Chapter 4: Carbon Stocks & Stock Changes in U.S. Forests

4.1 Summary

Forest ecosystems and forest products represent significant carbon sinks in the United States, approximately equal to 10% of total U.S. greenhouse gas (GHG) emissions (EPA 2007). The net amount of carbon stored—that is, annual incremental increase—by forests in the conterminous U.S. increased by an estimated 595 and 103 Tg CO_2 eq. in 2005 for forest ecosystems and harvested wood products, respectively. Total Sequestration in 2005 was estimated to be 699 Tg CO_2 eq. and the calculated 95% confidence interval for this flux was -890 to -513 Tg CO_2 eq. (Table 4-1). Compared to 1990, CO_2 sequestered by forest systems was about 17% greater in 2005 (Table 4-2). Current total carbon stocks in forest ecosystems of the conterminous United States are estimated at about 150 Pg CO_2 eq. (Table 4-2, Pg=1,000 Tg).

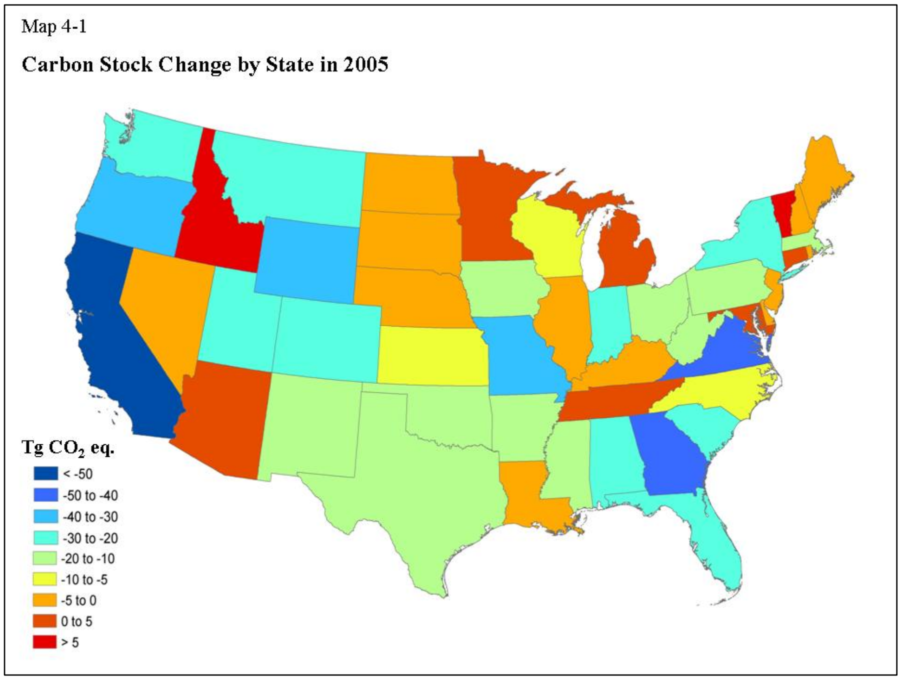
Periodic summary statistics on forestland in the conterminous United States indicate an approximately 2% increase in area over the interval from 1987 to 2002, that is, 246 to 251 million hectares (Smith et al. 2004a). In addition to the net accumulation of carbon in harvested wood pools, sequestration is a reflection of net forest growth and increasing forest area over this period. Generally, the largest stocks and net annual changes are in biomass carbon.

Table 4-1 Forest Carbon Stock Change Estimates and Uncertainty Intervals for 2005

	Estimate	95% Confidence Interval
Source	*Tg CO_2 eq.*	
Forest	(595)	(785) to (410)
Harvested Wood	(103)	(130) to (79)
Total	**(699)**	**(890) to (513)**

Note: Parentheses indicate net sequestration.

Carbon sequestration rates for forests and harvested wood products are greatest in California, followed by Virginia, Georgia, Oregon, Missouri, Wyoming, Montana, and Indiana (Map 4-1). Only eight States are losing forest carbon. Forest biomass, and thus carbon stocks, is greatest in The Pacific States, lowest in the Great Plains, and intermediate in the Rocky Mountain and Eastern States (Map 4-2). Eastern forests are storing slightly more carbon than Western forests (341 vs. 320 Tg CO_2 eq. yr^{-1}) but Western forests are sequestering carbon at a rate about 50% greater than Eastern forests on a per-hectare basis (3300 kg CO_2 Eq. ha^{-1} yr^{-1} vs. 2200 kg CO_2 Eq. ha^{-1} yr^{-1} in Eastern US forests, Table 4-3). Sequestration was greatest in the East in Oak/Hickory forests (246 Tg CO_2 Eq. per year). Of the Western forest types, California mixed conifers sequestered the most at 220 Tg CO_2 Eq. per year (Table 4-3).



Forestlands of the United States constitute 33% (303 million hectares) of total land area. This chapter summarizes carbon stocks and stock changes on the approximately 251 million hectares located in the conterminous 48 States. This is largely because these forestlands are well-defined by inventory data – a fundamental component of these estimates and a large proportion of these forests are managed for timber production. The relative proportion subject to management is based on the 80% of the 251 million hectares that are classified as timberland, meaning they meet minimum levels of productivity and are available for timber harvest. Separate effects of management or land use change, such as afforestation, increased productivity, reduced conversion to non-forest uses, lengthened rotations, and increased proportion and retention of carbon in harvested wood products, are not individually identified, but the effects are implicitly a part of the inventory and are thus reflected in carbon stocks and stock changes. Summaries of information included in this chapter represent updates of inventories and carbon estimations relative to the national forest carbon budgets reported in the first edition of the USDA Greenhouse Gas Inventory (Smith et al. 2004b).

Map 4-2

U.S. Forest Carbon Stocks in 2005

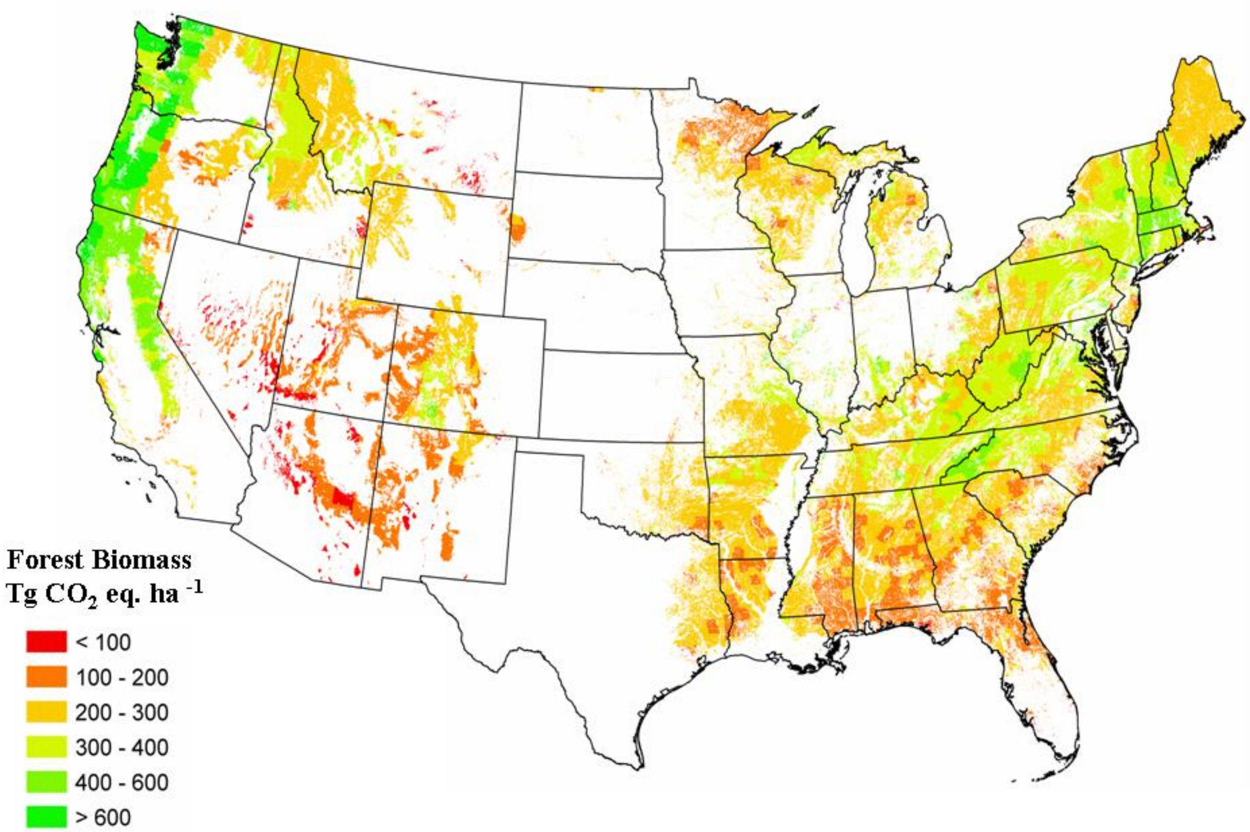


Table 4-2 Carbon Stocks and Annual Change for Forest and Wood Pools, 1990, 1998-2005[1]

