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Fire-induced carbon emissions and regrowth uptake in western U.S. forests: Documenting variation across forest types, fire severity, and climate regions

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[1] The forest area in the western United States that burns annually is increasing with warmer temperatures, more frequent droughts, and higher fuel densities. Studies that examine fire effects for regional carbon balances have tended to either focus on individual fires as examples or adopt generalizations without considering how forest type, fire severity, and regional climate influence carbon legacies. This study provides a more detailed characterization of fire effects and quantifies the full carbon impacts in relation to direct emissions, slow release of fire-killed biomass, and net carbon uptake from forest regrowth. We find important variations in fire-induced mortality and combustion across carbon pools (leaf, live wood, dead wood, litter, and duff) and across low- to high-severity classes. This corresponds to fire-induced direct emissions from 1984 to 2008 averaging 4 TgC yr^{-1} and biomass killed averaging 10.5 TgC yr^{-1}, with average burn area of 2723 km^2 yr^{-1} across the western United States. These direct emission and biomass killed rates were 1.4 and 3.7 times higher, respectively, for high-severity fires than those for low-severity fires. The results show that forest regrowth varies greatly by forest type and with severity and that these factors impose a sustained carbon uptake legacy. The western U.S. fires between 1984 and 2008 imposed a net source of 12.3 TgC yr^{-1} in 2008, accounting for both direct fire emissions (9.5 TgC yr^{-1}) and heterotrophic decomposition of fire-killed biomass (6.1 TgC yr^{-1}) as well as contemporary regrowth sinks (3.3 TgC yr^{-1}). A sizeable trend exists toward increasing emissions as a larger area burns annually.

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1. Introduction

[2] Forests of the western United States have recently experienced increased wildfire activity attributed to temperature increases, more frequent droughts [*Dale et al.*, 2001; *Running*, 2008; *Intergovernmental Panel on Climate Change*, 2007], or increases in fuels caused by historic fire suppression [*Westerling et al.*, 2006]. Large wildfires in western U.S. forests are now four times more frequent than during 1970–1986, and the total area burned has increased six and a half times since then [*Westerling et al.*, 2006]. The ecological, hydrological, and biogeochemical impacts of such changes are poorly understood. This is in part due to wide variation in fire effects, including tree mortality, organic matter combustion, and ensuing changes in forest composition, structure and function. These effects are known to be influenced by fire intensity and severity [*Dale et al.*, 2001], which are themselves controlled by a complex interaction of fuels, weather and topography [*Cochrane and Ryan*, 2009]. This work synthesizes published data on tree mortality and organic matter combustion across a wide range of forest types and fire severities to advance a more comprehensive model treatment that captures the diversity of fire-induced carbon dynamics in western U.S. forests.

[3] Carbon emissions from fires result from both direct and indirect effects. The direct effect is combustion of vegetation and dead organic matter, emitting carbon dioxide and other greenhouse gases to the atmosphere. Indirect effects do not directly consume biomass but cause mortality and thus transfer biomass to dead and decomposing pools where it decays and is slowly released to the atmosphere. The amount of direct and indirect emission varies with fire types (e.g., ground, surface and crown fires), which injure different

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vertical fuel strata [*Cochrane and Ryan*, 2009; *Hood*, 2010]. Ground fires injure the lower most vertical fuel stratum which is found below the ground surface (e.g., roots, soil organic matter, etc). In contrast, surface fires injure low-lying live fuels (e.g., under-storey plants, basal stem) and dead fuels (e.g., litter, coarse woody debris, fine woody debris) found near the ground surface, whereas crown fires injure the top vertical fuel strata (e.g., foliage, buds, upper branch and bark).

[4] Several studies have documented carbon fluxes in recently burned forests by employing field-based observations [*Campbell et al.*, 2007; *Gough et al.*, 2007; *Meigs et al.*, 2009; *Van Tuyl et al.*, 2005; *Wirth et al.*, 2002], eddy covariance measurements [*Amiro et al.*, 2006; *Amiro et al.*, 2010; *Dore et al.*, 2008; *Randerson et al.*, 2006], or biogeochemical models driven by remote sensing observations [*Hicke et al.*, 2003; *Law et al.*, 2004; *Turner et al.*, 2004; *Williams et al.*, 2012]. These studies have documented the following broad patterns of post-fire carbon dynamics. Forest productivity declines immediately after a fire due to biomass combustion, reduction in live photosynthesizing biomass, and the transfer of live carbon stocks to respiring dead pools [*Amiro et al.*, 2010; *Masek et al.*, 2008; *Running*, 2008; *Van Tuyl et al.*, 2005; *Wirth et al.*, 2002]. This initial post-fire decline in productivity causes forests to change from a net sink of carbon to a net source as evident in studies conducted in North American boreal forests [*Hicke et al.*, 2003], Yellowstone National Park [*Kashian et al.*, 2006] and Northern Michigan [*Gough et al.*, 2007]. This gives way to carbon sinks as stands recover productivity and actively regenerate [*Barford et al.*, 2001; *Odum*, 1969; *Thornton et al.*, 2002]. The rate of regeneration is dependent on fire severity, forest structure and composition, and climate conditions [*Aide et al.*, 2000; *Dale et al.*, 2001; *Savage et al.*, 1996].

[5] While instructive, local field-based studies on post-fire carbon dynamics in the United State's forests tend to focus on small localized areas within larger regions (mostly Pacific Northwest), encompass only a single fire [*Campbell et al.*, 2007; *Meigs et al.*, 2009; *Sun et al.*, 2004; *Van Tuyl et al.*, 2005] or have focused on few tree species [*Dore et al.*, 2008]. In contrast, large scale regional analyses using various combinations of biogeochemical models and remotely sensed observations [*Hicke et al.*, 2003; *Law et al.*, 2004; *Turner et al.*, 2004; *Van Tuyl et al.*, 2005; *Williams et al.*, 2012] do not undertake detailed parameterization needed to characterize the consumptive and non-consumptive effects of fires on different live and dead carbon pools. Moreover such studies have ignored post-fire recovery and fire severity effects on carbon balance.

[6] This study reviews the literature (e.g., restoration ecology and post-fire mortality studies) on fires across forests of the western U.S. to derive a comprehensive and detailed parameterization of their effects suitable for incorporation in a dynamic recovery version of the Carnegie Ames Stanford Approach (CASA) terrestrial carbon cycle model. The work integrates field observations of fire effects, forest inventory data on carbon stock recovery with stand development, and a carbon cycle model to obtain characteristic post-fire carbon trajectories specific to forest types and fire severity levels in the western U.S. forests. The specific questions addressed by this study are: (1) How do the direct and indirect effects of fires vary among low, medium, and high severities and in different forest types? and (2) How do these differences influence post-fire carbon flux-age trajectories and associated carbon source/sink dynamics?

2. Methods

2.1. Parameter Generation

[7] The existing body of literature on post-fire mortality effects on vegetation and restoration ecology (specific to fires) is used to parameterize direct combustion and mortality-induced carbon emissions in a terrestrial carbon cycle model (see Appendix A for details). The restoration ecology literature specific to fires deals with introduction of natural fire regime in order to restore the composition, structure and functioning of forests to what they were prior to fire suppression management. In contrast, post-fire mortality studies typically describe relationships between overall tree mortality with tree structural characteristics and mortality of individual tree parts using a regression model (usually logistic regression). Both sorts deal with the mortality of vegetation caused by fire, reporting estimates of whole tree mortality as well as mortality of individual tree parts, namely foliage, stem and roots [*Fowler and Sieg*, 2004].

[8] In this work, we pool values across studies to parameterize different processes related to the combustion and litterfall effects of fire on vegetation parts (e.g., foliage, stem and roots) in a terrestrial carbon cycle model for different fire severities and forest species groups. We focus on parameterizing three different processes, tree mortality, fuel consumption and foliage mortality. Rates of each are derived from the literature and stratified according to forest type groups, for those groups occupying an area of at least 5% within any of the four forest service regions (i.e., Pacific Northwest, Pacific Southwest, Rocky Mountain North and Rocky Mountain South) in western United States. The detailed steps used in deriving the parameters are as follows:

[9] 1. Tree mortality: Tree mortality rates are tabulated by forest type groups and fire severity levels, and subsequently averaged within these strata (see Appendix A). Missing mortality values ($M_{s*,f}$) for a specific forest type group (f) and fire severity level (s*) are interpolated by multiplying the known mortality ($M_{s,f}$) for that forest type group (f) at a different severity level (s) with a severity-level scalar (S_{s*}) derived from other forest types for which there are data across these severity levels as:

$$S_{S*} = \frac{\frac{\sum_f M_{S*,f}}{N_{S*,f}}}{\frac{\sum_f M_{S,f}}{N_{S,f}}} \tag{1}$$

$$M_{S*,f} = M_{S,f} S_{S*}, \tag{2}$$

where $N_{s*,f}$ is the total number of samples for the missing mortality values ($M_{s*,f}$), and $N_{s,f}$ is the total number of reported mortality values ($M_{s,f}$).

[10] For cases in which two values of S_{s*} are available for interpolation/extrapolation, the two values are averaged.

Any interpolated/extrapolated value greater than 100% is constrained to be 100%. The tabular data for species type are aggregated into forest type groups for different fire severity levels by computing the average mortality rates of each of the species found within the forest type groups. For forest type groups which did not have species in the literature, linear weighted combinations of averages of softwood and hardwood mortality rates are computed. The weights/proportions of softwood and hardwood are obtained for different forest type groups from *Smith et al.* [2006]. Proportion of tree mortality that is consumed due to direct combustion, or combustion factors, are derived based on maximum stem (tree) combustion factors of 3%, 7% and 8% for low, medium and high fire severities, respectively as reported by *Campbell et al.* [2007]. The stem consumption factors are subtracted from the mortality rates to obtain the stem non-consumption factors for each forest type group by fire severity class.

[11] 2. Fuel consumption: Three fuel types are considered in this study, namely dead woody, litter and duff. Dead woody fuels encompass fuels of any size generated from the death of woody plant parts. Most papers reported dead woody fuels as 1 h, 10 h, 100 h and 1000 h fuels (see Appendix A). Few papers reported dead woody fuels in the form of fine and coarse woody fuels (see Appendix A). The percent change from pre-fire levels in the mass of dead woody fuels across all sizes is considered as dead woody consumption. Similarly, litter and duff consumption are computed as the percent reduction of litter and duff mass from pre-fire levels. The wood, litter and duff consumption are tabulated for different species and fire severity levels. Interpolation and aggregation to forest species groups are performed similar to tree mortality rates.

