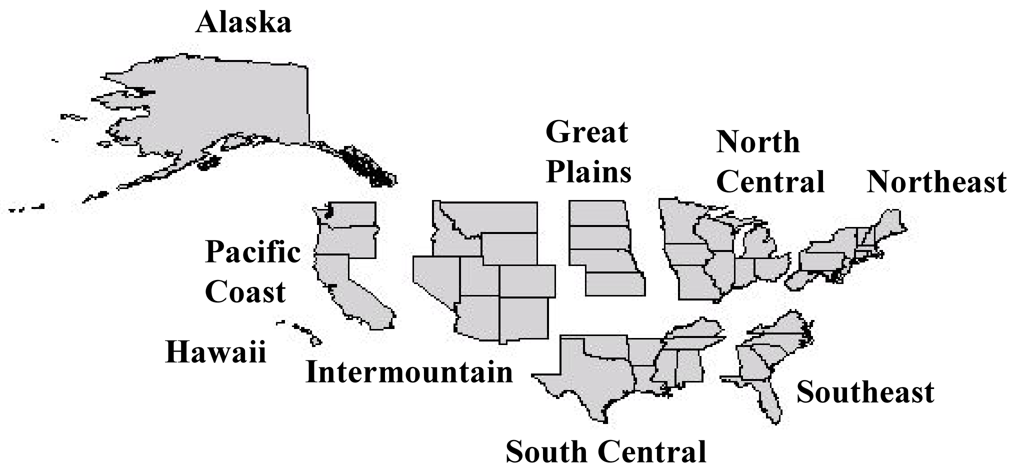

Figure 3.—The regions identified for this report.

Regional Overview

Because the United States is so large and diverse with respect to physiography, climate, and human impacts, understanding and monitoring carbon changes in U.S. forests requires analysis on a disaggregated scale. We identified seven regions of the conterminous United States for compiling many of the estimates and analyzing the results (Fig. 3). Alaska and Hawaii usually were treated separately.

Every region except the Great Plains has significant stocks of carbon in forests, but the distribution of carbon stocks among ecosystem components and wood products varies considerably (Fig. 4). Carbon in soils is consistently the largest stock, followed by biomass carbon except in Alaska, where carbon pools are higher in the forest floor and coarse woody debris. Carbon pools in the forest floor and coarse woody debris also are high in the Intermountain States. The relative importance of wood products varies according to the importance of forest industry in a region. The Southeast, South Central, and Pacific Coast have the highest amounts of carbon in wood products.

The change in carbon stocks for U.S. forests between 1987 and 1997 was highly variable, both between regions and between components among regions (Fig. 5). The rate of accumulation of carbon in forests is highest in the four eastern regions. Other regions also are accumulating carbon in forests except for Alaska, though the rate of accumulation is slower than in the eastern regions. For most regions, the accumulation of carbon in U.S. forests is highest in biomass and wood products. There were small losses of carbon in soil, forest floor, and coarse woody debris for the Pacific Coast and Alaska.

Northeast and North Central Regions

Carbon stocks in forests of the Northeast and North Central regions increased by 71 Mt/yr between 1987 and 1997 (Table 4). Most of the increase was in biomass and wood products. Forests in nonindustrial private ownership gained the most carbon. Forest industry lost carbon due primarily to a transfer of forest land to the nonindustrial private group (Table 5).

There was a significant shift in carbon stocks among forest types because of shifting species composition and increased occupancy of land by trees (Table 6). Maple-beech-birch and oak-hickory types gained carbon, while spruce-fir and white-red-jack pine types lost carbon. The area of nonstocked forest land (defined as forest but stocked with few trees) declined significantly as tree stocking and the amount of carbon/acre increased. Because of the decline in area, total carbon on nonstocked forest land decreased.

Land-use change between 1987 and 1997 in the Northeast and North Central caused a loss in carbon of approximately 6 Mt/yr, primarily in soil carbon pools (Table 7). These regions are similar in carbon stocks (Fig. 4) and rate of change (Fig. 5). North Central States gained 43 Mt/yr and Northeast States gained 28 Mt/yr from 1987 to 1997 (Table 8). All of the Northern states gained carbon except Maine and Delaware; Michigan and West Virginia gained the most forest carbon. Losses in Maine are attributed to harvest exceeding growth; losses in Delaware likely resulted from changes in landuse.

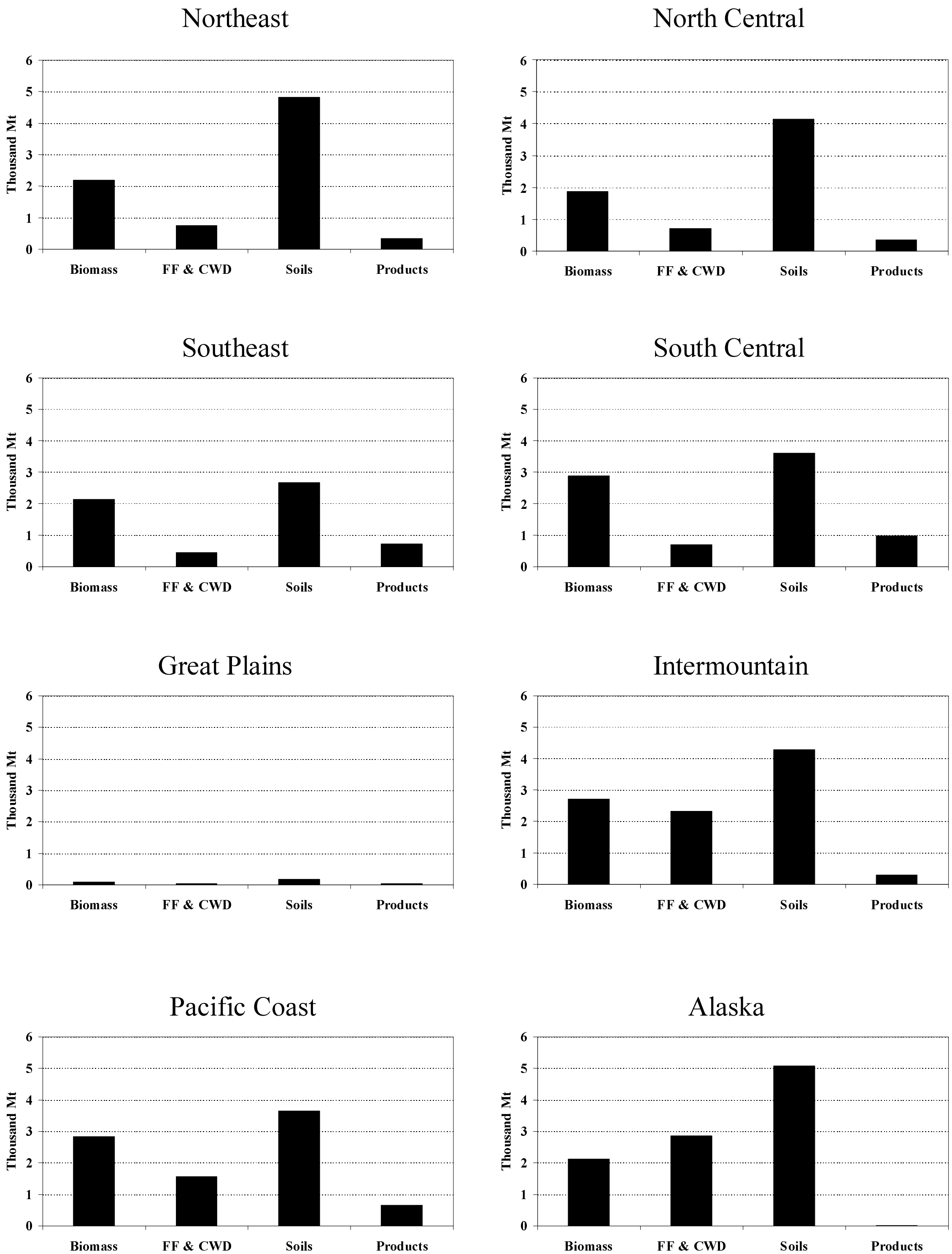

Figure 4.—Carbon stocks of U.S. forests by region and ecosystem component, 1997 (FF & CWD refers to forest floor and coarse woody debris).