	1990	1998	1999	2000	2001	2002	2003	2004	2005
Annual Change					*Tg CO_2 eq. yr^{-1}*				
Forest	**(467)**	**(584)**	**(552)**	**(529)**	**(556)**	**(595)**	**(595)**	**(595)**	**(595)**
Aboveground Biomass	(252)	(336)	(341)	(347)	(360)	(376)	(376)	(376)	(376)
Belowground Biomass	(64)	(71)	(73)	(74)	(76)	(80)	(80)	(80)	(80)
Dead Wood	(37)	(63)	(54)	(48)	(50)	(52)	(52)	(52)	(52)
Litter	(66)	(39)	(42)	(36)	(47)	(52)	(52)	(52)	(52)
Soil Organic Carbon[2]	(49)	(74)	(43)	(24)	(22)	(35)	(35)	(35)	(35)
Harvested Wood	**(132)**	**(111)**	**(116)**	**(109)**	**(90)**	**(93)**	**(91)**	**(102)**	**(103)**
Wood Products	(63)	(48)	(51)	(46)	(31)	(34)	(33)	(43)	(44)
Landfilled Wood	(69)	(63)	(65)	(63)	(59)	(59)	(58)	(59)	(59)
Total	**(599)**	**(695)**	**(668)**	**(639)**	**(646)**	**(688)**	**(687)**	**(697)**	**(699)**
Carbon Stock					*Tg CO_2 eq.*				
Forest	**143,095**	**147,644**	**148,228**	**148,780**	**149,309**	**149,865**	**150,460**	**151,055**	**151,651**
Aboveground Biomass	51,934	54,436	54,772	55,113	55,460	55,820	56,196	56,573	56,949
Belowground Biomass	10,243	10,792	10,864	10,936	11,010	11,086	11,166	11,245	11,325
Dead Wood	8,631	9,047	9,110	9,164	9,212	9,262	9,314	9,367	9,419
Litter	16,150	16,636	16,676	16,717	16,753	16,800	16,852	16,904	16,957
Soil Organic Carbon	56,138	56,733	56,807	56,850	56,875	56,896	56,931	56,966	57,001
Harvested Wood	**6,919**	**7,935**	**8,045**	**8,158**	**8,268**	**8,386**	**8,496**	**8,584**	**8,679**
Wood Products	4,341	4,814	4,866	4,917	4,965	5,016	5,064	5,093	5,130
Landfilled Wood	2,581	3,120	3,179	3,241	3,304	3,370	3,432	3,491	3,549
Total	**150,014**	**155,579**	**156,273**	**156,938**	**157,578**	**158,250**	**158,956**	**159,639**	**160,330**

Note: Parentheses indicate net sequestration

[1]Based on interpolation and extrapolation after aggregating plot-level data to state totals.

[2]Soil carbon does not include effects of past land use history.

Estimates of stocks and net annual stock change for carbon on forestlands and in harvested wood products for the conterminous United States presented here correspond to values reported for forestlands in Chapter 7 of the U.S. GHG Inventory (EPA 2007), and are consistent with reporting recommendations of the Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance for Land Use, Land-Use Change, and Forestry (IPCC 2003). Thus, the forest carbon estimates reported here expand on the information provided in the U.S. GHG Inventory (EPA 2007). The summary tables provided in this chapter and in appendix C provide additional detail by summarizing data according to forest types, ownerships, or other classifications.

Table 4-3 Forest Area, Carbon Stocks, and Net Annual Stock Change by Forest Type Group[1]

	Forest Area	Carbon Stocks: Biomass	Carbon Stocks: Dead Plant Matter	Carbon Stocks: SOC[2]	Net Annual Stock Change: Biomass	Net Annual Stock Change: Dead Plant Matter	Net Annual Stock Change: Per Hectare
Forest Type	*1000 ha*	*Tg CO_2 eq.*			*Tg CO_2 eq. Yr^{-1}*		*kg CO_2/ha*
East	**155,426**	**41,248**	**11,689**	**41,596**	**(308)**	**(34)**	**(2,196)**
Aspen/Birch	7,082	1,325	434	3,413	16.0	5.3	3,005
Elm/Ash/Cottonwood	7,630	1,951	719	2,767	(20.2)	(3.3)	(3,071)
Loblolly/Shortleaf Pine	21,955	4,391	1,199	4,449	(53.5)	(10.4)	(2,914)
Longleaf/Slash Pine	5,383	827	269	1,909	(9.8)	(1.0)	(2,005)
Maple/Beech/Birch	22,416	7,229	3,099	6,909	(50.5)	(10.7)	(2,730)
Oak/Gum/Cypress	9,644	3,066	559	3,536	22.8	4.3	2,809
Oak/Hickory	54,388	16,357	3,078	9,529	(214.7)	(31.7)	(4,530)
Oak/Pine	13,114	3,025	883	2,563	7.4	3.3	815
Spruce/Fir	6,098	1,252	929	4,039	11.6	13.1	4,058
White/Red/Jack Pine	4,220	1,404	354	1,444	(5.1)	1.6	(818)
Other East Type Groups	3,497	422	165	1,038	(11.6)	(4.3)	(4,535)
West	**96,132**	**25,775**	**14,433**	**15,101**	**(242)**	**(78)**	**(3,330)**
Alder/Maple	1,390	510	151	573	n/a	n/a	n/a
Aspen/Birch	3,175	743	460	670	n/a	n/a	n/a
California Mixed Conifer	3,763	1,946	915	687	(153.0)	(66.5)	(58,338)
Douglas-fir	15,584	7,033	3,237	3,721	(54.0)	2.5	(3,304)
Fir/Spruce/Mt. Hemlock	12,345	4,931	2,886	2,020	9.8	4.4	1,153
Hemlock/Sitka Spruce	2,207	1,520	617	844	(2.4)	1.5	(375)
Lodgepole Pine	6,306	1,511	826	838	14.0	6.7	3,280
Other Western Hardwoods	1,908	270	222	241	n/a	n/a	n/a
Other Western Softwoods	1,515	352	254	194	(4.3)	(2.6)	(4,547)
Pinyon/Juniper	22,123	2,145	1,791	1,748	(24.1)	(30.3)	(2,459)
Ponderosa Pine	8,939	1,930	1,073	1,191	(20.8)	9.4	(1,279)
Redwood	261	231	98	51	(3.3)	0.2	(11,683)
Tanoak/Laurel	1,101	585	168	219	n/a	n/a	n/a
Western Larch	749	210	142	105	(7.4)	(4.4)	(15,742)
Western Oak	7,084	1,494	860	891	n/a	n/a	n/a
Western White Pine	151	42	26	25	3.5	0.8	28,724
Other West Type Groups	7,532	323	707	1,083	n/a	n/a	n/a
Total	**251,558**	**67,023**	**26,122**	**56,697**	**(549)**	**(112)**	**(2,629)**

[1]As determined from the two most recent inventories for all forests. Stock change does not include soil carbon changes.

[2](SOC) Soil organic carbon, does not include effects of past land use history.

Note: Parentheses indicate net sequestration.

(n/a) Indicates not available.

4.2 Concepts and Conventions

For reporting purposes, carbon estimates in forest ecosystems are allocated to the following pools (IPCC 2003):

- Aboveground biomass, which includes all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. This category includes not only live trees, but live understory.
- Belowground biomass, which includes all living biomass of coarse living roots greater than 2 mm diameter.
- Dead wood, which includes all non-living woody biomass either standing, lying on the ground (but not including litter), or in the soil.
- Litter, which includes the litter, fumic, and humic layers, and all non-living biomass with a diameter less than 7.5 cm at transect intersection, lying on the ground.
- Soil organic carbon (SOC), all organic material, including fine roots, in soil to a depth of 1 meter but excluding the coarse roots of the belowground pools.

The two harvested wood products carbon pools are:

- Harvested wood products in use.
- Harvested wood products in solid waste disposal sites (SWDS).

The sign convention is to assign negative net change (or flux) to carbon accumulation within forests or harvested wood pools, which we have represented here by placing numbers representing sequestration in parentheses.

Continuous, regular annual surveys are not available over the time period of interest for each State; therefore, estimates for non-survey years were derived by interpolation between known data points. Survey years vary by State and the list of survey years and data can be found in Table 2 in Smith et al. (2007). Thus, the national estimates in Table 4-2 are a composite of individual State surveys, broken out in more detail in Appendix Table C-1. The same process applies to forest area for each year – annual data are not available and annualized average information between inventory years is presented here.

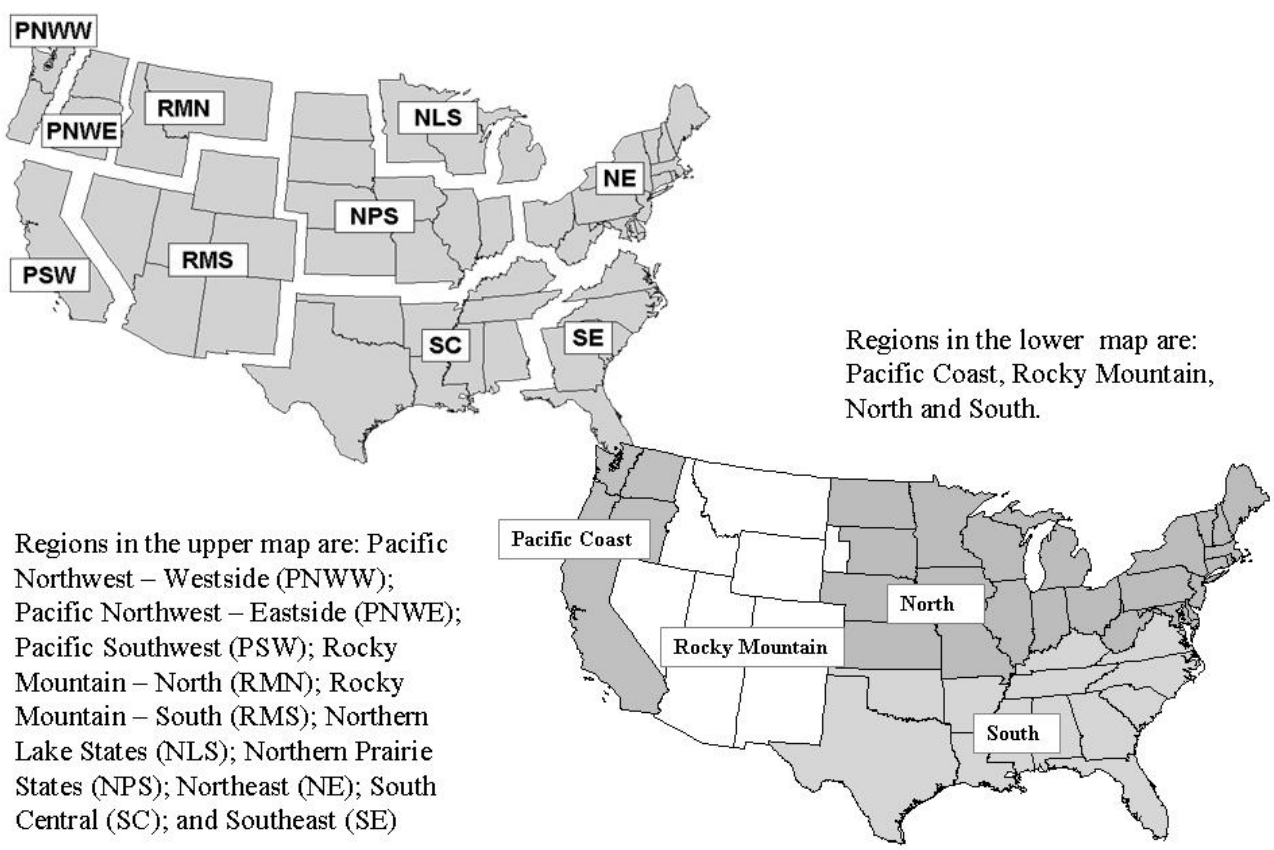
4.3 Carbon Stocks and Stock Changes by Forest Type, Region, and Ownership