[12] 3. Foliage mortality: Rates of foliage consumption and fire-induced foliar litter input are mostly directly obtained from the literature for different species and fire severity levels (see Appendix A). Interpolation and aggregation are not performed due to limited sample size. Instead average values are obtained across all species types for different fire severity levels. These average values are used for all forest type groups and fire severities.

[13] The fires surveyed in this study are assigned to low-, medium-, or high-fire severity classes. However, it is difficult to infer the level of fire severity from post-fire mortality studies due to the different fire severity definitions prevalent in the literature, unless directly stated. This inconsistency in defining fire severity occurs because severity is not only heterogeneous across space and time, but also varies by ecosystem components (understory, overstory, litter and soil), and individual tree parts (foliage, stem and roots). The authors of the studies reviewed in this paper were contacted and asked to best describe the level of fire severity on the basis of field samples collected for each fire on which they report considering a three-class scale of low-, medium- and high-severity fires. The fires reviewed in this study are assigned to severity classes on the basis of the response of the authors. For the remaining studies where author feedback was unavailable, severity classes are assigned qualitatively on the basis of assessing the mortality rates of whole trees and tree parts other than those used for direct parameterization, using our judgment as well as author severity rating responses as a guide to classify cases where author response was unavailable.

2.2. Data and Modeling

[14] This study utilizes a combination of Forest Inventory and Analysis (FIA) data, remote sensing data and Carnegie Ames Stanford Approach (CASA) terrestrial carbon cycle model. Post-fire characteristic net primary productivity-age trajectories are obtained by accumulating carbon stocks at a rate that is consistent with the inventory data. FIA data of different stand age groups are sampled by United States Forest Service (USFS) for (1) oven dry aboveground live biomass, and (2) forest area sampled. The ratio of aboveground live biomass and area (i.e., biomass per unit area) are obtained for different age groups. Subsequently, chronosequences (space for time substitutions) of biomass per unit area as a function of age are created for a combination of 28 forest types, 2 site productivity levels (lumped into high- and low-productivity classes, defined as 120 to >225 cubic feet acre^{-1} yr^{-1} and 20 to 119 cubic feet acre^{-1} yr^{-1}, respectively) and 4 geographic regions (namely Pacific Northwest, Pacific Southwest, Rocky Mountain North and Rocky Mountain South). These chronosequences represent the post-disturbance recovery of vegetation.

[15] Post-fire characteristic heterotrophic respiration-age trajectories are obtained for different forest species groups, productivity levels, fire severities and forest service regions using the CASA model. Remotely sensed observations of near surface meteorology and phenology are used to drive the CASA model. The data sets used in this study are time series of Goddard Institute of Space Studies (GISS) 1° monthly air temperature anomalies for 1982 to 2005 [*Hansen et al.*, 1999] added to temperature climatology [*Leemans and Cramer*, 1991], GISS 1° monthly solar radiation for 1984 to 2004 [*Zhang et al.*, 2004], Global Precipitation Climatology Project (GPCP) 1° monthly precipitation for 1982 to 2005 [*Adler et al.*, 2003], and MODIS 1 km monthly fraction of absorbed photosynthetically active radiation (FPAR) for 2000 to 2005 [*Nightingale et al.*, 2009]. Forest type group is defined by the 0.002243 × 0.004912 degree spatial resolution forest map [*Ruefenacht et al.*, 2008]. Each data set is resampled to the resolution of the forest type group map, and is used to generate a forest type group and region specific climatology from an average over all pixels in each region dominated by each forest type group. We use a monthly climatology to drive the CASA model instead of using the entire time series because the purpose of this study is to understand fire effects on carbon balance rather than climate effects.

[16] The CASA model is a light-use efficiency-based model where net primary productivity (NPP) is computed as a product of the light use efficiency parameter (rescaled by temperature and moisture stress parameters) and absorbed photosynthetically active radiation (PAR) [*Potter et al.*, 1993]. Monthly NPP is allocated to leaves, wood and roots based on a ratio of 1:1:1. Turnover occurs from one pool to another based on a turnover rate (k) that is the inverse of carbon pool age. For example, carbon turnover (C_t) in the dead carbon pools are modeled as a product of carbon content of dead pool i (C_i) and turnover rates (k_i) (rescaled by temperature (T_s) and moisture (W_s) stress parameters) as:

$$C_t(x,y,t)_i = C(x,y,t)_i \; k_i \; W_s(x,y,t) T_s(x,y,t), \qquad (3)$$

where x and y indicate spatial coordinates and t is an index in time.

[17] A certain proportion (D_ε) of the carbon turnover is decomposed and released as carbon dioxide (CO_2) to the atmosphere because of heterotrophic respiration and the remainder (1-D_ε) is transferred to the next dead carbon pool. R_h is computed as the sum of CO_2 released through decomposition of each dead carbon pool. Subsequently, heterotrophic respiration-age trajectories are obtained for different forest species groups, productivity levels, fire severities and forest service regions.

[18] Net ecosystem productivity (*NEP*) trajectory is computed by subtracting the heterotrophic respiration from NPP at each time point as:

$$NEP(x, y, t) = NPP(x, y, t) - R_h(x, y, t). \tag{4}$$

Terrestrial carbon cycle models such as CASA are suitable for representing the influence of climatic factors on carbon fluxes. However, processes related to disturbance recovery are not commonly well-represented by such models. In contrast, yield-based models use post-disturbance biomass-age trajectories to compute biomass increment on the basis of changes in biomass across successive time periods [*Kurz et al.*, 2009]. Yield-based models are useful to understand the change in carbon fluxes associated with disturbances but cannot be used to study climate-carbon interactions. As described by *Williams et al.* [2012], this study's method is a modification of the age-accumulation approach where instead of computing changes in biomass across successive time periods, the modeled accumulation of biomass with age is constrained to best fit the biomass-age trajectory described by the inventory (FIA) data.

[19] The modeling process combines the biomass fitting procedure with the CASA carbon cycle model. As a result, this modeling process derives characteristic NPP trajectories by accumulating post-disturbance biomass consistent with FIA data, and simultaneously tracks inter-pool carbon transfers using the CASA model to determine characteristic heterotrophic respiration trajectories. Subsequently characteristic NEP trajectories are obtained as the difference of NPP and heterotrophic respiration trajectories. There are three major steps in the biomass fitting process as described in greater detail in *Williams et al.* [2012] but briefly reviewed here. The first step involves calculation of the target biomass B^* from the mean of the older age classes (100–200 yrs) simulated 25 times from a normal distribution of aboveground biomass for different age classes. Successively younger classes at 20-yr increments are included if a minimum of two samples have not been included. The target biomass age A^* is then computed from the ages of the older biomass samples. For each (B^*, A^*) pair, a corresponding (P_w, A_w) pair is obtained by integrating the differential equation ($dB/dt = P_w - B/A_w$) with biomass ranging from zero to B^* at time zero to A^* to obtain:

$$P_w = \frac{B^*}{A_w\left(1 - e^{\frac{-A^*}{A_w}}\right)}, \tag{5}$$

where dB/dt is the change of biomass with respect to time, P_w is the aboveground wood NPP and A_w is the wood age. Subsequently an array of possible pairs of (P_w, A_w) is generated. The next step consists of selecting the (P_w, A_w) pair that best fits the biomass-age trajectory. The best fit criterion is assessed by minimizing the root mean square error between the modeled and sampled aboveground biomass chronosequence observations. Modeled biomass is computed as:

$$B(t, A_w) = B_0 e^{\frac{-t}{A_w}} + P_w A_w\left(1 - e^{\frac{-A^*}{A_w}}\right). \tag{6}$$

Finally, NPP values obtained by the CASA model are rescaled to match the NPP values generated by the fitting procedure.

[20] Initially, the CASA model is spun to equilibrium, and a disturbance is imposed. Disturbance recovery is based on the FIA biomass versus age trajectory. The next disturbance is imposed based on the average age of different forest species groups. The subsequent, post-fire forest regeneration is modeled using aboveground wood biomass versus age trajectory for each combination of forest type group, productivity level and forest service region.

[21] In contrast to our prior work [*Williams et al.*, 2012], in this study disturbances (particularly fires) are portrayed as partial mortality events in which fires reduce pre-fire live biomass pools (corresponding to a forest type group specific average age derived from the FIA data) based on the fractional tree mortality, which depends on forest type and fire severity class (i.e., high, medium and low). The amount of live biomass remaining after a fire is calculated from the fraction of vegetation mortality emerging from the literature survey. On the basis of literature-determined rates, fire-killed material is either directly combusted and released to the atmosphere or transferred to dead carbon pools. The same approach applies to foliage and root mortality, though roots are not directly combusted. Implementation in the model preserved the default carbon flows except in the case of fire-killed aboveground wood. For this we created a new snag (standing dead) pool assuming a fast turnover fall rate of 10 yrs [*Dunn*, 2011; *Morrison and Raphael*, 1993] following fire, from where it is then transferred to the coarse woody debris pool. Though dead carbon pools (dead woody, litter, and duff) may increase from fire-killed inputs, they are also vulnerable to consumption by fire and are correspondingly reduced according to a rate determined from the literature. Taken together, the entire procedure yields carbon flux and biomass trajectories with age for different forest types, site productivity classes, geographic regions, and fire severity classes (low, medium and high).

