Appendix H. Forestry

Overview

Forestland emissions refer to the net carbon dioxide (CO_2) flux[1] from forested lands in Alaska, which account for about 35% of the state's land area.[2] About 10% of Alaska's forests are temperate coastal forests with the remainder being the interior boreal forests. Sitka spruce, hemlock and cedar are the dominant species in the southeast and south-central coastal parts of the state, while white spruce, black spruce, black cottonwood, aspen, and paper birch are found in the interior forests.

Forestlands are net sinks of CO_2 in Alaska. Through photosynthesis, CO_2 is taken up by trees and plants and converted to carbon in biomass within the forests. CO_2 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 CO_2 removals from and emissions to the atmosphere from the processes described above.

CCS has also included information on methane emissions from Alaskan ecosystems. These emissions are considered natural sources of methane that may be indirectly influenced by climate change. The estimated emissions documented below are not included within the summary tables presented in the body of this report, since they are considered natural sources.

Inventory and Reference Case Projections

CO_2 Flux in Alaska's Forests

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.[3] The national estimates are compiled from state-level data. Unfortunately, the USFS has not yet developed estimates for Alaska due to a lack of comprehensive survey data for the State needed to develop these estimates.

Alaska is unique because a large fraction of the land base is essentially untouched, pristine forestland. GHG inventories principally account for *anthropogenic* emissions and sinks. In the forestry sector, experts have determined that a practical approach to quantifying anthropogenic emissions and sinks is to inventory carbon fluxes and non-CO2 emissions on "managed" forestland only. The USFS forest carbon accounting system incorporates these principles to a large degree because the Forest Inventory and Analysis survey (FIA) upon which they are based

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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] Alaska Forest Association, http://www.akforest.org/facts.htm, reports 129 million acres of forested lands. The total land area in AK is 365 million acres (http://www.netstate.com/states/geography/ak_geography.htm). Data used in this appendix from UAF are based on geographic information indicating that AK has about 162 million acres of forested lands (about 23 million acres are in the temperate (coastal) maritime forest).

[3] *US 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.

targets managed forestlands (although all forested lands are included in the carbon flux estimates).

CCS used research studies provided by experts from the University of Alaska to construct estimates of the forest carbon flux in Alaska that are comparable in principle to the standard USFS inventory approach. The methods and results presented here cover both the entire forestland base in AK, as well as the temperate (coastal) maritime forests. The coastal maritime forests are where much of Alaska's productive forests are and where most the management has occurred historically. For the purposes of this analysis, CCS considers these to represent the State's "managed" forests.

Yarie and Billings provided estimates for Alaska's boreal forests that indicated annual sequestration rates of about -35 $MMtCO_2$.[4] Boreal forests represent about one-third of the forests in Alaska. UAF researchers also provided recent estimates for carbon flux based on forest ecosystem modeling.[5] Carbon flux in Alaska's forests was modeled from 1950 through 2002. These carbon flux estimates are based on UAF's Terrestrial Ecosystem Model (TEM), which estimates net primary productivity for forest ecosystems and take into account carbon flux both forest biomass and soils. The effects of climate, fires, and CO_2 levels are evaluated within the modeling. Model runs were performed with and without the effects of fertilization from higher CO_2 levels. Figures H1a and b provide a summary of the modeling results.

The data shown in Figure H1a show the variation in carbon flux for all of Alaska's forests over the period of analysis. The average sequestration rate over the period of analysis is -10 $MMtCO_2$/yr and the range is from -94 to 143 $MMtCO_2$/yr (CCS converted the values in the figures from units of carbon to CO_2 to show these estimates). [Note: negative numbers used in this report represent sequestration; the only exception is Figures H1 and H2, where positive numbers were used in the UAF reports. Also, for this analysis, CCS reports the UAF modeling results for carbon flux without CO_2 fertilization effects for consistency with standard inventory approaches]. The large range in flux values is largely related to wildfire activity--years with net emissions are those where significant wildfire activity occurred. The summary statistics show that these data are negatively skewed, so the median value (-25 $MMtCO_2$/yr) is probably a better estimate of central tendency in the data.

