ANNEX O

Methodology for Estimating Net Changes in Forest Carbon Stocks

This annex presents a discussion of the methodology used to calculate net changes in carbon stocks in trees, understory, forest floor, down dead wood, forest soils, wood products and landfilled wood. More detailed discussions of selected topics may be found in the references cited in this annex.

The details of carbon conversion factors and procedures for calculating net CO_2 flux for forests are given in three steps. In addition, the USDA Forest Service forest sector modeling projection system is described briefly.

Step 1: Estimate Forest Carbon Stocks and Net Changes in Forest Carbon Stocks

Step 1a: Obtain Forest Inventory Data

Forest survey data in the United States by broad forest type and region for 1987 and 1997 were obtained from USDA Forest Service, Forest Inventory and Analysis estimates of forest resources, published in Waddell et al. (1989) and Smith et al. (2001). The Forest Inventory and Analysis data include: (1) growing stock volume per acre by forest type (referred to hereinafter as "growing stock volumes"); and (2) area by timberland and other forest land, for general forest types by region (referred to hereinafter as "forest areas"). For 2001, the same variables were obtained from model results as described in Haynes (2002). (See Forest Sector Modeling Projection System below). This information was combined with separate estimates of carbon density (carbon mass per unit area) to estimate carbon stocks.

Step 1b: Estimate Carbon in Living and Standing Dead Trees

To estimate live tree biomass, equations that convert forest tree volumes to total live tree dry biomass (Smith et al. in press) were applied to the growing stock volumes by forest type and region (obtained in Step 1a). Tree biomass includes aboveground biomass and belowground biomass of coarse roots. The minimum sized tree is one-inch diameter at diameter breast height (1.3 meter). Trees less than one-inch diameter are counted as carbon in understory vegetation. Biomass estimates were divided by two to obtain estimates of carbon in living trees (i.e., it was assumed that dry biomass is 50 percent carbon). Standing dead tree biomass was calculated by applying equations that estimate biomass for standing dead trees (Smith et al., in press) from growing stock volumes. Again, standing dead tree biomass was divided by two to estimate carbon in standing dead trees. Table O-1 lists the average living and standing dead tree carbon densities by forest type, as calculated by applying the equations to the 1997 data.

Table O-1: Average U.S. Carbon Densities of Forest Components* (Metric Tons C/ha)

Region[a]/Forest Type	Live and Standing Dead Tree Carbon	Forest Floor Carbon	Soil Organic Carbon[b]
Eastern			
White-red-jack pine	77.1	13.8	196.1
Spruce-fir	59.8	40.2	192.9
Longleaf-slash pine	42.4	9.2	136.3
Loblolly-shortleaf pine	49.3	9.1	91.7
Oak-pine	57.3	11.6	82.3
Oak-hickory	76.3	6.6	85.0
Oak-gum-cypress	86.0	6.0	152.2
Elm-ash-cottonwood	67.6	23.0	118.1
Maple-beech-birch	82.5	28.0	139.5
Aspen-birch	56.0	7.6	237.0
Other forest types	1.8	2.1	99.6
Nonstocked	3.7	3.5	99.6

Western			
Douglas-fir	110.8	30.7	89.6
Ponderosa pine	66.3	20.3	70.4
Western white pine	69.2	25.8	68.3
Fir-spruce	113.0	37.4	137.5
Hemlock-Sitka spruce	152.4	34.1	157.1
Larch	97.0	30.2	65.6
Lodgepole pine	67.8	23.9	62.7
Redwood	186.6	26.9	85.8
Hardwoods	89.0	9.9	79.5
Other forest types	55.4	28.2	90.1
Pinyon-juniper	20.8	21.1	56.3
Chaparral	17.5	25.7	58.7
Nonstocked	18.1	24.4	90.1

* Based on 1997 data for major forest types of the conterminous United States.

[a]Eastern United States is defined as states east of, and including, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas. Western United States includes the remaining conterminous states.

[b]Soil includes both mineral soils and organic soils (i.e., histosols); carbon densities are to a depth of 1 meter.

Step 1c: Estimate Carbon in Understory Vegetation

To estimate carbon in understory vegetation, equations based on Birdsey (1992) were applied to the database that was used to produce the compiled forest statistics in Smith et al. (2001). Understory vegetation is defined as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than one-inch diameter, measured at breast height. A ratio of understory carbon to live tree carbon was calculated, and multiplied by 100 to calculate the percentage of carbon in the understory relative to that in live trees. These percentages were then averaged for each forest type in each region. This percentage was multiplied by the live tree carbon data in 1987 and 1997 to calculate understory carbon. These percentages are given in Table O-2. This procedure was used instead of applying the Birdsey equations directly, because detailed databases are not available for inventory years prior to 1987. Using estimated average values results in consistent historical carbon estimates for all survey years.