2.3. Scaling Carbon Fluxes

[22] Carbon fluxes were scaled up to a regional level by utilizing the characteristic carbon trajectories, 30 m spatial resolution 1984–2008 burned area product from the Monitoring Trends in Burn Severity (MTBS) project [*Eidenshink et al.*, 2007], 0.002243 × 0.004912 degree spatial resolution forest type group [*Ruefenacht et al.*, 2008], and FIA derived high- and low-productivity maps. The 30 m spatial resolution individual fire burned area maps from 1984 to 2008 are mosaiced into a single fire burned area map (see Figure 1). The spatial burned area maps consists of 668 individual fires for Oregon, 311 for Washington, 1442 for California, 1094 for Idaho, 546 for Montana, 637 for Arizona, 234 for

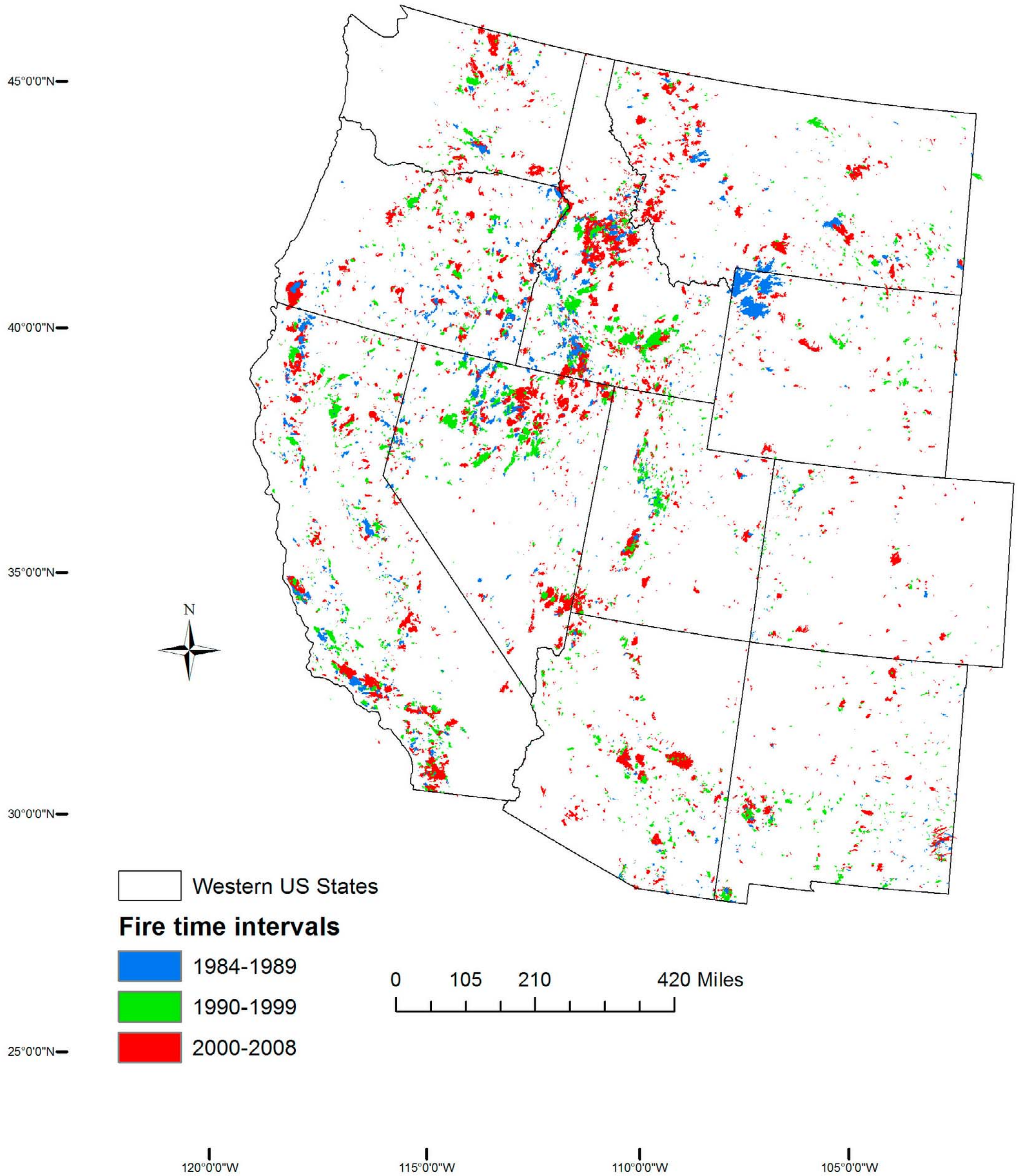

Figure 1. Spatial distribution of fires in different time intervals across the western United States.

Colorado, 816 for Nevada, 599 for New Mexico, 538 for Utah and 272 for Wyoming. The distinguishing feature of the MTBS burned area product is that it not only reports the year of fire occurrence, but also specifies a three class fire severity related to low, medium and high categories. However, only fires larger than 400 ha are reported in the MTBS database for the western United States. MTBS validation studies conducted with the National Interagency Coordination Center (NICC) statistics for 2004 show that the burn area reported by MTBS represents 96% of the area affected by wildfires in United States, and 73% of the area, if prescribed fires and wildland fire use are included in the wildfire statistics [*Eidenshink et al.*, 2007]. We projected our forest type group map to Albers Conical Equal Area and resampled it using nearest neighbor technique to a 30 m spatial resolution in order to match the resolution of the MTBS data. Similarly, fractions of forest in the high versus low productivity class were extracted for each county, projected to Albers Conical Equal Area and then rasterized to 30 m spatial resolution.

[23] The characteristic trajectories serve as look-up tables relating the carbon fluxes to the year since fire within the strata of forest type group, fire severity levels and productivity classes. The forest type group, and fire severity level are extracted from the forest type group map, and MTBS burn area map, respectively for both high- and low- productivity classes in order to select the appropriate characteristic carbon trajectory for each pixel. The year since fire is derived from the MTBS burned area map, and applied to the appropriate carbon trajectory look-up to determine carbon fluxes pertaining to high- and low-productivity classes. Carbon fluxes are weighted by the fraction of high and low productivity for each pixel. This procedure yields carbon flux map associated with fires that burned between 1984 and 2008 in western U.S. forests for the year 2008. Regional

Table 1. Mortality Rates of Forest Species Groups (Occupying Area of at Least 5% of Any Western Forest Service Region) for Different Fire Severity Levels

Forest Species Groups	Low-Severity Mortality (%)	Medium-Severity Mortality (%)	High-Severity Mortality (%)
Pinyon/Juniper	24.07	52.74	93.83
Douglas-fir	16.85	47.95	96.00
Ponderosa Pine	19.32	41.67	97.44
Fir/Spruce/Mountain Hemlock	25.19	51.34	94.03
Lodgepole Pine	29.00	59.46	87.95
Hemlock/Sitka Spruce	29.17	63.39	93.50
California Mixed Conifer	24.20	52.95	94.10
Elm/Ash/Cottonwood	26.62	57.04	99.33
Alder/Maple	25.87	55.78	97.71
Western Oak	14.38	53.16	73.00
Tanoak/Laurel	24.41	53.04	92.33

carbon fluxes are then aggregated across forest type groups, regions and fire severity classes.

3. Results

3.1. Fire Effects Parameters

[24] Table 1 shows the mortality rates (%) for combinations of different forest species groups and fire severity levels for western United States forests. As expected, increased mortality is associated with higher severity. Low-severity cases have less than 30% mortality, medium severity cases have between 40% and 64% mortality and higher severity cases have greater than 85% mortality with one exception. The same patterns are found for percent consumption of dead woody, litter and duff fuels (Table 2). Dead woody, litter and duff fuel consumptions increase with severity. Dead woody fuels have lower consumption rates than litter and duff fuels for corresponding levels of medium and high fire severity. Foliage consumption also increases with fire severity, with low-, medium- and high- severity fires having 10%, 20%, and 66% foliage consumption, respectively. In contrast, fire-induced foliar litter input is highest for medium-severity fires (54%) followed by low-severity fires (41%) and then high-severity fires (29%). We note, however that total foliage mortality is still highest for the high-severity class, with consumption and litterfall combining to about 95%.

3.2. Fire-Induced Direct Emissions and Biomass Killed

[25] Figure 2 shows the area burned with three fire severity levels from 1984 to 2008 in forests of western United States. The average area burned between 1984 and 2008 was 2723 km^2 yr^{-1} with a maximum area burned of 7992 km^2 in 2002 and minimum area burned of 269 km^2 in 1991. Figure 2 depicts the fire-induced direct carbon emissions from 1984 to 2008 for different fire severities in western United States forests. The fire-induced direct carbon emissions averaged between 1984 and 2008 was estimated at 4.01 TgC yr^{-1} with a maximum value of 16.04 TgC yr^{-1} in 2002 and minimum value of 0.19 TgC yr^{-1} in 1993. The cumulative direct carbon emission over the 1984 to 2008 time period was 100.29 TgC with low-, medium- and high-severity fires contributing to 28%, 31% and 41% of the cumulative emissions, respectively. Figure 2 shows the fire-induced biomass killed from 1984 to 2008 for different fire severities in western United States forests. Fire-induced biomass killed representing the biomass not directly consumed by fire but transferred to dead carbon pools was on average 10.52 TgC yr^{-1} between 1984 and 2008 with a maximum value of 39.40 TgC yr^{-1} in 2002 and a minimum value of 0.35 TgC yr^{-1} in 1993. The cumulative biomass killed from 1984 to 2008 was 262.89 TgC with low-, medium-, and high-severity fires making up 15%, 29% and 56% of the cumulative biomass killed, respectively. Combining fire-induced direct emissions

Table 2. Percent Consumption of Dead Woody, Litter and Duff Fuels for Different Forest Species Groups (Occupying at Least 5% of Any Western Forest Service Region) and Fire Severity Levels

	Low Severity			Medium Severity			High Severity		
Forest Species Groups	Dead Woody (%)	Litter (%)	Duff (%)	Dead Woody (%)	Litter (%)	Duff (%)	Dead Woody (%)	Litter (%)	Duff (%)
Pinyon/Juniper	56.11	62.92	47.52	62.11	76.83	77.31	80.54	96.84	96.88
Douglas-fir	52.73	70.13	47.06	59.98	72.60	81.34	81.05	97.00	96.50
Ponderosa Pine	51.51	65.47	53.53	65.43	74.78	84.10	81.88	95.99	97.19
Fir/Spruce/Mountain Hemlock	52.76	59.75	44.44	63.21	75.65	69.15	76.59	92.03	83.31
Lodgepole Pine	68.34	49.88	20.91	76.69	56.03	33.14	95.97	72.29	41.81
Hemlock/Sitka Spruce	58.78	75.00	54.00	58.28	76.00	51.00	77.06	100.00	99.00
California Mixed Conifer	56.18	63.53	47.68	62.30	76.70	77.31	80.39	96.98	96.97
Elm/Ash/Cottonwood	57.65	75.30	50.86	65.95	74.24	77.17	77.44	99.66	98.77
Aspen/Birch	42.66	76.81	40.30	47.87	73.92	63.89	59.91	100.00	80.60
Alder/Maple	61.57	75.87	32.69	58.28	76.00	51.00	77.06	100.00	99.00
Western Oak	55.67	75.57	50.29	66.86	80.44	79.24	80.92	98.49	94.55
Tanoak/Laurel	58.78	75.00	54.00	68.43	65.75	78.79	77.06	100.00	99.00