Figure H1b shows similar estimates covering only the coastal maritime forests (primarily those in the Chugach and Tongass National Forests). Based on the mean and median of these annual estimates, the historical carbon flux for these forests has been about -1.2 to -1.3 $MMtCO_2e$/yr (as with the data for Figure H1a, CCS converted carbon to CO_2 to report these estimates).

[4] Yarie, J. and S. Billings, "Carbon balance of the taiga forest within Alaska: present and future", *Canadian Journal of Forestry Research*, 32: 757–767 (2002).
[5] D. McGuire and M. Balshi, UAF, personal communication and data file provided to S. Roe, CCS, January 2007. Documentation is included within a manuscript currently under review by the Journal of Geophysical Research.

Figure H1a. Statewide Forest Carbon Flux

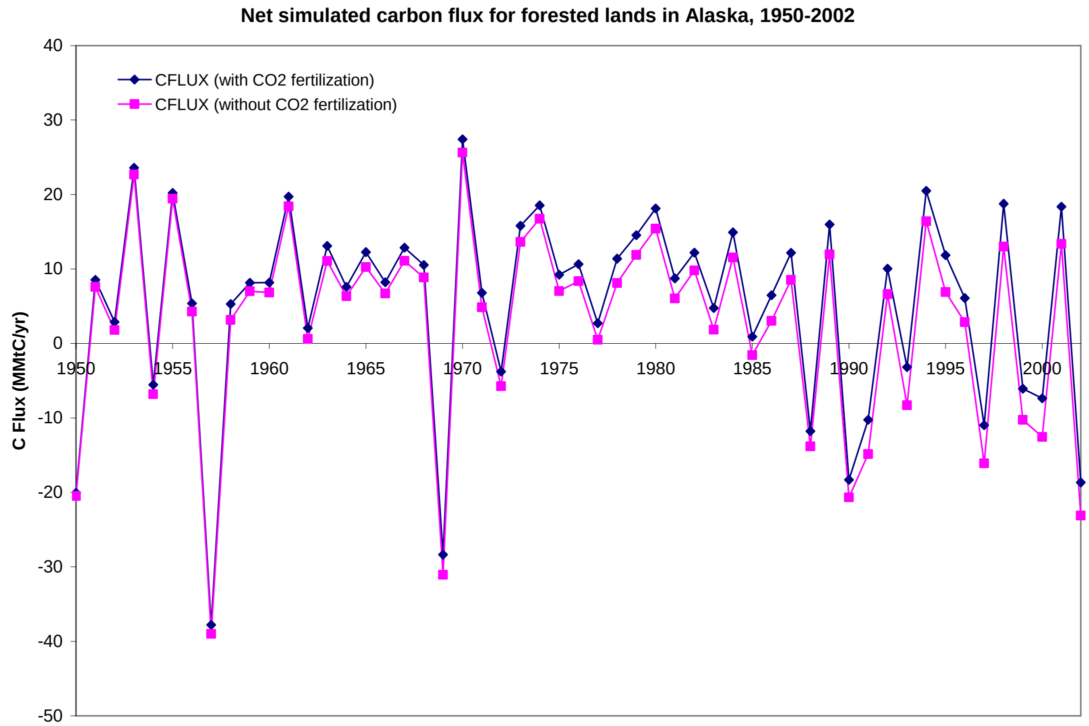
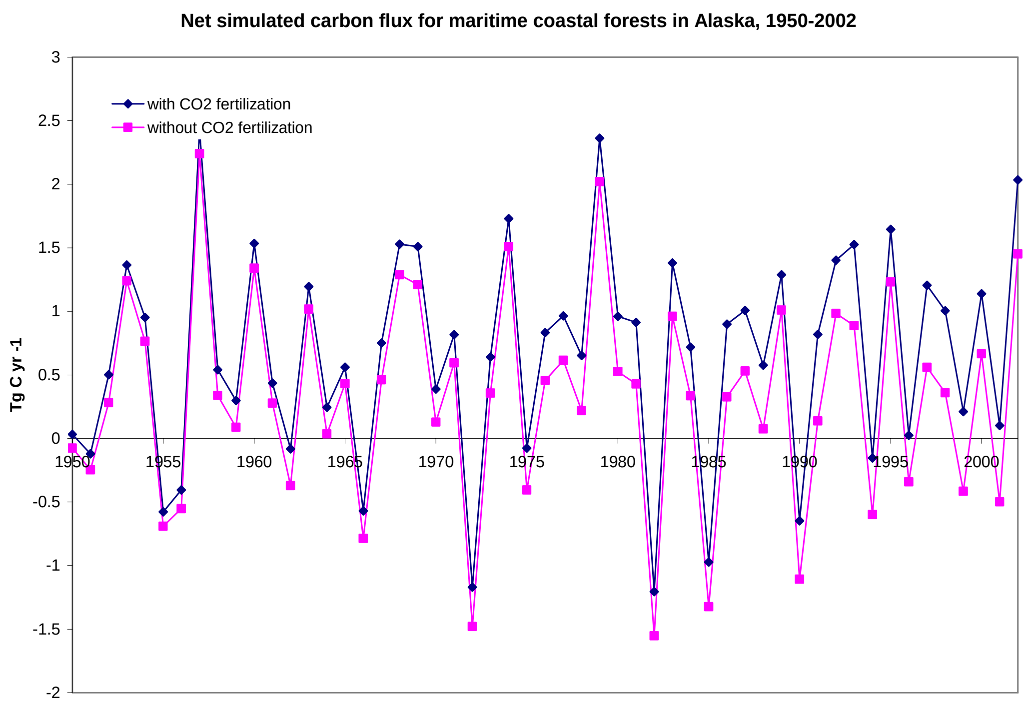