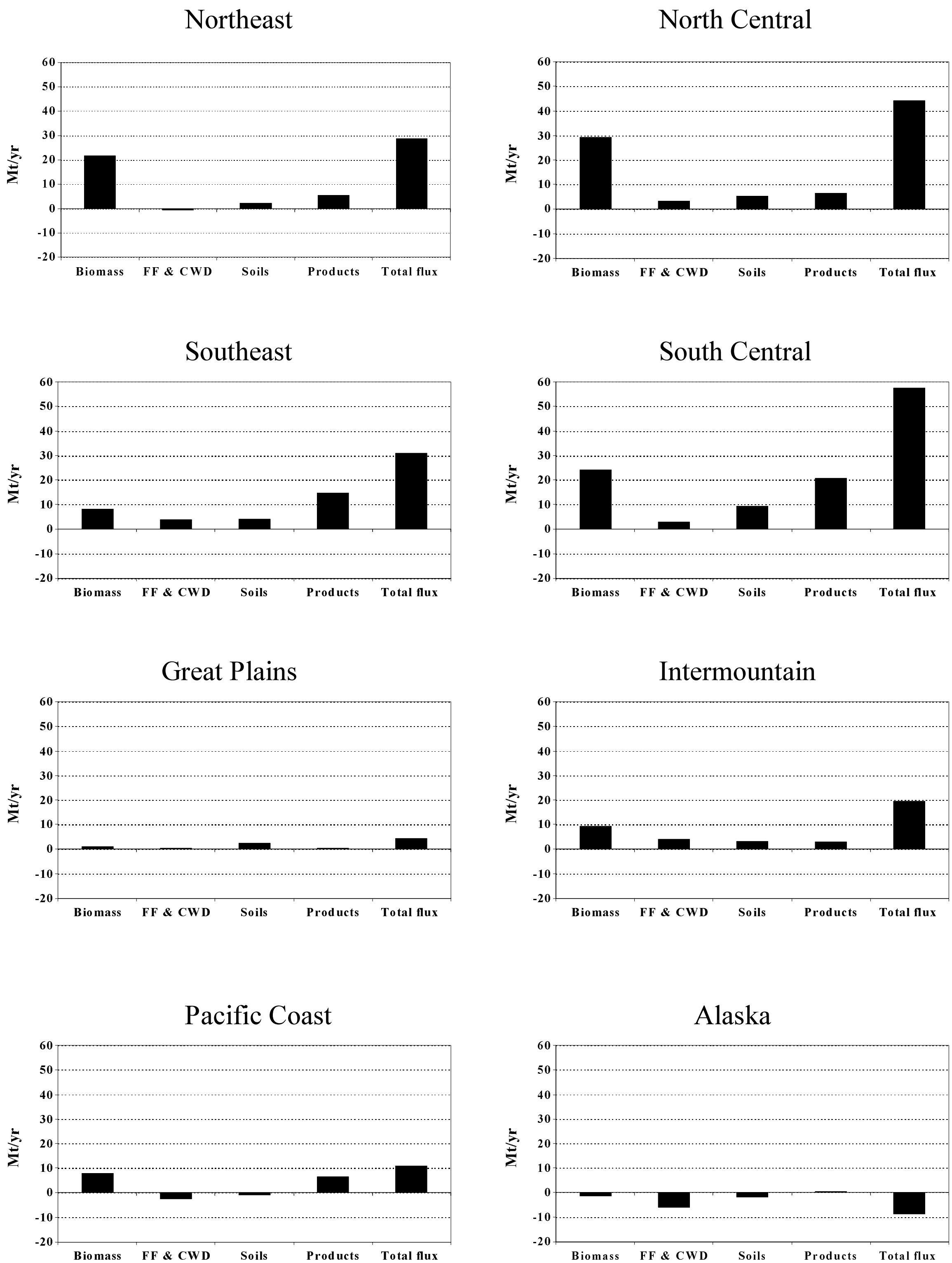

Figure 5.—Change in carbon stocks of U.S. forests by region and ecosystem component, 1987-1997 (FF & CWD refers to forest floor and coarse woody debris).

Table 4.—Total carbon stock on forest land and in harvested wood products in the Northeast and North Central regions, and annual change by accounting component, in Mt

Component	1987	1997	Avg. change per year 1987-97
Biomass	3,549.6	4,059.3	50.97
Forest floor/coarse woody debris	1,440.3	1,465.1	2.47
Soils	8,878.5	8,954.7	7.62
Wood products and landfills	488.2	592.0	10.38
Total	14,356.7	15,071.1	71.44

Table 5.—Total carbon stock on forest land and in harvested wood products, in the Northeast and North Central regions, and annual change by owner, in Mt

Owner group	1987	1997	Avg. change per year 1987-97
National forest	971.1	1,028.8	5.78
Other public	2,371.9	2,548.4	17.65
Forest industry	1,622.4	1,433.5	-18.89
Nonindustrial private	9,391.3	10,060.3	66.90
Total	14,356.7	15,071.1	71.44

Table 6.—Total carbon stock on forest land and in harvested wood products in the Northeast and North Central regions, and annual change by forest type, in Mt

Forest type	1987	1997	Avg. change per year 1987-97
White-red-jack pine	1,202.0	1,121.1	-8.09
Spruce-fir	1,739.3	1,528.4	-21.09
Longleaf-slash pine (planted)	0.0	0.0	0.00
Longleaf-slash pine (natural)	0.0	0.0	0.00
Loblolly-shortleaf pine (planted)	0.0	-1.0	-0.10
Loblolly-shortleaf pine (natural)	136.1	136.6	0.05
Oak-pine	237.6	258.0	2.04
Oak-hickory	3,970.4	4,363.0	39.26
Oak-gum-cypress	65.9	73.5	0.76
Elm-ash-cottonwood	843.9	791.8	-5.21
Maple-beech-birch	4,490.6	5,263.3	77.27
Aspen-birch	1,440.8	1,408.8	-3.20
Other forest types	67.0	75.9	0.89
Nonstocked	163.0	51.7	-11.13
Total	14,356.7	15,071.1	71.44

Table 7.—Change in total carbon stock on forest land and in harvested wood products attributed to land-use change since 1987 in the Northeast and North Central regions, in Mt

Component	Total change 1987-97	Avg. change per year 1987-97
Biomass	-13.4	-1.34
Forest floor/coarse woody debris	-14.7	-1.47
Soils	-40.1	-4.01
Wood products and landfills	8.1	0.81
Total	-60.1	-6.01

Table 8.—Total carbon stock on forest land and in harvested wood products in the Northeast and North Central regions, and annual change by state, in Mt

State	1987	1997	Avg. change per year 1987-97
		Northeast	
Connecticut	158.9	165.2	0.63
Delaware	32.7	32.1	-0.06
Maine	1,701.0	1,685.8	-1.52
Maryland	246.9	257.3	1.03
Massachusetts	271.6	290.4	1.88
New Hampshire	491.3	521.7	3.04
New Jersey	134.8	150.0	1.51
New York	1,702.2	1,754.2	5.20
Pennsylvania	1,567.8	1,588.8	2.10
Rhode Island	30.4	30.9	0.05
Vermont	440.5	490.0	4.95
West Virginia	999.4	1,091.6	9.23
Subtotal	7,777.4	8,057.9	28.05
		North Central	
Illinois	382.8	387.7	0.49
Indiana	392.8	435.5	4.27
Iowa	141.4	155.7	1.44
Michigan	1,546.2	1,695.7	14.94
Minnesota	1,322.8	1,350.1	2.73
Missouri	916.1	976.6	6.05
Ohio	598.4	672.1	7.37
Wisconsin	1,278.8	1,339.8	6.10
Subtotal	6,579.3	7,013.2	43.39
Total	14,356.7	15,071.1	71.4

Table 9.—Total carbon stock on forest land and in harvested wood products in the Southeast and South Central regions, and annual change by accounting component, in Mt

Component	1987	1997	Avg. change per year 1987-97
Biomass	4,692.8	5,017.8	32.49
Forest floor/coarse woody debris	1,077.2	1,141.5	6.43
Soils	6,150.6	6,274.6	12.39
Wood products and landfills	1,327.4	1,682.7	35.53
Total	13,248.1	14,116.5	86.84

Southeast and South Central Regions

Carbon stocks in the Southeast and South Central regions increased by 87 Mt/yr from 1987 to 1997 (Table 9). Most of this increase was in biomass and wood products. Forests in all ownership classes, led by nonindustrial private ownerships, gained carbon (Table 10).

There was a significant shift in carbon stocks among forest types due to the ongoing conversion of natural pine types to pine plantations, a shift in species composition, and an increase in the occupancy of forest land by trees (Table 11). Planted loblolly-shortleaf pine, oak-pine, oak-hickory, and oak-gum-cypress gained significant amounts of carbon, while natural loblolly-shortleaf pine lost the most carbon. The area of nonstocked forest land declined significantly as tree stocking and amount of carbon/acre increased. Because of the decline in area, total carbon on these lands decreased.

Changes in land use in the Southeast and South Central since 1987 led to a loss in carbon of about 7 Mt/yr. All carbon pools were affected except that for wood products, which showed a gain (Table 12). Utilization of harvested wood from land-use change helped offset losses of ecosystem carbon.

The Southeast and South Central are similar in carbon stocks (Fig. 4) and carbon fluxes (Fig. 5). South Central States gained 57 Mt/yr and Southeast States gained 30 Mt/yr from 1987 to 1997 (Table 13). All of the Southern States gained carbon except for Texas, which lost about 6 Mt/yr. Mississippi, Arkansas, Alabama, and Georgia gained the most forest carbon. Estimates for Texas primarily reflect changes in forested area and shifts in forest-type classifications in east Texas; complete forest inventories have not been conducted in central and west Texas.

Western Regions

Carbon stocks in Western regions (Great Plains, Intermountain, Pacific Coast, Alaska, and Hawaii) increased by 32 Mt/yr from 1987 to 1997 (Table 14). Most of the increase was in biomass and wood products while carbon pools in the forest floor and coarse woody debris showed a loss. National Forest lands gained a significant amount of forest carbon (Table 15). A shift in land classification from other public to nonindustrial private caused respective losses and gains in these two ownership groups.

There was a significant shift in carbon stocks among forest types (Table 16). In part this reflects shifting species composition, but an important confounding factor was changes in the way forests were classified by forest type. These changes were particularly significant for Alaska and for National Forest lands, both of which comprise large areas of the West. Another classification issue is the inclusion of the Great Plains States with the other Western States in this tabulation. The eastern portions of the Great Plains include eastern forest types that were added to similar western forest types in Table 16. Many forest types gained carbon while losses of carbon were significant in chaparral, fir-spruce, larch, and Douglas-fir.

Table 10.—Total carbon stock on forest land and in harvested wood products in the Southeast and South Central regions, and annual change by owner, in Mt

Owner group	1987	1997	Avg. change per year 1987-97
National forest	870.4	911.0	4.06
Other public	720.1	858.6	13.85
Forest industry	2,341.5	2,425.5	8.40
Nonindustrial private	9,316.1	9,921.4	60.53
Total	13,248.1	14,116.5	86.84

Table 11.—Total carbon stock on forest land and in harvested wood products in the Southeast and South Central regions, and annual change by forest type, in Mt

Forest type	1987	1997	Avg. change per year 1987-97
White-red-jack pine	69.5	83.0	1.35
Spruce-fir	4.8	1.0	-0.38
Longleaf-slash pine (planted)	396.6	419.8	2.32
Longleaf-slash pine (natural)	440.7	345.9	-9.48
Loblolly-shortleaf pine (planted)	672.6	1,197.3	52.47
Loblolly-shortleaf pine (natural)	2,235.1	1,883.4	-35.17
Oak-pine	1,718.3	1,924.7	20.64
Oak-hickory	5,211.4	5,388.9	17.75
Oak-gum-cypress	1,954.8	2,118.5	16.37
Elm-ash-cottonwood	211.6	159.2	-5.24
Maple-beech-birch	103.6	129.7	2.61
Aspen-birch	0.0	0.0	0.00
Other forest types	99.4	405.5	30.61
Nonstocked	129.6	59.4	-7.01
Total	13,248.1	14,116.5	86.84

Table 12.—Change in total carbon stock on forest land and in harvested wood products attributed to land-use change since 1987 in the Southeast and South Central regions, in Mt

Component	Total change 1987-97	Avg. change per year 1987-97
Biomass	-51.5	-5.15
Forest floor/coarse woody debris	-21.3	-2.13
Soils	-46.0	-4.60
Wood products and landfills	47.0	4.70
Total	-71.8	-7.18

