

A Greenhouse Gas Inventory of Oregon's Forests

Peter Kelly
Oregon Global Warming Commission Intern
Oregon Department of Energy
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Abstract

This document provides an inventory of the carbon flux, i.e., carbon stored in and released (in the form of CO₂), from Oregon's forests each year between 1990 and 2002 in order to support Oregon's efforts to inventory its net annual greenhouse gas emissions. The primary drivers of the ability of Oregon's forests to act as an increasing pool of carbon each year are the growth of trees, the rate of timber harvest, and the amount of forest lost to fire. Estimates suggest that Oregon's forests sequestered, on average, 18 million metric tons (MMT) CO₂ per year between 1990 and 2002, but with wide variability: 30 MMT CO₂ were sequestered in 1996 due to a combination of strong forest growth and decreased timber harvest, but in 2002 the forests released more CO₂ than they sequestered (due to dry weather that slowed forest growth and an unusually large fire—the Biscuit fire—that year), meaning they were an emissions source of 20 MMT CO₂ for that year. Greenhouse gas emissions from fossil fuel use and industrial processes in Oregon ranged from 55 MMT and 65 MMT CO₂-equivalent per year over the same time period. Data are outputs of a biogeochemistry model developed by the ORCA project, which is funded by the US Department of Energy and led by researchers at Oregon State University.

The Context of this Forest Inventory

In 2007, the Oregon legislature passed a bill¹ setting goals to reduce the state's emissions of greenhouse gases:

SECTION 2. (1) The Legislative Assembly declares that it is the policy of this state to reduce greenhouse gas emissions in Oregon pursuant to the following greenhouse gas emissions reduction goals:

- (a) By 2010, arrest the growth of Oregon's greenhouse gas emissions and begin to reduce greenhouse gas emissions.
- (b) By 2020, achieve greenhouse gas levels that are 10 percent below 1990 levels.
- (c) By 2050, achieve greenhouse gas levels that are at least 75 percent below 1990 levels.

In support of this effort the Oregon Department of Energy inventories the state's emissions of greenhouse gases with the cooperation of other state agencies. The majority of Oregon's GHG Inventory is performed using the State Inventory Tool from the US EPA². The EPA tool was not used for performing the GHG inventory of Oregon's forests; however, as its estimates diverged from the estimates of studies by Oregon State University and WESTCARB (described below). As such, a separate effort was necessary to assess the carbon stored in Oregon's forests (translated to CO₂ for inventory purposes) that could be incorporated into the other output from the EPA State Inventory Tool.

About 28 million of Oregon's 61 million-acre land base is forest land, and while other parts of the country have experienced extensive forest land loss to development, Oregon retains about 92% of the forest cover that was present in 1850. The data used in this inventory are based on a definition of forest land provided by the 2001 National Land Cover Database: "Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover."³

The Forest as a Carbon Pool

To understand this inventory it is helpful to think about a forest as a pool of carbon: when carbon is stored in the forest pool, it cannot be in the atmosphere, the ocean, or in the form of fossil fuels. Forests store carbon in the biomass of live and dead vegetation and in soil. Additionally, standard GHG accounting requires estimation of the carbon stored in harvested wood products that remain in use for a long time (wood frames for houses, for example), including while those products are partially decomposed. Carbon enters the forest pool by becoming live vegetation through photosynthesis, and leaves it through combustion (fire), plant decomposition, product decomposition in landfills, and soil decomposition. As carbon is released into the atmosphere it joins with oxygen to become CO₂ at a ratio of 1 unit of carbon to 3.67 units of CO₂.

Though data reported here are in million metric tons CO₂ for the purposes of conforming to greenhouse gas accounting standards, the qualitative descriptions in the inventory attempt to reflect reality by referring to either "carbon" or "CO₂" as appropriate—carbon when solid biological matter is being referred to, and CO₂ when a greenhouse gas is being referred to.

Any time carbon is removed or kept out of the atmosphere it is considered "sequestered" in a "pool" of carbon, and as it re-enters the atmosphere it is considered a "release" or an "emission". More commonly both positive and negative flows of carbon in and out of the forest "pool" are captured in the single term "carbon flux". Positive flux is sequestration, and negative flux means that the forest is acting as a source of emissions. An illustration of the forest carbon cycle is below, taken from the US EPA's National

¹ House Bill 3543 can be found at: <http://www.leg.state.or.us/07reg/measures/hb3500.dir/hb3543.en.html>

² Sectors for which the EPA tool is not used are waste, energy, forestry, and agriculture.

³ National Land Cover Database website. Definitions available at http://www.mrlc.gov/nlcd_definitions.php

Inventory of Greenhouse Gas Emissions and Sinks⁴. Note that the forestry inventory considers changes on both forested land and changes in forest carbon when it leaves the forest as harvested wood product (estimated here as Net Product Sink).