Total forest ecosystem areas, carbon stocks, and net annual stock change according to forest type group are listed in Table 4-3. Minor type groups in the East and West are pooled, for example, tropical and exotic hardwood groups in both regions. Carbon classifications in this table are for biomass, nonliving plant mass, and soil organic carbon. Biomass includes live trees plus live understory vegetation. Non-living plant mass includes standing dead trees, down dead wood, and the forest floor. Carbon estimates include aboveground and belowground components.

Estimates of stock change according to forest type group were developed by subdividing the State or sub-State classifications according to forest type group (USDA FS 2006) before calculating annualized stock or stock change. Note that changes in classifications have occurred in forest type groups definitions between the RPA and FIADB datasets, which limits the estimates of change available in Table 4-3 (and later in Appendix Table C-6) when both data sources are included in a calculation. Thus, totals calculated this way do not necessarily add to totals calculated as more aggregate stocks. The RPA and FIADB datasets are based on surveys and are explained in detail in Section 4.5.

Regional summaries were developed for the regions indicated in Map 4-3; the 10-region classifications are used in Figures 4-1 and 4-2, while the 4-region set is used for additional tables in the appendix. Total forest ecosystem carbon stocks are generally greater in eastern regions than in the West (Figure 4-1a). However, this trend is not apparent when comparing regional average values for carbon density (Figure 4-1b). Mass of carbon per unit area is greatest in the Pacific Northwest-Westside and the Northern Lake States due to large pools of biomass and SOC, respectively. The most apparent regional trends in ecosystem pool carbon density are: greater carbon in biomass in the Pacific Northwest-Westside; greater SOC pools in northern regions; and smaller pools of down dead wood and forest floor in the South. Net annual stock changes are shown in Figure 4-2, which includes estimated changes in

Map 4-3
Regions Used for Carbon Stock Summaries



Regions in the lower map are: Pacific Coast, Rocky Mountain, North and South.

Regions in the upper map are: Pacific Northwest – Westside (PNWW); Pacific Northwest – Eastside (PNWE); Pacific Southwest (PSW); Rocky Mountain – North (RMN); Rocky Mountain – South (RMS); Northern Lake States (NLS); Northern Prairie States (NPS); Northeast (NE); South Central (SC); and Southeast (SE) harvested wood product pools.

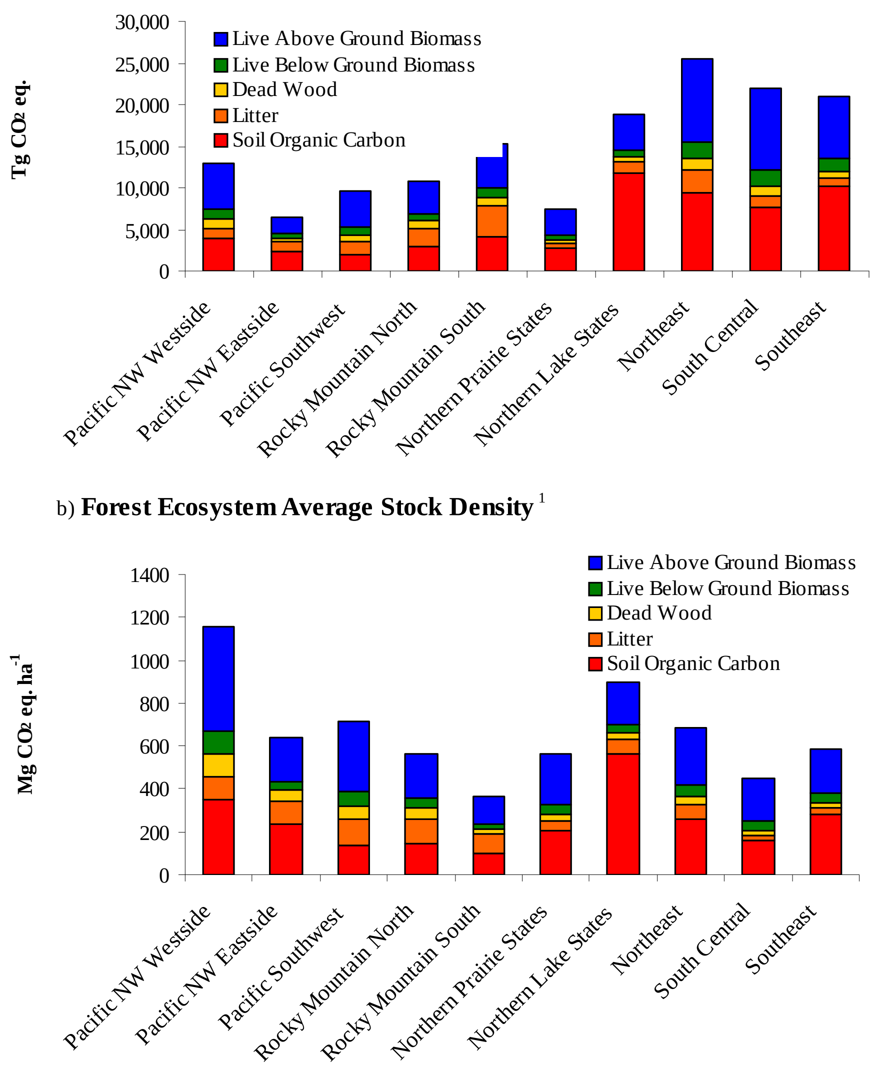
Forestland in the conterminous United States is distributed over all 48 of the States. Carbon density of live trees, both above- and belowground, is shown in Map 4-2, which illustrates both the spatial distribution of forest ecosystem carbon and average carbon density over the lower 48 States. This map is based on the most recent inventory data available per State. State-wide summaries of total forest area and non-soil ecosystem carbon stock are presented in Appendix Table C-1. This table also includes net change for area, non-soil ecosystem carbon stock, and stock of carbon in harvested wood products for 2005. Carbon stock change in harvested wood is allocated according to total roundwood removals per State from Table 1.10 of Johnson (2001). Calculated values for net annual change reflect estimated carbon densities and forest areas reported in the two most recent surveys per State.

Estimates of net annual change calculated as the difference between two successive inventories are sensitive to changes in forestland over the interval as well as changes in average carbon density. Even small differences in carbon density can contribute to large differences if the change is applied to large areas. Whether change of area or density is the controlling factor is dependent on the situation. Most estimates of net ecosystem carbon change provided in Tables 4-2 and 4-3, Figure 4-2 and Appendix Table C-1 correspond to similar changes in forest area. That is, net gains in forest carbon are most often accompanied by increases in forestland and visa-versa. There are exceptions, and most of these involve net gains in

Figure 4-1

a) **Forest Ecosystem Carbon Stocks**

b) **Forest Ecosystem Average Stock Density** [1]

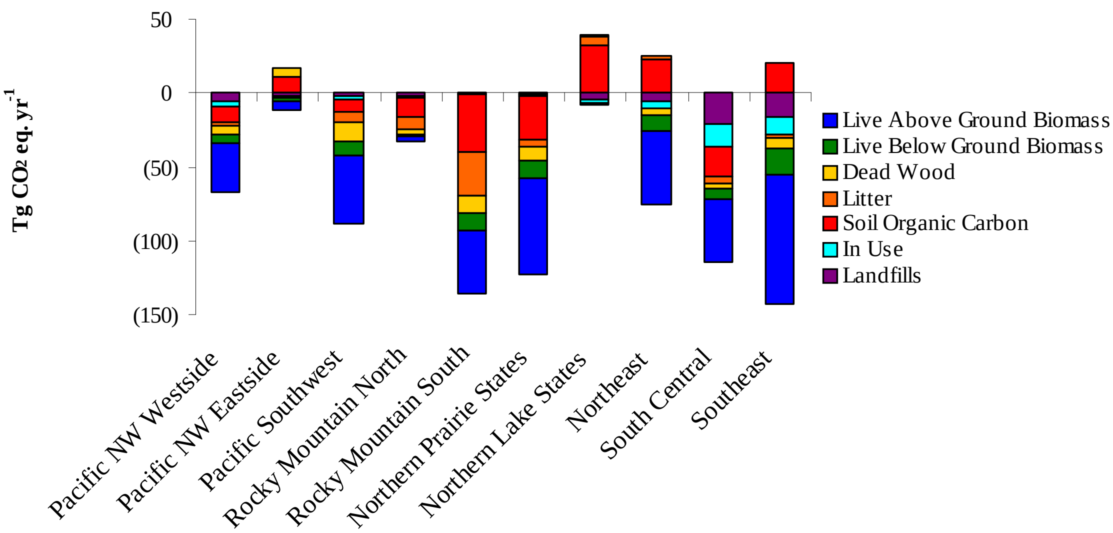


Note: Soil carbon does not include effects of past land use history.