Table 13.—Total carbon stock on forest land and in harvested wood products in the Southeast and South Central regions, and annual change by state, in Mt

State	1987	1997	Avg. change per year 1987-97
		Southeast	
Florida	881.5	916.2	3.47
Georgia	1,514.5	1,624.1	10.96
North Carolina	1,363.3	1,427.3	6.39
South Carolina	790.0	813.7	2.37
Virginia	1,123.6	1,187.8	6.42
Subtotal	5,672.9	5,969.1	29.62
		South Central	
Alabama	1,309.1	1,426.3	11.73
Arkansas	1,090.0	1,234.8	14.49
Kentucky	873.8	909.1	3.53
Louisiana	916.6	972.4	5.58
Mississippi	1,088.7	1,246.9	15.81
Oklahoma	327.3	364.5	3.72
Tennessee	859.9	940.3	8.05
Texas	1,109.8	1,053.0	-5.67
Subtotal	7,575.1	8,147.4	57.23
Total	13,248.1	14,116.5	86.84

Table 14.—Total carbon stock on forest land and in harvested wood products, and annual change by accounting component, Western regions, in Mt

Component	1987	1997	Avg. change per year 1987-97
Biomass	7,590.7	7,761.0	17.03
Forest floor/coarse woody debris	6,883.8	6,849.1	-3.47
Soils	13,392.4	13,434.2	4.18
Wood products and landfills	1,104.0	1,245.7	14.17
Total	28,970.9	29,290.0	31.91

Table 15.—Total carbon stock on forest land and in harvested wood products, and annual change by owner, Western regions, in Mt

Owner group	1987	1997	Avg. change per year 1987-97
National forest	9,862.0	10,305.8	44.39
Other public	10,390.4	9,938.5	-45.19
Forest industry	1,732.9	1,700.0	-3.29
Nonindustrial private	6,985.7	7,345.6	36.00
Total	28,970.9	29,290.0	31.91

Table 16.—Total carbon stock on forest land and in harvested wood products, and annual change by forest type, Western regions, in Mt

Forest type	1987	1997	Avg. change per year 1987-97
Douglas-fir	4,337.3	4,262.6	-7.47
Ponderosa pine	2,314.8	2,463.0	14.82
Western white pine	66.1	59.2	-0.69
Fir-spruce	6,171.1	6,037.0	-13.41
Hemlock-Sitka spruce	1,753.0	2,049.2	29.62
Larch	284.7	129.5	-15.53
Lodgepole pine	1,266.7	1,234.7	-3.20
Redwood	177.0	142.1	-3.48
Other hardwoods	2,669.5	2,980.0	31.05
Other forest types	5,647.8	6,087.4	43.97
Pinyon-juniper	3,293.1	3,228.4	-6.47
Chaparral	614.7	390.3	-22.44
Nonstocked	375.3	226.7	-14.86
Total	28,970.9	29,290.0	31.91

Table 17.—Change in total carbon stock on forest land and in harvested wood products attributed to land-use change since 1987 in the Western regions, in Mt

Component	1987-97	Avg. change per year 1987-97
Biomass	-40.0	-4.00
Forest floor/coarse woody debris	-41.7	-4.17
Soils	-43.4	-4.34
Wood products and landfills	29.3	2.93
Total	-95.8	-9.58

Table 18.—Total carbon stock on forest land and in harvested wood products in the Western regions, and annual change by state, in Mt

State	1987	1997	Avg. change per year 1987-97
		Great Plains	
Kansas	96.3	119.5	2.32
Nebraska	50.1	64.0	1.39
North Dakota	32.3	44.2	1.19
South Dakota	123.0	117.8	-0.52
Subtotal	301.6	345.4	4.38
		Intermountain	
Arizona	1,267.2	1,303.1	3.59
Colorado	1,490.4	1,494.7	0.42
Idaho	1,820.8	1,858.2	3.74
Montana	1,751.8	1,869.3	11.75
Nevada	648.5	699.3	5.08
New Mexico	950.5	926.7	-2.37
Utah	1,130.5	1,110.5	-2.00
Wyoming	781.2	811.1	2.99
Subtotal	9,840.9	10,072.9	23.20
		Pacific Coast	
Alaska	10,158.2	10,073.2	-8.50
California	3,375.5	3,436.4	6.09
Hawaii	90.3	90.3	0.00
Oregon	2,873.8	2,962.4	8.86
Washington	2,330.7	2,309.5	-2.12
Subtotal	18,828.5	18,871.7	4.32
Total	28,970.9	29,290.0	31.91

Changes in land use in the West since 1987 caused a loss of carbon of about 10 Mt/yr, affecting all carbon pools except that for wood products, which showed a gain (Table 17). The utilization of harvested wood resulting from land-use change helped offset losses of ecosystem carbon.

In contrast to the North and South, regions in the West differed in patterns of carbon stocks (Fig. 4) and changes in carbon stocks (Fig. 5). The Great Plains, with little forest land, has the least amount of forest carbon. The Intermountain and Pacific Coast have large carbon stocks, but changes from 1987 to 1997 were not as significant as for the eastern regions. Because of increasing fire frequency since 1997, it is likely that the carbon stock in the Intermountain and Pacific Coast is increasing at a much lower rate than shown in Figure 5, or even decreasing. Alaska has high carbon stocks in forests, though the only available trend data indicate a small loss of carbon from 1987 to 1997. This reflects the harvesting of old forests and replacement by young forests (primarily in southeast Alaska), widespread mortality due to pests and fire, and shifts in species composition.

The Intermountain gained 23 Mt/yr of carbon from 1987 to 1997 (Table 18). Pacific Coast and Great Plains States gained small amounts of carbon. Of the Western States, Montana and Oregon gained the most carbon, while South Dakota, New Mexico, Utah, and Washington lost small amounts. The estimated substantial loss of carbon in Alaska is suspect due to sparse remeasurement data from inventory plots. The reported losses are attributed almost entirely to the reclassification of forest types and may not reflect a true change in carbon stocks.

Summary and Conclusions

According to our estimates, carbon stocks on forest land and in harvested wood products increased between 1987 and 1997 at an annual rate of 190 Mt. Most of this increase was in biomass, followed closely by wood products and landfills. Changes in land use since 1987 caused a small decrease in carbon stocks, but this loss was offset by large gains on existing forest land. The East had the greatest gain in carbon stocks with smaller gains for the West; Alaska showed a small decrease but this is suspect due to a reliance on sparse trend data from forest inventories. Some regions showed significant shifts in carbon stocks among forest types, an indication of changes in species composition and management intensity. For example, in the South there was a significant shift in carbon stocks from natural to plantation pines.

Most of the individual states showed increases in ecosystem and wood-products carbon. Observed changes were attributed to distinct regional and local factors, e.g., timber production, land-use change, and natural disturbance. This information can be the basis for determining the potential gain or loss of forest carbon resulting from management and policy decisions.

By analyzing the underlying inventory data, it is possible to identify many of the factors that cause changes in forest carbon stocks. However, it may be difficult to determine the relative influence of the identified factors without conducting a more detailed analysis than attempted here. Inconsistency in the way data were collected or reported, or unavailability of previously compiled data, can obscure the factors that cause changes in carbon stocks.

The methods demonstrated here for converting inventory data to carbon stocks can be applied more rigorously at the state level. Ongoing changes in the way inventory data are collected, e.g., the conversion from a periodic to annual inventory, will facilitate reporting changes in ecosystem and wood-products carbon on an annual basis. Gaps in data collection are being filled, particularly for Alaska, Hawaii, Texas, Oklahoma, and parts of the Southwest. These changes, along with improvements in methodology, will reduce the uncertainty of estimates of forest carbon from inventory data.

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Appendix 1: Description of Data and Methods

Forest-Ecosystem Databases

An extensive and comprehensive forestry data collection, management, and reporting system underlies carbon estimates and analyses (Powell et al. 1993; Smith et al. 2001). The comprehensive national inventory of forest lands in the United States began in the 1930s. By the early 1950s, all states except Alaska (interior) had been inventoried at least once. Until recently, each state was inventoried about every 5 to 15 years, with national statistics compiled every 5 years. Recent compilations of national statistics are for 1987, 1992, and 1997. For most states, data for 1992 are identical or only partially updated from 1987; therefore, the principal databases we used are those for 1987 and 1997. Ongoing changes in the way national forest inventories are implemented will facilitate annual reporting of basic statistics, which, in turn, will facilitate reporting of carbon flux on an annual basis.

The most comprehensive ecosystem measurements available are from intensive, long-term ecosystem studies such as those comprising the network of Long Term Ecological Research (LTER) sites. LTER and similar sites typically have a long history of repeated measurements of a common and comprehensive suite of ecological variables, including soil and litter carbon, that are unavailable from extensive statistical sampling networks. Unlike national forest inventories, intensive studies are concentrated on relatively undisturbed sites. This information can be used only in conjunction with forest-inventory data by making appropriate adjustments (see assumptions described elsewhere in this section) to represent the range of conditions in the statistical sample.

Sampling Design of Forest Inventories

Since World War II, U.S. forest inventories have used multiphase sampling designs that include remote sensing and ground measurements (Birdsey and Schreuder 1992). The first sample phase typically consists of interpretation of high-altitude color infrared photography, widely available and highly accurate for estimating changes in forest area and locating field sample plots. Interpreters classify more than 3 million sample points nationally to monitor activities such as timber harvest and land use that may change the photo classification from forest to nonforest cover. The inventory is in the process of changing from high-altitude photography to satellite imagery for phase 1.

The second sample phase consists of more than 150,000 permanent field sample locations that are remeasured periodically to provide statistics on disturbance (e.g., harvest and mortality), growth, change in species composition, and numerous observed and calculated site descriptors such as ownership and forest type. At each sample location, a rigorous protocol is followed to select and measure a representative sample of trees. These measurements are then expanded to the population level using statistics from phase 1. A subsample of phase 2 plots (Forest Health Monitoring plots) is the basis for more intensive ecosystem measurements. Soils, coarse woody debris, understory vegetation, and other ecological variables may be collected on this subsample, which is linked statistically to the phase 1 and 2 samples. The subsample of phase 2 consists of about 5,000 plots. Successive measurements have been initiated on about half of this subsample.