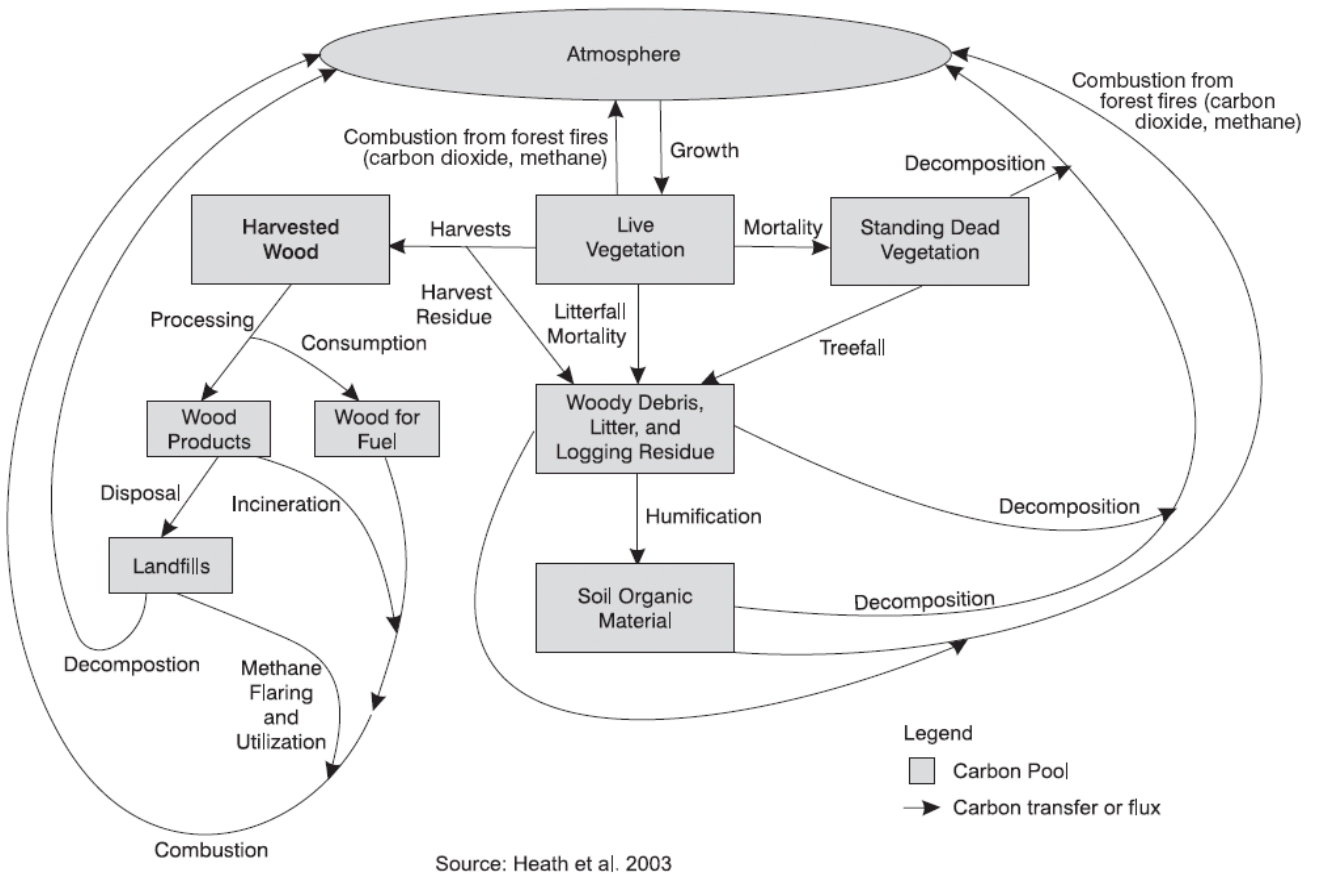


Figure 1: Forest Carbon Cycle. Source: EPA 2008

The typical method for estimating forest sequestration is to sample sections of the forested area at two points in time⁵, estimating the carbon stored in the sample area using a combination of direct measurement and derived estimates. Researchers at Oregon State University, however, are conducting research that allows for annual estimates based on a combination of site-survey data, forest ecosystem modeling, and estimates of forest disturbances like fire and harvest. This allows for estimates of forest sequestration that vary in response to changes in forest growth, fire, and harvest.

One last note of importance is to clarify that this inventory focuses on Oregon's *forests*, not on Oregon's *forestry sector*. It estimates the change in CO₂ sequestered in Oregon's forest in any given year—it does not try to account for the emissions associated with timber and biomass production activities such as transportation or lumber processing⁶. Timber harvest removals impact the amount of carbon stored in the forest—and harvest is accounted for in this inventory—but this is not the same as accounting for the emissions associated with the harvest, processing, delivery, or use of the timber product.

⁴ *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2006*. EPA 2008, page 78. Available on the web at http://www.usda.gov/oce/global_change/AFGGInventory1990_2005.htm

⁵ This is the stock-difference method described in *Alternate Methods for Performing a Forest Inventory*. The two points in time are generally six to 10 years apart, due both to logistical reasons and the fact that forest ecosystems are so dynamic that changes in a smaller time period will be due to inter-annual climate changes.

⁶ Transportation and Industry are covered under separate parts of Oregon's GHG inventory.

Carbon Flux from Oregon's Forests 1990 to 2002

The inventory shows that Oregon's forests sequester CO₂ each year in the form of carbon stored in the biomass of trees, fallen tree parts and litter, and soil carbon. On average, this was about 18.5 million metric tons (MMT) CO₂ per year between 1990 and 2002, but with wide variability: 46.5 MMT CO₂ were sequestered in 1996 due to a combination of strong forest growth and decreased timber harvest, and in 2002 the forests released more CO₂ than they sequestered (due to dry weather that slowed forest growth and an unusually large fire—the Biscuit fire—that year), meaning they were an emissions source of 6.8 MMT CO₂ for that year. As a comparison, emissions from fossil fuels and industrial processes in Oregon have varied between 55 MMT and 68 MMT CO₂ per year.

The dominant drivers of a forest's ability to store carbon are forest growth, the quantity of wood that is removed as harvested timber, and the quantity of wood that is lost in fire. In most years, forest growth is significantly larger than the amount of wood removed by harvest or fire, and so carbon is sequestered in the biomass of the forest. In Oregon, land-use change is not considered a major contributor to forest carbon sequestration patterns, as discussed later. In this inventory, most data are presented as CO₂ for consistency and comparison to the rest of the state's greenhouse gas inventory.

