Appendix H. Forestry

Overview

Forestland emissions refer to the net CO_2 flux[1] from forested lands in Montana, which account for about 24% of the state's land area.[2] The dominant forest type in MT is Douglas Fir, which make up about 32% of forested lands.[3] Other important forest types are Lodgepole Pine (22%), Fir-Spruce (21%), and Ponderosa Pine (13%).

Forestlands are net sinks of CO_2 in Montana. Through photosynthesis, carbon dioxide is taken up by trees and plants and converted to carbon in biomass within the forests. Carbon dioxide emissions occur from respiration in live trees and decay of dead biomass. In addition, carbon is stored for long time periods when forest biomass is harvested for use in durable wood products. CO_2 flux is the net balance of carbon dioxide removals from and emissions to the atmosphere from the processes described above.

Inventory and Reference Case Projections

For over a decade, the United State Forest Service (USFS) has been developing and refining a forest carbon modeling system for the purposes of estimating forest carbon inventories. The methodology is used to develop national forest CO_2 fluxes for the official US Inventory of Greenhouse Gas Emissions and Sinks.[4] The national estimates are compiled from state-level data. The Montana forest CO_2 flux data in this report come from the national analysis and are provided by the USFS.

The forest CO_2 flux methodology relies on input data in the form of plot level forest 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 survey data to give estimates of C density (Mg per hectare) for a number of separate C pools.

CO_2 flux is estimated as the change in carbon mass for each carbon pool over a specified time frame. Forest volume data from at least two points in time are required. The change in carbon stocks between time intervals is estimated at the plot level for specific carbon pools (Live Tree, Standing Dead Wood, Under-story, Down & Dead Wood, Forest Floor, and Soil Organic Carbon) and divided by the number of years between inventory samples. Annual increases in carbon density reflect carbon sequestration in a specific pool; decreases in carbon density reveal CO_2 emissions or carbon transfers out of that pool (e.g., death of a standing tree transfers carbon

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[1] "Flux" refers to both emissions of CO_2 to the atmosphere and removal (sinks) of CO_2 from the atmosphere.
[2] Table 9 in "Montana's Forest Resources", USDA Forest Service, Resource Bulletin INT-81, September 1993, Conner, Roger C. and O'Brien, Renee A. There are a total of 22,400,000 acres of timberland and 91,000 acres of woodland in Montana. The same table shows Montana has a total land and water area of 94,109,000 acres.
[3] Based on data from the USFS: http://www.fs.fed.us/ne/global/pubs/books/epa/states/MT.htm.
[4] U.S. Inventory of Greenhouse Gas Emissions and Sinks: 1990-2004 (and earlier editions), US Environmental Protection Agency, Report # 430-R-06-002, April 2006. Available at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

from the live tree to either the standing dead wood or down & dead pool). The amount of carbon in each pool is also influenced by changes in forest area (e.g. an increase in area could lead to an increase in the associated forest carbon pools and the estimated flux). The sum of carbon stock changes for all forest carbon pools yields a total net CO_2 flux for forest ecosystems.

In preparing these estimates, USFS estimates the amount of forest carbon in different forest types as well as different carbon pools. The different forests include those in the national forest system and those that are not federally-owned (private and other public forests). USFS also provides information on forests categorized as being either woodlands (forests with low productivity) and non-woodlands (e.g. timberlands or productive forest systems).

Carbon pool data for two periods are used to estimate CO_2 flux for each pool. The data shown in Table H1 are a summary of the FIA data used to derive the carbon pool and flux estimates that are summarized in Table H2. As shown in Table H1, the current forest carbon pool estimates are derived from 2004 FIA data. The previous inventory data came from a previous FIA cycle in 1989.