[1] Based on plot-level data from the most recent inventory available per state.

forest carbon (negative flux) despite decreases in area. This is the case in Table 4-3 for Eastern White/Red/Jack Pine and Western Douglas-fir, Hemlock/Sitka Spruce, Ponderosa Pine, and Redwood forest type groups. Specifically, each of these type groups decreased in area through the two most recent inventories for their respective locations (data not shown), yet total carbon in biomass increased. Similarly, Appendix Table C-1 shows both of these patterns – carbon stock trend counter to forest area trend – in 12 of the lower 48 States. The four instances of net carbon loss accompanying area gains involve relatively low rates of change (0.2% or less).

Figure 4-2
Net Annual Forest Carbon Stock Change[1]



[1]Based on plot-level data from the most recent inventory available per state.
Parentheses indicate a net sequestration. Soil carbon does not include effects of past land use history.

Additional tabular summaries of forest ecosystem carbon stocks are provided in Appendix Tables C-2 through C-5. The distribution of carbon stocks among forest age classes is shown in Appendix Table C-2 for privately owned and Appendix Table C-3 for publicly owned forests. The tables illustrate that the greater proportion of forest carbon stocks in the East is under private ownership while the greater proportion in the West is under public ownership. Distributions according to age are shifted toward older forests on public lands; this is the case for all four regions but is more apparent in the West. Similarly, distribution according to stand size class (Appendix Table C-4) shows a greater proportion in larger size-class stands in the West. Patterns of carbon stocks among forest types and ownerships are presented by forest ecosystem pools (excluding soils) in Appendix Table C-5. Ownership is classified as public or private for timberlands (forests of minimum productivity and available for harvesting). The remaining forestland, both public and private, is either reserved from harvesting or is considered less productive (and thus probably not managed for commercial wood products). The net annual stock change corresponding to Appendix Table C-5 is provided in Appendix Table C-6. Note that Appendix Table C-6 is affected by the same data limitations as discussed above for Table 4-2. For more information about forest inventory variables such as forest classifications of ownership, productivity, forest type, and stand size class, see Smith et al. (2004a) and USDA Forest Service (2006).

A large proportion of non-forest trees in the United States are in urban areas – approximately 3% of total tree cover in the conterminous United States (Nowak et al. 2001). Advances in design and deployment of trees in urban environments can provide significant fossil fuel savings for heating and cooling, through microclimate management (Dwyer et al. 2000). Development of urban tree waste management and recycling processes and systems would reduce emissions and increase sequestration opportunities. Methods have been developed for estimating carbon sequestration rates for urban trees of the United States (Nowak & Crane 2002). Net flux of carbon into urban trees for 2005 is estimated at 88 Tg CO_2 eq. per year (EPA 2007).

4.4 Mechanisms of Carbon Transfer

Carbon sequestration is a function of the continuous exchange of carbon dioxide between forest ecosystems and the atmosphere, which is illustrated by Figure 4-3. Forest carbon balance also includes some non-CO_2 emissions, but the majority of exchange is in terms of CO_2, which is the focus of this chapter. Tree growth results in the net accumulation of CO_2 in forests (removal from the atmosphere), whereas other processes such as respiration, decomposition, or combustion remove CO_2 from the forest. Photosynthesis provides the energy for the conversion of carbon dioxide to organic carbon; this assimilation of CO_2 by trees most often exceeds any simultaneous losses through respiration, resulting in net tree growth. Forests convert much of the accumulated carbon to wood, which stores carbon and energy. Processes that control the fate of wood grown in a forest largely determine the subsequent loss of CO_2 to the atmosphere. Mortality and disturbance add to the pools of down dead wood and forest floor, which are subject to decay. Carbon can also be removed from forest ecosystems through runoff or leaching through soil. Mechanisms of relatively rapid carbon loss from specific forestlands include disturbances such as fire or the harvest of wood. However, a portion of the carbon in harvested wood is not immediately returned to the atmosphere, rather it is retained in wood products. Once in a product pool, the carbon is emitted as CO_2 over time through combustion or decay of the wood product. Net release of carbon from wood products can vary considerably depending on the product, its end use, and the means of disposal (Skog & Nicholson 1998, Smith et al. 2006, Skog in prep).

Forest management affects carbon stocks and stock changes by controlling mechanisms associated with carbon gain and loss (Houghton & Hackler 2000, Johnson & Curtis 2001). For example, increasing tree volume per area of forest generally increases carbon sequestration. Forest management can be defined as activities involving the regeneration, tending, protection, harvest, and utilization of forest resources to meet goals defined by the forestland owner. Management often focuses on more than one outcome and can vary by forest ecosystem, landowner objectives, and economic possibilities. Example goals, or expected outcomes, of management include productivity and resource conservation. Relatively passive management may include tree harvest and removal, followed by natural regeneration, or riparian area management such as consciously retaining a buffer strip of trees along a watercourse. Intensive management may consist of site preparation, improved stocking, species conversion, planting genetically improved stock, application of pesticides or fertilizer, and improvement cuttings such as thinning or pre-commercial thinning.

Increased net carbon sequestration is generally associated with forest systems under improved forest management practices, although some practices may reduce carbon storage for a given site-age-type dynamic. Examples of improved management practices include afforestation, increased productivity, reduced conversion to non-forest uses, lengthened rotations in some systems, and increased proportion and retention of carbon in harvested wood products. Afforestation offers significant opportunities to capture and store carbon on lands that are not currently forested (Houghton & Goodale 2004, Woodbury et al. 2006). This is a particularly useful tool for marginal agricultural lands. Similarly, reductions in conversion to non-forest land uses contribute to maintaining carbon stocks, particularly through the additional organic carbon storage in forest soils (Lal 2005). Sustainable short-rotation woody crops systems offer the opportunity to rapidly deploy new, faster growing genetic material, sequester carbon in the soil, add to the wood products pool, and provide energy feedstocks as fossil fuel offsets. Improvements in the management of wood products in use and in landfills provide a number of opportunities to reduce emissions and increase sequestration. Continuing development of wood products can increase their use as substitutes for nonrenewable materials and extend their durability and thus expected lifespan (Perez-Garcia et al. 2005).

Harvested wood carbon pools lengthen the time before which carbon returns to the atmosphere. Emissions can occur from wood burned for energy, or from decay or burning of wood without energy capture (Figure 4-3). This distinction between the two paths for carbon emitted to the atmosphere is useful to assess potential displacement of other fuel sources. Average annual carbon emissions from harvested wood are estimated at 382 Tg CO_2 eq. over the period 1990 through 2005 (EPA 2007, see Table A-199 of Annex 3.12). The newly revised estimates (Skog in prep.) do not specify the portion of emitted carbon that is associated with energy capture (including firewood and wood from products), but previous estimates were about 59% (Skog & Nicholson 1998), which is approximately 225 Tg CO_2 eq. Net annual carbon sequestration via harvested wood, after accounting for these emissions, is specified in Table 4-2.

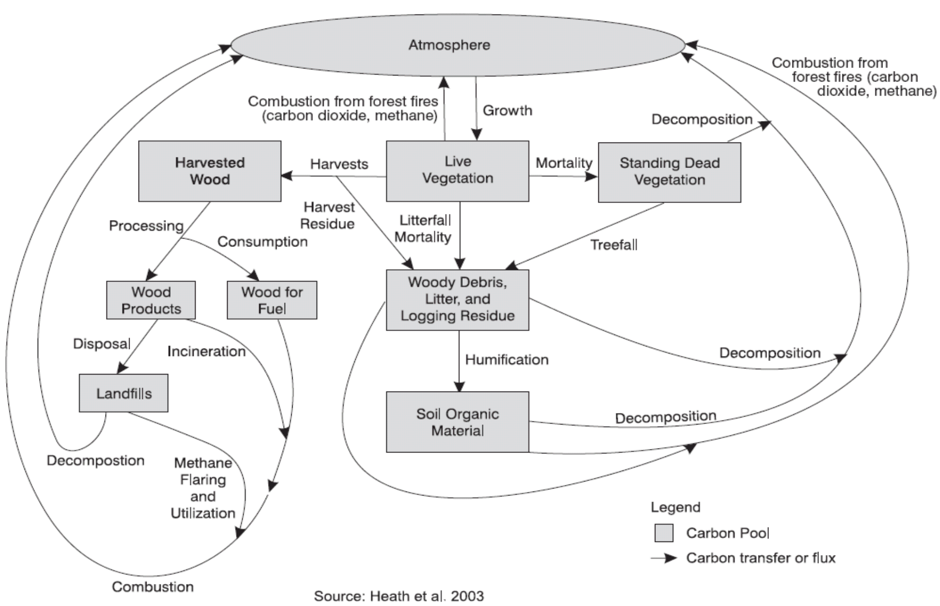
4.5 Methods

The stock change method, which is the basic approach to estimating forest ecosystem carbon as reported here, is to apply factors characteristic of forest carbon pools to inventory data. The USDA Forest Service, Forest Inventory and Analysis (FIA) Program forest inventory data consist of a series of surveys per State, which in the past have been 5 to 10 years apart. The number and frequency of inventories vary from State to State. The new national survey protocol (USDA FS 2006, 2007) calls for a portion of each State to be surveyed each year.