The forest greenhouse gas inventory includes data on:

- Net Biome Productivity, as defined below in the section Ecosystem Productivity (NEP)
- carbon lost due to timber harvest,
- carbon stored in the form of long-lived consumer wood products, and
- carbon lost due to wildfire.

Forest fires emit N₂O and methane in addition to CO₂ as a result of the chemistry of combustion, but those gases are excluded; only the CO₂ emissions (i.e., the carbon taken from the forest pool and released to become a greenhouse gas) are estimated in this inventory.

The chart below indicates the annual total CO₂ sequestered by Oregon's forests (except 2002, when the forests were a source of emissions) and the contribution of timber harvest, forest product, and fire to carbon flux. Note that the "Net Forest Carbon Flux" line includes the contribution of the other lines.

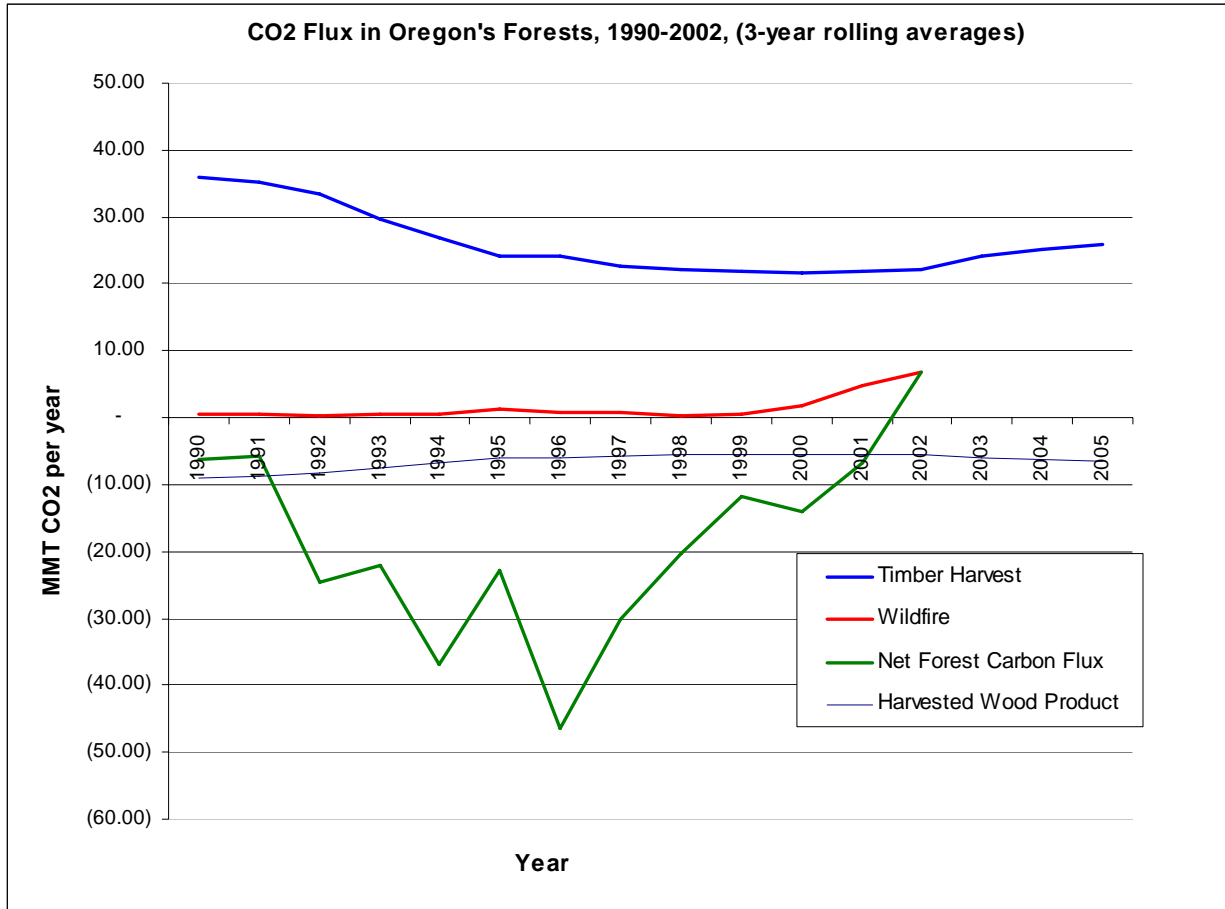


Figure 2: Inventory (as 3-year rolling average) of GHG Sources and Sinks for Oregon's Forests, 1990-2002

There were significantly larger rates of sequestration in the mid-late 1990s (on average 40.2 MMT CO₂/year), compared to the rest of the study period. This is largely due to favorable climate for forest growth—1993 was particularly cool, and the years since 2000 have been relatively dry. The end of the study period indicates that Oregon's forest became a source rather than a sink for CO₂, due to a combination of low forest growth (due to dry weather) and high fire emissions. The 2001 and 2002 removals from the carbon pool are abnormal, however, and it is expected that future years will show that Oregon's forests revert to being a carbon sink. Data from 2002-2005 are forthcoming and will supplement this forest inventory when they are available.

Supporting Data and Analysis

Below the data and analysis used for the inventory are summarized. In order to better reflect the long-term processes involved with carbon flux 3-year rolling averages are used for the inventory because annual estimates are highly variable and, when placed in the context of annual greenhouse gas accounting schemes, tend to overemphasize artificial short-term fluctuations at the expense of identifying long-term trends. The variability in annual estimates is largely due to the high variability in Forest NBP as explained below. Terminology used in these tables is explained below on the last page of this document.

Table 1: Forest Carbon Flux Inventory, with Comparison to Oregon Gross GHG Emissions. A positive value indicates a source of emissions and a negative value indicates sequestration.