Table H1. Forestry Data Used to Estimate Forest CO_2 Flux

Forest	Current Inventory Source	Past Inventory Source	Avg. Year[1]	Interval[2] (yr)	Current Forest Area (10^3 hectares)	Previous Forest Area (10^3 hectares)
National Forests	FISDB21_MT_02_2005	FISDB21_MT_01_1989	2004.6	8.6	6,154	5,909
Non-Nat Forests	FISDB21_MT_02_2005	FISDB21_MT_01_1989	2004.6	15.6	3,784	3,090
				Totals	**9,938**	**8,999**

[1] Average year for the current FIA inventory data.
[2] The number of years between the current inventory source and the past inventory source (does not match database years).

The data in Table H1 show an increase of 939 kilo-hectares (2.3 million acres) in forested area during the period of analysis (1989-2004), which is approximately 0.7% or 63 kilo-hectares per year. As mentioned under key uncertainties below, some of this difference is likely driven by methodological differences in survey methods between the two FIA cycles. Another forest grouping assessed by the USFS was the non-National Forests reserved forests (areas where no timber harvesting occurs). Because these areas were not well represented in the earlier FIA cycle, USFS suggested that CCS leave these out of the estimation of forest flux (essentially assuming that no net changes in carbon pools occurred in these areas). Hence, they are not shown in Table H1 and excluded from the flux estimates in Table H2.

Table H2 provides a summary of the size of the forest carbon pools for the final survey period and the resultant flux estimates (in units of C and CO_2) developed by the USFS. A total of 34 $MMtCO_2$ is estimated to be sequestered in Montana forests each year with most of this accumulating in the live tree, forest floor and soil organic carbon pools. Note that this analysis averages out annual fluctuations in carbon sequestration rates over an approximate 9 year time interval in National Forests and 16 years in non-National Forest areas.

In addition to the forest carbon pools, additional carbon stored as biomass is removed from the forest for the production of durable wood products; carbon remains stored in the products pool or is transferred to landfills where much of the carbon remains stored over a long period of time. An estimated 2.5 $MMtCO_2e$ is sequestered annually in wood products; these data are based on the latest estimates from USFS.[5] Additional details on all of the forest carbon inventory methods can be found in Annex 3 to EPA's 2006 GHG inventory for the U.S.[6]

Table H2. Forestry CO_2 Flux Estimates for Montana

Forest	Carbon Pool (MMt Carbon)					
	Live Tree	Standing Dead	Under-story	Down & Dead	Forest Floor	Soil Organic Carbon
National Forests	464	57	15	34	203	243
Non-National Forests	163	23	12	12	106	148
Totals	**627**	**80**	**26**	**46**	**309**	**391**

Forest	Carbon Pool Flux (MMt C/yr)					
	Live Tree	Standing Dead	Under-story	Down & Dead	Forest Floor	Soil Organic Carbon
National Forests	-2.60	-0.53	-0.10	-0.21	-1.23	-1.24
Non-National Forests	-0.10	-0.22	-0.19	0.00	-0.93	-1.85
Totals	**-2.7**	**-0.75**	**-0.29**	**-0.21**	**-2.2**	**-3.1**

Forest	Carbon Pool Flux (MMt CO_2/yr)					
	Live Tree	Standing Dead	Under-story	Down & Dead	Forest Floor	Soil Organic Carbon
National Forests	-9.53	-1.95	-0.38	-0.76	-4.52	-4.53
Non-National Forests	-0.37	-0.81	-0.70	-0.02	-3.41	-6.79
Totals	**-9.9**	**-2.8**	**-1.1**	**-0.78**	**-7.9**	**-11.3**

Total Forest Flux =	**-33.8**
Harvested Wood Products =	**-2.5**
Total Statewide Flux =	**-36.3**

NOTE: Totals may not add exactly due to rounding.

For the 1990 and 2000 historic emission estimates as well as the reference case projections, the annual forest carbon fluxes of forestlands were assumed to be at the same levels as those shown in Table H2. This assumes that the underlying increase in forest area continues into the future at a constant annual rate and that growth rates of existing forests also remain constant. This may overestimate the real future forestry sink, however there is no clear approach to adjusting the flux estimates. Also, it is unclear whether near term climate change (10-15 year) will impact the current flux estimates significantly. Hence, we have assumed no change in the estimated future sinks for 2010 and 2020.