Figure H1b. Forest Carbon Flux in Coastal Maritime Forests



Note: Positive values in these graphs represent annual net sequestration. Source: M. Balshi, UAF, unpublished manuscript.

Figures H2a and b show the same modeling data from UAF as ten year averages of CO_2 sequestration in Alaska's forests. Ten year averages were selected to provide a comparison of sequestration rates in other western states.[6] An assessment of longer term averages also provides a sense of the sequestration potential of Alaskan forests during a typical year (a year that is not strongly influenced by large wildfire activity or no wildfire activity). The data in Figure H2a show that since the 1970s, average sequestration potential has decreased significantly. Historically, average sequestration rates were -20 to -30 $MMtCO_2$/yr. In recent decades, net sequestration has turned into net emissions of over 10 $MMtCO_2$/yr. Data for the 2000 time-frame were available through 2002. It appears that due to increased wildfire activity, Alaska's forests have entered into a period of net CO_2 emission during an average year.[7] Figure H3 provides ten year averages for statewide wildfire acres burned. The figure shows the upward trend in acres burned since the 1960's.[8]

Figure H2b shows the ten year averages of CO_2e flux for coastal maritime forests. The data show that the net sequestration rates have stayed fairly constant over time, at around -1.4 $MMtCO_2$e/yr. According to UAF researchers, since there was no significant wildfire activity in the 1990's time-frame, the lower sequestration rates shown for that period are probably due to climate factors (additional analysis would be needed to confirm this and the specific factors involved).

The statewide results from UAF show a trend where the CO_2 sequestration rate approaches zero and transition to a net emission rate as a result of high fire activity. This finding is consistent with a 2006 study published in *Science*.[9] This study indicated an increasing frequency of wildfire activity in the western US since the mid-1980s driven by a longer fire season and higher average temperatures.

[6] In other western states assessed by CCS, the US Forest Service uses Forest Inventory and Analysis survey data to estimate carbon in forest carbon pools; the period between surveys is typically about 10 years. The ten year averages shown in Table H2 represent the 10 year period bracketing the year indicated (for example, the 1990 average is derived from the estimates for 1985-1994; 1995-2002 were used for the 2000 average).

[7] According to M. Balshi of UAF, the area burned during the period 2000-2005 (UAF simulations only go through 2002 due to climate data restraints) already exceeds that of every decade on record.