	Forest NEP (3-yr rolling average), in MMT CO ₂	Timber Harvest Removal (3-yr rolling average), in MMT CO ₂	Wildfire (3-yr rolling average) in MMT CO ₂	Forest NBP (3-yr rolling average) in MMT CO ₂	Net Product Sink (NPS) ⁷ (3-yr rolling average), in MMT CO ₂	Net Forest Carbon Flux (3-yr rolling average), in MMT CO ₂	Oregon Gross GHG Emissions (3-yr rolling average), in MMT CO ₂	Net Forest Carbon Flux as percent of Oregon Gross GHG Emissions (3-yr rolling average), in MMT CO ₂
1990	(33.69)	36.04	0.41	2.76	(9.01)	(6.25)	55.52	-11%
1991	(32.63)	35.24	0.46	3.07	(8.81)	(5.74)	56.83	-10%
1992	(49.81)	33.43	0.24	(16.13)	(8.36)	(24.49)	59.09	-41%
1993	(44.97)	29.70	0.61	(14.66)	(7.42)	(22.08)	60.85	-36%
1994	(57.48)	26.89	0.52	(30.08)	(6.72)	(36.80)	63.01	-58%
1995	(42.09)	24.21	1.18	(16.70)	(6.05)	(22.75)	64.27	-35%
1996	(65.33)	24.04	0.81	(40.49)	(6.01)	(46.50)	65.46	-71%
1997	(47.87)	22.53	0.78	(24.57)	(5.63)	(30.20)	66.32	-46%
1998	(37.28)	22.21	0.21	(14.86)	(5.55)	(20.41)	67.34	-30%
1999	(28.66)	21.77	0.51	(6.38)	(5.44)	(11.82)	68.27	-17%
2000	(32.07)	21.59	1.89	(8.59)	(5.40)	(13.99)	68.56	-20%
2001	(28.21)	21.91	4.91	(1.39)	(5.48)	(6.86)	67.62	-10%
2002	(16.05)	21.57	6.87	12.40	(5.39)	7.00	66.33	31%

⁷ Note that the pool of carbon stored in long-lived consumer wood products—Net Product Sink (NPS)—is estimated as a percent of Harvest Removal. NPS is estimated here by multiplying Harvest Removal for that year by 25% and again by -1 to indicate that it is a carbon sink. The factor of 25% was chosen based on academic research by Dr. Mark Harmon at Oregon State University, and is described below.

Table 2: Same as Table 1, but using annual estimates rather than 3-yr rolling averages

	Forest NEP (MMT CO ₂)	Timber Harvest Removal (MMT CO ₂)	Wildfire (MMT CO ₂)	Forest NBP (MMT CO ₂)	Net Product Sink (NPS) (MMT CO ₂)	Net Forest Carbon Flux (MMT CO ₂)	Oregon Gross GHG Emissions (MMT CO ₂)	Net Forest Carbon Flux as percent of Oregon Gross GHG Emissions (MMT CO ₂)
1990	(44.17)	36.44	0.71	(7.02)	(9.11)	(16.13)	55.5	-29%
1991	(23.20)	35.63	0.12	12.55	(8.91)	3.64	57.6	6%
1992	(30.51)	33.65	0.55	3.69	(8.41)	(4.72)	57.4	-8%
1993	(95.72)	31.02	0.06	(64.64)	(7.76)	(72.39)	62.3	-116%
1994	(8.67)	24.42	1.22	16.97	(6.10)	10.86	62.9	17%
1995	(68.05)	25.22	0.27	(42.56)	(6.31)	(48.86)	63.8	-77%
1996	(49.55)	22.98	2.06	(24.51)	(5.75)	(30.25)	66.1	-46%
1997	(78.40)	23.92	0.09	(54.40)	(5.98)	(60.38)	66.5	-91%
1998	(15.67)	20.70	0.18	5.21	(5.17)	0.03	66.4	0%
1999	(17.78)	22.03	0.36	4.62	(5.51)	(0.89)	69.2	-1%
2000	(52.53)	22.58	1.00	(28.95)	(5.65)	(34.60)	69.3	-50%
2001	(25.91)	20.16	4.32	(1.44)	(5.04)	(6.48)	67.3	-10%
2002	(6.18)	22.98	9.43	26.23	(5.75)	20.48	66.3	31%
2003	-	23.45	-	-	(5.86)	-	-	-
2004	-	26.08	-	-	(6.52)	-	-	-
2005	-	25.52	-	-	(6.38)	-	-	-

Alternate Methods for Performing a Forest Inventory

The Intergovernmental Panel on Climate Change (IPCC) provides guidelines on performing greenhouse gas inventories for forests. Its recommendations are broadly divided into two methods: the stock-difference method and the gain-loss method.⁸ In the stock-difference method, an inventory is taken of the total stock of forest carbon in two years, and the difference between the two is found by subtracting the earlier year from the later one—the difference represents the total gain or loss in the carbon pool over that time period, and annual estimates are derived by dividing the total change by the number of years between the two inventories. In the gain-loss method, changes in the forest carbon pool are estimated for each year individually.

Oregon's forestry inventory is performed using the gain-loss method because it allows for greater insights driven by an understanding of year-by-year variability. The data critical to the gain-loss method are available from researchers at Oregon State University (the ORCA project, detailed below), making such an inventory possible. It is important, however, that the output from Oregon's Forest Inventory be comparable to the national inventory for the United States and, ideally, to that of Oregon's neighboring states. For that reason a variety of methodologies were investigated before settling on the methodology employed in this report. The following methods and data sources are presented so as to provide comparison with the method chosen for this inventory.

WESTCARB report

The West Coast Regional Carbon Sequestration Partnership (WESTCARB) is a federally-funded research partnership to characterize carbon sequestration opportunities in the western United States. According to the WESTCARB website⁹:

Established in Fall 2003, WESTCARB is one of seven research partnerships co-funded by the U.S. Department of Energy (DOE) to characterize regional carbon sequestration opportunities and conduct technology validation field tests. The California Energy Commission manages WESTCARB and is a major co-funder.