Carbon stocks for each forest classification, ecosystem carbon pool, and inventory are separately calculated and aggregated to total stocks for a specific year for each State. The term "survey" is used here to describe a complete inventory for a State, which is repeated at regular intervals. The inventories for some States are further divided into separate sub-State classifications for consistency in each consecutive series of carbon stocks. Net annual stock change (also referred to as flux) is the difference between successive stocks divided by the interval of time between surveys. Carbon estimates for harvested wood products are based on a separate stock change method and input data that are not directly related to forest inventory data.

The overall goal in reporting these pools is to be as consistent as possible with: 1) the format and estimates provided in the previous USDA forest carbon inventory (USDA 2004); 2) current forest carbon estimates (EPA 2007); and 3) the carbon estimation methods applied to the available inventory data. As a result, the sequence and identity of figures and tables describing forest carbon are similar to the previous inventory (USDA 2004), but the estimates are updated to those in EPA (2007). Classifications, or groupings, of values within tables or figures have changed somewhat due to corresponding changes in forest inventories or carbon pools identified for United Nations Framework Convention on Climate Change (UNFCCC) reporting purposes. Methods are described below with additional details in EPA (2007).

Figure 4-3. Summary diagram of forest carbon stocks and carbon transfer among stocks



Forest survey

data for the United States are available from the "snapshot" Forest Inventory and Analysis DataBase (FIADB), version 2.1 (USDA FS 2007). Surveys from the FIADB are supplemented with some older surveys from FIA Resources Planning Act Assessment (RPA) databases, which are periodic summaries of State inventories, along with older FIA tree-level data for some States. More complete information about these data, both FIADB and RPA, is available on the Internet at the Forest Inventory and Analysis Datacenter (USDA FS 2007). All FIADB surveys used for carbon stock estimates were obtained from the FIADB site on September 8, 2006. See Table 2 of Smith et al. (2007) for a list of the specific surveys, sub-State classifications, and corresponding survey years.

Carbon estimation factors (described below) are applied to the plot-level inventory data and summed to calculate carbon stocks for each survey of each State. Each survey is associated with an average year for field collection of data. Carbon stocks for each State or sub-State classification are assigned to those average years with net stock change—or flux—based on the interval (in years) between the stocks. In this way, State-wide annualized estimates of ecosystem stock and flux can be calculated and summed to U.S totals as presented in EPA (2007) and Table 4-2. A similar approach is taken to produce the additional estimates disaggregated by categories presented in the figures and tables.

Forest ecosystem carbon is estimated for each inventory plot as six separate pools: live tree, understory vegetation, standing dead tree, down dead wood, forest floor, and soil organic carbon. Live tree and understory are also allocated to above and belowground portions. For each inventory summary in each State, each carbon pool is estimated using coefficients from the FORCARB2 model (Birdsey & Heath 1995, Birdsey & Heath 2001, Heath et al. 2003, Smith et al. 2004c). Coefficients of the model are applied to the survey data at the scale of FIA inventory plots; the results are estimates of carbon density (Mg per hectare). These densities are then converted to CO_2 equivalents. The pools are then merged into the set of five reporting pools. FORCARB2's live tree and understory carbon pools are pooled as biomass in this inventory. Similarly, standing dead trees and down dead wood are pooled as dead wood in this inventory. Definitions of forest floor and SOC in FORCARB2 correspond to litter and forest soils, respectively, as defined in IPCC 2003.

Biomass, or live plant mass, includes trees and understory vegetation. Tree carbon includes aboveground and belowground (coarse root) carbon mass of live trees. Separate estimates are made for whole-tree and aboveground-only biomass. Thus, the belowground portion is determined as the difference between the two estimates. Tree carbon estimates are based on equations in Jenkins et al. (2003) and are functions of tree species and diameter as well as forest type and region. Tree carbon in the RPA plots, which do not include individual tree data, are estimated from plot-level growing stock volume of live trees and equations based on Smith et al. (2003). Carbon mass of wood is 50% of dry weight (IPCC 1997). The minimum-sized tree included in these FIA data is one-inch diameter (2.54 cm) at breast height (1.3 meter); this represents the minimum size included in the tree carbon pools. Understory vegetation is defined in FORCARB2 as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than one-inch diameter, measured at breast height. We estimated that 10% of understory carbon mass is belowground. This general root-to-shoot ratio (0.11) is near the lower range of temperate forest values provided in IPCC 2003, and was selected based on two general assumptions: 1) ratios are likely to be lower for light-limited understory vegetation as compared with larger trees, and 2) a greater proportion of all root mass will be less than 2 mm diameter. Understory carbon density estimates are based on Birdsey (1996).

Dead wood includes the FORCARB2 pools of down dead wood and standing dead trees. Down dead wood is defined as pieces of dead wood greater than 7.5 cm diameter, at transect intersection, that are not attached to live or standing dead trees. Down dead wood includes stumps and roots of harvested trees. Ratio estimates of down dead wood to live tree biomass were developed by FORCARB2 simulations and applied at the plot level (Smith et al. 2004c). The standing dead tree carbon pool in FORCARB2 includes aboveground and belowground (coarse root) mass. Estimates are based on Smith et al. (2003) and are functions of plot-level growing stock volume of live trees, carbon density of live trees, forest type, and region. Coefficients used for estimating standing dead tree carbon are presented in EPA 2007 (Table A-193).

Estimates of forest floor and SOC are not based on carbon density of trees. Forest floor carbon is the pool of organic carbon (litter, duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. Estimates are based on equations of Smith and Heath (2002) applied at the plot level. Forest floor and woody debris remaining after harvests are also included as part of calculations of forest ecosystem carbon pools. Estimates of SOC are based on the national STATSGO spatial database (USDA SCS 1991, USDA NRCS 2006) and the general approach described by Amichev and Galbraith (2004). In their procedure, SOC was calculated for the conterminous United States using the STATSGO database, and data gaps were filled by representative values from similar soils. The SOC estimates are based on region and forest type only. Links to region and forest type groups were developed with the assistance of the USDA Forest Service FIA Geospatial Service Center by overlaying FIA forest inventory plots on the soil carbon map. Historical land use change effects are currently not included in the estimate of the soil carbon pool. That is, soil carbon for areas which were cleared and plowed at one time, and then reverted to forest, are probably still accruing soil carbon. However, we currently assume that all forests of a given forest type within a region have the same amount of SOC. Future inventories will include the effects of land use, following the methodology of Woodbury et al. (2007).

The tabular forest carbon summary values are based on a short sequence of calculations, these are: 1) determine carbon density for individual inventory plots; 2) identify the date (year) associated with each survey based on when data were collected; 3) sum total carbon within each State or sub-State classification for each survey to get carbon stock according to specific classification and year; and 4) linearly interpolate, or extrapolate, to determine annualized stocks and net stock change. In this way, carbon stocks are calculated separately for each State based on inventories available since 1990 and for the most recent inventory prior to 1990. With this method, stock and flux since the most recent survey are based on extrapolating estimates from the last two surveys. Thus, the annualized estimates (based on extrapolation) for 2005 will not exactly match the latest (most recent) data per State. In the results presented in this chapter, all estimates of current (2005) net stock change (or flux) are based on the difference between the two most recent surveys (extrapolated values). Most values for carbon stock or forest area are based on the most recent data available for each State; the only exception is the set of annualized stocks provided in Table 4-2.

Calculations in carbon in harvested wood products are completely separate from the ecosystem estimates because the datasets and methods are largely unrelated. These estimates focus on carbon in wood removed from the forest; logging residues are part of the ecosystem pools. Carbon in harvested wood that is either in products in use or in products discarded in solid waste disposal sites (SWDS) are based on the methods described by Skog and Nicholson (1998) and substantially revised by Skog (in prep). Estimates were developed for years from 1910 onward based on historical data from the USDA Forest Service (USDA 1964, Ulrich 1989, Howard 2001), and historical data as implemented in the framework underlying the North American Pulp and Paper (NAPAP, Ince 1994), the Timber Assessment Market, and the Aggregate Timberland Assessment System Timber Inventory models (TAMM/ATLAS, Haynes 2003, Mills & Kincaid 1992). From these data on annual wood and paper production, the fate of carbon in harvested wood was tracked for each year from 1910 through 2005; this included the change in carbon stocks in wood products, in SWDS, and carbon emitted to the atmosphere. The carbon conversion factors and decay rates for harvested carbon removed from the forest are taken from Skog (in prep). To account for imports and exports, the production approach is used, meaning that carbon in exported wood is counted as if it remained in the United States, and carbon in imported wood is not counted. The carbon stock changes presented in this chapter represent the net amounts of carbon that continue to be stored in a product pool. Allocation of the national estimates to regions or States is based on estimates in Johnson (2001).

4.6 Major Changes Compared to Previous Inventories

The estimates provided in Table 4-2 reflect two substantial changes between EPA (2006) and EPA (2007) in terms of net stock change since 1990. First, net forest ecosystem carbon sequestration in the early 1990s is revised downward (that is, less negative), and this is accompanied by greater net sequestration in recent years. Thus the overall trend is a shift toward greater carbon accumulation in forests over the interval. This result is not from changes in carbon conversion methods, but rather from availability and resolution of some older inventory data. See Smith et al. (2007) for more discussion of how inventory data were used to develop the current 1990-2005 estimates. For comparison of the respective inventory sets, see Tables A-180 and A-186 of EPA (2006) and EPA (2007), respectively. The significant changes in the use of inventories between the two years were: 1) recognition that "chaparral" was included in older data as a forest type but not in current inventories; 2) the additional sub-State classifications used for identifying sequential sets of carbon stocks; and 3) the addition of the older FIA tree-level data formats. The second substantial change is in the estimates of carbon in harvested wood; see Skog (in prep.) for more information.