[5] Data provided by Jim Smith, USFS, to CCS in December 2006.
[6] Annex 3 to EPA's 2006 report can be downloaded at: http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/RAMR6MBLNQ/$File/06_annex_Chapter3.pdf.

In order to provide a more comprehensive understanding of GHG sources/sinks from the forestry sector, CCS also developed some rough estimates of state-wide emissions for methane and nitrous oxide from wildfires and prescribed burns. A study published earlier this year in *Science* indicated an increasing frequency of wildfire activity in the western U.S. driven by a longer fire season and higher temperatures.[7]

CCS used 2002 emissions data developed by the Western Regional Air Partnership (WRAP) to estimate CO_2e emissions for wildfires and prescribed burns.[8] The CO_2e from methane emissions from this study were added to an estimate of CO_2e for nitrous oxide to estimate a total CO_2e for fires (the carbon dioxide emissions from fires are captured within the carbon pool accounting methods described above). The nitrous oxide estimate was made assuming that N_2O was 1% of the emissions of nitrogen oxides (NO_x) from the WRAP study. The 1% estimate is a common rule of thumb for the N_2O content of NO_x from combustion sources.

The results for 2002 are that fires contributed about 0.21 MMtCO_2e of methane and nitrous oxide from about 190,000 acres burned. Over 90% of the CO_2e was contributed by CH_4. Note that this level of activity compares to a similar area burned in Montana in 1996 (186,000).[9] A comparison 2002 estimate was made using emission factors from a 2001 global biomass burning study[10] and the total tons of biomass burned from the 2002 WRAP fires emissions inventory. This estimate is nearly 0.26 MMtCO_2e with about equal contributions from methane and nitrous oxide on a CO_2e basis. Although not indicated by the estimates provided above for 1996 and 2002, there are large swings in fire activity from year to year. Because of this and the current lack of data for multiple years, CCS did not include these estimates in with the annual forestry flux estimates presented in the emissions summaries of this report. However, it appears that CH_4 and N_2O emissions from forest fires typically contribute less than 1 MMtCO_2e/yr in MT.

Key Uncertainties

It is important to note that there were methodological differences in the two FIA cycles that can produce different estimates of forested area and carbon density. Recent FIA surveys are a result of an expanded focus in the FIA program, which historically was only concerned with timber resources, while more recent surveys have aimed at a more comprehensive gathering of forest biomass data. In addition the FIA program has moved from a periodic to annual sampling design. These changes are believed to have resulted in more forest being sampled in recent years than in the past and direct comparison of old and new FIA datasets can show larger than real changes in forest areas in certain places. In addition, surveys since 1999 include all dead trees on the plots, but data prior to that are variable in terms of these data.

The effect of these changes in survey methods has not been systematically addressed by the USFS. The decision to exclude carbon fluxes on non-NF reserved lands in MT was done in consultation with the USFS to account in part for this potential systematic error.

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[7] Westerling, A.L. et al, "Warming and Earlier Spring Increases Western U.S. Forest Wildfire Activity", *Sciencexpress*, July 6, 2006.

[8] *2002 Fire Emission Inventory for the WRAP Region Phase I – Essential Documentation*, prepared by Air Sciences, Inc., June 2004.

[9] *1996 Fire Emission Inventory*, Draft Final Report, prepared by Air Sciences, Inc., December 2002.

[10] M. O. Andreae and P. Merlet, "Emission of trace gases and aerosols from biomass burning", *Global Biogeochemical Cycles*, Vol. 15, No. 4, pp. 955-966, December 2001.

As stated in the previous section, emission estimates for methane and nitrous oxide from fires were left out of the statewide flux estimates due to a lack of data for years other than 1996 and 2002 (emissions of carbon dioxide from fires are captured in the carbon flux accounting methods used by the USFS). Based on the level of activity in 2002, these additional emissions are on the order of 0.2 $MMtCO_2e$/yr and would not have a significant impact on the overall flux estimates shown in Table H2.