Appendix G – Climate Change

Carbon Storage Modeling

Analysis of Net Carbon Storage

The analysis of net carbon storage estimated the amount of carbon stored in the forest and in harvested wood products as well as carbon stored in non-forest portions of the decision area. The analysis divided carbon into three pools:

- Live and dead vegetation
- Soil to 1 m depth (3.3 ft.)
- Harvested wood

The BLM summed the carbon in these three pools to estimate the total net carbon stored by alternative and the Proposed RMP. The BLM assumed carbon stored in soil and in non-forest portions of the planning area was constant through time, largely due to the lack of information about how these pools change over time.

Net Carbon Storage in Live Trees

The BLM estimated net carbon storage in live trees for each alternative and the Proposed RMP, and included a No Timber Harvest reference analysis, using the following process:

1. Obtain estimates of standing tree volumes for each period from the Woodstock model. See Appendix C – Vegetation Modeling for more detail on how the BLM estimated volume over time.
2. Convert live tree volume in thousand board feet (Mbf) to cubic feet using the following formula: $ft^3 = (Mbf \div 6.0) \times 1000$.
3. Estimate the composite density of wood (lb./ft.^{3}) based on specific gravity at 12 percent moisture content for several species, but primarily Douglas-fir {Forest Products Laboratory, 2010 #76}
4. Convert cubic foot volume to pounds using the following formula:
$$pounds = ft^3 \times 33.5 \frac{lb}{ft^3}$$
5. Multiply pounds of wood by 0.5 to estimate pounds of carbon {Smith, 2006 #61}.
6. Estimate megagrams of carbon (Mg C) for whole trees (branches, roots, and bark) using the following formula:
$$Mg\ C = (lb\ C \times 1.85) \div 2200$$

The BLM based initial tree volumes on the total gross volume, or the estimated volume per acre multiplied by the number of acres. This estimate avoided the need to convert from acres to hectares for live tree carbon storage.

Net Carbon Storage in Forest Vegetation Other than Live Trees

Forest vegetation other than live trees includes snags, understory vegetation, downed wood, and the forest floor (litter and duff). The BLM downloaded tables of carbon stock estimates using the Carbon OnLine Tool version 3.0 (COLE 3.0), available at http://www.ncasi2.org/GCOLE3/gcole.shtml. The BLM generated reports using the county or counties that comprise most of the individual districts. The BLM applied a filter consisting of Federal lands within the county. Although the BLM could have filtered for just BLM-administered lands, the data used to generate the estimates did not include enough plots on BLM-administered lands for statistically sound estimates. The analysis used Table 1 of the report, which consists of estimates of carbon stocks by age class for years 0 through 100, subtracting out the estimates for soil and live trees. Since many stands are older than age 100, the BLM needed to estimate understory carbon beyond year 100. Using the COLE Table 1, the BLM plotted the understory carbon stock estimates for every decade between year 10 and year 100 in an Excel spreadsheet and then used the trendline tool to create a regression equation for each district. The BLM then used the resulting equation to estimate understory carbon stocks for every decade between year 110 and 210, assuming that after year 210, understory carbon reaches equilibrium between input and decay.

Net Carbon Storage in Soil

Little is actually known about carbon storage in soils due to the difficulties and expense in studying this carbon pool (Johnson and Curtis 2001). The scientific community knows even less about how soil carbon changes over time following natural disturbances and management, although some studies have attempted to understand soil carbon dynamics better. Decreases in soil carbon have generally been low and of relatively short duration (Smith *et al*. 2006, McKinley *et al*. 2011). For that reason, the BLM assumed no changes in soil carbon over time. The BLM used the soil column from Table 1 of each COLE 3.0 output and multiplied that value by the number of hectares analyzed on each district to estimate the Mg C stored in soils.

Net Carbon Storage in Harvested Wood

Carbon stored in harvested wood depends on the volume of wood harvested, the resulting wood product, and the amount of carbon in that wood emitted through harvesting, processing, waste, disposal, and decomposition. Earles *et al.* (2012) developed decay equations for harvested wood based on the above factors for various parts of the world. Although the BLM was unable to obtain copies of the actual equations, the BLM developed a regression function based on the graphs for the U.S. Pacific Northwest provided in the supplemental information for the study:

$$Percent\ C\ remaining = (-0.0026 \times years\ since\ harvest) + 0.4989$$

This regression accounts for the life expectancy of different wood products such as paper, fiberboard, and lumber.