[8] S.K. Todd and H.A. Jewkes, *Wildland Fire in Alaska: A History of Organized Fire Suppression and Management in the Last Frontier*, Agricultural and Forestry Experiment Station Research Bulletin #114, University of Alaska, Fairbanks, March 2006. These rough estimates assume similar fuel loading/acre as used to develop the WRAP's 2002 fire estimates. As with the ten year carbon dioxide flux averages mentioned in the footnote above, CCS used 1985-1994 to represent the 1990 ten year average, etc. For the 2000 average, data for 1996-2004 were used.

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

Figure H2a. Ten-Year Average Forest CO_2 Flux in Statewide Forests

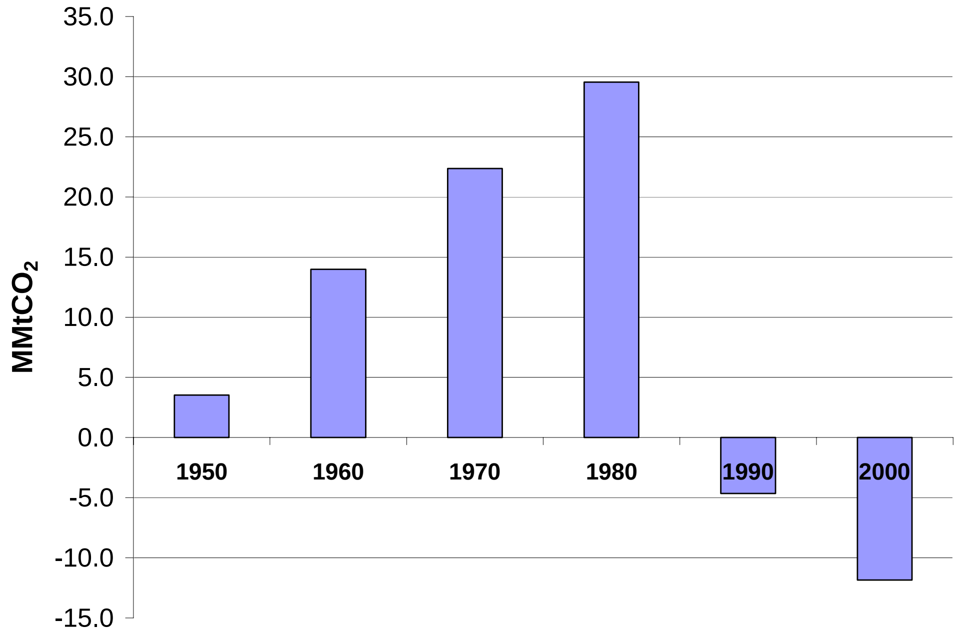
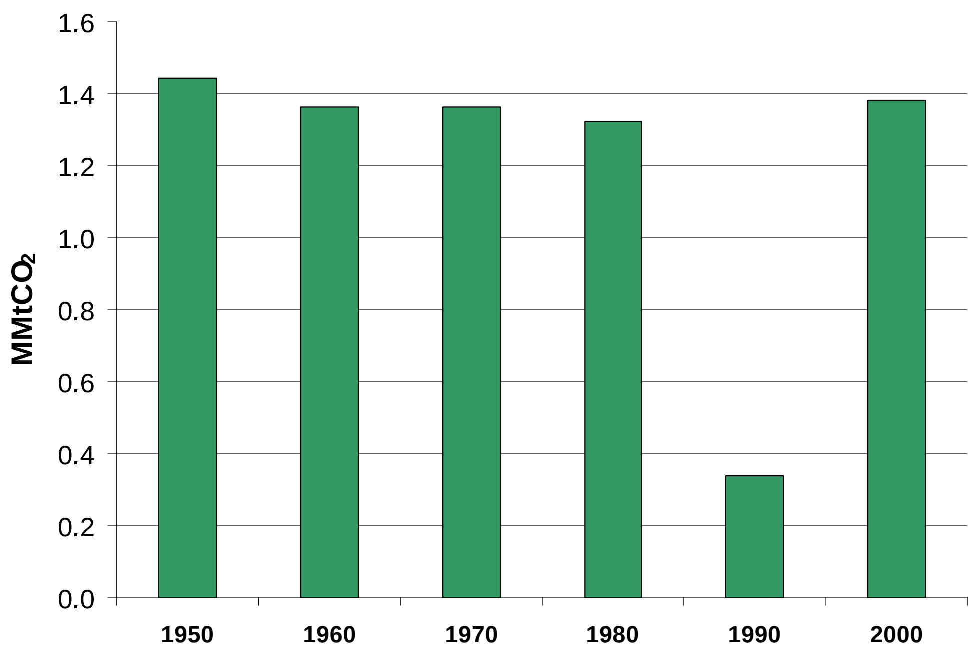
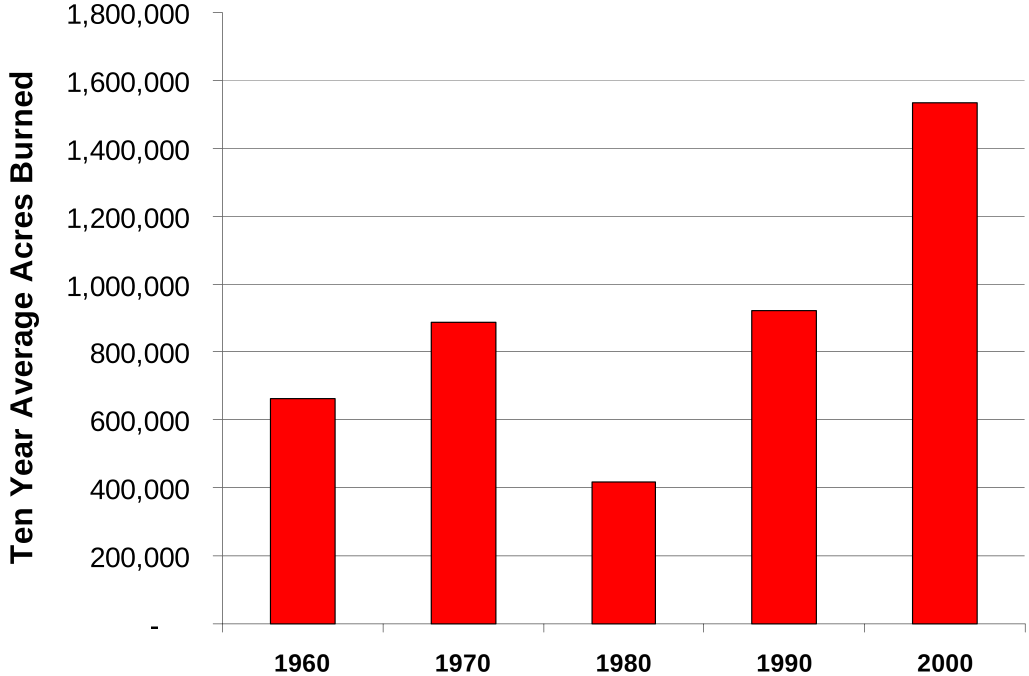