Estimating Carbon in Trees

The quantity of carbon in live and dead trees is derived from volume and biomass estimates from the national forest inventory. Methods for estimating volume, biomass, and the components of change (growth, removals, and mortality) are reviewed in Birdsey and Schreuder (1992). Estimates of growing-stock volume (the merchantable part of trees) are converted to tree carbon in a two-stage process. First, total tree volume is estimated from growing-stock volume using a ratio to account for the additional tree parts excluded from the definition of growing stock: tops and branches, rough and rotten trees, small trees (less than 5.0 inches in diameter at breast height), standing dead trees, stump sections, roots, and bark. A factor is added to account for carbon in foliage. Separate ratios are computed for softwoods and hardwoods to account for differences in the average ratio of total volume to growing-stock volume. Ratios are derived from two principal sources: a nationwide biomass study prepared by the USDA Forest Service containing estimates of above-ground biomass by tree component (Cost et al. 1990), and a report containing estimates of the proportion of below-ground tree volume.[1] Separate ratios are derived for each region of the United States to account for differences in tree

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[1]Koch, P. 1989. Estimates by species group and region in the USA of: I. Below-ground root weight as a percentage of ovendry complete-tree weight; and II. carbon content of tree portions. Unpublished report on file at USDA Forest Service, Newtown Square, PA.

form and to be consistent with regional data used to develop yield tables for timber-projection models. The validity of this method rests on the assumption that the ratio of total above-ground biomass to merchantable biomass (estimated in dry weight units) equals the ratio of total above-ground volume to merchantable volume. There is considerable variation in the ratios of total to merchantable volumes among regions and species groups (Birdsey 1992). For the Nation, the average ratio of total to merchantable volume is 1.91 for softwoods and 2.44 for hardwoods.

The second step entails converting total tree volume in cubic feet to carbon in pounds. Separate factors are used for major forest types and for softwoods and hardwoods within each forest type, and for broad geographic regions. The volume-to-carbon conversion factor is computed in two steps. First, volume in cubic feet is converted to biomass in dry pounds by multiplying the number of cubic feet by the mean specific gravity by the weight of a cubic foot of water (62.4 lb). A weighted mean specific gravity for softwoods or hardwoods is estimated from the relative frequency of the three predominant hardwood or softwood species in each forest type and region. Second, the biomass in dry pounds is multiplied by a factor to account for the average carbon content of the tree. Estimates of the carbon content of trees used in past studies generally have ranged from 45 to 50 percent (Houghton et al. 1985) though another study[1] for the United States found that the average percentage of carbon was 52.1 for softwoods and 49.1 for hardwoods; there were slight regional variations. The final factors used to convert volume (cubic feet) to carbon (pounds) for U.S. forest types range from 11.41 to 17.76 for softwoods, and from 11.76 to 19.82 for hardwoods (Birdsey 1992). A separate set of conversion factors for pure stands of plantation species also was developed (Birdsey 1996).

Estimating Carbon in Forest Floor and Coarse Woody Debris

Estimates of the amount of carbon or organic matter on the forest floor, including coarse woody material, are available for both broad forest classifications and for specific ecological types. The estimates of Vogt et al. (1986) for broad forest-ecosystems are applied to the forest types common in each state. These reference estimates are assumed to be representative of relatively undisturbed, unmanaged, mature secondary forests.

A weighting procedure is used to account for the relative age structure of forest types in a state or region. This procedure is identical to that used for estimating soil carbon, that is, comparing the average age with the reference age to determine a weighting factor. The factor is then multiplied by the corresponding estimate of carbon in the forest floor from Vogt et al. (1986).

Additional assumptions are made to estimate the dynamics of carbon in the forest floor. For reforestation of cropland or pasture, it is assumed that there is no organic matter on the forest floor at age zero, and that the reference estimates are reached at age 50 in the South and age 55 elsewhere. For cutover forest land in the South, it is assumed that there is no organic matter on the forest floor after harvest because of the general use of intensive site preparation prior to planting. Elsewhere, it is assumed that the quantity of organic matter on the forest floor is equal to 33 percent of the reference estimate after harvest. After the reference estimates at age 50 or 55 are reached, organic matter accumulates on the forest floor at a decreasing rate.

Woody debris after harvest is estimated by inverting the factors used to convert merchantable volume to carbon, assuming that nonmerchantable carbon remained in the forest and merchantable carbon entered the harvested carbon pool. Then, the rate of loss of carbon in woody debris is estimated using published decomposition constants (Turner et al. 1995).

Estimating Carbon in Soils

Carbon in soil is estimated with models that relate the quantity of organic matter to temperature, precipitation, age class, and land-use history. Data are from a variety of ecosystem studies. The approach follows that of Burke et al. (1989), who used a multiple regression procedure to find the best predictive equations for soil organic carbon in cropland and grassland in the Central Plains and adjacent areas. Data from Post et al. (1982) were used to estimate regression coefficients for a similar, compatible model for forest lands. The methodology is explained in Plantinga and Birdsey (1993) and Birdsey (1992).

Estimates of soil carbon developed by Post et al. (1982) for temperate forests and used to derive estimates for the United States represent relatively undisturbed, unmanaged, mature secondary forests. These estimates are considered reference points and used to generate simple functions to describe changes in soil carbon associated with harvesting and land-use change. Diagrams of the different cases of harvesting and land-use change are in Plantinga and Birdsey (1993).

Because we lack comprehensive statistical databases of soil carbon linked with above-ground measurements, which could be used to derive empirical estimates of soil carbon changes from harvesting and land use, we develop a series of assumptions based on continuing literature reviews. The most recent compilation of our assumptions is presented in Heath and Smith (2000). In general, we use assumptions about: (1) soil carbon at initial conditions, (2) age associated with the reference estimates for mature secondary forests, (3) rate of transition from initial conditions to reference conditions, and (4) changes after reference conditions are attained. The literature is inconclusive about many aspects of the dynamics of soil carbon. For example, Johnson (1992) found a variety of responses of soil carbon to harvesting, including both increases and decreases in soil carbon.

Our assumptions about changes in soil carbon are similar to those of Houghton et al. (1983, 1985). For the South, we assume that clearcut harvest is followed by intensive site preparation, which results in a loss in soil carbon of 20 percent by age 10. After age 10 we assume a linear increase to the reference age. For less intensive harvesting such as partial cutting or regeneration methods that exclude soil disturbance, no soil carbon loss is estimated. It is assumed that changes between reference points are linear, and the rate of change after reaching reference levels (assumed to be 50 years) is reduced linearly to zero over a few decades. For regions other than the South, loss of soil carbon after clearcut harvest is assumed to be zero, resulting in a constant level throughout the yield period.

Tree plantations or natural vegetation established on agricultural land with depleted organic matter can cause a substantial accumulation of soil organic matter depending on species, soil characteristics, and climate (Johnson 1992). For example, *Populus* spp. established on sandy soils showed large increases in soil and forest-floor carbon due to high litter production (Dewar and Cannell 1992).

For replanted pasture in all regions, soil carbon at age zero is the higher of either: (1) the level estimated with the equation from Burke et al. (1989), or (2) two-thirds of the average for secondary forests at the reference age. For replanted cropland in all regions, soil carbon at age zero is the higher of either: (1) the level estimated by Burke et al. (1989), or (2) one-half of the average for secondary forests at the reference age. It is assumed that soil carbon increases linearly from the lowest level to the reference age. In all cases after the reference age is reached, the rate of accumulation of soil carbon declines as the forest matures.

Carbon in Wood Products and Landfills

Harvested carbon includes wood removed from the forest for manufacturing of products or fuelwood. Logging debris, which remains in the forest, is included in the forest floor and coarse woody debris.

We used a modification of the stock-change approach for wood products because a complete inventory of the volume or mass of carbon in wood products and landfills is not available. We simulated the most dynamic portion of the inventory of carbon retained in wood products and landfills by compiling estimates of wood production periodically from 1952 to 1997, and applying to these estimates a model of carbon retention in various harvest carbon pools (Row and Phelps 1991). We calculated the carbon inventory in wood products and landfills for 1987 and 1997 by estimating the amount of carbon remaining in these pools from each of the periodic estimates, which were summed to obtain the totals. Then the estimate for 1987 was subtracted from the 1997 estimate to obtain the difference in a compatible way with that for forest-ecosystem-components. We used the "production approach" for wood products, that is, all of the accounting is attributed to the land area where the wood is grown regardless of the eventual location and disposition of wood products (Heath et al. 1996). Imported wood is ignored in this approach.

The model HARVCARB (Row and Phelps 1991) estimates four disposition categories— products, landfills, energy, and emissions. Products and landfills are combined to monitor the stock of carbon in harvested wood products. Products are goods manufactured or processed from wood, including lumber and plywood for housing and furniture, and paper for packaging and newsprint. Landfills store carbon as discarded products that eventually decompose, releasing carbon as emissions.

The harvested carbon model tracks the fate of carbon as the harvested wood is processed from roundwood to products in use to eventual disposition in landfills, or as burned or decomposed carbon emitted to the atmosphere. HARVCARB traces removals through three transformation phases. In the first phase, roundwood is processed into primary products, e.g., lumber, plywood, paper, and paperboard. Then, primary products are transformed into end-use products such as housing, packaging, and newsprint. The first two phases generate substantial amounts of byproducts that are used primarily in energy cogeneration. The third phase describes the disposal of end-use products, reflecting the length of time products remain in use, and final disposition patterns. HARVCARB was run by region, species group, and harvest type to develop equations that track the harvested carbon pools for use in the estimation process.

Accounting for Land-Use Change

For land-use change we began with the land base in 1987 and accounted only for change between 1987 and 1997. This approach does not account for any long-term effects of prior land-use changes on soil carbon. We counted only the real changes in carbon stocks from land-use change, ignoring apparent changes that can occur because of a change in land classification. For example, if a land area was reclassified from forest to nonforest, we deducted the change in soil carbon caused by the shift but not the remaining soil carbon that was transferred to the new land use. Likewise, for land reclassified from nonforest to forest, we did not include the estimated carbon already on the land prior to reclassification as forest.

The area of land-use change was estimated by using 1987 as the base year. Estimates of losses of forest land to agriculture and urban use, and corresponding gains in forest land, are from forest- inventory databases from successive and recent inventories (if available), and from USDA Natural Resources Inventory data when forest-inventory data are not available (Nat. Resour. Conserv. Serv. 2000).