4.7 Uncertainty

Uncertainty about forest inventory data and the carbon conversion factors applied to the inventory contributes to overall uncertainty of the carbon estimates. Contributing components include: errors in sampling or measurements; unknowns or errors in the largely empirical models used to develop the carbon factors; and variability across forests, which are represented by averages. Elements of inventory and carbon conversion unknowns can be addressed separately.

Confidence intervals about volumes and areas are well-defined for forest inventories (Phillips et al. 2000, USDA FS 2006). Additional sources of error in this use of inventory data are related to resolving a State's forest inventory to carbon stock for a defined forest area at a single point in time. Some small error is possible if surveys conducted over a 2- or 3-year period are averaged to a single year. However, if significant portions of a State's forest inventory were sampled on a completely different schedule, then the error would increase. For this reason, stocks and stock changes were separately determined at sub-State levels such as national forests, in some western States (also see EPA 2007 for additional details). The potential for an additional minor error comes from the use of successive surveys and the need for consistent definition, identification and inclusion of all forestlands within a State. If small areas or ownerships are omitted from one of a pair of successive surveys, then a portion of the resulting Statewide flux (net annual change) is due to the apparent change in forestland. Such problems with definition or inclusion of forestlands can have significant effects on calculated net flux, as suggested by States with relatively high rates of change in forestland. For example, current calculations for Utah (Table C-1) produce a relative growth rate of over 2% or 173,000 hectares per year, which may be related to definitions of forestlands in successive inventories. Ongoing work will improve resolution of carbon and inventory data.

Uncertainty associated with the estimates of specific carbon stocks varies by carbon pool and forest type. Carbon in trees is relatively well-defined, and information on errors in estimates (Jenkins et al. 2003) makes it possible to develop quantitative estimates of uncertainty. Relative errors in the estimates for other ecosystem carbon pools are greater; these carbon conversion factors are generally based on extrapolations of site-specific studies, which may not adequately represent regional averages. Additionally, representative data are not available for all forest types; this also increases uncertainty as substitutions are required. An important source of uncertainty is high variability and general lack of precision possible in assigning estimates of SOC. Soil carbon is a large pool, but it changes relatively slowly. There is limited information available for assessing soil carbon or the cumulative effects of land use change, which can amount to significant stock changes when summed over large forest areas (Woodbury et al. 2006).

A quantitative uncertainty analysis was developed for estimates of total carbon flux. The analysis incorporated the information from preliminary uncertainty analyses and estimates of uncertainty in the carbon conversion factors (Heath & Smith 2000, Smith & Heath 2001, Skog et al. 2004, Skog in prep). Additional details on the analysis are provided in Chapter 7 and Annex 3.12 of EPA (2007). The uncertainty analysis was performed using the IPCC-recommended Tier 2 uncertainty estimation methodology, that is, the Monte Carlo simulation technique. The 2005 forest carbon stock changes are estimated to lie between -890 and -513 Tg CO_2 eq. at a 95% confidence level, at a sink of -699 Tg CO_2 eq. (Table 4-1). The 95% confidence intervals for forest sequestration are -785 to -410 Tg CO_2 eq. and -130 to -79 Tg CO_2 eq. for harvested wood products.

4.8 Planned Improvements

The ongoing annualized surveys by the FIA Program will improve precision of forest carbon estimates as new State surveys become available. The annualized surveys will also better reflect the effects of disturbances on forest carbon. In addition, the more intensive sampling of down dead wood, forest floor, and SOC on some of the permanent plots will substantially improve resolution of carbon pools at the plot-level. As more information becomes available about historical land use, the ongoing effects of changes in land use and forest management will be better accounted for in estimates of soil carbon. Urban trees and agroforestry systems represent two broad classes of carbon sequestration by trees that are on lands not currently identified as forest for purposes of the FIA inventories. Estimates of carbon sequestration by urban forests are included in U.S. GHG Inventory (EPA 2007), but future collection of field data (which is underway) as well as reconciling these areas with FIA forest data should improve overall estimates of sequestration. The estimates of carbon stored in harvested wood products are currently being revised using more detailed wood products production and use data, and more detailed parameters on disposition and decay of products.

Agroforestry systems are not currently included in FIA inventory data. Agroforestry practices, such as windbreaks or riparian forest buffers along waterways, are generally not included in forest carbon estimates. Additional research is underway to develop methods for including these systems in nationwide inventories (Perry et al. 2005). This should lead to the inclusion of carbon stock and flux estimates in the forest greenhouse gas inventories. Annual surveys will also eventually include all 50 States. This is particularly important for Alaska which has a large area of forested land.

Appendix C: Carbon Stocks

Appendix C

C-1 Forest Area, Stock, and Stock Change by State
C-2 Carbon Stock Pools on Private Forestland by Region and Age-Class
C-3 Carbon Stock Pools on Public Forestland by Region and Age-Class
C-4 Carbon Stock Pools on Timberlands by Region and Stand Size Class
C-5 Carbon Stocks on all Forestland by Forest Type Group and Ownership
C-6 Net Annual Carbon Stock Change on all Forestland by Forest Type Group and Ownership

Appendix Table C-1 Forest Area, Stock, and Stock Change by State[1]

State	Forest Area	Net Area Change	Non-Soil Stocks	SOC[2]	Non-Soil Change	Harvested Wood Products Change
	1000 ha	*1000 ha yr^{-1}*	*Tg CO_2 eq.*	*Tg CO_2 eq.*	*Tg CO_2 eq. yr^{-1}*	
Alabama	9,286	(4.7)	2,435	1467	(11.1)	(9.6)
Arizona	8,395	60.0	1,647	712	2.4	(0.1)
Arkansas	7,620	2.1	2,356	1173	(13.5)	(4.7)
California	13,451	56.9	7,776	1878	(75.4)	(4.1)
Colorado	9,425	60.6	3,382	1087	(23.9)	(0.1)
Connecticut	704	(8.5)	326	158	3.2	(0.1)
Delaware	159	0.7	70	37	(1.2)	(0.1)
Florida	6,534	12.4	1,597	2435	(20.6)	(3.9)
Georgia	10,006	27.2	2,760	3023	(31.5)	(9.7)
Idaho	8,963	5.1	3,833	1348	7.1	(1.8)
Illinois	1,790	6.7	732	368	(2.6)	(0.3)
Indiana	1,913	34.0	829	385	(24.3)	(0.5)
Iowa	1,112	38.0	404	244	(14.1)	(0.1)
Kansas	860	26.8	270	258	(6.6)	(0.0)
Kentucky	4,844	(19.2)	1,734	719	(3.3)	(1.4)
Louisiana	5,713	11.8	1,637	964	(0.2)	(4.6)
Maine	7,165	0.3	2,666	2174	2.9	(3.5)
Maryland	953	(16.7)	449	224	1.5	(0.3)
Massachusetts	1,282	2.6	659	324	(10.0)	(0.1)
Michigan	7,815	1.3	2,945	4292	6.8	(2.6)
Minnesota	6,554	(18.3)	1,905	4054	5.9	(2.2)
Mississippi	7,525	93.5	1,933	1202	(9.4)	(7.6)
Missouri	5,933	36.6	2,084	1054	(38.0)	(1.0)
Montana	10,446	80.2	4,177	1506	(23.7)	(1.2)
Nebraska	507	14.4	169	133	(4.5)	(0.1)
Nevada	4,807	39.3	927	380	(4.8)	(0.0)
New Hampshire	1,948	(0.7)	920	529	(2.5)	(1.1)
New Jersey	776	(13.8)	324	191	(0.9)	(0.0)
New Mexico	6,751	22.8	1,759	594	(14.4)	(0.1)
New York	7,472	10.4	3,323	1960	(20.9)	(1.1)
North Carolina	7,393	(20.4)	2,503	1866	(0.3)	(6.1)
North Dakota	293	2.4	86	88	(1.1)	(0.0)
Ohio	3,281	8.5	1,286	768	(13.9)	(0.7)
Oklahoma	3,102	37.2	825	465	(16.4)	(0.8)
Oregon	12,332	26.3	7,059	3465	(33.7)	(6.0)
Pennsylvania	6,708	(10.4)	2,879	1566	(15.5)	(1.7)
Rhode Island	146	(2.3)	67	34	(0.9)	(0.0)
South Carolina	5,158	36.7	1,542	1436	(19.8)	(4.6)
South Dakota	663	1.6	170	132	(0.3)	(0.1)
Tennessee	5,719	(27.6)	2,102	842	3.2	(2.1)
Texas	4,909	7.2	1,342	778	(7.3)	(5.3)
Utah	7,978	173.2	1,912	783	(20.3)	(0.1)
Vermont	1,822	(6.6)	850	495	6.7	(0.6)
Virginia	6,529	94.0	2,436	1360	(42.7)	(3.4)
Washington	8,951	15.6	6,035	2847	(16.9)	(6.0)
West Virginia	4,740	(28.5)	2,115	1034	(11.8)	(1.2)
Wisconsin	6,490	4.1	2,207	3363	(6.6)	(2.6)
Wyoming	4,632	29.7	1,701	501	(35.2)	(0.1)
Total	**251,558**	**903**	**93,145**	**56,697**	**(561)**	**(103)**

[1] soil carbon does not include effects of past land use history.

Net change reflects differences reported in the two most recent inventories per state.