DOE will combine WESTCARB's findings with those of other partnerships to create an interactive national "carbon atlas" (NATCARB) to better understand how sequestration technology can help the United States and Canada reduce the carbon intensity of their economies and mitigate changes in the climate.

In 2007, WESTCARB published *Baseline Greenhouse Gas Emissions and Removals for Forests and Agricultural Lands in Oregon*¹⁰. As described in page 1 of the report:

The forest baseline is separated into three components: a general forests baseline, a baseline effect of development, and a baseline effect from fire. The general forests baseline is presented at the state level for all forest lands, based on U.S. Department of Agriculture (USDA) Forest Service data, detailing change in forest area and change in carbon stocks, but with no attribution to the causes for the change. Using additional databases, the specific cases of emissions associated with development and emissions associated with fire are further examined.

⁸ See for more information, see *Carbon Inventory Methods: Handbook for Greenhouse Gas Inventory, Carbon Mitigation, and Roundwood Production Projects*, by N.H. Ravindranath and Madelen Ostwald (2008).

⁹ http://www.westcarb.org/about_overview.htm

¹⁰ See the WESTCARB Phase 1 report *Baseline Greenhouse Gas Emissions and Removals for Forest and Agricultural Lands in Oregon*, November 2007. Available online at <http://www.energy.ca.gov/2007publications/CEC-500-2007-025/CEC-500-2007-025.PDF>

The WESTCARB report uses the stock-difference method, though it only analyzes above-ground biomass, ignoring soil carbon and below-ground biomass. It estimates that Oregon sequestered, on average each year, 23 MMT CO₂ between 1987 and 1997, and 34.4 MMT between 1997 and 2003. These estimates are generally similar to the multi-year averaged annual estimates in this inventory. However, the WESTCARB report does not provide annual estimates, and for that reason is not as useful for greenhouse gas inventory accounting as the methodology used in this report.

The State of Washington

Washington's GHG Inventory for Forest and Rangeland¹¹ estimates a fixed annual rate of CO₂ sequestration by its forests and uses that number as a constant sink of CO₂ in its total inventory. It follows the methodology of the US EPA and uses Forest Service data sets by estimating forest stock in 1991 and 2005, determining the difference between the two, and deriving an annual estimate. This approach, however, does not provide the year-by-year insight that the gain-loss estimate provides.

As described in the Washington inventory:

The forest CO₂ flux methodology relies on input data in the form of plot level forest area and volume statistics from the Forest Inventory Analysis (FIA). FIA data on forest volumes are converted to values for ecosystem carbon stocks (i.e., the amount of carbon stored in forest carbon pools) using the FORCARB2 modeling system. Coefficients from FORCARB2 are applied to the plot level tree measurements to give estimates of C density (Mg per hectare) for the tree carbon pool. The carbon content of other pools is estimated using relationships between tree carbon and those pools. Soil carbon is estimated as a function of forest cover type.

The State of California

California's GHG Inventory for Forest and Rangelands¹² follows the stock-difference method and excludes inventory of soil organic carbon, agricultural lands, wetlands, and urban areas. Estimates for carbon in forest and rangeland is based on surveys of three forested areas in the northern part of the state in 1994 and 2000, scaled to the rest of the state, forecasted to 2004, and backcasted to 1990. Scaling of data from the three study areas to the rest of the state is based on the fraction of statewide forest and range lands represented in the study areas.

California does not use EPA's State Inventory Tool, the CCT, or the FORCARB model described by Washington. Instead, it relies on research from WESTCARB.

The US National Inventory

The EPA's national inventory¹³ uses the stock-difference method, including the following subcategories for forests:

- Aboveground Biomass
- Belowground Biomass
- Dead Wood

¹¹ See Washington's *Inventory at Greenhouse Gas Inventory and Reference Case Projections, 1990-2020*. Prepared by the Center for Climate Strategies in December 2007. Forestry is discussed in Appendix H, on page 86 of the report. Available at: http://www.ecy.wa.gov/climatechange/GHG_inventory.htm

¹² Description and Technical Support Document are available at <http://www.arb.ca.gov/cc/inventory/sectors/forest/forest.htm>

¹³ The EPA's Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2007 is available at <http://epa.gov/climatechange/emissions/usinventoryreport.html>

- Litter
- Soil Organic Carbon
- Wood products and landfills

The categories taken from ORCA research (NEP, harvest emissions, and fire emissions) are not equivalent to IPCC categories, but their sum—NBP—is equivalent to the first five categories. Though the Biome-BCG model details changes across all the above-listed carbon pools, the primary pool that contributes to changes in any given year are in the above-ground biomass (specifically the bole-wood) carbon store. Net Product Sink is equivalent to the IPCC category of “Wood products and landfills”.

US EPA Inventory Categories

- Aboveground Biomass
- Belowground Biomass
- Dead Wood
- Litter
- Soil Organic Carbon
- Wood products and landfills



Oregon Inventory Categories

NBP (Net Biome Productivity) is a sum of:

- NEP (Net Ecosystem Productivity)
- Fire emissions
- Harvest (removal) emissions



NPS (Net Product Sink)

The national inventory also includes within its forest inventory an inventory of rangeland, agricultural land, wetlands, and urban areas. Though agricultural land is included as a supplement to this Forest Inventory, wetlands, rangelands, and urban areas are not explicitly calculated.

The EPA State Inventory Tool

The EPA provides a tool to state agencies preparing state-level emission inventories, called the State Inventory Tool (SIT), which is used by Oregon for most aspects of its greenhouse gas inventory process. The SIT relies on the USDA’s Forest Carbon Calculation Tool (CCT) to determine state-level forest carbon estimates according to the stock-difference method. The gain-loss method was preferred for Oregon’s forest inventory.