For the existing condition, the BLM used annual harvest records from the Oregon Department of Forestry (http://www.oregon.gov/odf/Pages/state_forests/frp/RP_Home.aspx#Annual_Timber_Harvest_Report) to estimate the volume harvested over time from BLM-administered lands within the planning area. The BLM converted the volume in thousands of board feet (Mbf) to carbon using the conversion factor of 0.443 Mg C per Mbf (Smith *et al*. 2006, p. 35). Total carbon remaining equaled the percent carbon remaining multiplied by the total carbon initially in the harvested wood.

To estimate the effects of the alternatives and the Proposed RMP, the BLM multiplied the estimated volume harvested per decade by the same conversion factor to carbon and the same regression function as for the existing condition. The BLM added these results to the estimated carbon stored in previously harvested wood products as of 2013.

Carbon in Polygons with No Data

A certain portion of each district consisted of polygons for which there was no vegetation information. For the purposes of this analysis, the BLM assumed vegetation was present but that the predominant vegetation was not forest. To estimate aboveground carbon, the BLM used biomass information based on the Fuels Characteristic Class System (FCCS) version 3.0 for savanna, shrubland and grassland types considered representative of typical non-forest plant communities for each district or group of districts. Since the BLM did not know the relative abundance of the non-forest plant communities, it used a simple average of the estimated aboveground carbon for the selected FCCS fuelbeds. The BLM multiplied the result by the estimated number of hectares in non-forest community types to estimate aboveground carbon stored in each district and assumed these carbon stocks did not change over time.

Effects of Wildfire on Carbon Storage

The Woodstock model included occurrence of high- and mixed-severity wildfire on each district in each decade based on historical occurrence levels. Following high-severity wildfire, the model reset stand age to zero in the decade in which the fire occurred. To mimic the effects of burning on aboveground carbon in a high-severity wildfire, the BLM estimated the remaining carbon to equal 25 percent of the carbon at age zero in the COLE tables. The BLM based this reduction on a combination of experience in assessing post-fire effects following fires considered high severity and the standard definition of high severity used by LANDFIRE (high severity equals greater than 75 percent mortality of the dominant plant life form). Thereafter, the BLM based carbon on stand age.

The BLM did not reset stand age following a mixed-severity wildfire. The BLM assumed 50 percent of the carbon associated with the stand age at the time of the fire was lost, based on the standard definition of mixed severity used by LANDFIRE (mixed severity equals 25–75 percent mortality of the dominant plant life form). The BLM assumed subsequent ages to contain only 75 percent of the carbon that would have been present in the absence of fire. While full recovery to carbon likely does occur, at some point, there is no scientific basis for determining when full recovery would occur. Further, recovery rates differ widely across the planning area.

Sources of Uncertainty in Carbon Estimates

There are a large number of sources of uncertainty in estimating the amount of carbon stored on the BLM-administered lands within the planning area. These include the quality of the inventory data used, estimation methodology selected, and reliability of the data. Inventory data for live trees is generally the highest quality and most accurate, but the amount of time since the inventory and subsequent disturbance types and severities affect the accuracy of that data. Further, BLM does not have a comprehensive vegetation database that includes direct information for species, extent, and biomass for litter and duff, dead wood, herbaceous vegetation, shrubs, and non-commercial tree species.

There are several methodologies available for estimating the amount of carbon in a given unit of land and in harvested wood products; the likelihood of obtaining the same answer using different methodologies is low. Estimating soil carbon is particularly problematic due to the lack of data and different authors have generated estimates to differing depths in the soil profile. The BLM did not locate any studies that estimated time to full recovery of carbon to the equivalent of an unburned stand of the same age and general species composition following a mixed-severity wildfire.

Since many of the sources used to estimate carbon do not include measures of uncertainty, variance, or error, the level of uncertainty is not known, but likely large and could well exceed 50 percent. As such, the potential error in the estimate for any one alternative or the Proposed RMP likely exceeds the amount of variance between the alternatives and the Proposed RMP.

References

Earles, J. M., S. Yeh, and K. E. Skog. 2012. Timing of carbon emissions from global forest clearance. Nature Climate Change **2**(9): 682–685. http://www.fpl.fs.fed.us/documnts/pdf2012/fpl_2012_earles001.pdf.

Forest Products Laboratory. 2010. Wood handbook—wood as an engineering material. General Technical Report FPL-GTR-190. USDA Forest Service, Forest Products Laboratory, Madison, WI. 508 pp. http://www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr190.pdf.