Appendix Table C-2 Carbon Stock Pools on Private Forestland by Region and Age-Class

	Age Class	SOC[1]	Dead Plant Matter	Biomass	***Total***
Region	*Years*		*Tg CO_2 eq.*		
North		**16,317**	**5,301**	**15,222**	**36,839**
	<20	1,473	224	295	**1,992**
	20-40	2,402	548	1,408	**4,357**
	40-60	4,757	1,487	4,286	**10,529**
	60-80	4,881	1,849	5,651	**12,380**
	80-100	2,042	866	2,631	**5,539**
	100-150	683	298	879	**1,859**
	150-200	36	14	32	**81**
	200+	4	1	5	**10**
	Uneven	40	15	35	**91**
South		**15,072**	**3,729**	**17,270**	**36,071**
	<20	4,944	703	2,451	**8,098**
	20-40	3,164	756	3,339	**7,259**
	40-60	3,064	958	4,747	**8,769**
	60-80	1,924	664	3,564	**6,153**
	80-100	574	196	1,094	**1,865**
	100-150	189	60	333	**581**
	150-200	7	2	10	**18**
	200+	1,205	390	1,731	**3,327**
Pacific Coast		**3,309**	**2,091**	**4,361**	**9,762**
	<20	777	247	196	**1,220**
	20-40	612	293	734	**1,639**
	40-60	627	414	1,023	**2,063**
	60-80	556	422	915	**1,893**
	80-100	370	314	654	**1,338**
	100-150	224	221	473	**919**
	150-200	51	62	145	**257**
	200+	38	47	97	**181**
	Uneven	54	71	125	**251**
Rocky Mountain		**1,554**	**1,587**	**1,897**	**5,038**
	<20	357	295	136	**789**
	20-40	114	89	71	**274**
	40-60	120	111	124	**355**
	60-80	226	224	295	**745**
	80-100	268	298	417	**983**
	100-150	310	374	572	**1,257**
	150-200	94	118	173	**384**
	200+	64	77	110	**251**
Total		**36,252**	**12,708**	**38,750**	**87,710**

[1] (SOC) Soil organic carbon, soil carbon does not include effects of past land use history.

Appendix Table C-3 Carbon Stock Pools on Public Forestland by Region and Age-Class

	Age class	SOC[1]	Dead Plant Matter	Biomass	***Total***
Region	*Years*		*Tg CO_2 eq.*		
North		**7,548**	**1,942**	**5,271**	**14,761**
	<20	740	72	102	**915**
	20-40	983	153	372	**1,507**
	40-60	1,711	379	1,022	**3,111**
	60-80	2,252	673	1,918	**4,843**
	80-100	1,222	442	1,282	**2,946**
	100-150	570	199	510	**1,280**
	150-200	52	18	44	**114**
	200+	8	3	8	**19**
	Uneven	9	4	13	**26**
South		**2,659**	**718**	**3,485**	**6,862**
	<20	373	41	144	**558**
	20-40	407	77	321	**805**
	40-60	632	170	812	**1,614**
	60-80	710	237	1,189	**2,136**
	80-100	277	96	522	**895**
	100-150	110	41	232	**383**
	150-200	6	2	7	**15**
	Uneven	145	54	256	**455**
Pacific Coast		**4,881**	**4,357**	**10,060**	**19,298**
	<20	575	252	146	**973**
	20-40	499	240	495	**1,234**
	40-60	412	267	621	**1,300**
	60-80	663	529	1,241	**2,432**
	80-100	632	571	1,309	**2,512**
	100-150	860	892	2,105	**3,857**
	150-200	405	488	1,194	**2,087**
	200+	807	1,083	2,872	**4,761**
	Uneven	29	37	77	**142**
Rocky Mountain		**5,357**	**6,397**	**9,457**	**21,212**
	<20	907	739	310	**1,955**
	20-40	263	220	173	**655**
	40-60	213	201	239	**653**
	60-80	574	622	991	**2,188**
	80-100	861	1,018	1,680	**3,559**
	100-150	1,447	1,994	3,352	**6,792**
	150-200	729	1,072	1,810	**3,612**
	200+	364	531	903	**1,799**
Total		**20,445**	**13,414**	**28,273**	**62,132**

[1] (SOC) Soil organic carbon, soil carbon does not include effects of past land use history.

Appendix Table C-4 Carbon Stock Pools on Timberlands by Region and Stand Size Class

	Stand Size Class	SOC[1]	Dead Plant Matter	Biomass	***Total***
Region			*Tg CO_2 eq.*		
North		**22,630**	**6,844**	**19,478**	**48,952**
	Nonstocked	269	16	10	**295**
	Seedling/ Sapling	4,629	781	999	**6,408**
	Poletimber	7,797	2,158	5,337	**15,293**
	Sawtimber	9,935	3,889	13,132	**26,955**
South		**17,233**	**4,320**	**20,099**	**41,652**
	Nonstocked	197	7	16	**221**
	Seedling/ Sapling	4,412	623	1,708	**6,743**
	Poletimber	4,886	1,187	5,310	**11,383**
	Sawtimber	7,737	2,503	13,064	**23,305**
Pacific Coast		**6,546**	**4,819**	**11,123**	**22,489**
	Nonstocked	240	94	34	**368**
	Seedling/ Sapling	1,002	380	293	**1,675**
	Poletimber	756	377	777	**1,910**
	Sawtimber	4,548	3,968	10,019	**18,535**
Rocky Mountain		**3,661**	**4,450**	**7,186**	**15,297**
	Nonstocked	201	155	50	**406**
	Seedling/ Sapling	544	452	315	**1,312**
	Poletimber	711	729	1,180	**2,620**
	Sawtimber	2,205	3,114	5,642	**10,960**
Total		**50,070**	**20,433**	**57,886**	**128,390**

[1] (SOC) Soil organic carbon, soil carbon does not include effects of past land use history.

Appendix Table C-5 Carbon Stocks[1] on all Forestland by Forest Type Group and Ownership

	Private	Public	Reserve/Other
Forest Type Group		*Tg* CO_2 *eq.*	
East	**41,194**	**9,547**	**2,196**
Aspen/Birch	1,020	644	95
Elm/Ash/Cottonwood	2,125	449	96
Loblolly/Shortleaf Pine	4,819	729	42
Longleaf/Slash Pine	821	262	13
Maple/Beech/Birch	7,705	1,965	658
Oak/Gum/Cypress	2,912	595	119
Oak/Hickory	15,787	2,918	730
Oak/Pine	3,162	643	103
Spruce/Fir	1,341	671	168
White/Red/Jack Pine	1,131	497	131
Other East Type Groups	372	174	41
West	**7,887**	**19,692**	**12,629**
Alder/Maple	451	195	15
Aspen/Birch	238	794	170
California Mixed Conifer	620	1,637	603
Douglas-fir	2,668	6,443	1,159
Fir/Spruce/Mt. Hemlock	607	4,712	2,498
Hemlock/Sitka Spruce	539	1,093	506
Lodgepole Pine	186	1,422	728
Other Western Hardwoods	120	78	293
Other Western Softwoods	30	271	305
Pinyon/Juniper	7	45	3,884
Ponderosa Pine	966	1,830	206
Redwood	208	13	108
Tanoak/Laurel	422	221	109
Western Larch	49	264	38
Western Oak	545	391	1,418
Western White Pine	1	23	45
Other West Type Groups	229	258	543
Total	**49,080**	**29,239**	**14,826**

[1] Excluding soils.

Appendix Table C-6 Net Annual Carbon Stock Change[1] on all Forestland by Forest Type Group and Ownership

	Private	Public	Reserve/Other
Forest Type Group		*Tg CO_2 eq. yr^{-1}*	
East	**(193.2)**	**(190.0)**	**(24.8)**
Aspen/Birch	15.7	0.5	1.9
Elm/Ash/Cottonwood	(16.0)	(17.5)	(1.1)
Loblolly/Shortleaf Pine	(58.5)	(10.8)	0.2
Longleaf/Slash Pine	(3.4)	(9.0)	(0.5)
Maple/Beech/Birch	(52.5)	(34.7)	13.0
Oak/Gum/Cypress	52.5	(20.3)	(7.5)
Oak/Hickory	(172.3)	(65.7)	(21.0)
Oak/Pine	26.9	(13.6)	(8.1)
Spruce/Fir	22.1	(1.5)	3.9
White/Red/Jack Pine	11.9	(12.8)	(7.7)
Other East Type Groups	(19.7)	(4.6)	2.2
West	**(56.6)**	**(190.3)**	**(96.4)**
Alder/Maple	-	-	-
Aspen/Birch	-	-	-
California Mixed Conifer	(62.1)	(124.0)	(33.4)
Douglas-fir	(7.5)	(46.0)	(0.9)
Fir/Spruce/Mt. Hemlock	(0.3)	(2.3)	14.3
Hemlock/Sitka Spruce	6.5	8.2	(17.8)
Lodgepole Pine	2.0	13.7	3.5
Other Western Hardwoods	-	-	-
Other Western Softwoods	(0.3)	(2.4)	(7.4)
Pinyon/Juniper	(0.8)	(2.3)	(51.6)
Ponderosa Pine	0.0	(26.0)	5.1
Redwood	5.3	2.2	(10.6)
Tanoak/Laurel	-	-	-
Western Larch	0.5	(11.0)	(1.3)
Western Oak	-	-	-
Western White Pine	(0.0)	(0.6)	3.6
Other West Type Groups	-	-	-
***Total*[2]**	**(249.8)**	**(380.3)**	**(121.2)**

[1] Excluding soils.

[2] Includes carbon storage in urban trees.

- Indicates no data available.

Literature Cited

Amichev, B.Y., and J.M. Galbraith (2004) A revised methodology for estimation of forest soil carbon from spatial soils and forest inventory data sets. Environmental Management, 33(S1): S74-S86.

Birdsey, R.A. (1996) Carbon storage for major forest types and regions in the coterminous United States. P. 1-25 and Appendixes 2-4 and *Forests and global change, vol. 2: Forest management opportunities for mitigating carbon emissions.* R.N. Sampson and D. Hair, editors. American Forests, Washington, DC.