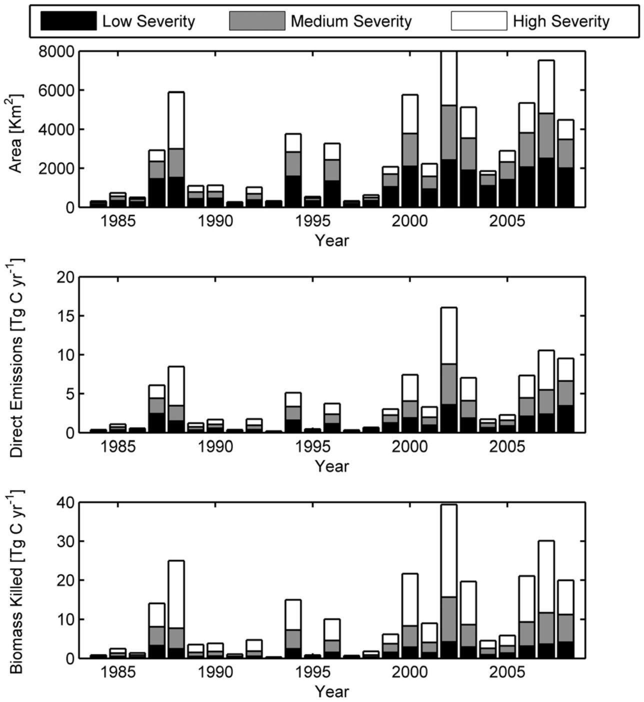

Figure 2. (top) Area burned, (middle) direct emissions and (bottom) biomass killed (i.e., non-consumptive carbon transfers from live to dead pools) associated with three fire severity levels between 1984 and 2008 across western U.S. forests.

plus biomass killed yielded an average 14.53 TgC yr^{-1} transferred to atmosphere and dead pools from areas burned during the period 1984 to 2008. We have also reported the area-normalized fire-induced direct emissions and biomass killed (expressed in kgC m^{-2}) stratified by forest species groups, fire severity levels, regions and productivity classes (see Table B1 in Appendix B). These normalized fire-induced emissions are consistent with those reported by *French et al.* [2011]. The pre-fire pool sizes of leaf, stem, root, dead woody and surface pools are used for computing the fire-induced direct emissions and biomass killed, and are stratified by forest species groups, fire severity levels, regions and productivity classes (Table C1 in Appendix C).

[26] Table 3 reports the prompt pool-to-pool carbon transfers induced immediately by fires averaged from 1984 to 2008. The largest carbon source pool is aboveground wood which contributes 8359 GgC yr^{-1} to the snag pool and 1048 GgC yr^{-1} to the atmosphere. The largest release to the atmosphere is from combustion of dead woody fuel (1865 GgC yr^{-1}) followed by aboveground wood (1048 GgC yr^{-1}), surface (982 GgC yr^{-1}) and then leaf (118 GgC yr^{-1}) pools. The largest fire-induced carbon transfer to the soil is from belowground wood (1792 GgC yr^{-1}) whereas the smallest transfer is from fine roots (210 GgC yr^{-1}).

3.3. Characteristic Carbon Trajectories

[27] Figure 3 illustrates the modeled average of 25 simulations for post-fire biomass, NPP, heterotrophic respiration, and NEP curves for three fire severity levels in Pacific Northwest high-productivity Douglas-fir forests. Forests experiencing higher severity fires begin regrowth from a lower biomass because of greater mortality. The NPP curve is identical with slight differences related to age-based biomass simulations for the three fire severity levels because at the end of the simulation period of 200 yrs since disturbance, the biomass trajectories regrow to the same amount of biomass. In the immediate post-fire years, heterotrophic respiration increases, with high-severity fires having the highest increase because of greater mortality. After a few decades of forest recovery (e.g., years since disturbance >50) heterotrophic respiration decreases compared to the immediate post-fire time as fire-killed carbon inputs become largely decomposed. The minimum heterotrophic respiration during this time period occurs for high-severity fires because they have less aboveground biomass vulnerable to natural mortality and correspondingly lower carbon inputs to dead pools. Two important patterns emerge from these post-fire NEP trajectories. First, post-fire NEP crossover time from source (indicated by negative values) to sink (indicated by positive values) increases with increasing fire severity, related to the larger and more persistent elevation of heterotrophic respiration for higher severity fires. Second, higher fire severity causes a larger increase in NEP between 50 and 100 yrs post-disturbance because of the large drop in heterotrophic respiration in the same time period.

[28] Figure 4 shows the characteristic post-fire NEP trajectories (produced as model outputs) for high-productivity forest type groups at different fire severity levels. The general shapes of these post-fire NEP trajectories are consistent with those reported in the literature [e.g., *Bond-Lamberty*

Table 3. Disturbance Matrix for First-Order Fire-Induced Carbon Transfers From Source to Receiving Pools (Gg C yr^{-1}) Averaged From 1984 to 2008[a]

	Receiving Pools								
Source Pools	Leaf	Aboveground Wood	Belowground Wood	Fine Root	Snag	Dead Woody	Surface[b]	Soil	Atmosphere
Leaf							156		118
Aboveground Wood					8359				1048
Belowground Wood								1792	
Fine Root								210	
Snag									
Dead Woody									1865
Surface									982
Soil									
Atmosphere									

[a]The table shows first-order carbon transfers that occur promptly due to fires.
[b]Surface pool has components for both litter and duff.

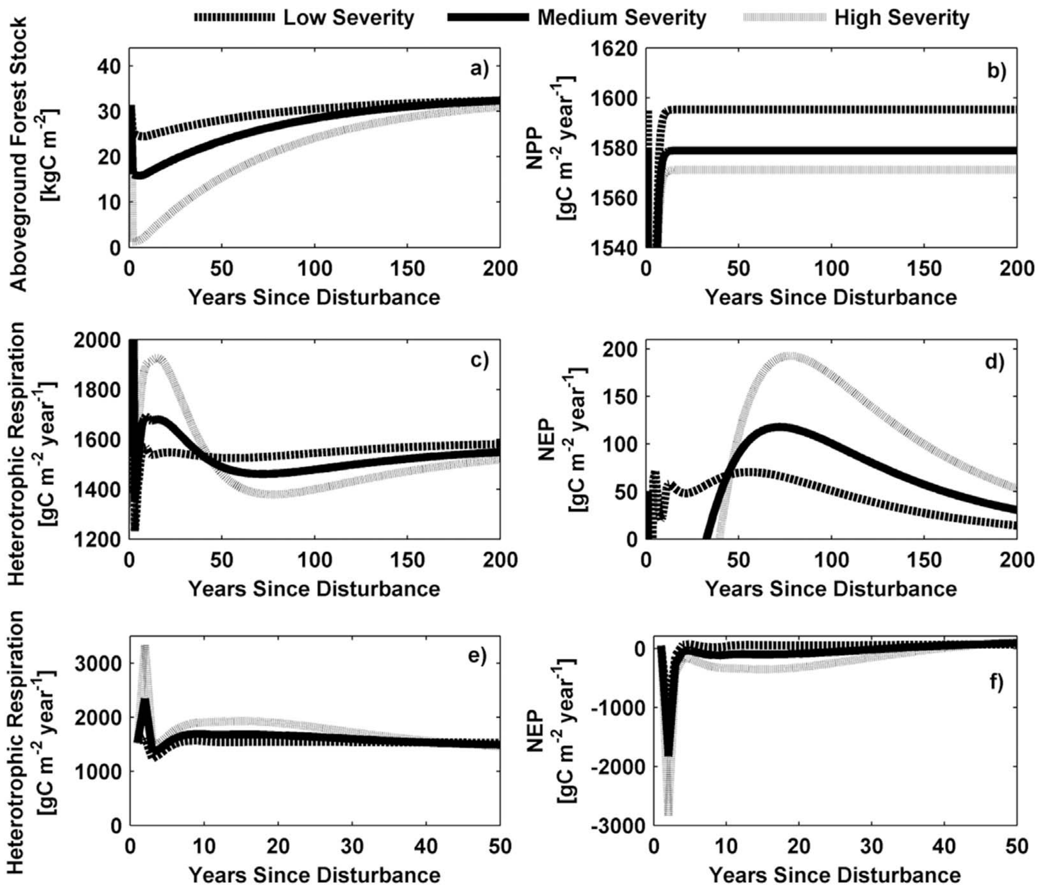

Figure 3. Post-fire (a) aboveground forest stock (biomass), (b) NPP, (c) heterotrophic respiration, (d) NEP, (e) heterotrophic respiration (zoomed in) and (f) NEP (zoomed in) trajectories for three fire severities in Pacific Northwest high-productivity Douglas-fir forests. The *x*- and *y*-axes have been rescaled in Figures 3e and 3f to show the trajectory dips in the earlier post-fire recovery periods.

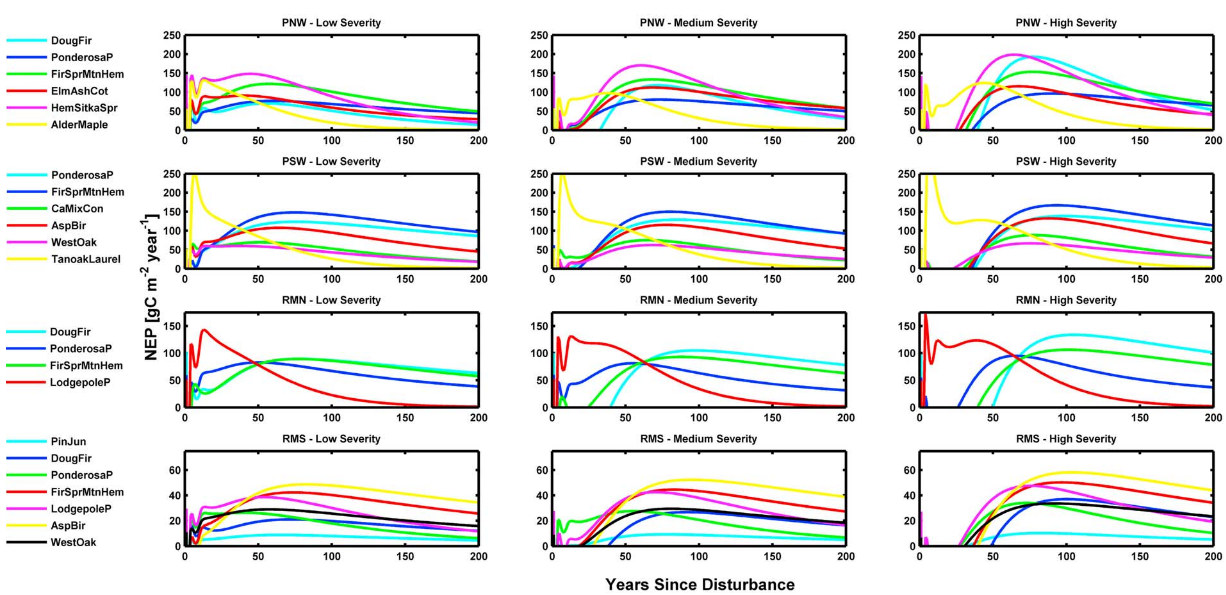

Figure 4. Post-fire characteristic carbon trajectories of net ecosystem productivity (produced as model outputs) for high-productivity forest species groups and fire severity levels. Each row of panels has a unique legend relating to forest species groups occupying at least 5% of the area in any western forest service region.