The CCT is a “computer application that reads USDA Forest Service’s Forest Inventory and Analysis Program (FIA) data and generates state-level annualized estimates of carbon stock and stock change on forests. This tool reads publicly available FIA forest inventory data and replicates the process to generate forest carbon estimates supplied to the U.S. Environmental Protection Agency for the annual inventory of U.S. greenhouse gas emissions and sinks.”¹⁴ The CCT relies on the FORCARB2 modeling system to generate estimates.

Methodology and Supporting Research Used in this Inventory

This inventory was developed using data and analysis from the ORCA project¹⁵, a study aimed at understanding disturbance and climate effects on the carbon balance of Oregon and Northern California. The project is funded by the US Department of Energy and implemented by the Terrestrial Ecosystem Research and Regional Analysis Group – Pacific Northwest (TERRA-PNW)¹⁶. Professors Beverly Law

¹⁴ From a factsheet on the USDA website: http://www.nrs.fs.fed.us/carbon/local-resources/downloads/CCT_NRS13.pdf

¹⁵ <http://terraweb.forestry.oregonstate.edu/orca.htm>

¹⁶ <http://terraweb.forestry.oregonstate.edu/projects.htm>

and Dave Turner at Oregon State University lead this effort and provided critical information and consultation in the preparation of this forest inventory.

Estimates for Net Forest carbon flux for the inventory are arrived at by taking the total carbon sequestered by the forest ecosystem¹⁷, subtracting carbon loss due to fire and timber harvest, and adding back in carbon stored in wood products¹⁸. All data are in Million Metric Tons (MMT) CO₂.

Annual Forest Carbon Flux Estimate = ecosystem productivity of forested land (NEP) – fire emissions – timber harvest + carbon stored in durable wood products

Each variable included in the annual forest carbon flux estimate is described below.

Ecosystem Productivity (NEP)

Net Ecosystem Productivity (NEP) describes the difference between plant sequestration¹⁹ of CO₂ and the respiration of all non-plant organisms living in the forest.

NEP is an output of ORCA's Biome-BCG model. Biome-BCG is a biogeochemistry model that takes input data from a variety of sources, models the photosynthesis, respiration, and decomposition of a forest ecosystem, and outputs the Net Ecosystem Productivity of the forest across time. It uses as its inputs:

- LANDSAT satellite imaging data taken every 2-5 years to determine forest age and type, as well as to identify disturbances to forest canopy cover due to major fire and logging events²⁰;
- Meteorological data that include temperature, precipitation, humidity, and solar radiation.

The Biome-BCG model combines LANDSAT and site-specific survey data to describe 25 meter grid cells of Oregon's forest, and then simulates changes in forest age and size for each grid cell from 1980 to 2002. These simulations incorporate the effects of fire and logging (as observed from LANDSAT data), meteorological data, and growth estimates.

Land-Use Change

Changes in the amount of total forested land in Oregon are not counted in the ORCA methodology. The model fixes the total forested land in Oregon at the 2001 estimates for the purposes of scaling up from site surveys. Forested land lost due to land-use change has been constant and small relative to Oregon's total forest land, and so is not considered a primary driver of the emissions profile of Oregon's forests.

Other research corroborates this decision: in 2007, the WESTCARB study of Oregon's forests noted earlier estimated that at most 1.54 MMT CO₂ per year are emitted due to land-use change on private forestland.²¹

Fire Emissions

Data on fire emissions came from ORCA and are based on satellite data. They are considered strongly conservative numbers because they only capture biomass that has been lost in forests where over 50%

¹⁷ Defined in the section Ecosystem Productivity (NEP)

¹⁸ Defined in the section Net Product Sink.

¹⁹ Plant sequestration is itself the difference between plant photosynthesis (defined as Gross Primary Productivity, or GPP) and plant respiration. GPP is less important to policy-makers than to foresters, and so is excluded from this summary.

²⁰ Land-use change is not considered in the Biome-BCG model.

²¹ See the WESTCARB Phase 1 report *Baseline Greenhouse Gas Emissions and Removals for Forest and Agricultural Lands in Oregon*, November 2007. Available online at <http://www.energy.ca.gov/2007publications/CEC-500-2007-025/CEC-500-2007-025.PDF>

of crown-cover is burned, thus omitting areas that are partially burned or only have understory fires. They assume 100% of foliar, fine root, and litter carbon is emitted, and that 7% of aboveground wood is emitted (Turner et al., 2007 p. 601). Though a variety of methods exist for estimating fire emissions, it was decided to use the estimates from ORCA since data on NBP is also coming from the same source.

Timber Harvest

Timber harvest data are also from ORCA, who received them from the Oregon Department of Forestry. Data include harvest from both public and private lands. Unlike other data within the inventory, data on timber harvest prior to 1990 and after 2002 are available. They indicate that timber harvest significantly declined around 1990, and have been stable in recent years. Note that Timber Harvest does not account for the carbon stored in long-lived forest product or in landfills, which is accounted for in the category “Net Product Sink” and is estimated at 25% of the annual Timber Harvest.

Table 3: Carbon (expressed as MMT CO₂) removed by timber harvest removal, 1980-2005

	Harvest Removal (in MMT CO ₂)		Harvest Removal (in MMT CO ₂)
1980	38.91	1993	31.02
1981	33.37	1994	24.42
1982	33.74	1995	25.22
1983	43.74	1996	22.98
1984	44.24	1997	23.92
1985	47.63	1998	20.70
1986	51.23	1999	22.03
1987	48.14	2000	22.58
1988	50.48	2001	20.16
1989	49.34	2002	22.98
1990	36.44	2003	23.45
1991	35.63	2004	26.08
1992	33.65	2005	25.52

Note that some of this carbon stays sequestered in the form of harvested wood product, as described in Net Product Sink below.