Johnson, D. W., and P. S. Curtis. 2001. Effects of forest management on soil C and N storage: meta analysis. Forest Ecology and Management **140**(2): 227–238. http://www.fsl.orst.edu/ltep/Biscuit/Biscuit_files/Refs/Johnson%20FEM2001%20fire.pdf.

McKinley, D. C., M. G. Ryan, R. A. Birdsey, C. P. Giardina, M. E. Harmon, L. S. Heath, R. A. Houghton, R. B. Jackson, J. F. Morrison, B. C. Murray, D. E. Pataki, and K. E. Skog. 2011. A synthesis of current knowledge on forests and carbon storage in the united states. Ecological Applications **21**(6): 1902–1924. http://www.ncrs.fs.fed.us/pubs/jrnl/2011/nrs_2011_mckinley_001.pdf.

Smith, J. E., L. S. Heath, K. E. Skog, and R. A. Birdsey. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. General Technical Report NE-343. USDA FS, Northeastern Research Station, Newtown Square, PA. 216 pp. http://www.actrees.org/files/Research/ne_gtr343.pdf.

Greenhouse Gas Emissions Estimation

Analysis of Greenhouse Gas Emissions

For this planning effort, the BLM estimated greenhouse gas emissions from four sources:

- Enteric fermentation from permitted livestock grazing on BLM-administered lands
- Timber harvest operations
- Prescribed burning
- Wildfires

The BLM summed emissions for each alternative and the Proposed RMP, although emissions from livestock grazing, the hazardous fuels program, and wildfires would not vary.

Greenhouse gases emitted by activities on BLM-administered lands include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Both CH_4 and N_2O emissions have a greater global warming potential than CO_2 so the BLM multiplied the estimates by 25 and 298, respectively, to estimate carbon dioxide equivalents (CO_2e). The BLM converted all greenhouse gas emissions to the standard megagrams of carbon dioxide equivalent (Mg CO_2e) used for reporting greenhouse gas emissions nationally and globally.

Enteric Fermentation (Livestock Grazing)

The BLM based livestock grazing emissions on the number of permitted animal unit months on BLM-administered lands in the planning area. Although the actual number of cow-calf pairs are less than the permitted number for the past several years, this analysis used the permitted number. The BLM derived the formula used to estimate livestock grazing emissions from IPCC guidelines (Eggleston *et al*. 2006, Chapter 10):

$$\left(AUMs \times \left(\frac{4.4\ kg\ CH4}{month}\right) \div 1000\right) \times 25 = Mg\ CO2e$$

The CH_4 emissions factor of 4.4 kg mo^{-1} equals the annual emission factor in North America for beef cattle divided by 12 (EPA 2014).

Harvest Operations

Greenhouse gas emissions from harvest operations are based on the study by Sonne (2006) in the Oregon Coast Range for private industrial lands and on harvest records maintained by the Oregon Department of Forestry (ODF) for all lands in western Oregon and for Klamath County in eastern Oregon (available at: http://www.oregon.gov/odf/pages/pubs/publications.aspx#agency_annual_reports). The BLM first converted harvest records in thousands of board feet to millions of board feet and divided by six to estimate millions of cubic feet. From Sonne (2006), BLM used the expected greenhouse gas emissions based on planting 1,235 trees per acre, and applying a pre-commercial thinning, commercial thinning, and fertilization prior to final harvest:

$$\left(\left(\frac{1.38\ Mg\ Co2e}{100\ m^3}\right) \times \left(\frac{100\ m^3}{3531.467\ ft^3}\right) \times 1{,}000{,}000 = 390.77\ \frac{Mg\ CO2e}{MMcf}\right)$$

The BLM then multiplied the number of million cubic feet harvested by 390.77 to estimate Mg CO_2e. This emission factor is based on a shorter rotation and more intensive management practices than BLM typically uses and, therefore, may somewhat overestimate emissions from harvest activities on BLM-administered lands as well as on other Federal lands.