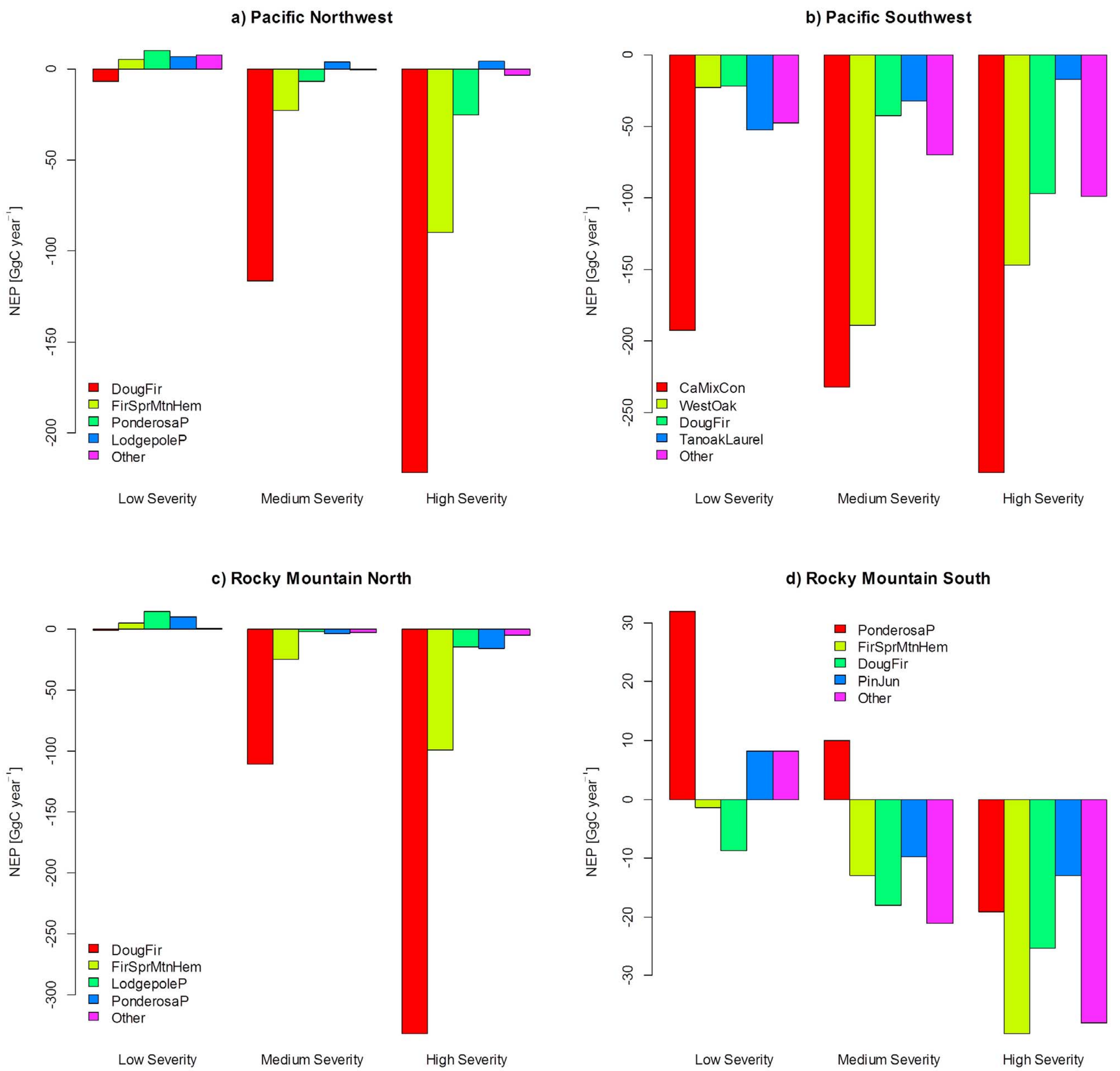

Figure 5. Net ecosystem productivity in 2008 associated with fires between 1984 and 2008 for combinations of fire severity levels and forest groups in (a) Pacific Northwest, (b) Pacific Southwest, (c) Rocky Mountain North, and (d) Rocky Mountain South forest service regions.

et al., 2004; *Gough et al.*, 2007; *Goulden et al.*, 2011; *Law et al.*, 2004; *Litvak et al.*, 2003; *Noormets et al.*, 2007; *Pregitzer and Euskirchen*, 2004]. However, we find large differences in the rates of emissions and carbon accumulation across forest type groups, with forest types recovering stocks at different rates, crossing from source to sink at different times, and reaching different peaks in NEP. Fire severity also has a substantial influence on the magnitude and rate of NEP recovery. Change from source (negative NEP) to sink (positive NEP) is observed earlier for lower severity fires than higher severity fires irrespective of forest type groups. Additionally, larger and later peaks in NEP recovery are observed for high-severity fires in comparison to low-severity fires. Assessment of the characteristic trajectories by regions depicts that forests in the Pacific Northwest are the most productive (i.e., higher NEP magnitude and peak) followed by forests in Pacific Southwest, Rocky Mountain North and Rocky Mountain South respectively.

3.4. Scaling Carbon Fluxes

[29] NEP in 2008 associated with areas affected by fires from 1984 to 2008 for different forest service regions, fire severities, and forest type groups is shown in Figure 5. The total NEP in 2008 associated with areas that burned between 1984 and 2008 in western U.S. forests was -2.75 TgC yr^{-1} (source). Pacific Southwest region was the largest carbon source of -1.55 TgC yr^{-1} followed by Rocky Mountain North region (-0.59 TgC yr^{-1}), Pacific Northwest region (-0.46 TgC yr^{-1}) and Rocky Mountain South (-0.15 TgC

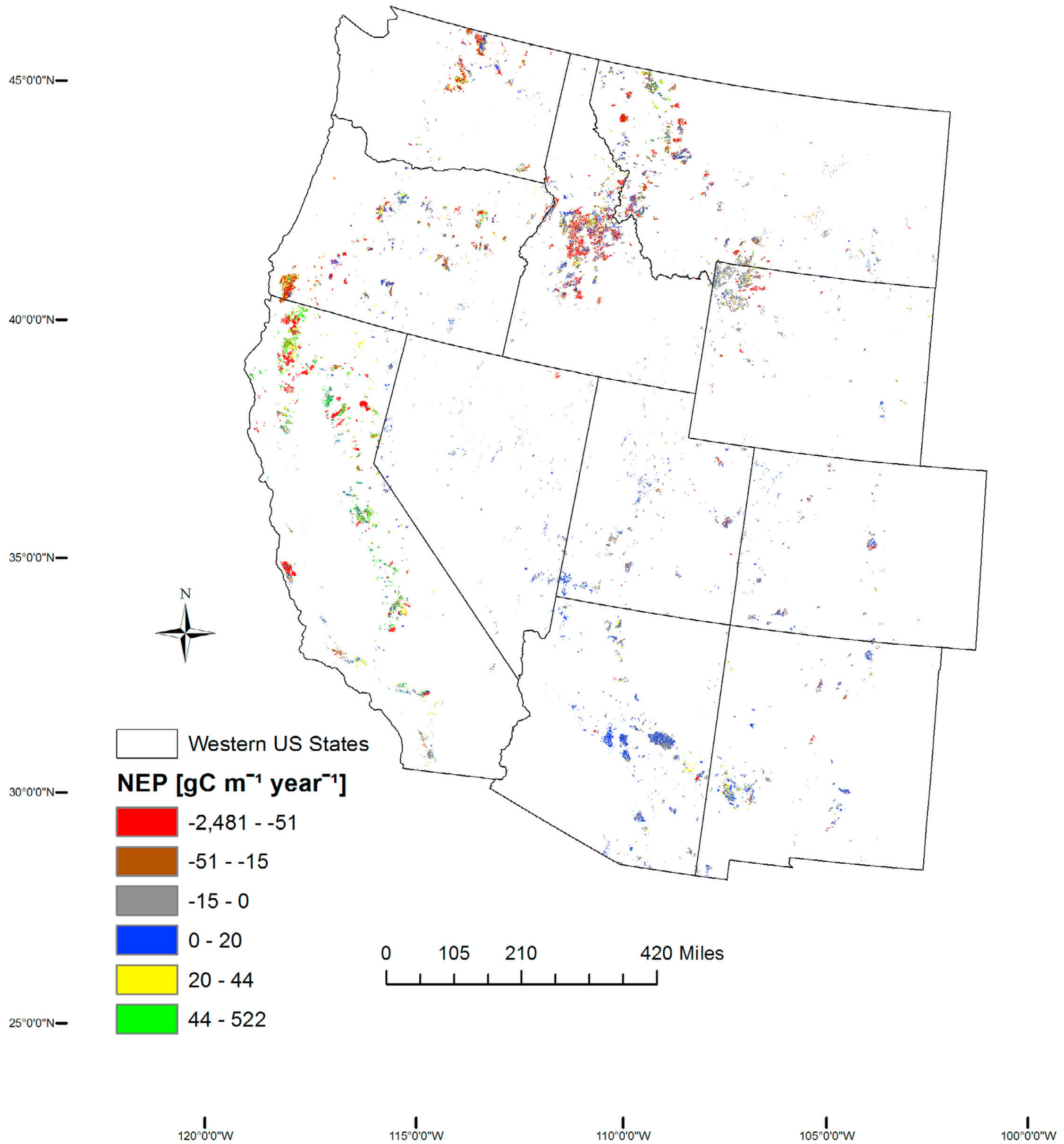

Figure 6. Spatial distribution of NEP in 2008 associated with fires between 1984 and 2008 across western U.S. forests.

yr^{-1}). Figure 6 shows the spatial distribution of NEP in 2008 for areas that burned between 1984 and 2008. In general, it can be inferred from Figure 5 that high-severity fires were a net source of -1.59 TgC yr^{-1} compared to medium-severity fires (-0.91 TgC yr^{-1}) and low-severity fires (-0.25 TgC yr^{-1}). Douglas-fir followed by California mixed conifer and Fir/Spruce/Mountain Hemlock were the largest carbon sources of -1.00 TgC yr^{-1}, -0.71 TgC yr^{-1} and -0.37 TgC yr^{-1} respectively.