Average changes in each carbon pool are estimated by region and forest type and multiplied by the estimated area change. There was a separate accounting for effects of land-use change on each carbon pool. Biomass of new forest plots from nonforest plots was estimated from the inventory databases. Biomass of new nonforest plots from forest plots was estimated from values published for urban areas by Dwyer et al. (2000). Estimates for soil, forest floor, and coarse woody debris carbon were made following the assumptions described previously. Estimates of carbon retained in wood products from land clearing were made by estimating the quantity of merchantable biomass and assuming that all was used for products.

Note that the effects of land-use change, while treated separately in the estimation process, are embedded in each of the reported tables (except where noted) for complete accounting. Some of the tables include only the changes in carbon stock attributed to land-use change between 1987 and 1997. Estimates in these tables can be subtracted from corresponding tables with complete carbon accounting to determine how carbon stocks changed on lands that were classified as forest in both 1987 and 1997.

Estimation Errors and Data Gaps

The most comprehensive and accurate regional estimates of carbon flux using inventory data are for above-ground biomass. However, there are significant gaps in data for areas that are not inventoried frequently, e.g., interior Alaska. In addition to sampling and measurement errors, which are typically small, there also are estimation errors of the regression models used to estimate tree biomass from field measurements.

Data on soil and litter carbon are from ecosystem studies that were not part of a regional statistical sample. Therefore, regional estimates from these sources include unknown estimation errors when such data are extrapolated using empirical models. Also, for many long-term but suspected significant changes in quantities of soil carbon, we use assumptions that are logical but that remain untested.

We did not attempt to estimate the uncertainty of the estimates presented here because of the variety of information sources, most of which did not include error estimates. Estimated changes of small magnitude may not be significant due to the uncertainty of the estimation process. Important progress has been made in applying the principles of uncertainty analysis (Smith and Heath 2000) and error analysis (Phillips et al. 2000) in evaluating the results of our estimation process, and in determining where resources should be allocated for significant improvements.

The inventory approach does not include all factors of environmental change. For example, atmospheric deposition of nitrogen compounds to forest soils affects soil carbon dynamics and perhaps the allometric relationships used to estimate tree biomass, yet deposition effects are not considered. Such factors could be addressed by linking the current integrated modeling system with process models that model key dynamic factors.

Appendix 2: Comparison of Estimates and Methods

Summary

Continuing studies have produced estimation methods that were unavailable at the time the estimates for this report were compiled. As a result, our estimates differ from those in the EPA greenhouse gas inventory for 2000 (Environ. Prot. Agency 2002) and similar Forest Service reports published over the last decade. The following tabulation compares EPA estimates for 1990 and 1997 with the estimates in this report (1987-97, excluding Alaska and Hawaii), in Mt/yr:

Carbon component	EPA inventory 1990	EPA inventory 1997	Average for 1987-97
Biomass	131	128	102
Forest floor/ coarse woody debris	22	8	11
Soil	58	15	25
Products and landfills	57	58	58
Total	268	207	196

Even with many differences in methodology outlined in the following section, the estimates of changes in carbon stock by component are similar except for changes in soil carbon.

Tree Biomass

The higher estimate for 1997 in the EPA inventory is attributed primarily to the use of a new set of biomass equations and application of unique volume-to-carbon conversion factors by tree-size class rather than one factor for all tree classes. The new nationally consistent set of biomass equations (Jenkins et al. 2003) produces a higher estimate for most tree species and diameter classes than is contained in biomass estimates of inventory databases. The higher estimate for 1990 has a different cause: trees were accumulating carbon at a faster rate in 1990 than 1997 due to numerous factors that affect growth rates.

Forest Floor and Coarse Woody Debris

For this report and some older Forest Service reports, data for forest floor and coarse woody debris were combined. Because the data used in the estimation models did not sufficiently represent coarse woody debris, that component was underestimated. The estimates in the EPA greenhouse-gas report are calculated individually by region, owner, and forest type, and as a function of the area by age class for each of these categories. In this report, the calculations were a function of the volume by region and owner.

Soil

Many approaches are being considered for the difficult task of estimating changes in soil carbon for forests. Differences in estimates are attributed to several factors. The stock of soil carbon in the EPA greenhouse-gas report was based on soil and forest-type maps rather than on simple models. Land-use change and the long-term effects of past land-use change were treated differently in accounting, so the estimation processes were different. Likewise, the effects of forest type shifts were treated differently. The high estimate for 1990 (relative to other years) is the result of an estimation process that linked below-ground to above-ground carbon in a proportional manner.

Wood Products

The new estimates of carbon flux in wood products and landfills are nearly identical to the old estimates at both the national and regional scales. A different model of the disposition of carbon in wood products was used, as was the historical starting point for the calculations. These changes in methodology may have produced offsetting results.

Point-by-point Comparison

The following tabulation is intended to provide additional details about the ongoing development of estimation methods. The table does not strictly compare the methods used in this or the EPA greenhouse-gas report, but looks at how methods are changing. The italics under the column labeled "Birdsey and Heath 1995" identify specific accounting changes for this report.

Carbon pool	Birdsey and Heath 1995	Heath et al. 2002
Tree biomass	Used FIA standard biomass equations (Cost et al. 1990) Live and dead trees combined Root ratios for softwoods and hardwoods Volume-to-carbon conversion factors by region and forest type Historical estimates from conversion of RPA volume estimates to mass	Used nationally consistent biomass equations (Jenkins et al. 2003) Live and dead trees separate Root ratios for 10 species groups Volume-to-carbon conversion factors by region, species, and size class (Smith et al. 2003) Historical estimates from conversion of RPA volume estimates to mass
Understory biomass	Percent of overstory biomass by forest type and age class	Percent of overstory biomass by forest type and age class
Forest floor/coarse woody debris	Forest floor and coarse woody debris combined Used data in Vogt et al. (1986) Single estimate by region and forest type, weighted by age class distribution Simple dynamics for harvesting and land-use change *CWD decay functions from Turner et al. 1995 (used for logging debris)* Historical estimates calculated as a function of RPA volume	Developed equations by region, forest type, and age class (Smith and Heath 2002) Data from a comprehensive literature review (Smith and Heath 2002) Historical estimates calculated as a function of region and forest type Simulated ratio of woody residue to live tree C from growth, management, and harvest (Chojnacky and Heath 2002) Data from research studies Separate relationships by region, forest type, and owner CWD decay functions from Turner et al. (1995) Historical estimates calculated as a function of region and forest type
Soil	Multiple regression procedure to estimate soil carbon from temperature and precipitation (Post et al. 1982) Type shifts affect soil carbon in projections only Assumed clearcut affected soil carbon in the South Simple dynamics for land-use change projections beginning in 1980 *(1987)* Assumptions for land-use change effects from Houghton et al. (1983, 1985) Soil carbon changes deducted for land-use change	Soil carbon based on U.S. soil map with GIS overlay of forest types Type shifts affect historical and projected soil carbon Assumed clearcut did not affect soil carbon anywhere Simple dynamics for land-use change beginning in 1909 Data for land-use change effects from Post and Kwon (2001) Soil carbon changes deducted for land-use change
Wood products	Used model results from Row and Phelps (1991) Based on wood production from all domestic sources *(by state)* Historical data began in 1980 *(1952)*	Used model results from Skog and Nicholson (1998) Based on wood production from all domestic sources Historical data began in 1900

Appendix 3: Methods for Individual States

The following are considerations for developing a forest carbon budget at the state level:

- Conflicts between actual dates of the original forest inventory data and required reporting dates.
- Changes in standards for data collection.
- Missing data.
- Availability of unique state-level data sets.
- Applicability of generic regional or national estimation methods to specific states.
- Familiarity of staff with inventory methods and methods for estimating carbon.

The actual dates of data collection used in the most recent compilation of National Forest statistics are shown in Table 19. These also are the most recent data used in compiling the state estimates in this report. In some cases, more recent inventory data may be available for states that already have adopted a continuous (annual) inventory system, or that recently completed periodic inventories. Estimated trends between 1987 and 1997 are based on the dates shown in Table 19 and the most recent prior inventory, which on average for the United States was completed 10 years prior to the dates shown. If the date of the most recent inventory is earlier than 1987, reported trends between 1987 and 1997 are highly suspect.

Changes in data collection standards occur frequently. In many cases, particularly for the estimates reported in Smith et al. (2001), adjustments are made to older data to make them conform to newer data. Nonetheless, we discovered the following inconsistencies that likely affected the conversion of inventory data to carbon estimates as well as the reported trends between 1987 and 1997:

- Change in the definition of forest land for some western National Forests.
- Changes in the definitions of forest types for some western National Forests and some states.
- Information on age class not available from earlier inventories, or collected in a different manner than for subsequent inventories.
- Forest areas within a state not fully inventoried, e.g., only forest-area statistics available for the Adirondack Preserve in New York, and large portions of West Texas and West Oklahoma.

As mentioned previously, data may be missing or absent, e.g., parts of Alaska have not been inventoried, or variables may be missing from online databases. We used an "imputation" technique for some areas that lacked data, and for small states with too few inventory sample points to develop statistically accurate distributions of areas by age class and owner group. Imputation entails assigning values to areas with missing data based on values for other areas with similar characteristics.

The availability of additional and possibly unique data sets should be evaluated. Remote sensing products can be used to monitor changes in land cover. Also, some states have completed fire fuel inventories, and special land-resource studies may have been conducted for states or regions.

The applicability of the generic estimation process used here should be questioned. We applied regionally specific methods to states within a region. Improved methods for estimating carbon stocks and stock changes in forests are becoming available and should be considered as substitutes for our methods.

Our estimates represent a first approximation of the contribution of the forestry sector to a state's greenhouse-gas inventory. We encourage individual states to develop expertise in the estimation process so that individual circumstances can be evaluated carefully and, where feasible, represented in the estimates. For some states, the data used in this report may not be the most recent available, or there may be other data sets available that can improve the estimates. Methodology for monitoring carbon changes on the land is changing, so it may be worthwhile for states to consider enhancements to the methods used here, or alternate methods.