Table O-2: Ratios of Understory and Down Dead Wood Carbon to Live Tree Carbon* (Percent)

Region/Forest Type	Ratio of Understory Carbon to Live Tree Carbon	Ratio of Down Dead Wood Carbon to Live Tree Carbon
Northeast		
White-red-jack pine	2.5	10.8
Spruce-fir	2.6	13.3
Longleaf-Slash pine	2.5	10.8
Loblolly-shortleaf pine	2.5	10.8
Oak-pine	2.8	12.9
Oak-hickory	2.4	10.9
Oak-gum-cypress	2.6	11.1
Elm-ash-cottonwood	2.6	11.1
Maple-beech-birch	1.9	11.1
Aspen-birch	2.7	13.6
Other Forest Types	8.9	3.8
Nonstocked	8.9	3.8
North Central		
White-red-jack pine	1.8	9.8
Spruce-fir	2.2	17.4
Longleaf-Slash pine	2.4	7.4
Loblolly-shortleaf pine	2.4	7.4
Oak-pine	1.9	7.2
Oak-hickory	2.3	9.6
Oak-gum-cypress	2.3	9.6
Elm-ash-cottonwood	2.2	10.8
Maple-beech-birch	2.2	10.8
Aspen-birch	2.8	13.3
Other Forest Types	5.5	4.1
Nonstocked	5.5	4.1

Southeast		
White-red-jack pine	6.8	23.9
Spruce-fir	6.8	23.9
Longleaf-Slash pine	6.8	23.9
Loblolly-shortleaf pine	6.8	23.9
Oak-pine	5.2	28.0
Oak-hickory	4.4	24.2
Oak-gum-cypress	2.2	21.8
Elm-ash-cottonwood	2.2	21.8
Maple-beech-birch	4.4	24.2
Aspen-birch	2.2	21.8
Other Forest Types	11.9	2.0
Nonstocked	11.9	2.0
South Central		
White-red-jack pine	5.9	18.6
Spruce-fir	5.9	18.6
Longleaf-Slash pine	5.9	18.6
Loblolly-shortleaf pine	5.9	18.6
Oak-pine	4.4	17.3
Oak-hickory	3.7	15.0
Oak-gum-cypress	2.2	15.7
Elm-ash-cottonwood	2.2	15.7
Maple-beech-birch	3.7	15.0
Aspen-birch	2.2	15.7
Other Forest Types	16.9	1.7
Nonstocked	16.9	1.7
Pacific Northwest Eastside of Cascades		
Douglas-fir	1.6	10.0
Ponderosa Pine	2.5	12.6
Western White Pine	1.6	10.0
Fir-Spruce	1.1	15.7
Hemlock-Sitka spruce	1.6	10.0
Larch	1.6	10.0
Lodgepole pine	2.6	21.3
Redwood	1.9	25.8
Other hardwoods	1.4	8.9
Unclassified & other	2.5	12.6
Pinyon-Juniper	10.7	3.7
Chaparral	9.7	2.1
Nonstocked	9.7	2.1
Pacific Northwest Westside of Cascades		
Douglas-fir	2.0	11.9
Ponderosa Pine	2.5	18.1
Western White Pine	2.5	18.1
Fir-Spruce	1.0	13.7
Hemlock-Sitka spruce	1.0	13.7
Larch	2.0	11.9
Lodgepole pine	1.7	16.4
Redwood	2.0	11.9
Other hardwoods	4.5	3.9
Unclassified & other	1.7	16.4
Pinyon-Juniper	20.2	3.7
Chaparral	14.2	3.0
Nonstocked	14.2	3.0
Rocky Mountain, Northern		
Douglas-fir	2.6	19.2
Ponderosa Pine	2.4	19.6
Western White Pine	2.2	9.7
Fir-Spruce	1.7	14.8
Hemlock-Sitka spruce	2.0	18.7
Larch	2.2	9.7
Lodgepole pine	2.4	19.6