Figure H2b. Ten-Year Average Forest CO_2 Flux in Coastal Maritime Forests



Note: Positive values in these graphs represent annual net sequestration. Based on data from M. Balshi, UAF, unpublished manuscript.

Figure H3. Ten Year Averages of Statewide Wildfire Acres



Non-CO_2 Emissions from Wildfires

The UAF modeling of carbon flux described above included total carbon emissions, which would include CO_2, carbon monoxide, and methane (CH_4). In order to provide an estimate of CO_2e emissions for CH_4 and a more comprehensive understanding of GHG sources/sinks from the forestry sector, CCS developed rough estimates of state-wide emissions for methane (in CO_2 equivalents) and nitrous oxide (N_2O, in CO_2 equivalents) from wildfires and prescribed burns.[10] A separate estimate was also made for "managed" (coastal maritime) forests.

CCS used 2002 emissions data developed by the Western Regional Air Partnership (WRAP) to estimate CO_2e emissions for wildfires and prescribed burns.[11] The CO_2e from CH_4 emissions from this study were added to an estimate of CO_2e for N_2O to estimate a total CO_2e for fires. 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 10.0 $MMtCO_2e$ of CH_4 and NO_x from about 1.95 million acres burned (2002 was a fairly high wildfire activity year in Alaska and the western US). About 95% of the CO_2e was contributed by CH_4. For the purposes of comparison, another

[10] As with the CO_2 flux estimates for non-managed forests, the non-CO_2 emissions associated with fires on non-managed lands could also be considered non-anthropogenic (since wildfires are a natural occurrence). For the purposes of this study and for comparison to other state inventories prepared by CCS, these emissions are being provided at the state level as well as in "managed" forests.