Table 19.—Dates of most recent FIA data used for carbon estimates by state

State	Non-NFS lands	NFS lands
	Northeast	
Connecticut	1985	
Delaware	1986	
Maine	1995	1995
Maryland	1986	
Massachusetts	1985	
New Hampshire	1997	1997
New Jersey	1986	
New York	1993	1995
Pennsylvania	1989	1995
Rhode Island	1985	
Vermont	1997	1997
West Virginia	1989	1995
	North Central	
Illinois	1985	1985
Indiana	1997	1997
Iowa	1990	
Michigan	1993	1993
Minnesota	1990	1990
Missouri	1989	1989
Ohio	1994	1995
Wisconsin	1996	1996
	Southeast	
Florida	1995	1995
Georgia	1997	1997
North Carolina	1990	1990
South Carolina	1993	1993
Virginia	1992	1992
	South Central	
Alabama	1990	1990
Arkansas	1995	1995
Kentucky	1988	1988
Louisiana	1991	1991
Mississippi	1994	1994
Oklahoma	1989-93	1993
Tennessee	1989	1989
Texas	1992	1992
	Great Plains	
Kansas	1990	
Nebraska	1994	1994
North Dakota	1994	1994
South Dakota	1996	1986

Table 19.—Continued

State	Non-NFS lands	NFS lands
	Intermountain	
Arizona	1985	1996
Colorado	1983	1981-88
Idaho	1990	1990-95
Montana	1988	1995
Nevada	1989	1987
New Mexico	1987	1987
Utah	1993	1993
Wyoming	1984	1985-93
	Pacific	
Alaska	1977-94	1978-95
Oregon	1992	1994-96
Washington	1988-91	1995
California	1994	1995
Hawaii	1985	

Appendix 4: Basic Tables for the 50 United States

Table 20.—Area of forest land in the United States by region, state, and forest land class, 1987, in thousands of acres

State	Forest-land class: All forest land	Unreserved timberland	Reserved timberland	Other forest land
		Southeast		
Florida	16,721	14,983	493	1,245
Georgia	24,187	23,660	509	18
North Carolina	19,281	18,749	489	43
South Carolina	12,257	12,179	78	0
Virginia	16,108	15,570	476	62
Subtotal	88,554	85,140	2,045	1,368
		South Central		
Alabama	21,725	21,659	66	0
Arkansas	16,987	16,673	91	223
Kentucky	12,256	11,908	267	81
Louisiana	13,883	13,873	10	0
Mississippi	16,694	16,673	9	12
Oklahoma	7,283	6,087	11	1,185
Tennessee	13,258	12,839	395	24
Texas	20,505	12,414	780	7,311
Subtotal	122,591	112,126	1,629	8,836
		Northeast		
Connecticut	1,815	1,776	23	16
Delaware	398	388	3	7
Maine	17,713	17,175	276	262
Maryland	2,632	2,461	153	18
Massachusetts	3,097	3,010	0	87
New Hampshire	5,021	4,803	70	148
New Jersey	1,985	1,914	41	30
New York	18,776	15,799	2,739	238
Pennsylvania	16,997	15,918	708	371
Rhode Island	399	368	8	22
Vermont	4,509	4,424	39	46
West Virginia	11,942	11,799	116	27
Subtotal	85,281	79,835	4,177	1,270
		North Central		
Illinois	4,266	4,030	236	0
Indiana	4,439	4,296	143	0
Iowa	1,562	1,459	76	27
Michigan	18,221	17,364	623	234
Minnesota	16,583	13,571	1,178	1,834
Missouri	12,523	11,996	224	303
Ohio	7,309	7,141	119	49
Wisconsin	15,319	14,727	261	331
Subtotal	80,222	74,584	2,860	2,778

Continued

Table 20.—Continued

State	Forest-land class			
	All forest land	Unreserved timberland	Reserved timberland	Other forest land
	Great Plains			
Kansas	1,358	1,207	23	128
Nebraska	722	536	23	163
North Dakota	460	337	0	123
South Dakota	1,689	1,447	23	220
Subtotal	4,229	3,527	69	634
	Intermountain			
Arizona	19,384	3,789	2,066	13,529
Colorado	21,338	11,739	1,933	7,665
Idaho	21,818	14,533	3,790	3,495
Montana	21,909	14,736	2,795	4,379
Nevada	8,928	221	294	8,413
New Mexico	15,826	5,180	1,233	9,413
Utah	16,234	3,078	990	12,165
Wyoming	9,966	4,332	3,253	2,381
Subtotal	135,403	57,608	16,355	61,440
	Pacific Coast			
Alaska	129,045	15,763	8,042	105,240
California	39,381	16,712	4,903	17,766
Hawaii	1,749	700	196	853
Oregon	28,773	22,801	1,923	4,049
Washington	22,521	17,514	3,297	1,710
Subtotal	221,469	73,490	18,361	129,618
Total	737,749	486,310	45,495	205,944

Table 21.—Area of forest land in the United States by region, state, and forest land class, 1997, in thousands of acres

State	Forest-land class: All forest land	Unreserved timberland	Reserved timberland	Other forest land
		Southeast		
Florida	16,254	14,605	602	1,047
Georgia	24,413	23,796	595	22
North Carolina	19,298	18,639	615	44
South Carolina	12,651	12,419	232	0
Virginia	16,047	15,345	655	47
Subtotal	88,662	84,803	2,699	1,160
		South Central		
Alabama	21,964	21,911	52	0
Arkansas	18,790	18,392	231	167
Kentucky	12,684	12,347	305	32
Louisiana	13,783	13,693	90	0
Mississippi	18,595	18,587	8	0
Oklahoma	7,665	6,234	45	1,387
Tennessee	13,603	13,265	337	0
Texas	18,354	11,766	133	6,455
Subtotal	125,438	116,196	1,202	8,040
		Northeast		
Connecticut	1,863	1,815	23	25
Delaware	389	376	3	10
Maine	17,710	16,952	346	412
Maryland	2,701	2,423	153	124
Massachusetts	3,264	2,965	149	150
New Hampshire	4,955	4,551	117	287
New Jersey	1,991	1,864	105	21
New York	18,581	15,406	2,953	222
Pennsylvania	16,905	15,853	833	219
Rhode Island	409	356	8	45
Vermont	4,607	4,461	91	55
West Virginia	12,108	11,900	181	27
Subtotal	85,484	78,923	4,963	1,598
		North Central		
Illinois	4,294	4,058	236	0
Indiana	4,501	4,342	159	0
Iowa	2,050	1,944	88	19
Michigan	19,335	18,667	577	90
Minnesota	16,796	14,819	1,136	842
Missouri	14,047	13,411	325	311
Ohio	7,855	7,568	140	147
Wisconsin	15,963	15,701	201	61
Subtotal	84,842	80,510	2,862	1,470

Continued

Table 21.—Continued

State	Forest-land class: All forest land	Unreserved timberland	Reserved timberland	Other forest land
	Great Plains			
Kansas	1,545	1,491	18	37
Nebraska	947	898	32	18
North Dakota	674	442	0	232
South Dakota	1,632	1,487	22	123
Subtotal	4,798	4,317	71	409
	Intermountain			
Arizona	19,926	4,073	1,771	14,082
Colorado	21,270	11,555	2,407	7,307
Idaho	21,937	17,123	3,529	1,285
Montana	23,232	19,164	3,620	448
Nevada	9,928	169	688	9,071
New Mexico	15,505	4,833	1,420	9,252
Utah	15,705	4,700	770	10,235
Wyoming	10,945	5,085	3,903	1,957
Subtotal	138,448	66,702	18,108	53,637
	Pacific Coast			
Alaska	127,380	12,395	9,836	105,148
California	38,546	17,952	5,968	14,626
Hawaii	1,749	700	196	853
Oregon	29,720	23,749	2,482	3,489
Washington	21,893	17,418	3,495	980
Subtotal	219,288	72,214	21,977	125,096
Total	746,959	503,666	51,883	191,410

Table 22.—Average storage of carbon in the United States by region, state, and forest-ecosystem component, 1987, in pounds per acre

State	Total	Trees	Soil	Forest floor	Understory
			Forest-ecosystem component		
			Southeast		
Florida	106,874	30,972	64,451	10,820	632
Georgia	120,349	45,098	63,477	10,853	920
North Carolina	141,438	62,489	67,548	10,126	1,275
South Carolina	126,612	50,125	64,317	11,147	1,023
Virginia	141,915	63,350	67,904	9,369	1,293
Average	127,438	50,407	65,539	10,463	1,029
			South Central		
Alabama	115,947	41,730	59,940	13,425	852
Arkansas	123,931	49,504	62,650	10,767	1,010
Kentucky	152,083	65,151	75,262	10,340	1,330
Louisiana	128,032	54,090	60,679	12,159	1,104
Mississippi	123,410	49,581	61,611	11,208	1,012
Oklahoma	93,999	16,628	63,160	13,872	339
Tennessee	130,861	56,036	63,598	10,084	1,144
Texas	110,811	34,229	63,362	12,521	699
Average	122,384	45,869	63,783	11,797	936
			Northeast		
Connecticut	185,460	58,306	108,897	17,066	1,190
Delaware	169,145	64,567	88,284	14,977	1,318
Maine	203,133	38,927	140,154	23,257	794
Maryland	184,613	72,274	95,064	15,800	1,475
Massachusetts	191,418	55,285	116,662	18,343	1,128
New Hampshire	210,188	55,056	132,580	21,428	1,124
New Jersey	142,628	38,281	89,650	13,916	781
New York	195,511	45,400	130,526	18,659	927
Pennsylvania	198,533	59,544	118,584	19,190	1,215
Rhode Island	161,262	45,534	99,309	15,490	929
Vermont	209,309	48,329	139,268	20,725	986
West Virginia	180,375	53,849	107,408	18,020	1,099
Average	185,964	52,946	113,865	18,072	1,081
			North Central		
Illinois	186,965	58,275	109,133	18,368	1,189
Indiana	187,337	58,260	110,783	17,106	1,189
Iowa	168,789	42,130	108,272	17,527	860
Michigan	180,858	45,321	115,249	19,363	925
Minnesota	171,597	35,017	116,251	19,615	715
Missouri	154,557	32,860	103,327	17,699	671
Ohio	174,170	47,422	107,718	18,062	968
Wisconsin	176,630	42,625	114,324	18,811	870
Average	175,113	45,239	110,632	18,319	923