Redwood	2.2	9.7
Other hardwoods	1.9	14.2
Unclassified & other	2.2	9.7
Pinyon-Juniper	16.1	3.2
Chaparral	16.1	3.2
Nonstocked	16.1	3.2
Rocky Mountain, Southern		
Douglas-fir	2.8	19.4
Ponderosa Pine	4.1	21.6
Western White Pine	2.8	19.4
Fir-Spruce	2.2	17.4
Hemlock-Sitka spruce	2.8	19.4
Larch	2.8	19.4
Lodgepole pine	3.1	12.8
Redwood	2.8	19.4
Other hardwoods	9.2	26.7
Unclassified & other	10.7	3.3
Pinyon-Juniper	9.8	3.9
Chaparral	9.8	3.9
Nonstocked	2.6	15.2
Pacific Southwest		
Douglas-fir	2.3	15.5
Ponderosa Pine	2.6	15.2
Western White Pine	2.2	11.5
Fir-Spruce	2.6	15.2
Hemlock-Sitka spruce	2.6	15.2
Larch	4.6	10.8
Lodgepole pine	2.6	15.2
Redwood	4.4	9.7
Other hardwoods	2.8	11.5
Unclassified & other	9.9	3.1
Pinyon-Juniper	15.3	3.5
Chaparral	15.3	3.5
Nonstocked	2.5	10.8

* Based on data from 1997. Regions are defined in Figure 6-2 of the Land-Use Change and Forestry Chapter.

Step 1d: Estimate Carbon in Forest Floor

Forest floor carbon is the pool of organic carbon (litter, duff, humus, and small woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. To estimate carbon in the forest floor, equations developed by Smith and Heath (in press) were applied to the dataset described in Step 1a. Table O-1 shows the average forest floor carbon densities by forest type, as calculated based on the 1997 data.

Step 1e: Estimate Carbon in Down Dead Wood

Down dead wood is defined as pieces of dead wood greater than 7.5 cm diameter that are not attached to trees. Down dead wood includes stumps and roots of harvested trees. To estimate carbon in down dead wood, a procedure similar to estimating carbon in understory vegetation was used. Down dead wood was estimated in the projections by using decay rates applied to logging residue, along with equations that estimate the amount of down dead wood from causes other than harvesting. The percentage of down dead wood carbon relative to that in live trees was calculated. As for the understory carbon, average values of down dead wood were derived for each forest type in each region. This percentage was multiplied by the live tree carbon data from the dataset described in step 1a to calculate the total amount of carbon in down dead wood. These percentages are given in Table O-2. This procedure was used because detailed databases are not available for older data. By using this procedure, carbon estimates from historical data are consistent with carbon estimates from current Forest Inventory and Analysis data.

Step 1f: Estimate Forest Soil Carbon

To estimate the amount of carbon in forest soils, data for soils from the surface down to a depth of 1 meter were obtained from the STATSGO spatial database (USDA 1991). Then a spatial data set delineating forest types throughout the conterminous United States (Powell et al. 1993) was overlaid onto the soil carbon data from STATSGO. An estimate of the average amount of carbon in the soil was then calculated for each forest type. Estimates included both mineral soils and organic soils.[1] Coarse roots were included with tree carbon estimates rather than with soils. The soil carbon estimates are given in Table O-1. These estimates were multiplied by the area of forest land in each forest type for all years. Thus, any change in soil carbon is a reflection of changes in the area of forest land or changes in forest type.

Step 1g: Calculate Net Carbon Stock Changes

After calculation of all forest carbon stocks, the final step was to calculate the average annual net carbon stock change for each forest carbon pool for the years from 1990 through 2001. The net annual stock change for each pool for 1987 through 1997 was derived by subtracting the 1987 stock from the 1997 stock, and dividing by the number of years between estimates (10 years). The stocks, by definition, correspond to the stock as of January 1 of the given year. The net annual stock changes for 1997 through 2001 were derived in the same way using the 1997 and 2002 stocks. The procedure for estimating carbon stocks in 2002 is described below under the heading "Forest Sector Modeling Projection System."

Step 2: Estimate Harvested Wood Carbon Fluxes

The first step in estimating stocks and fluxes of harvested wood (i.e., wood products and landfilled wood) was to compile historical data on: the production of lumber, plywood and veneer, pulp and other products; product and log imports and exports; and fuelwood (in terms of million cubic feet of roundwood equivalent beginning in the year 1900, as described in Skog and Nicholson 1998). Data were obtained from USDA (1964), Ulrich (1989), and Howard (2001). Projected values for wood products and roundwood use were obtained from the models used for the USDA Forest Service 2000 Resource Planning Act Assessment (Haynes 2002, Ince 1994, see "Forest Sector Modeling Projection System" below). Roundwood products include logs, bolts, and other round timber generated from harvesting trees for industrial or consumer use. The harvested wood-to-carbon conversion factors presented by Skog and Nicholson (1998) were applied to annual estimates and projections to estimate the amount of carbon in roundwood and wood products. The amount of roundwood consumed was categorized according to product such as lumber, railroad ties, and paper, because the length of time that carbon remains in these products differs substantially. The dynamics of carbon loss through decay or through disposal of the product is summarized as the half-life of each product (Skog and Nicholson 1998). The resulting estimates were applied to products to derive the net carbon change in wood products and landfills. Note that, unlike forest carbon stock estimates, carbon in harvested wood products estimates are derived as a carbon stock change. In other words, the annual roundwood production is a change variable already before it is converted to carbon.