4. Discussion

4.1. Fire Effects Parameters

[30] This work provides a comprehensive suite of parameters describing direct and indirect effects of fires which can be applied to carbon cycle models to enhance understanding of carbon balance across different fire severity and forest type groups. The set of parameters should be useful for large regional scale analyses of fire effects as well as more local scale work seeking to quantify fire effects of individual events but where data may be lacking on mortality and combustion rates.

[31] While useful, our work uncovered a number of important uncertainties that should be the focus of future work. Though tree mortality rates are one of the most common fire effects reported, the fraction of fire-killed trees that were combusted is poorly reported. We found only few studies, one of which was undertaken by *Campbell et al.* [2007] that determined the combustion of trees (boles and barks) for different fire severities which are used to derive the amount of stem combusted in this study. Another study by *van der Werf et al.* [2010] reported a stem combustion

factor of 40% which is possibly an extreme upper estimate for temperate forest ecosystems, and thus is not used in this study. Clearly, studies estimating combustion factors are lacking in temperate forests of the western United States. Fire effects on foliage were one of the most difficult parameters to obtain in part due to ambiguity of terms used in the literature. Crown scorch is frequently specified as the pre-fire crown scorched in terms of height or volume. Other studies have used the term crown killed in terms of volume or height. However, there is no clear distinction whether these terms relate to crown consumption, non-consumption or a combination of both consumption and non-consumption. Without these distinctions their parameterization in a terrestrial carbon cycle model remains ambiguous. Only few studies have attempted to distinguish between crown consumption and non-combustive mortality [*Campbell et al.*, 2007; *Keyser et al.*, 2008; *McHugh and Kolb*, 2003; *Sieg et al.*, 2006; *Wyant et al.*, 1986], and we have had to rely on this small sample in the present work.

[32] Another important source of uncertainty in this study is the assignment of fire severity, which is a subjective process influenced by spatial and temporal heterogeneity. Spatial heterogeneity in severity is common because different parts of the landscape are affected by fires of different magnitudes and severities dependent on climatic conditions, topography, and amounts of live and dead pools. As a result, post-fire response of vegetation is characterized by patches of vegetation of differing age related to fire severity. An additional source of uncertainty is temporal variability in fire effects due to delayed mortality of vegetation. For example, immediately after a fire there could be low mortality of vegetation, but over the immediate post-fire years mortality can increase due to degradation of substrate quality, adverse impacts on photosynthetic capacity, damage to different plant parts, decreased availability of nutrients and unfavorable climatic factors. In this study, the mortality over the immediate post-fire time period is aggregated, and this aggregated mortality is assumed to occur at the time of the fire. The first order effects of fires could also interact with second order effects (such as bark beetles, droughts, etc) to increase mortality in the subsequent years after fires. These types of interactions with other disturbance types are beyond the scope of the current study. While the temporal and spatial aspects of fire severity are important, the differing fire effects on different vegetation strata, soils and dead fuels also make severity assignment difficult. The literature does not indicate a consistent approach to quantify severity and most studies have not attempted to provide measures of fire severity. One candidate for standardization is the composite burn index (CBI). Although studies have reported that the composite burn index (CBI) has limitations in detecting burn severity [*Kasischke et al.*, 2008], improvements in CBI have been proposed [*De Santis and Chuvieco*, 2009]. Continuing improvements in CBI could make it a suitable fire severity measure which studies could use to rate burn severity. The advantages of this index are that it combines the fire effects on live vegetation parts, dead fuels and soils, and has extended applications in remote sensing.

4.2. Fire-Induced Direct Emissions and Biomass Killed

[33] This study estimated that the direct emission averaged from 1984 and 2008 was 4.01 TgC yr^{-1}. *Wiedinmyer and Neff* [2007] reported that the average 2002 to 2006 emissions in western United States was 105 $\pm$ 42 $TgCO_2$ yr^{-1}, or 29 $\pm$ 11 TgC yr^{-1} assuming that all the carbon is combusted as CO_2. Our study estimated that the direct emission averaged over the 2002 to 2006 time period was 6.88 TgC yr^{-1} which is lower than the mean estimate of 29 TgC yr^{-1} reported by *Wiedinmyer and Neff* [2007]. The differences in the estimates can be attributed to the different data sets and approaches used by different studies to obtain combustion factors, burned area and fuel loading (i.e., biomass per area burned). Our own analysis using the CASA Global Fire Emissions Database [*van der Werf et al.*, 2010] produced mean forest fire emissions for the western U.S. of 3.5 TgC yr^{-1} for 2002–2006. The mean estimate of fire emissions for the United States using MTBS from the Wildland Fire Emissions Information System (WFEIS, http://wfeis.mtri.org) for 2002–2006 is 22.5 TgC yr^{-1}. About half of U.S. forest fire burned area [*Smith et al.*, 2009] and 60% of the carbon emissions (derived from CASA GFED3 simulations) occur within the domain of our study area, and about 65% of carbon emissions are from forest fires (CASA GFED3 simulations) bringing the WFEIS to about 7 TgC yr^{-1} for western forest fire emissions, close to our result (6.88 TgC yr^{-1} for 2002–2006) and higher than that of GFED3 (3.5 TgC yr^{-1}), all of which are lower than *Wiedinmyer and Neff* [2007] (29 TgC yr^{-1}).

[34] While undertaking these comparisons, it should be noted that the consumption factor for trees (i.e., live woody fuels) is based on a study by *Campbell et al.* [2007], and uncertainty in the consumption factor estimates can be reduced, if additional studies reporting consumption factors of live woody fuels are conducted in representative ecosystems in western United States. In addition, the estimates of direct emissions and biomass killed by fires are underestimates as the burn area reported by MTBS in the United States represents 96% of the area affected by wildfires, and 73% of the area affected by wildfires, wildland fire use and prescribed fires [*Eidenshink et al.*, 2007]. Moreover the consumption factor (i.e., combustion completeness) of the dead fuels (woody, duff and litter) for some of the studies reviewed may be underestimates as fire-induced transfers from live to dead pools may also be included in the dead pool consumption rates. Data are not available to factor out such additions and so we cannot estimate the degree of underestimation, if any that may have influenced our results. However, the remaining studies reviewed accessed consumption by factoring out such additions, and thus the inclusion of such studies reduces the uncertainty in the consumption factor estimates.

[35] Several studies have reported the direct fire emissions but have neglected the fire-induced biomass killed (associated with fire-induced non-consumptive transfer of biomass from live to dead pools), particularly at large regional scales in temperate forests of western United States. Thus, the fire-induced biomass killed between 1984 and 2008 obtained in this study is one of the first regional estimates reported in the literature for western United States forests. A study conducted in Canada's managed forest from 1990 to 2008 reported average direct emissions of 23 TgC yr^{-1} and biomass killed of 27 TgC yr^{-1} due to fires with biomass killed approximately 1.2 times higher than direct emissions [*Stinson et al.*, 2011]. Compared to the Canadian study, both our fire-induced direct emissions of 4.34 TgC yr^{-1} and biomass killed of 11.35 TgC yr^{-1} during the same time period (1990–2008) was lower with biomass killed 2.6 times higher than direct emissions.

4.3. Characteristic Carbon Trajectories

[36] The post-fire carbon trajectories obtained from this new parameterization are broadly consistent with those obtained from the literature. However, a striking feature of the NEP trajectories is that there is a short spike in NEP in the early part of post-fire vegetation recovery due to slower dead wood decomposition. Earlier studies do not highlight this feature because they have either assumed that all the wood is combusted or is taken off site [*Williams et al.*, 2012], estimated temporally smoothed post-disturbance NEP by computing 5-yr moving averages [*Kurz et al.*, 2009], modeled carbon flux exclusively in the boreal regions [*Hicke et al.*, 2003], derived disturbance induced regional carbon fluxes without determining characteristic carbon trajectories [*Law et al.*, 2004; *Turner et al.*, 2004], or measured post-disturbance NEP chronosequences at widely spaced temporal intervals [*Gough et al.*, 2007; *Litvak et al.*, 2003]. A study by *Harmon et al.* [2011] reported that theoretically multiple pulses of heterotrophic respiration are possible due to differences in decomposition rates of multiple types of detritus left by disturbances as well as lags in disturbance associated mortality and/or decomposition.

[37] Our findings also conform to fundamental biogeographical expectations. For example, differences in characteristic trajectories exist among forest type groups in a given region, related to climate as well as soils and the basic physiological properties of the species present in each. We would note, however, that our use of FIA-based carbon accumulation curves assume that after fire the same successional forest type groups regenerate in the area. However, in reality post-fire successional species can be different from pre-fire species depending on seed and nutrient availability, climate, and fire severity which is beyond the scope of the present study. Additionally, the productivity level of a forest may not remain the same since, after a fire, forest stands may change from being highly productive to one that has low productivity and vice versa with changes in site nutrition, hydrology, and species composition. There is also increasing concern that climate change, and carbon dioxide and nitrogen fertilization may cause the post-fire regeneration trajectory of stands to be steeper or flatter depending on whether climate is conducive or detrimental to stand productivity. Unfortunately data are lacking to describe all of these complicating factors that may change the nature of post-fire carbon dynamics. The characteristic post-fire trajectories for high- and low-productivity classes accounts for the differences in productivity of the same forest group. For example, Douglas-fir forests in the interior and coast have significant differences in productivity and much of this variation is already represented by the low- and high-productivity classes we separate in the modeling.