Prescribed Burning

Greenhouse gas emissions from past prescribed burning are based on estimated tons of biomass consumed as reported to the Oregon Department of Forestry (ODF) under the State's smoke management plan (available at http://www.oregon.gov/odf/pages/fire/smp/smkmgtannualrpts.aspx). ODF's reports include prescribed burns on BLM-administered lands in the Other Federal category, which includes U.S. Fish and Wildlife Service and Bureau of Indian Affairs, and consolidates prescribed burns for both Lake and Klamath Counties into a single number. The BLM conducts most of the prescribed burning in the Other Federal category, as indicated by the harvest records. The BLM calculated the various greenhouse gas types emitted from burning wood (CO_2, CH_4, and N_2O) using two different processes. The BLM obtained estimates of CO_2 and CH_4 from Consume 3.0 and the estimate of N_2O by multiplying the tons consumed with EPA-provided emission factors (EPA 2014, Table 1). For N_2O, the BLM used an emission factor for burning wood and wood residuals for power generation. Since power generation typically consumes all material, the BLM may have overestimated emissions as compared to open burning where larger pieces of wood may not be completely consumed.

The BLM used two different methods to estimate emissions from future prescribed burning. For pile burning (hand piles, machine piles, and landing piles), the BLM used a standard description for each type of pile (size, shape, and composition) and a standard estimate of the number of piles per acre to estimate emissions per acre using the pile utility in Consume. The BLM multiplied these estimates by the number of acres treated by piling. The Woodstock model provided estimates of the acres treated by each type of piling method for harvest treatments and historical averages used for the hazardous fuels program. For broadcast and under burning, BLM selected a single representative fuel bed for each district that would result in the approximate number of tons consumed that had been estimated by past burning, as reported by the Interdisciplinary Team's Fuels Specialist.

Wildfires

Wildfire emissions are much more difficult to estimate since there are no records of how much material any given fire consumes. The BLM used the following procedures to estimate greenhouse gas emissions from past wildfires.

The BLM downloaded records of all wildfires for Coos Bay, Eugene, Lakeview, Medford, Roseburg, and Salem Districts from the FAMWEB site (http://fam.nwcg.gov/fam-web/weatherfirecd/), imported the records into FireFamily Plus 4.1, extracted all wildfires 100+ acres in size, and exported the results into an Excel Spreadsheet. Using a variety of methods, the BLM deleted as many fires as could be identified that burned in the Lakeview Field Office to select just the data for the Klamath Falls Field Office. The BLM combined the data for Coos Bay, Eugene, and Salem into one group and the data for Medford and Roseburg into one group. Over the 34-year period of record (1980–2013), 7,763 acres burned in the Coos Bay-Eugene-Salem Districts group, 277,605 acres in the Medford-Roseburg Districts group, and 29,447 acres in Klamath Falls Field Office.

The BLM downloaded assessments of burn severity for individual large fires that originated on BLM-administered lands between 1984 and 2012, the latest year available, from the Monitoring Trends in Burn Severity website (http://mtbs.gov/data/individualfiredata.html). The BLM averaged acres burned in the difference categories of unburned to low, low, moderate, high, increased greenness, and mask and calculated the proportion for each category. Mask areas consist of features such as clouds, water and rock as well as missing lines of image data. The BLM combined high, increased greenness, and mask into a single high severity category; and unburned to low and low into a single low severity category. The resulting proportions of area burned were 59.1 percent low severity, 21.8 percent mixed severity (i.e., moderate), and 19.0 percent high severity. Because the documented fire severity record is sparse, the BLM used these same severity proportions across the planning area.

Since preburn fuel loadings are not known, the BLM used the Fuels Characteristic Class System (FCCS) module in Fuel & Fire Tools (FERA and UW 2014) to select representative fuelbeds (**Table G-1**). Because the BLM did not know the relative proportion of each fuelbed included in each analysis group, it equally weighted all fuelbeds. In order to assess emissions from the different burn severities, the BLM multiplied the total number of acres burned in each group by the proportional amount in the low, mixed, and high severity classes and created separate units in Fuel & Fire Tools. For example, the group comprised of Coos Bay, Eugene, and Salem Districts had three units labeled low, mixed, and high with assigned acres equaling the proportion estimated for each severity class (**Table G-2**). Each unit consisted of the set of fuelbeds selected through FCCS. The Consume module in Fuel & Fire Tools used this information to estimate greenhouse gas emissions for CO_2 and CH_4. Since the Consume module only uses 1000-hour and duff fuel moisture to drive the consumption algorithms, the BLM could not fully meet its intent of adjusting the amount of live fuel consumed.