Step 3: Sum the Results from Step 1 and Step 2 for the Total Net Flux from U.S. Forests

In the final step, net changes in forest carbon stocks are added to net changes in harvested wood carbon stocks, to obtain estimates of total net forest flux (see Table O-3).

Table O-3: Net CO_2 Flux from U.S. Forest Carbon Stocks (Tg CO_2 Eq.)

Description	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Forests	**(773.7)**	**(773.7)**	**(773.7)**	**(773.7)**	**(773.7)**	**(773.7)**	**(773.7)**	**(546.3)**	**(546.3)**	**(546.3)**	**(546.3)**	**(546.3)**
Trees	(469.3)	(469.3)	(469.3)	(469.3)	(469.3)	(469.3)	(469.3)	(447.3)	(447.3)	(447.3)	(447.3)	(447.3)
Understory	(11.0)	(11.0)	(11.0)	(11.0)	(11.0)	(11.0)	(11.0)	(14.7)	(14.7)	(14.7)	(14.7)	(14.7)
Forest Floor	(25.7)	(25.7)	(25.7)	(25.7)	(25.7)	(25.7)	(25.7)	29.3	29.3	29.3	29.3	29.3
Down Dead Wood	(55.0)	(55.0)	(55.0)	(55.0)	(55.0)	(55.0)	(55.0)	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)
Forest Soils	(212.7)	(212.7)	(212.7)	(212.7)	(212.7)	(212.7)	(212.7)	(55.0)	(55.0)	(55.0)	(55.0)	(55.0)

[1] Organic soils, otherwise known as histosols, are soils that develop in wetland areas and have greater than 20 to 30 percent organic matter by weight depending on clay content.

Harvested Wood	**(209.0)**	**(198.0)**	**(202.8)**	**(203.9)**	**(210.5)**	**(205.3)**	**(205.3)**	**(212.7)**	**(205.3)**	**(216.3)**	**(209.0)**	**(212.7)**
Wood Products	(47.7)	(40.7)	(46.6)	(54.6)	(60.9)	(55.0)	(55.0)	(58.7)	(51.3)	(62.3)	(58.7)	(58.7)
Landfilled Wood	(161.3)	(157.3)	(156.2)	(149.2)	(149.6)	(150.3)	(150.3)	(154.0)	(154.0)	(154.0)	(150.3)	(154)
Total	**(982.7)**	**(971.7)**	**(976.4)**	**(977.5)**	**(984.1)**	**(979.0)**	**(979.0)**	**(759.0)**	**(751.7)**	**(762.7)**	**(755.3)**	**(759.0)**

Note: Parentheses indicate net carbon "sequestration" (i.e., accumulation into the carbon pool minus emissions or stock removal from the carbon pool). The sum of the net stock changes in this table (i.e., total net flux) is an estimate of the actual net flux between the total forest carbon pool and the atmosphere. Lightly shaded areas indicate values based on a combination of historical data and projections. Forest values are based on periodic measurements; harvested wood estimates are based on annual surveys. Totals may not sum due to independent rounding.

Forest Sector Modeling Projection System

The modeling projection system is a set of models that has been used for the USDA Forest Service, Resource Planning Act Assessment since the late 1980s (Figure O-1). The models include an area change model (Alig 1985), a timber market model (TAMM; Adams and Haynes 1980), a pulp and paper model (NAPAP; Ince 1994) and an inventory model (ATLAS; Mills and Kincaid 1992). Many of these models are econometric models, designed to project the demand and supply and prices in the forest sector. Results of the projection include timber volume, forest areas, harvests, and primary product production. For a description of the assumptions and results of the modeling system, see Haynes (2002).

The FORCARB model (Plantinga and Birdsey 1993, Heath and Birdsey 1993, and Heath et al. 1996) uses data on timber volume, forest areas, and harvests from the modeling system to estimate carbon in trees using biometrical relationships between carbon and live tree volume. FORCARB estimates carbon in all other forest ecosystem components, producing carbon density estimates similar to those in Table O-1 and Table O-2. The model WOODCARB (Skog and Nicholson 1998) uses harvested roundwood product statistics, along with end-use, decay rate, and duration information to estimate carbon in harvested wood.

Figure O-1 illustrates the connections between the various models, data inputs, and data outputs that comprise the forest sector modeling projection system. Names of model authors are in parentheses in each model box to facilitate identification of model citations. Data that are external to the models are marked with double lines.

Figure O-1: Forest Sector Modeling Projection System

Figure 0-1: Forest Sector Modeling Projection System