Net Product Sink

Researchers estimate that there is “disequilibrium between harvest emissions from all previous harvests and total current harvests”.²² That leads to the estimate that between 20-25% of a year’s harvested forest

²² Turner, D.P, W.D. Ritts, B.E. Law, W.B. Cohen, Z. Yang, T. Hudiburg, J.L. Campbell, M. Duane. 2007. Scaling net ecosystem production and net biome production over a heterogeneous region in the western United States. *Biogeosciences Discussions* 4:1-43. Available at <http://terraweb.forestry.oregonstate.edu/publications.htm#2007>

product is stored in long-lived products. As such, this row of data merely reflects 25% of total harvest for that year.²³

This estimate is not as strict an accounting procedure as recommended by the IPCC for Harvested Wood Product (HWP)²⁴, but further work on defining this sub-pool was limited by time and budget.

Agriculture NBP

The ORCA model also includes data on carbon sequestration in agricultural lands and for Oregon as a whole. Agriculture NBP refers to the Net Biome Productivity of agricultural land in Oregon. It represents the annual sequestration of CO₂ into agricultural land, primarily in the form of carbon stored in agricultural soil. The NBP for Agriculture and Forest do not sum to Oregon Total NBP because there is also NBP in miscellaneous other ecosystem types, such as rangelands and wetlands. For purposes of comparison, carbon sequestration numbers for these categories are included below.

Table 4: Comparison of Agricultural, Forest, and Total NBP

	Agriculture NBP (3-yr rolling average), in MMT CO ₂	Forest NBP (3-yr rolling average), in MMT CO ₂	Other NBP (3-yr rolling average), in MMT CO ₂	Oregon Total NBP (3-yr rolling average), in MMT CO ₂
1990	2.30	2.76	(4.66)	0.4
1991	(1.44)	3.07	3.87	5.5
1992	1.26	(16.13)	(14.73)	(29.6)
1993	(2.63)	(14.66)	4.59	(12.7)
1994	1.45	(30.08)	(19.87)	(48.5)
1995	(1.20)	(16.70)	(6.8)	(24.7)
1996	2.48	(40.49)	(27.49)	(65.5)
1997	(0.71)	(24.57)	(10.62)	(35.9)
1998	(3.02)	(14.86)	4.98	(12.9)
1999	(1.72)	(6.38)	6.6	(1.5)
2000	(3.06)	(8.59)	22.45	10.8
2001	(3.27)	(1.39)	24.76	20.1
2002	(7.03)	12.40	41.13	46.5

WESTCARB also estimates carbon sequestration on agricultural lands, and estimates that agricultural land was a source of about .06 MMT CO₂ emitted each year between 1987 and 1997 due to land-use changes that affect biological sequestration on agricultural land in Oregon.²⁵ The estimate of .06 MMT CO₂ emitted per year compares to ORCA's estimate of .02 MMT CO₂ sequestered per year (.02 is the average of ORCA's estimates from 1990-1997). Therefore, although there is a difference in sign between

²³ *Ibid.* Turner *et al* refer to Harmon, M. E., Harmon, J. M., Ferrell, W. K., and Brooks, D.: Modeling carbon stores in Oregon and Washington forest products: 1900–1992, *Climatic Change*, 33, 521–550, 1996. Harmon has also stated that an estimated 20% of a harvest is stored in long-lived forest products, as available in this presentation: <http://www.orwoodlandco-op.com/ForestCarbonBasics.pdf>

²⁴ IPCC guidelines available at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html>

²⁵ WESTCARB also considers agricultural emissions due to fertilizer use; this estimate does not include those emissions.

the two estimates, they both demonstrate that agricultural lands are likely neutral, i.e., given the likely margins of error these lands are neither a significant sink nor a source of greenhouse gas emissions.

Explanation of Annual Data Variability

Both photosynthesis and respiration transfer very large amounts of carbon—photosynthesis from the atmosphere and respiration back into it. Biome-BCG estimates both of these numbers independently and then subtracts the difference to arrive at NEP. Because both numbers are so large and are driven by different factors, relatively small changes in either can result in a large change in NEP. In short, a large difference in NEP is driven by a small divergence between two extremely large numbers. Because the change in carbon stocks is based on NEP, a large change in NEP will significantly affect the sequestration for that year.

The chart below illustrates the variation in Biome-BCG’s output data. The green line determines NBP using a 3-year rolling average for NEP, Timber Harvest Removal, and Wildfire data. A 3-year rolling average was chosen because it minimizes large swings in NEP estimates while retaining a sense of variability from year to year. This allows for a focus on the long-term trend rather than year-over-year variability.