[38] One of the unique contributions of our approach is that it not only generates post-fire carbon trajectories across a range of forest type groups and forest service regions, but also distinguishes the contributions of direct and indirect fire effects on carbon balance. In addition, our approach offers important new details by representing how carbon dynamics vary with fire severity. It provides new quantitative descriptions of how post-fire trajectories of high-severity fires start off at a lower biomass due to a higher loss of biomass but have a higher carbon uptake caused by young trees which actively regenerate. Previous studies have not sought to capture such variations, and have usually focused on fires as spatially homogeneous events with a single severity class [*Hicke et al.*, 2003; *Turner et al.*, 2004; *Williams et al.*, 2012]. However, fires in most forests in western United States lead to spatial patterns of differing fire severity associated with varying degrees of biomass mortality.

[39] The family of post-fire carbon trajectories derived in this study offers a more detailed account than previously available, including immediate, short-term, and long-lasting, legacy effects. The immediate effect is prompt emission of carbon directly through combustion and subsequently over a short-term more indirectly through increased decomposition of dead carbon pools. Over this short-term post-fire time period, NEP is negative because carbon lost through decomposition exceeds carbon gained by vegetation regrowth. Over medium post-fire time intervals (usually greater than a decade), forest changes from a source to a sink because carbon gained by actively growing young forest stands outweighs the carbon lost by decomposition. Subsequently there is a peak followed by a decline in NEP. Over longer time periods, in the absence of disturbances at that given area, forest stands regain the carbon lost due to fire. These trajectories also offer an important advance because they can readily be applied to remotely sensed burned area observations to scale up carbon stocks and fluxes to a regional scale.

4.4. Scaling Carbon Fluxes

[40] Regional NEP varies by forest service region, fire severities and forest group types. These variations of NEP are closely related to differences in climatic conditions, water availability and soil quality as well as the characteristics of different forest types, and variability in magnitude/severity of disturbance events. Pacific Southwest region is the largest source of carbon in 2008 in areas affected by fires from 1984 to 2008 due to higher heterotrophic respiration from greater amounts of biomass per area killed and transferred to dead carbon pools, and larger burnt area. In contrast, Rocky Mountain South is the smallest carbon source because the lower magnitude of heterotrophic respiration related to reduced biomass per area burnt. Generally, forests affected by lower fire severities were sinks of carbon (except in Pacific Southwest region) because of lower amounts of biomass killed and left to decompose slowly onsite compared to carbon sequestered by forest regrowth. In contrast, forests influenced by higher fire severities were sources of carbon due to higher amounts of decomposing biomass due to greater mortality rates. Douglas-fir followed by California mixed conifer and Fir/Spruce/Mountain Hemlock are the largest carbon sources due to larger area burnt, and greater fuel loading resulting in higher biomass killed which is available for decomposition in these forests.

[41] The regional carbon fluxes show that the forests of the western United States were a net source of 12.26 TgC yr^{-1} in 2008 due to fires between 1984 and 2008. This results from the gross carbon sources of direct fire emissions (9.51 TgC yr^{-1}) and heterotrophic decomposition (committed emissions) of fire-killed biomass (6.09 TgC yr^{-1}) outweighing the small regrowth sink from NPP (22.81 TgC yr^{-1}) minus heterotrophic decomposition from natural mortality and turnover (19.47 TgC yr^{-1}). Interestingly, heterotrophic decomposition of biomass associated with disturbances and natural

mortality is nearly balanced by post-disturbance NPP recovery due to previous fires. However, a longer period of time is required for NPP recovery to offset both direct emissions and disturbance-induced heterotrophic respiration (indirect emissions). It should be noted that our study ignores the fire impacts on carbon balance during time periods prior to 1984 as well as after 2008. As a result, we do not consider the reduction in primary productivity and increase in heterotrophic respiration that occur in 1984–2008 due to biomass killed prior to 1984 as well as the impacts of the 1984–2008 fires into the future as reduction of primary productivity and increase in heterotrophic respiration (i.e., committed emissions) from fire-killed biomass in 1984–2008. Future studies will need to consider better techniques of representing the emissions from fire-killed biomass given the time-dynamic nature of this term, especially with a flux legacy (e.g., 50 yrs) that lasts longer than the period of study (1984–2008). This issue is further complicated by a non-steady fire process, meaning the rise in fire frequency.

5. Conclusion

[42] With this study's detailed parameterization of fire effects on forest carbon pools we have provided more precise quantitative estimates of how ecosystem carbon stocks and fluxes respond to fires of differing severity across a wide range of forest types in the western United States. Results show that tree mortality and consumption of live and dead fuels increases with higher fire severity which has severity related consequences for the post-fire carbon flux trajectories. The carbon flux trajectories vary by forest type with the maximum NEP and its timing, minimum NEP, and NEP crossover time all increasing with increasing fire severities. On average, mortality increased from 28% to 93%, foliage consumption from 10% to 66%, dead woody fuel consumption from 56% to 79%, litter consumption from 69% to 96%, and duff consumption from 45% to 90% across low- to high-severity classes. This causes average fire-induced direct emissions and biomass killed of 4.01 TgC yr^{-1} and 10.52 TgC yr^{-1} respectively from 1984 to 2008. The fire-induced total direct emissions and biomass killed from 1984 to 2008 were 1.4 times and 3.7 times higher for high- compared to low-severity fires, respectively. Additionally, both the fire-induced total direct emissions and biomass killed increase 2.6 times from the 1984–1995 to 1996–2008 time periods. All of this underscores the importance of accounting for how post-fire carbon dynamics vary across forest types and with severity. The corresponding parameterization presented here is useful for local to regional estimation of fire effects on ecosystem carbon balance in western U.S. forests, and could be readily applied to examine carbon consequences of anticipated increases in fire frequency and severity stimulated by climate change.

Appendix A: Fire Effects on Whole Trees and Tree Parts

A1. Foliage

[43] Foliage injury has been frequently reported as one of the most important factors influencing post-fire tree mortality. The process of photosynthesis which is responsible for storing energy in the form of carbohydrates is adversely affected due to foliage injury because of the reduction in foliage area to capture carbon dioxide and light.

[44] The total damage to foliage is associated with two processes, direct (consumption) and indirect (scorching/non-consumption). Foliage consumption is related to the direct combustion of foliage and is associated with the emission of a sudden pulse of carbon dioxide into the atmosphere. In contrast, foliage scorch is the damage due to direct contact or indirect convective heating from fire flames and is associated with the discoloration of foliage from green to yellow and/or brown. The scorched foliage is usually dead and falls on the forest surface as litter. Post-fire mortality studies use different terms to describe foliage consumption and scorch. The term *percent crown scorch* is usually expressed as the percentage of pre-fire crown scorched by the fire in terms of height or volume. However, there is ambiguity regarding the term *scorch*, as some authors have reported that crown scorch also includes crown consumption, unless otherwise specified in post-fire mortality papers by separating the scorch and consumption components. So it is very difficult to determine if foliage scorch refers to non-consumption or both consumption and non-consumption of foliage. Thus, foliage scorch has not been used to parameterize fire effects on foliage. Rather only studies that have directly specified foliage consumption and/or non-consumption have been used. In post-fire mortality studies, the term *percent crown consumed* usually is specified as the percentage of pre-fire crown consumed by the fire either in terms of height or volume. *Foliage consumption* is used to refer to crown consumption in this study.

[45] In terms of carbon cycle modeling, foliage consumption is associated with the consumptive effects of fire on foliage causing direct transfer of carbon to the atmosphere. In contrast, foliage non-consumption triggers the transfer of carbon from the foliage to the litter pool. The leaf pool corresponds to foliage in CASA model. Table A1 shows the foliage consumption and non-consumption rates (%) compiled from the literature survey.

A2. Stem

[46] Stem damage is physiologically associated with the injury of cambium tissue in plant stems. Cambium damage can lead to tree mortality because it disrupts the production of xylem and phloem tissues. These tissues are important for plant functioning because xylem is responsible for the transfer of water and nutrients upwards toward the crown whereas phloem transports food downward toward the roots. Most papers have used proxy measures for cambium damage in plant stems. There is no consistent use of stem damage parameters with both qualitative and quantitative measure being used. Different papers have used different measures specified in terms of bole, basal or cambium damage and expressed as height or circumference. It is very difficult to compile and combine all these indicators consistently. Moreover these stem damage indicators do not necessarily distinguish between consumptive and non-consumptive fire effects on stems. Instead consumptive and non-consumptive fire effects on stems can be derived from tree mortality rates

Table A1. Foliage Consumption and Non-consumption Rates for Different Species and Fire Severity Levels

State	Species[a]	Consumption (%)	Non-consumption (%)	Reference	Severity
Colorado	DF	27.20	62.75	*Wyant et al.* [1986]	Medium
Colorado	PP	11.03	48.46	*Wyant et al.* [1986]	Low
Arizona	PP	0.00	46.00	*McHugh and Kolb* [2003]	Low
Arizona	PP	10.30	55.30	*McHugh and Kolb* [2003]	Medium
Arizona	PP	4.30	27.20	*McHugh and Kolb* [2003]	Medium
South Dakota	PP	96.00	4.00	*Keyser et al.* [2008]	High
South Dakota	PP	7.00	78.00	*Keyser et al.* [2008]	Medium
South Dakota	PP	0.00	30.00	*Keyser et al.* [2008]	Low
Oregon, California	Conifers	74.82		*Campbell et al.* [2007]	High
Oregon, California	Hardwoods	68.38		*Campbell et al.* [2007]	High
Oregon, California	Conifers	52.38		*Campbell et al.* [2007]	Medium
Oregon, California	Hardwoods	61.09		*Campbell et al.* [2007]	Medium
Oregon, California	Conifers	20.22		*Campbell et al.* [2007]	Low
Oregon, California	Hardwoods	20.09		*Campbell et al.* [2007]	Low
Arizona	PP	9.70	45.80	*Sieg et al.* [2006]	Medium
Colorado	PP	8.70	58.30	*Sieg et al.* [2006]	Medium
South Dakota	PP	12.50	49.20	*Sieg et al.* [2006]	Medium
Montana	PP	8.50	54.60	*Sieg et al.* [2006]	Medium
South Dakota	PP	24.70	54.20	*Sieg et al.* [2006]	High

[a]Species codes: DF = Douglas-fir; PP = Ponderosa Pine.

under the assumption that stem mortality rates are similar in magnitude to tree mortality rates. We found a study by *Campbell et al.* [2007] that determined the combustion of trees (boles and barks) which is used to derive the amount of stem combusted in this study. The consumption factors are used as the consumptive effect and the non-consumptive effects are computed by subtracting these consumption factors from the mortality rates.