[11] *2002 Fire Emission Inventory for the WRAP Region Phase I – Essential Documentation,* prepared by Air Sciences, Inc., June 2004.

2002 estimate was made using emission factors from a 2001 global biomass burning study[12] and the total tons of biomass burned from the 2002 WRAP fires emissions inventory. This estimate is about 11.8 $MMtCO_2e$ showing good agreement with the estimate above; however, there were about equal contributions from methane and nitrous oxide on a CO_2e basis.

In order to estimate non-CO_2 GHG emissions for other years, CCS used wildfire acreage estimates for Alaska compiled in a recent report by UAF researchers.[13] For years other than 2002, the emission estimate was made by multiplying the 2002 estimate described above (10 $MMtCO_2e$ by a ratio of the acres burned in each year to those burned in 2002. The fire acreages and emission estimates for 1985-2002 are presented in Table H1 below. For comparison to the CO_2 flux estimates, ten year averages are 4.7 $MMtCO_2e$/yr in 1990 and 4.9 $MMtCO_2e$/yr in 2000.[14]

UAF provided wildfire acreage estimates for managed forests in each year. As was done to estimate the statewide emissions, the ratio of these acreages to the acreage for 2002 was used to estimate emissions of the non-CO_2 gases. There was very limited wildfire activity in the coastal maritime forests: about 500 acres in 1996; and about 1,500 acres in 2001.

Table H2 provides a summary of the CO_2 flux estimates for Alaska's forests. The table provides both a state-wide estimate as well as an estimate for managed forests in the state (coastal maritime forests). Estimates of managed forestlands are developed and used within this report of state-wide emissions to maintain consistency with IPCC guidelines for national GHG reporting. Additional explanatory notes are included at the end of this appendix. Post-2000 flux estimates are assumed to remain constant at the 2000 levels.

CH_4 Emissions from Alaskan Ecosystems

Alaska's ecosystems are expected to experience earlier and more drastic changes from global warming compared with lower latitude ecosystems.[15] The projected changes are consistent with changes that have been observed in recent decades, which include increases in mean annual air temperatures, thawing of permafrost, and longer growing seasons. Changes in climate, plant and soil conditions will have implications for CH_4 dynamics and carbon storage in Alaska's soils.

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[12] 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.

[13] S.K. Todd and H.A. Jewkes, *Wildland Fire in Alaska: A History of Organized Fire Suppression and Management in the Last Frontier*, Agricultural and Forestry Experiment Station Research Bulletin #114, University of Alaska, Fairbanks, March 2006. These rough estimates assume similar fuel loading/acre as used to develop the WRAP's 2002 fire estimates.

[14] The ten year average stated for 2000 is based on data from 1995-2002. If data through 2004 were available, the estimated emissions would be larger due to high fire activity through 2004.

[15] Zhuang, Q., J. M. Melillo, A.D. McGuire, D.W. Kicklighter, R.G. Prinn, P.A. Steudler, B.S. Felzer, and S. Hu. 2007. "Net land-atmosphere exchanges of CH_4 and CO_2 in Alaska: Implications for the region's greenhouse gas budget", *Ecological Applications*, in press.

Table H1. Statewide Non-CO_2 GHG Emissions Estimates from Wildfires

Year	Acreage	Non-CO_2 Emissions ($MMtCO_2e$)	Year	Acreage	Non-CO_2 Emissions ($MMtCO_2e$)
1985	407,300	2.1	1994	265,722	1.4
1986	477,455	2.4	1995	43,946	0.2
1987	169,145	0.9	1996	599,267	3.1
1988	2,134,539	11	1997	2,026,899	10
1989	64,810	0.3	1998	120,752	0.6
1990	3,189,078	16	1999	1,005,427	5.2
1991	1,667,950	8.6	2000	756,296	3.9
1992	150,006	0.8	2001	216,039	1.1
1993	712,869	3.7	2002	1,950,000[a]	10[a]

[a] Acreage and emissions estimates based on the WRAP's 2002 Fire Inventory.