Table G-1. Fuels Characteristic Classification System fuelbeds used in each analysis group to estimate greenhouse gas emissions from wildfire

District/ Field Office	Fuelbed Number	Fuelbed Name
Coos Bay – Eugene – Salem	2	Western hemlock – western redcedar – Douglas-fir
	5	Douglas-fir – white fir
	8	Western hemlock – Douglas-fir – western redcedar/vine maple
	9	Douglas-fir – western hemlock – western redcedar/vine maple
	10	Western hemlock – Douglas-fir – Sitka spruce
	11	Douglas-fir – western hemlock – Sitka spruce
	18	Douglas-fir/oceanspray
	24	Pacific ponderosa pine – Douglas-fir
	52	Douglas-fir – Pacific ponderosa pine/oceanspray
	208	Grand fir – Douglas-fir
	322	Sitka spruce – western hemlock
Klamath Falls	20	Western juniper/curl-leaf mountain mahogany
	24	Pacific ponderosa pine – Douglas-fir
	25	Pinyon – Utah juniper
	53	Pacific ponderosa pine
	55	Western juniper/sagebrush
	58	Western juniper/sagebrush
	67	Interior ponderosa pine – Douglas-fir
	210	Pinyon – Utah juniper
Medford – Roseburg	2	Western hemlock – western redcedar – Douglas-fir
	4	Douglas-fir/*Ceanothus*
	5	Douglas-fir – white fir
	6	Oregon white oak – Douglas-fir
	7	Douglas-fir – sugar pine – tanoak
	15	Jeffrey pine – red fir – white fir/greenleaf - snowbrush
	16	Jeffrey pine – ponderosa pine – Douglas-fir – California black oak
	24	Pacific ponderosa pine – Douglas-fir
	37	Ponderosa pine – Jeffrey pine
	38	Douglas-fir – madrone – tanoak
	39	Sugar pine – Douglas-fir – oak
	208	Grand fir – Douglas-fir
	215	Douglas-fir – madrone – tanoak
	239	Douglas-fir – sugar pine – tanoak

Table G-2. Acres, fuel moistures, and targeted consumption rates for live woody fuels in each severity class for past wildfires

Live Woody Fuels	Low Severity (Targeted Consumption Rate)	Mixed Severity (Targeted Consumption Rate)	High Severity (Targeted Consumption Rate)
1,000-hour Fuel Moisture	20%	10%	6%
Duff Moisture	200%	100%	10%
Shrub Black	-	50%	100%
Crown Black	-	50%	100%
District/ Field Office	**Low Severity (Acres)**	**Mixed Severity (Acres)**	**High Severity (Acres)**
Coos Bay – Eugene – Salem	1,475	1,692	4,588
Klamath Falls	5,595	6,419	17,403
Medford – Roseburg	52,745	60,518	164,065

Large fires that originate on BLM-administered lands typically burn onto other lands. However, the future wildfire acres burned applied only to BLM-administered lands. In order to provide an appropriate comparison, the BLM had to adjust the emissions from past fires downward. The BLM calculated the average number of acres burned using the data for fires that originated on BLM-administered lands and compared that to the average number of acres burned just on BLM-administered lands as reported in Davis *et al*. (2014, p. 7), resulting in a reduction of 62 percent.

Consume does not estimate N_2O. However, the amount of N_2O emitted by wood is relatively small (EPA 2014, Table 1). In addition, since the consumption algorithms in Consume are largely based on data collected during prescribed burning of logging debris, the program typically over-predicts consumption of natural fuels (Prichard *et al*. no date).

To estimate greenhouse gas emissions from future wildfires, BLM used the estimated acres burned in mixed- and high-severity fires each period from the Woodstock model. Using the same set of FCCS fuelbeds from **Table G-1** and the same fuel moistures and targeted consumption rates from **Table G-2**, BLM used Consume to estimate the per acre emissions for methane and carbon dioxide and converted the mass measure of pounds per acre to megagrams per acre. Because Consume does not include an estimate for nitrous oxide, BLM used the EPA (2014) emission factor for N_2O for wood products of 63 g per short ton. Since low-severity fire was not included in Woodstock under the assumption that there was no impact to timber volume, the BLM assumed maintenance of the proportional relationship between low-, mixed-, and high-severity fire and used the acres burned in mixed and high severity combined to estimate the acres burned in low-severity fire.

Uncertainties in Greenhouse Gas Emissions

Several factors can affect the actual greenhouse gas emissions from the different sectors analyzed in this document. Generally, limited input data, measurement errors associated with the available data, the need to simplify complex systems, and creating or using models based on limited data are the main sources of uncertainty in emissions estimation (Eve *et al*. 2014, p. 8-4).