Continued

Table 22.—Continued

State	Forest-ecosystem component				
	Total	Trees	Soil	Forest floor	Understory
			Great Plains		
Kansas	126,289	33,018	79,292	13,304	674
Nebraska	126,727	38,156	74,206	13,588	779
North Dakota	134,619	28,452	90,116	15,470	581
South Dakota	153,285	42,650	79,298	30,466	870
Average	135,230	35,569	80,728	18,207	726
			Intermountain		
Arizona	137,699	38,111	68,084	30,726	778
Colorado	153,172	38,546	70,973	42,867	787
Idaho	174,305	56,899	79,680	36,565	1,161
Montana	166,680	53,546	79,034	33,008	1,093
Nevada	160,131	35,867	67,700	55,832	732
New Mexico	128,318	28,245	67,964	31,533	576
Utah	152,688	32,885	70,591	48,541	671
Wyoming	154,252	39,950	78,464	35,022	815
Average	153,406	40,506	72,811	39,262	827
			Pacific Coast		
Alaska	173,287	35,776	87,000	49,781	730
California	179,328	52,858	87,000	38,392	1,079
Hawaii	113,815	5,681	86,985	21,032	116
Oregon	197,560	69,522	87,112	39,507	1,419
Washington	207,610	82,532	87,234	36,160	1,684
Average	174,320	49,274	87,066	36,974	1,006
U.S. average	153,408	45,687	84,918	21,871	932

Table 23.—Average storage of carbon in the United States by region, state, and forest-ecosystem component, 1997, in pounds per acre

State	Forest-ecosystem component				
	Total	Trees	Soil	Forest floor	Understory
			Southeast		
Florida	111,748	33,428	65,533	12,105	682
Georgia	124,780	47,255	64,214	12,346	964
North Carolina	144,691	64,529	68,476	10,369	1,317
South Carolina	122,591	46,992	62,500	12,140	959
Virginia	148,533	67,823	69,770	9,557	1,384
Average	130,469	52,005	66,099	11,303	1,061
			South Central		
Alabama	120,959	45,118	61,172	13,748	921
Arkansas	125,717	51,389	61,850	11,429	1,049
Kentucky	151,825	68,879	72,102	9,438	1,406
Louisiana	133,301	55,945	64,086	12,127	1,142
Mississippi	124,378	47,846	61,820	13,736	976
Oklahoma	98,408	24,922	60,814	12,163	509
Tennessee	137,879	63,976	62,993	9,604	1,306
Texas	114,297	36,153	64,957	12,449	738
Average	125,845	49,279	63,724	11,837	1,006
			Northeast		
Connecticut	187,546	58,718	109,550	18,080	1,198
Delaware	168,581	71,425	80,544	15,153	1,458
Maine	199,397	38,352	138,019	22,244	783
Maryland	186,838	74,237	94,785	16,301	1,515
Massachusetts	193,187	58,213	115,102	18,683	1,188
New Hampshire	224,535	66,952	134,969	21,248	1,366
New Jersey	157,734	50,424	91,053	15,228	1,029
New York	202,824	50,077	133,043	18,682	1,022
Pennsylvania	201,290	60,363	120,761	18,934	1,232
Rhode Island	159,437	44,804	97,298	16,421	914
Vermont	227,104	67,267	137,458	21,006	1,373
West Virginia	194,114	68,568	106,442	17,705	1,399
Average	191,882	59,117	113,252	18,307	1,206
			North Central		
Illinois	186,564	57,892	109,082	18,409	1,181
Indiana	203,714	76,014	109,030	17,119	1,551
Iowa	143,618	42,575	82,207	17,967	869
Michigan	185,832	54,745	110,533	19,437	1,117
Minnesota	171,600	36,439	114,935	19,482	744
Missouri	146,439	33,320	94,908	17,531	680
Ohio	181,639	59,575	102,391	18,458	1,216
Wisconsin	175,875	46,185	110,992	17,755	943
Average	174,410	50,843	104,260	18,270	1,038

Continued

Table 23.—Continued

State	Forest-ecosystem component				
	Total	Trees	Soil	Forest floor	Understory
			Great Plains		
Kansas	142,937	39,757	88,631	13,737	811
Nebraska	127,053	42,401	69,933	13,854	865
North Dakota	131,224	29,829	82,581	18,205	609
South Dakota	150,160	36,891	82,817	29,699	753
Average	137,844	37,220	80,990	18,874	760
			Intermountain		
Arizona	137,274	37,354	68,966	30,192	762
Colorado	153,791	39,752	71,247	41,982	811
Idaho	175,622	60,089	78,724	35,582	1,226
Montana	164,911	52,614	75,515	35,708	1,074
Nevada	155,243	36,107	62,327	56,072	737
New Mexico	127,899	26,467	69,472	31,420	540
Utah	154,896	34,330	72,203	47,662	701
Wyoming	148,134	40,090	73,105	34,121	818
Average	152,221	40,850	71,445	39,092	834
			Pacific Coast		
Alaska	173,978	36,006	87,850	49,388	735
California	184,771	56,840	88,403	38,367	1,160
Hawaii	113,809	5,680	86,964	21,050	116
Oregon	196,230	71,964	84,976	37,822	1,469
Washington	208,688	81,430	88,916	36,681	1,662
Average	175,495	50,384	87,422	36,661	1,028
U.S. average	155,452	48,528	83,885	22,049	990

Table 24.—Total storage of carbon in the United States by region, state, and forest-ecosystem component, 1987, in thousands of metric tons

State	Forest-ecosystem component					
	Total	Trees	Soil	Forest floor	Understory	Products
			Southeast			
Florida	881,457	234,901	488,820	82,063	4,794	70,880
Georgia	1,514,509	494,782	696,418	119,070	10,098	194,143
North Carolina	1,363,318	546,512	590,762	88,562	11,153	126,329
South Carolina	790,006	278,680	357,583	61,977	5,687	86,079
Virginia	1,123,620	462,869	496,141	68,454	9,446	86,710
Subtotal	5,672,911	2,017,744	2,629,724	420,125	41,178	564,140
			South Central			
Alabama	1,309,064	411,225	590,665	132,296	8,392	166,485
Arkansas	1,089,981	381,443	482,741	82,963	7,785	135,049
Kentucky	873,848	362,204	418,416	57,483	7,392	28,353
Louisiana	916,608	340,611	382,106	76,566	6,951	110,375
Mississippi	1,088,740	375,438	466,532	84,867	7,662	154,241
Oklahoma	327,266	54,932	208,651	45,827	1,121	16,735
Tennessee	859,862	336,987	382,467	60,641	6,877	72,890
Texas	1,109,773	318,363	589,331	116,462	6,497	79,120
Subtotal	7,575,142	2,581,203	3,520,910	657,104	52,678	763,248
			Northeast			
Connecticut	158,877	48,002	89,653	14,050	980	6,192
Delaware	32,657	11,647	15,926	2,702	238	2,144
Maine	1,700,979	312,757	1,126,052	186,859	6,383	68,929
Maryland	246,916	86,284	113,491	18,863	1,761	26,518
Massachusetts	271,579	77,653	163,863	25,764	1,585	2,713
New Hampshire	491,268	125,386	301,941	48,800	2,559	12,581
New Jersey	134,827	34,466	80,714	12,529	703	6,415
New York	1,702,154	386,652	1,111,637	158,909	7,891	37,066
Pennsylvania	1,567,850	459,073	914,255	147,948	9,369	37,205
Rhode Island	30,407	8,234	17,957	2,801	168	1,247
Vermont	440,539	98,848	284,846	42,389	2,017	12,439
West Virginia	999,358	291,680	581,795	97,606	5,953	22,324
Subtotal	7,777,410	1,940,681	4,802,131	759,219	39,606	235,773
			North Central			
Illinois	382,816	112,765	211,177	35,543	2,301	21,031
Indiana	392,802	117,304	223,059	34,442	2,394	15,603
Iowa	141,353	29,850	76,712	12,418	609	21,763
Michigan	1,546,249	374,572	952,530	160,035	7,644	51,468
Minnesota	1,322,776	263,397	874,437	147,545	5,375	32,021
Missouri	916,081	186,655	586,932	100,538	3,809	38,147
Ohio	598,370	157,230	357,147	59,885	3,209	20,900
Wisconsin	1,278,826	296,189	794,400	130,710	6,045	51,482
Subtotal	6,579,273	1,537,962	4,076,394	681,116	31,387	252,414

Continued

Table 24.—Continued

State	Forest-ecosystem component					
	Total	Trees	Soil	Forest floor	Understory	Products
			Great Plains			
Kansas	96,264	20,337	48,839	8,195	415	18,478
Nebraska	50,073	12,490	24,291	4,448	255	8,590
North Dakota	32,291	5,937	18,803	3,228	121	4,202
South Dakota	122,997	32,682	60,765	23,346	667	5,536
Subtotal	301,626	71,446	152,699	39,217	1,458	36,806
			Intermountain			
Arizona	1,267,238	335,096	598,629	270,159	6,839	56,515
Colorado	1,490,435	373,073	686,928	414,902	7,614	7,918
Idaho	1,820,791	563,120	788,574	361,875	11,492	95,729
Montana	1,751,765	532,139	785,443	328,035	10,860	95,288
Nevada	648,534	145,245	274,150	226,091	2,964	84
New Mexico	950,454	202,761	487,888	226,363	4,138	29,304
Utah	1,130,492	242,148	519,792	357,432	4,942	6,178
Wyoming	781,152	180,600	354,706	158,322	3,686	83,837
Subtotal	9,840,859	2,574,182	4,496,110	2,343,180	52,534	374,853
			Pacific Coast			
Alaska	10,158,232	2,094,119	5,092,489	2,913,879	42,737	15,007
California	3,375,477	944,209	1,554,093	685,808	19,270	172,098
Hawaii	90,271	4,506	68,992	16,682	92	
Oregon	2,873,802	907,354	1,136,927	515,621	18,517	295,382
Washington	2,330,685	843,107	891,137	369,387	17,206	209,847
Subtotal	18,828,468	4,793,295	8,743,638	4,501,378	97,822	692,334
Total	56,575,690	15,516,515	28,421,605	9,401,338	316,664	2,919,569

Table 25.—Total storage of carbon in the United States by region, state, and forest-ecosystem component, 1997, in thousands of metric tons