Table H2. Forestry CO_2e Flux Estimates for Alaska

Source	CO_2e Flux ($MMtCO_2e$)[a]				
	1990	2000	2005	2010	2020
State-Level Forest Flux					
CO_2 Flux	4.6	12	12	12	12
Non-CO_2 Gases from Fire	4.5	4.9	4.9	4.9	4.9
CH_4 Flux[b]	16	21	24	26	31
Total State-Level	**25**	**38**	**41**	**43**	**48**
Flux for Managed Forests[c]					
CO_2 Flux	-0.3	-1.4	-1.4	-1.4	-1.4
Non-CO_2 Gases from Fire	0.0	<0.01	<0.01	<0.01	<0.01
CH_4 Flux	n/a	n/a	n/a	n/a	n/a
Total – Managed Forests	**-0.3**	**-1.4**	**-1.4**	**-1.4**	**-1.4**

Positive values represent net CO_2e emissions. Non-CO_2 gases are methane and nitrous oxide.
[a] Values reported are ten year averages of annual data surrounding the year reported (e.g., 1990 average is the average of data for 1985-1994). For 2000, data only available through 2002. After 2000, flux estimates are assumed to remain constant.
[b] UAF estimate for the 1980-1996 period used for 1990. UAF growth rate of 0.5 $MMtCO_2e$/yr used for forecast years. See Section on CH_4 emissions from Alaskan ecosystems.
[c] Managed forests are the coastal maritime forests of the state. CH_4 flux estimates were not available for managed forests.

Further, according to UAF researchers, one-third of the global soil carbon stocks are located in the Arctic. The fate of this stored soil carbon under altered climate is a major question, since microbes can respond quickly to temperature changes in high latitude ecosystems. Soil microbial activity includes organic matter decomposition under aerobic conditions that releases CO_2 to the atmosphere. Under anaerobic conditions, warming and changes in hydrology could trigger rapid CH_4 emissions in response to the early spring thawing in sub-arctic mire ecosystems. Methane dynamics are also influenced by the increase in the depth to which permafrost thaws each summer and any changes in the water table of northern peatlands that may result from changes in the water cycle. While CH_4 flux is considered to be non-anthropogenic, estimates are provided in this appendix for information purposes, given the influence of climate change.

UAF has conducted studies using its TEM model of CH_4 flux from Taiga (interior forests) and Tundra (treeless) ecosystems in Alaska. These ecosystems are estimated to be net sources of CH_4. Net emissions of 3.1 MMtCH_4/yr (65 MMtCO_2e/yr) estimated for the period of 1980-1996 are expected to almost double to 5.7 MMtCH_4/yr (120 MMtCO_2e/yr) by the 2080-2099 period. The growth rate in emissions is estimated at 0.026 MMtCH_4/yr (0.5 MMtCO_2e/yr). Of the 3.1 MMtCH_4/yr emitted in the 1980-1996 period, 0.76 MMtCH_4/yr is emitted in the Taiga ecosystem (16 MMtCO_2e/yr). These estimates were incorporated into the statewide estimates presented in Table H2. Note that these emissions do not include the previously-described CH_4 emissions that occur as a result of fire. No data were available for methane flux from coastal forest ecosystems.

Key Uncertainties

Both the estimates of forest CO_2e flux and ecosystem CH_4 flux presented here should be viewed as preliminary estimates based on process-based modeling of Alaska's ecosystems. For CH_4 flux, UAF comparisons against site-specific measurements suggest that the uncertainty around the flux estimate is probably plus or minus 50% overall. As described above, from year to year, CO_2 flux in forested lands varies dramatically depending on the level of wildfire activity. Years with high wildfire activity result in large net emissions of CO_2 to the atmosphere, while, in years with low activity, a significant level of CO_2 sequestration occurs. To provide a better sense of changes that are occurring in net carbon flux over time as well as a data set for comparison to other states, CCS has provided results in ten year averages.