Emissions from livestock grazing account only for the emissions from the animals and not for emissions from the soil that can arise based on grazing system, stocking rate, utilization levels, and season of grazing (Eve *et al*. 2014). Further, greenhouse gas emissions from grazing also depend on animal size and growth rate, which the BLM does not know for this analysis and likely varies from year-to-year. Thus, the estimation method the BLM used in this analysis has an estimated uncertainty of ± 50 percent (Eggleston *et al*. 2006, p. 10.33).

Emissions from harvest operations used in this analysis are based on a life cycle analysis conducted by Sonne (2006), which attempted to account for emissions from fuel used by vehicles and equipment, electricity, and fertilizer production in order to harvest trees; prepare sites for planting using prescribed fire or herbicides; produce, transport and plant seedlings; fertilize the site, and conduct one or more thinning operations before the final harvest of the subsequent stand. Although Sonne (2006) examined several different rotation ages, this analysis used age 60, the longest. The BLM typically manages stands on longer rotations than other landowners in the planning area and, under the 1995 RMPs, conducts far more thinning operations than final harvests, affecting actual greenhouse gas emissions. Further, the BLM conducts some uneven-aged management in the drier forests, which likely results in different emissions levels than even-aged management, although whether uneven-aged management produces less or greater emissions than even-aged management is not known. The BLM does not know the uncertainty associated with harvest operations, but expects that it is greater than 50 percent.

Greenhouse gas emissions from fire are particularly large. Estimates of preburn biomass and the amount of biomass consumed vary widely and the BLM does not know this information in sufficient detail for wildfires. Various estimating tools are available for prescribed fires, such as the debris prediction module in the Forest Vegetation Simulator (Rebain 2014) and the pile calculator in Fuel & Fire Tools (FERA and UW 2014). However, the districts may or may not use these tools in a given situation, and the BLM does not know the consistency of use. The tons recorded by ODF are simply those reported by the people who conducted the burn, who do not have effective methods for estimating actual consumption. Canopy consumption in wildfires of both trees and shrubs is particularly difficult to estimate, with high variability both within and between wildfires. As with harvest operations, the BLM does not know the uncertainty associated with emissions from fire, but expects that it varies by a factor of two (between half and twice as much as the estimate).

References

Davis, R., L. Evers, Y. Gallimore, J. Volpe, and C. Belongie. 2014. Modeling large stochastic wildfires and fire severity within the range of the northern spotted owl. Unpublished report.

Eggleston, S., L. Buendia, K. Miwa, T. Ngara, and K. Tanabe, editors. 2006. IPCC guidelines for national greenhouse gas inventories volume 4: agriculture, forestry and other land use. Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan.

Eve, M., D. Pape, M. Flugge, R. Steele, D. Man, M. Riley-Gilbert, and S. Biggar (eds.). 2014. Quantifying greenhouse gas fluxes in agriculture and forestry: Methods for entity-scale inventory. USDA, Office of the Chief Economist, Washington, D.C. 606 pp.

Fire and Environmental Research Applications Team (FERA), and University of Washington (UW). 2014. Fuel & Fire Tools. USDA Forest Service, Pacific Northwest Research Station, Pacific Wildland Fire Sciences Laboratory, Seattle, WA.

Prichard, S. J., R. D. Ottmar, and G. Anderson. No date. Consume 3.0 user's guide. USDA Forest Service, Pacific Northwest Research Station, Pacific Wildland Fire Sciences Laboratory, Seattle, WA. 235 pp.

Rebain, S. A. (ed.) 2014. The fire and fuels extension to the forest vegetation simulator: updated model documentation. USDA Forest Service, Forest Management Service Center, Fort Collins, CO. 409 pp.

Sonne, E. 2006. Greenhouse gas emissions from forestry operations. Journal of Environmental Quality **35**(4): 1439–1450. http://www.lanecounty.org/Departments/PW/LMD/LandUse/Documents/Lane%20County%20Land%20Use%20Task%20Force/Jim%20Just_Greenhouse%20Gas%20Emissions%20from%20Forestry%20Operations.pdf.

U.S. Environmental Protection Agency (EPA). 2014. Inventory of U.S. greenhouse gas emissions and sinks: 1990–2012. EPA 430-R-14-003. Washington, D.C. 529 pp.