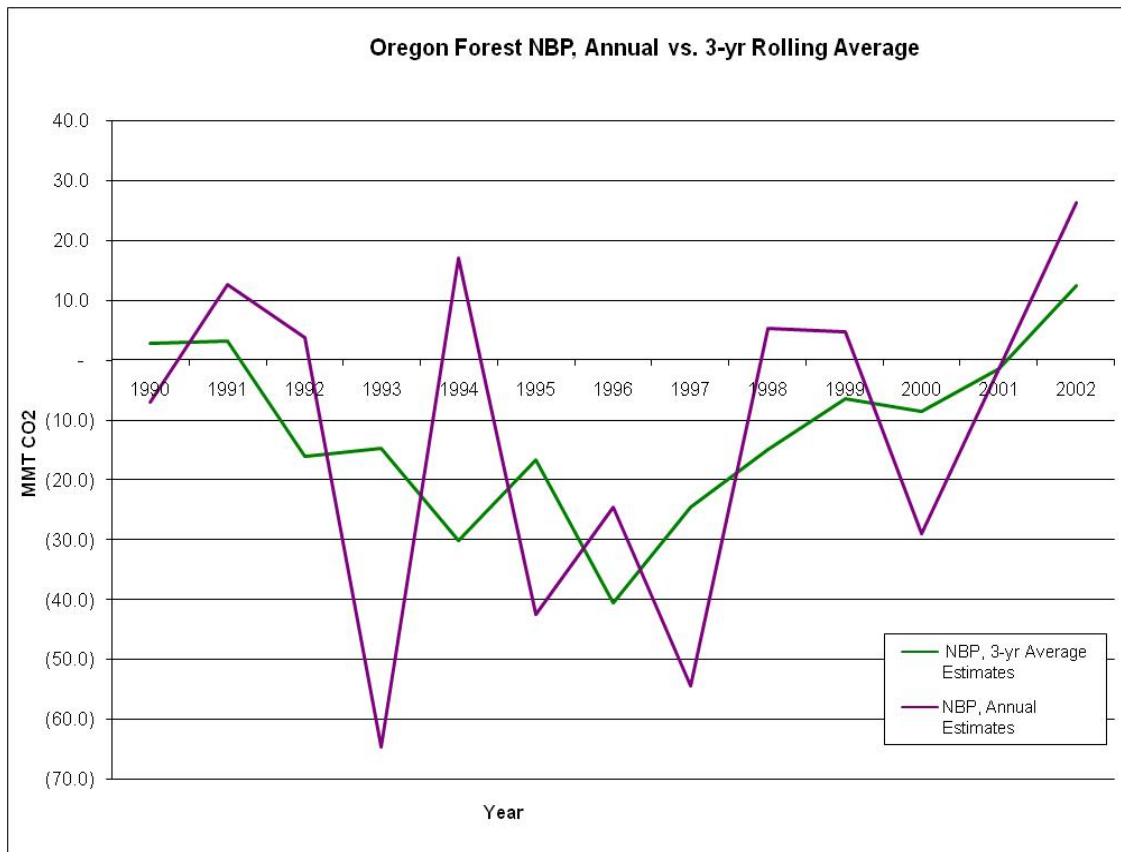


Figure 3: Comparison of Annual and 3-year Rolling Average Estimates

Modifications Made to ORCA Data

Some modifications were made to the data from ORCA to convert them into standard GHG accounting units as suggested by the IPCC and performed by the EPA State Inventory Tool. Modifications were limited to:

- Units were changed from Teragrams carbon (TgC) into Million Metric Tons Carbon (MMT C) using a conversion factor of 1 TgC to 1 MMT C;
- Carbon was converted to CO₂ using a conversion factor of 1 MMTC to 3.67 MMT CO₂;
- NEP and NBP, both considered positive numbers in the Biome-BCG model, were multiplied by negative 1 for the purposes of comparison to gross emission numbers (that is, to indicate that these categories generally represent carbon sinks).
- A three-year rolling average was applied, and both the three-year rolling average and the annual estimate were provided in the report. The rationale for this is explained above.

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Disclaimer

These estimates do not represent an “official” inventory of the State of Oregon, but rather a working “white paper” document intended to offer one approach to interpreting these data. Though many thanks are due to Oregon State University, WESTCARB, the Oregon Department of Forestry, and the California Air Resources Board, this analysis does not represent the official views of those bodies.

This analysis was prepared independently from Oregon State University and responsibility for the interpretation of these data, including errors in that interpretation or the resulting analysis, lies solely with the author and his supervisor at the Oregon Department of Energy.

Terms, Acronyms, and Important Definitions

MMT	Million Metric Tons. The standard unit of measure for GHG reporting.
NPP	Net Primary Productivity. Represents the net effect of photosynthesis and plant respiration
NEP	Net Ecosystem Productivity. Represents NPP minus respiration associated with bacterial decomposition.
NBP	Net Biome Productivity. Represents NEP minus harvest removal minus wildfire. Is not the same as the complete forest inventory because it does not consider carbon stored in long-lived wood products, estimated here as NPS.
NPS	Net Product Sink. Represents change in carbon stored in consumer products made of wood or in landfills
TERRA-PNW	The Terrestrial Ecosystem Research and Regional Analysis – Pacific Northwest program. TERRA-PNW is performing the ORCA research
ORCA	A study aimed at understanding disturbance and climate effects on the carbon balance of Oregon and Northern California, funded by DOE, and lead by researchers at Oregon State University. http://terraweb.forestry.oregonstate.edu/orca.htm
Biome-BCG	A biogeochemistry model that takes input data from a variety of sources, models the photosynthesis, respiration, and decomposition of a forest ecosystem, and outputs the Net Ecosystem Productivity of the forest across time.
Carbon to CO ₂	1 unit of carbon is considered equivalent to 3.67 units of CO ₂
FIA	Forest Inventory and Analysis. The USDA's census of forested land. Website is: http://www.fia.fs.fed.us/tools-data/
Sequestered	Refers to carbon stored in a pool other than the atmosphere
Sink	Refers to anything that sequesters more CO ₂ from the atmosphere than it emits or that retains carbon, keeping it from becoming atmospheric CO ₂ . Examples include forest biomass, forest soil, harvested wood products, oceans, and uncombusted fossil fuels
Source	Refers to anything that emits more CO ₂ to the atmosphere than it sequesters. Forests can become sources of CO ₂ emissions rather than sinks if timber harvest and fire emissions are greater than the amount of carbon sequestered in forest biomass
Flux	The transfer of carbon, from any pool, to the atmosphere as CO ₂
Gross emissions	Emissions from fossil fuels, industrial gases, and other anthropogenic sources; the emissions included in Oregon's existing inventory.