The issue of what constitutes managed forests in Alaska may need further consideration and refinement (see additional notes on this issue from IPCC guidance below). Although fire suppression has occurred throughout state forests in previous decades, it is questionable whether the level of suppression was significant enough to designate much of the State's forests to be "managed". For the purposes of this initial assessment, CCS assumed that managed forests are those in the coastal maritime forests of Alaska (primarily those in the Chugach and Tongass National Forests). These coastal forests have much different net CO_2 flux from Alaska's interior forests (due to both sequestration potential and fire occurrence). It is possible that some of the interior forests have received sufficient intervention to be considered managed forests (e.g., those surrounding communities, productive forests).

CCS estimates that the estimates that uncertainty in the non-CO_2 emissions from wildfires is +/- a factor of two. This is based on comparisons with estimates in a recent paper from French et al on the uncertainty in GHG emissions from boreal forests.[16] The estimates provided here for non-CO_2 data made by extrapolating the WRAP's 2002 fire estimates are higher than those reported in this study by over a factor of two. One primary difference is that the estimates reported here include N_2O, while the French et al paper included carbon-containing compounds only. There is a lot of uncertainty specifically on the issue of N_2O emissions from wildfires; however it could contribute substantially to the total CO_2e emissions for fires. The other main issues are the emission factors used in either the WRAP or French et al study for methane, as well as fuel loading factors, handling of emissions from different phases of wildfires (especially smoldering),

[16] French, N.H.F., P. Goovaerts, E.S. Kasichke, "Uncertainty in estimating carbon emissions from boreal forest fires", *Journal of Geophysical Research*, vol. 19, D14S08, 2004.

and possibly other factors. A more in-depth analysis of the differences in these studies was beyond the scope of this initial assessment.

Forecasting of forest carbon flux is particularly challenging. UAF is currently engaged in developing forecasts of carbon flux, and these data should be reviewed for incorporation when available. Although the statewide trend appears to be moving in the direction of increased CO_2e emissions, the sequestration rates in the managed forests have remained fairly constant over time. For the purposes of this assessment, CCS assumes that the flux rates will stay constant at the 2000 levels.

Additional Notes: IPCC Guidelines for Agriculture, Forestry, and Other Land Uses (AFOLU)
The AFOLU Sector has some unique characteristics with respect to developing inventory methods. There are many processes leading to emissions and removals of greenhouse gases, which can be widely-dispersed in space and highly variable in time. The factors governing emissions and removals can be both natural and anthropogenic (direct and indirect) and it can be difficult to clearly distinguish between causal factors. While recognizing this complexity, inventory methods need to be practical and operational. The 2006 IPCC Guidelines are designed to assist in estimating and reporting national inventories of anthropogenic greenhouse gas emissions and removals. For the AFOLU Sector, anthropogenic greenhouse gas emissions and removals by sinks are defined as all those occurring on 'managed land'. Managed land is land where human interventions and practices have been applied to perform production, ecological or social functions. All land definitions and classifications should be specified at the national level, described in a transparent manner, and be applied consistently over time. Emissions/removals of greenhouse gases do not need to be reported for unmanaged land. However, it is good practice for countries to quantify, and track over time, the area of unmanaged land so that consistency in area accounting is maintained as land-use change occurs.

The use of managed land as a proxy for anthropogenic effects is in use in the present IPCC guidelines. The key rationale for this approach is that the preponderance of anthropogenic effects occurs on managed lands. By definition, all direct human-induced effects on greenhouse gas emissions and removals occur on managed lands only. While it is recognized that no area of the Earth's surface is entirely free of human influence (e.g., CO_2 fertilization), many indirect human influences on greenhouse gases (e.g., increased N deposition, accidental fire) will be manifested predominately on managed lands, where human activities are concentrated. Finally, while local and short-term variability in emissions and removals due to natural causes can be substantial (e.g., emissions from fire), the natural 'background' of greenhouse gas emissions and removals by sinks tends to average out over time and space. This leaves the greenhouse gas emissions and removals from managed lands as the dominant result of human activity.

Specific Guidance for Forests: Countries should consistently apply national definitions of managed forests over time. National definitions should cover all forests subject to human intervention, including the full range of management practices from protecting forests, raising plantations, promoting natural regeneration, commercial timber production, non-commercial fuel wood extraction, and abandonment of managed land.