State	Forest-ecosystem component					
	Total	Trees	Soil	Forest floor	Understory	Products
			Southeast			
Florida	916,173	246,454	483,162	89,249	5,030	92,279
Georgia	1,624,103	523,277	711,078	136,714	10,679	242,355
North Carolina	1,427,267	564,845	599,389	90,760	11,527	160,746
South Carolina	813,720	269,670	358,663	69,665	5,503	110,219
Virginia	1,187,812	493,659	507,832	69,560	10,075	106,686
Subtotal	5,969,074	2,097,905	2,660,123	455,948	42,814	712,284
			South Central			
Alabama	1,426,321	449,496	609,438	136,968	9,173	221,246
Arkansas	1,234,842	437,992	527,145	97,414	8,939	163,353
Kentucky	909,113	396,299	414,845	54,305	8,088	35,576
Louisiana	972,417	349,766	400,661	75,820	7,138	139,032
Mississippi	1,246,852	403,568	521,441	115,862	8,236	197,745
Oklahoma	364,492	86,652	211,444	42,290	1,768	22,336
Tennessee	940,338	394,739	388,670	59,256	8,056	89,618
Texas	1,053,030	300,990	540,791	103,642	6,143	101,464
Subtotal	8,147,405	2,819,503	3,614,434	685,555	57,541	970,371
			Northeast			
Connecticut	165,157	49,611	92,560	15,276	1,012	6,698
Delaware	32,052	12,618	14,229	2,677	258	2,270
Maine	1,685,808	308,092	1,108,755	178,690	6,288	83,983
Maryland	257,266	90,939	116,110	19,968	1,856	28,393
Massachusetts	290,414	86,193	170,425	27,663	1,759	4,373
New Hampshire	521,669	150,482	303,359	47,758	3,071	17,000
New Jersey	149,970	45,542	82,237	13,753	929	7,508
New York	1,754,185	422,062	1,121,331	157,458	8,614	44,721
Pennsylvania	1,588,828	462,858	925,983	145,183	9,446	45,357
Rhode Island	30,938	8,316	18,059	3,048	170	1,345
Vermont	490,012	140,575	287,259	43,899	2,869	15,410
West Virginia	1,091,609	376,586	584,592	97,237	7,685	25,508
Subtotal	8,057,907	2,153,874	4,824,900	752,610	43,957	282,566
			North Central			
Illinois	387,708	112,770	212,484	35,859	2,301	24,294
Indiana	435,537	155,207	222,621	34,955	3,167	19,587
Iowa	155,754	39,593	76,450	16,709	808	22,195
Michigan	1,695,653	480,124	969,388	170,464	9,798	65,879
Minnesota	1,350,092	277,618	875,656	148,426	5,666	42,725
Missouri	976,576	212,297	604,712	111,702	4,333	43,533
Ohio	672,114	212,269	364,827	65,768	4,332	24,918
Wisconsin	1,339,790	334,411	803,670	128,563	6,825	66,321
Subtotal	7,013,224	1,824,290	4,129,808	712,445	37,230	309,451

Continued

Table 25.—Continued

State	Forest-ecosystem component					
	Total	Trees	Soil	Forest floor	Understory	Products
			Great Plains			
Kansas	119,463	27,864	62,117	9,627	569	19,286
Nebraska	63,986	18,222	30,054	5,954	372	9,384
North Dakota	44,218	9,114	25,231	5,562	186	4,124
South Dakota	117,763	27,305	61,298	21,983	557	6,620
Subtotal	345,429	82,505	178,700	43,126	1,684	39,414
			Intermountain			
Arizona	1,303,092	337,613	623,332	272,886	6,890	62,370
Colorado	1,494,658	383,527	687,394	405,042	7,827	10,868
Idaho	1,858,184	597,918	783,352	354,065	12,202	110,647
Montana	1,869,287	554,445	795,772	376,290	11,315	131,466
Nevada	699,284	162,603	280,677	252,510	3,318	175
New Mexico	926,744	186,141	488,598	220,976	3,799	27,230
Utah	1,110,523	244,553	514,343	339,524	4,991	7,112
Wyoming	811,091	199,030	362,938	169,398	4,062	75,663
Subtotal	10,072,863	2,665,830	4,536,406	2,390,692	54,405	425,531
			Pacific Coast			
Alaska	10,073,220	2,080,362	5,075,902	2,853,571	42,456	20,928
California	3,436,367	993,819	1,545,685	670,831	20,282	205,751
Hawaii	90,289	4,506	68,992	16,700	92	—
Oregon	2,962,380	970,136	1,145,547	509,871	19,799	317,026
Washington	2,309,458	808,649	882,986	364,261	16,503	237,059
Subtotal	18,871,715	4,857,473	8,719,112	4,415,234	99,132	780,764
Total	58,477,619	16,501,381	28,663,483	9,455,609	336,763	3,520,382

Appendix 5: Sample Tables for Pennsylvania

A set of tables in this format is available for each state at: http://www.fs.fed.us/ne/global.

Table 1.—Area in Pennsylvania by land class, in thousands of acres

				Average annual change		
Land class	1987	1992	1997	1987-92	1992-97	1987-97
Timberland	15,918	15,885	15,853	-7	-7	-7
Other forest land	371	295	219	-15	-15	-15
Reserved timberland	708	771	833	12	12	12
Total	16,997	16,951	16,905	-9	-9	-9

Table 2.—Area of forest land in Pennsylvania by forest type, in thousands of acres

				Average annual change		
Forest type	1987	1992	1997	1987-92	1992-97	1987-97
White-red-jack-pine	887	851	814	-7	-7	-7
Spruce-fir	56	66	75	2	2	2
Longleaf-slash pine (planted)	0	0	0	0	0	0
Longleaf-slash pine (natural)	0	0	0	0	0	0
Loblolly-shortleaf pine (planted)	0	0	0	0	0	0
Loblolly-shortleaf pine (natural)	147	145	143	0	0	0
Oak-pine	288	324	359	7	7	7
Oak-hickory	8,457	8,237	8,016	-44	-44	-44
Oak-gum-cypress	0	12	24	2	2	2
Elm-ash-cottonwood	569	485	400	-17	-17	-17
Maple-beech-birch	5,995	6,319	6,644	65	65	65
Aspen-birch	441	414	387	-5	-5	-5
Other forest types	0	0	0	0	0	0
Nonstocked	155	99	43	-11	-11	-11
Total	16,997	16,951	16,905	-9	-9	-9

Table 3.—Total carbon stock on forest land and in harvested wood products in Pennsylvania, and annual change by forest type, in Mt

Forest type	1987	1992	1997	Average annual change 1987-92	1992-97	1987-97
White-red-jack-pine	88.7	87.7	86.6	-0.20	-0.23	-0.21
Spruce-fir	5.3	5.9	6.3	0.11	0.10	0.10
Longleaf-slash pine (planted)	0.0	0.0	0.0	0.00	0.00	0.00
Longleaf-slash pine (natural)	0.0	0.0	0.0	0.00	0.00	0.00
Loblolly-shortleaf pine (planted)	0.0	0.0	0.0	0.00	0.00	0.00
Loblolly-shortleaf pine (natural)	7.6	8.1	8.4	0.09	0.08	0.08
Oak-pine	19.9	21.3	22.8	0.29	0.30	0.29
Oak-hickory	724.4	703.7	682.2	-4.14	-4.29	-4.21
Oak-gum-cypress	0.0	0.6	1.1	0.11	0.11	0.11
Elm-ash-cottonwood	31.5	26.7	21.9	-0.97	-0.95	-0.96
Maple-beech-birch	641.1	680.4	718.9	7.86	7.70	7.78
Aspen-birch	32.3	31.3	30.2	-0.21	-0.21	-0.21
Other forest types	6.6	7.2	7.7	0.13	0.11	0.12
Nonstocked	10.4	6.4	2.5	-0.80	-0.78	-0.79
Total	1,567.8	1,579.2	1,588.8	2.27	1.93	2.10

Table 4.—Total carbon stock on forest land and in harvested wood products in Pennsylvania, and annual change by accounting component, in Mt

Component	1987	1992	1997	Average annual change 1987-92	1992-97	1987-97
Biomass	468.4	470.3	472.3	0.37	0.40	0.39
Forest floor/coarse woody debris	147.9	146.6	145.2	-0.27	-0.29	-0.28
Soils	914.3	920.1	926.0	1.17	1.17	1.17
Wood products and landfills	37.2	42.2	45.4	0.99	0.64	0.82
Total	1,567.8	1,579.2	1,588.8	2.27	1.93	2.10

Table 5.—Total carbon stock on forest land and in harvested wood products in Pennsylvania, and annual change by owner, in Mt

Owner group	1987	1992	1997	Average annual change 1987-92	1992-97	1987-97
National forest	58.0	55.8	53.5	-0.44	-0.45	-0.45
Other public	358.7	359.2	359.2	0.10	0.01	0.05
Forest industry	82.3	76.9	71.4	-1.07	-1.10	-1.09
Other private	1,068.9	1,087.3	1,104.7	3.68	3.48	3.58
Total	1,567.8	1,579.2	1,588.8	2.27	1.93	2.10

Table 6.— Change in total carbon stock on forest land and in harvested wood products in Pennsylvania, attributed to land-use change, in Mt

				Average annual change		
Component	1987	1992	1997	1987-92	1992-97	1987-97
Biomass	0.0	-2.7	-5.1	-0.55	-0.47	-0.51
Forest floor/coarse woody debris	0.0	-1.0	-1.9	-0.19	-0.19	-0.19
Soils	0.0	-3.0	-5.5	-0.59	-0.50	-0.55
Wood products and landfills	0.0	0.3	0.7	0.06	0.07	0.07
Total	0.0	-6.3	-11.8	-1.27	-1.09	-1.18

Birdsey, R.A.; Lewis, G.M. 2003. **Carbon in U.S. forests and wood products, 1987-1997: state-by-state estimates.** Gen. Tech. Rep. NE-310. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 42 p.

Estimated changes in carbon stocks are reported for the forests and wood products of the 50 U.S. States. Carbon stocks on forest land and in harvested wood products increased between 1987 and 1997 at an annual rate of 190 million metric tons. Most of this increase was in biomass, followed closely by wood products and landfills. Changes in land use since 1987 caused a small decrease in carbon stocks, but this loss was offset by large gains on existing forest land. The East had the greatest gain in carbon stocks with smaller gains estimated for the West. Most of the individual states showed increases in ecosystem and wood-products carbon. Observed changes were attributed to distinct regional and local factors, e.g., timber production, land-use change, and natural disturbance.

Keywords: global change, forest carbon, forest inventory

Headquarters of the Northeastern Research Station is in Newtown Square, Pennsylvania. Field laboratories are maintained at:

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