Birdsey, R.A., and L.S. Heath (1995) Carbon changes in U.S. forests. In Productivity of America's forests and climate change, General Technical Report RM-271. L.A. Joyce, editor. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Birdsey, R., and L.S. Heath (2001) Forest inventory data, models, and assumptions for monitoring carbon flux. P. 125-135 in *Soil carbon sequestration and the greenhouse effect*. Soil Science Society of America, Madison, WI.

Dwyer, J.F., D.J. Nowak, M.H. Noble, and S.M Sisinni (2000) Connecting people with ecosystems in the 21st century: An Assessment of Our Nation’s Urban Forests. General Technical Report PNW-GTR-490, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

EPA. (2006) Inventory of U. S. greenhouse gas emissions and sinks: 1990 – 2004. EPA 430-R-06-002. United States Environmental Protection Agency, Office of Atmospheric Programs, Washington, D.C. Available online at <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>.

EPA. (2007) Inventory of U. S. greenhouse gas emissions and sinks: 1990 – 2005. EPA 430-R-06-0. United States Environmental Protection Agency, Office of Atmospheric Programs, Washington, D.C. Available online at <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>.

Haynes, R.W., coord. (2003) An analysis of the timber situation in the United States: 1952-2050. General Technical Report PNW-560. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. 254 p.

Heath, L.S., and J.E. Smith (2000) An assessment of uncertainty in forest carbon budget projections. Environmental Science and Policy 3:73-82.

Heath, L.S., J.E. Smith, and R.A. Birdsey (2003) Carbon trends in U. S. forest lands: A context for the role of soils in forest carbon sequestration. In *The potential of US forest soils to sequester carbon and mitigate the greenhouse effect.* J. M. Kimble, L. S. Heath, R. A. Birdsey, and R. Lal, editors. CRC Press, New York, NY.

Houghton, R.A., and J.L. Hackler (2000) Changes in terrestrial carbon storage in the United States. 1: The roles of agriculture and forestry. Global Ecology and Biogeography, 9:125-144.

Houghton, R.A., and C.L. Goodale (2004) Effects of land-use change on the carbon balance of terrestrial ecosystems. Geophysical Monograph Series 153. P. 85-98 in *Ecosystems and Land Use Change*. R.S. DeFries, G.P. Asner, and R.A. Houghton, editors. American Geophysical Union, Washington, DC.

Howard, J.L. (2001) U.S. timber production, trade, consumption, and price statistics 1965-1999. Research Paper RP-595, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI.

Ince, P. (1994) Recycling and long-range timber outlook. General Technical Report RM-242, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

IPCC (1997) Revised 1996 IPCC guidelines for national greenhouse gas inventories, vol. 1-3. Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Cooperation and Development, International Energy Agency, Paris, France. Available online at <http://www.iea.org/ipcc/invs6.htm>.

Jenkins, J.C., D.C. Chojnacky, L.S. Heath, and R.A. Birdsey (2003) National-scale biomass estimators for United States tree species. Forest Science, 49:12-35.

Johnson, D.W., and P.S. Curtis (2001) Effects of forest management on soil C and N storage: meta analysis. Forest Ecology and Management, 140:227-238.

Johnson, T.G., ed. (2001) United States timber industry—an assessment of timber product output and use, 1996. General Technical Report SRS–45. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC. 145 p.

Lal, R. (2005) Forest soils and carbon sequestration. Forest Ecology and Management, 220:242-258.

Mills, J., and J. Kincaid (1992) The aggregate timberland analysis system—ATLAS: a comprehensive timber projection model. General Technical Report PNW-281. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. 160 p.

Nowak, D.J., M.H. Noble, S.M. Sisinni, and J.F. Dwyer (2001) Assessing the U.S. urban forest resource. Journal of Forestry, 99(3): 37-42.

Nowak, D.J., and D.E. Crane (2002) Carbon storage and sequestration by urban trees in the United States. Environmental Pollution, 116(3):381-389.

IPCC (2003) Good practice guidance for land use, land use change, and forestry. J. Penman, M. Gytarsky, T. Hiraishi, [et al.], editors. Intergovernmental Panel on Climate Change, National

Greenhouse Gas Inventories Programme, Technical Support Unit, Kanagawa, Japan. Available online at <http: //www.ipcc-nggip.iges.or.jp>.

Perez-Garcia, J., B. Lippke, J. Comnick, and C. Manriquez (2005) An assessment of carbon pools, storage, and wood products market substitution using life-cycle analysis results. Wood and Fiber Science, 37:140-148.

Phillips, D.L., S.L. Brown, P.E. Schroeder, and R.A. Birdsey (2000) Toward error analysis of large-scale forest carbon budgets. Global Ecology and Biogeography, 9:305-313.

Skog, K.E., and G.A. Nicholson (1998) Carbon cycling through wood products: the role of wood and paper products in carbon sequestration. Forest Products Journal, 48(7/8):75-83.

Skog, K.E., K. Pingoud, and J.E. Smith (2004) A method countries can use to estimate changes in carbon stored in harvested wood products and the uncertainty of such estimates. Environmental Management, 33(S1): S65-S73.

Skog, K.E. (2008) Sequestration of carbon in harvested wood products for the United States. In preparation.

Smith, J.E., and L.S. Heath (2001) Identifying influences on model uncertainty: an application using a forest carbon budget model. Environmental Management, 27:253-267.

Smith, J.E., and L.S. Heath (2002) A model of forest floor carbon mass for United States forest types. Res. Pap. NE-722. U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, PA. 37 p.

Smith, J.E., L.S. Heath, and J.C. Jenkins (2003) Forest volume-to-biomass models and estimates of mass for live and standing dead trees of U.S. forests. General Technical Report NE-298. U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, PA. 57 p.

Smith, J.E., L.S. Heath, and P.B. Woodbury (2004a) How to estimate forest carbon for large areas from inventory data. Journal of Forestry, 102: 25-31.

Smith, J.E., P.B. Woodbury, and L.S. Heath (2004b) Forest carbon sequestration and products storage. P. 80-93 and Appendix C in: *U.S. agriculture and forestry greenhouse gas inventory: 1990-2001*. USDA Technical Bulletin No. 1907. U.S. Department of Agriculture, Office of the Chief Economist, Washington, DC.

Smith, W.B., P.D. Miles, J.S. Vissage, and S.A. Pugh (2004c) Forest resources of the United States, 2002. General Technical Report NC-241. U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN. 137 p.

Smith, J.E., L.S. Heath, K.E. Skog, and R.A. Birdsey (2006) Methods for calculating forest ecosystem and harvested carbon, with standard estimates for forest types of the United States.

General Technical Report NE-343. U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, PA. 216 p.

Smith, J.E., L.S. Heath, and M.C. Nichols (2007) U.S. forest carbon calculation tool user's guide: forestland carbon stocks and net annual stock change. General Technical Report NRS-13. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA.

Ulrich, A.H. (1989) U. S. timber production, trade, consumption, and price statistics, 1950-1987. USDA Miscellaneous Publication No. 1471, U. S. Department of Agriculture, Forest Service, Washington, DC.

USDA. (1964) The demand and price situation for forest products, 1964. Miscellaneous Publication 983, U.S. Department of Agriculture, Washington, DC.

U.S. Department of Agriculture, Soil Conservation Service. (1991) State soil geographic (STATSGO) data base data use information. Misc. Publication Number 1492, USDA, Natural Resources Conservation Service, National Soil Survey Center, Fort Worth, TX.

USDA (2004) U.S. Agriculture and forestry greenhouse gas inventory: 1990-2001. Technical Bulletin No. 1907. U. S. Department of Agriculture, Office of the Chief Economist. 163 pp.

USDA FS (2006) Users guide to the forest inventory snapshot database version 2.1. U.S. Department of Agriculture, Forest Service. Available online at <http://www.ncrs2.fs.fed.us/4801/FIADB/fiadb_documentation/SNAPSHOT_DB_V2pt1_JULY_2006.pdf>.

USDA Forest Service. (2007) Forest inventory and analysis data center. U.S. Department of Agriculture, Forest Service, Washington, DC. Available online at <http://ncrs2.fs.fed.us/4801/fiadb/index.htm.>

USDA NRCS. (2006) State Soil Geographic (STATSGO) Database. Digital data. U.S. Department of Agriculture, Natural Resources Conservation Service. <http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/>.

Woodbury, P.B., L.S. Heath, and J.E. Smith. (2006). Land use change effects on forest carbon cycling throughout the southern USA. Journal of Environmental Quality, 35: 1348-1363.

Glossary of Terms and Units

CO_2	Carbon dioxide
CH_4	Methane
N_2O	Nitrous oxide
NO_x	Nitrogen oxides
C	Carbon
GHG	Greenhouse gas
GWP	Global warming potential
Tg	Teragram (1012 grams)
Tg CO_2 eq.	Teragrams of carbon dioxide equivalent
Gg	Gigagram (109 grams)
Mg	Megagram (106 grams)
t	Metric ton (1,000 kg)
ha	Hectares
DE	Digestible energy (percent)
Y_m	Fraction of gross energy converted to CH4
TDN	Total digestible nutrients
VOCs	Volatile organic compounds
VS	Volatile solids
DM	Dry matter
Btu	British thermal unit
Qbtu	Quadrillion British thermal units
Tbtu	Trillion British thermal units
EF	Emission factor
MCF	Methane conversion factor

Smith, James E., and Linda S. Heath. 2008. Carbon stocks and stock changes in U.S. forests, and Appendix C. P. 65-80, C-1-C-7 in: U.S. Department of Agriculture. U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2005. Technical Bulletin No. 1921. Washington, DC: Office of the Chief Economist.

This is only the forest section of the report.

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