[47] In the structure of the CASA model, the aboveground wood pool corresponds to the stem. While implementing stem mortality in CASA, fire related stem consumption is associated with the direct transfer of carbon to the atmosphere and stem non-consumption represents the transfer of carbon from the aboveground wood pool to the snag pool. Table A2 shows the tree mortality rates (%) collected from the literature.

A3. Roots

[48] Roots are important indicators of post-fire mortality because they not only support the aboveground tree components but also extract soil nutrients and moisture for tree growth. Damage to the roots is the most difficult parameter to measure because roots are the belowground components of vegetation. Few studies have used direct quantitative measures of root damage due to fires as reported by *Swezy and Agee* [1991]. Most studies have used indirect measures of root damage (e.g., ground char classes, reduction of duff and litter layers, and/or exposure of mineral soil). However, there is no clear relationship between the amount of root damage and the indirect quantitative measures of proportion of duff/litter layer reduction and/or exposure of mineral soil. Thus these measures cannot be used to quantify root damage. Instead root mortality rates are assumed to be proportional to tree mortality rates.

[49] In the structure of the CASA model, the belowground wood pool corresponds to the coarse roots, and fine root pool corresponds to the fine roots. While implementing root mortality in CASA, fire related direct consumption of roots does not occur but instead non-consumption of roots transfers carbon from belowground wood pool to the soil metabolic and structural pools. This non-consumption of roots is proportional to tree mortality rates. The mortality rates compiled in Table A2 are used to specify belowground wood non-consumption in the CASA model.

A4. Dead Woody Fuel

[50] In most studies, dead woody fuels are reported as 1 h, 10 h, 100 h and 1000 h (time lag) fuels depending on the size of the woody fuel (see Table A3). The time lag means that dead woody debris would take approximately a certain amount of time (specified as 1hr, 10 h, 100 h or 1000 h) to exchange moisture in order to attain 63.2% of its new equilibrium moisture content in a changed environment. Other studies have specified dead woody fuels as amounts of fine woody debris and coarse woody debris (see Table A3). Dead woody fuel consumption is considered as the percent change from pre-fire levels in the mass of dead woody fuels across all sizes. The dead woody fuel has been implemented as the dead woody debris pool in the CASA model. In the CASA model the consumption of dead woody debris pool transfers carbon from the dead woody debris pool to the atmosphere. Literature values of the consumption of dead woody fuels are compiled in Table A3. Negative reduction rates for dead woody, litter and duff have been removed from the table as these reflect fire-induced transfer of carbon from live to dead pools rather than consumption. The consumption values in the table for some of the studies reviewed may be underestimates as fire-induced transfers from live to dead pools may also be included in the dead pool consumption rates. Data are not available to factor out such additions and so we cannot estimate the degree of underestimation, if any that may have influenced our results. However, the remaining studies reviewed accessed consumption by factoring out such additions, and thus the inclusion of such studies reduces the uncertainty in the consumption factor estimates.

Table A2. Tree Mortality Rates Corresponding to Different Tree Species and Fire Severity Levels

State	Species[a]	Mortality (%)	Reference	Severity
Colorado	DF	62.14	*Wyant et al.* [1986]	Medium
Colorado	PP	25.26	*Wyant et al.* [1986]	Low
California	WF	16.83	*Kobziar et al.* [2006]	Medium
California	IC	17.72	*Kobziar et al.* [2006]	Medium
California	T	58.01	*Kobziar et al.* [2006]	Medium
California	SP	3.17	*Kobziar et al.* [2006]	Medium
California	PP	12.17	*Kobziar et al.* [2006]	Medium
California	DF	26.44	*Kobziar et al.* [2006]	Medium
California	CBO	52.55	*Kobziar et al.* [2006]	Medium
Oregon	PP	16.11	*Thies et al.* [2006]	Low
California	PP	67.73	*Regelbrugge and Conard* [1993]	Medium
California	IC	33.33	*Regelbrugge and Conard* [1993]	Medium
California	CLO	83.91	*Regelbrugge and Conard* [1993]	Medium
California	CBO	73.68	*Regelbrugge and Conard* [1993]	Medium
South Dakota	PP	100.00	*Keyser et al.* [2008]	High
South Dakota	PP	63.53	*Keyser et al.* [2008]	Medium
South Dakota	PP	28.94	*Keyser et al.* [2008]	Low
Oregon	MC	29.00	*Meigs et al.* [2009]	Low
Oregon	MC	58.00	*Meigs et al.* [2009]	Medium
Oregon	MC	96.00	*Meigs et al.* [2009]	High
Oregon	PP	14.00	*Meigs et al.* [2009]	Low
Oregon	PP	49.00	*Meigs et al.* [2009]	Medium
Oregon	PP	100.00	*Meigs et al.* [2009]	High
Montana, Wyoming	DF	62.60	*Hood and Bentz* [2007]	Medium
California	RF	22.33	*Hood et al.* [2007]	Medium
California	IC	11.91	*Hood et al.* [2007]	Medium
California	WF	42.92	*Hood et al.* [2007]	Medium
California	WF	50.21	*Hood et al.* [2007]	Medium
California	YP	65.45	*Hood et al.* [2007]	Medium
Arizona	WF	75.76	*Fulé et al.* [2004]	Medium
Arizona	PP	13.35	*Fulé et al.* [2004]	Medium
Arizona	QA	81.98	*Fulé et al.* [2004]	Medium
Arizona	DF	57.90	*Fulé et al.* [2004]	Medium
Arizona	NML	100.00	*Fulé et al.* [2004]	Medium
Idaho, Montana, Oregon, Washington	DF	20.20	*Ryan and Reinhardt* [1988]	Low
Idaho, Montana, Oregon, Washington	WL	15.70	*Ryan and Reinhardt* [1988]	Low
Idaho, Montana, Oregon, Washington	ES	87.50	*Ryan and Reinhardt* [1988]	High
Idaho, Montana, Oregon, Washington	LP	79.90	*Ryan and Reinhardt* [1988]	High
Idaho, Montana, Oregon, Washington	SF	85.50	*Ryan and Reinhardt* [1988]	High
Idaho, Montana, Oregon, Washington	WRC	76.80	*Ryan and Reinhardt* [1988]	Medium
Idaho, Montana, Oregon, Washington	WH	87.00	*Ryan and Reinhardt* [1988]	High
Arizona	PP	36.50	*Sieg et al.* [2006]	Medium
Colorado	PP	63.60	*Sieg et al.* [2006]	Medium
South Dakota	PP	47.90	*Sieg et al.* [2006]	Medium
Montana	PP	62.70	*Sieg et al.* [2006]	Medium
South Dakota	PP	83.40	*Sieg et al.* [2006]	High
Arizona	PP	10.00	*Kaufmann and Covington* [2001]	Low
Arizona	PP	27.00	*Kaufmann and Covington* [2001]	Low
Arizona	PP	13.00	*Kaufmann and Covington* [2001]	Low
Arizona	PP	12.00	*Kaufmann and Covington* [2001]	Low
Colorado	PP	12.00	*Harrington* [1993]	Low
Colorado	PP	28.00	*Harrington* [1993]	Low
Colorado	PP	30.00	*Harrington* [1993]	Medium
Arizona	PP	18.02	*McHugh et al.* [2003]	Low
Arizona	PP	32.37	*McHugh et al.* [2003]	Medium
Arizona	PP	13.93	*McHugh et al.* [2003]	Medium
Arizona	PP	15.00	*Fulé and Laughlin* [2007]	Low
Arizona	GO	42.00	*Fulé and Laughlin* [2007]	Low
Arizona	NML	100.00	*Fulé and Laughlin* [2007]	Low
Arizona	WF	55.00	*Fulé and Laughlin* [2007]	Medium
Arizona	PP	31.00	*Fulé and Laughlin* [2007]	Medium
Arizona	QA	65.00	*Fulé and Laughlin* [2007]	Medium
Arizona	RMDF	61.00	*Fulé and Laughlin* [2007]	Medium
Arizona	NML	100.00	*Fulé and Laughlin* [2007]	Medium
Arizona	WF	60.00	*Fulé and Laughlin* [2007]	Medium
Arizona	SF	68.00	*Fulé and Laughlin* [2007]	Medium
Arizona	ES,BS	53.00	*Fulé and Laughlin* [2007]	Medium
Arizona	PP	22.00	*Fulé and Laughlin* [2007]	Medium
Arizona	QA	65.00	*Fulé and Laughlin* [2007]	Medium
Arizona	RMDF	19.00	*Fulé and Laughlin* [2007]	Medium
Arizona	NML	100.00	*Fulé and Laughlin* [2007]	Medium

Table A2. (continued)

State	Species[a]	Mortality (%)	Reference	Severity
California	IC, RF, JP, PP, MD, BO	37.59	*Schwilk et al.* [2006]	Medium
California	WF	35.62	*Schwilk et al.* [2006]	Medium
California	SP	46.51	*Schwilk et al.* [2006]	Medium
California	IC, RF, JP, PP, MD, BO	55.10	*Schwilk et al.* [2006]	Medium
California	WF	50.32	*Schwilk et al.* [2006]	Medium
California	SP	61.34	*Schwilk et al.* [2006]	Medium
WY	A	100.00	*Brown and DeByle* [1987]	High
WY	A	92.00	*Brown and DeByle* [1987]	Medium
WY	A	80.00	*Brown and DeByle* [1987]	Low
Oregon	PP, DF, GF	7.00	*Wright et al.* [2003]	Low
Oregon	PP, DF, GF	12.00	*Wright et al.* [2003]	Low
California	Conifers	99.00	*Franklin et al.* [2006]	High
California	Oaks	14.00	*Franklin et al.* [2006]	Low
California	Conifers	39.00	*Franklin et al.* [2006]	Medium
California	Oaks	25.00	*Franklin et al.* [2006]	Medium
California	Conifers	17.00	*Franklin et al.* [2006]	Low
California	Oaks	9.00	*Franklin et al.* [2006]	Low
California	Sierran mixed conifer	25.04	*Vaillant et al.* [2009]	Medium
California	Klamath mixed conifer	30.65	*Vaillant et al.* [2009]	Low
California	PP	17.35	*Vaillant et al.* [2009]	Low
California	JP	6.31	*Vaillant et al.* [2009]	Low
California	Eastside pine	15.16	*Vaillant et al.* [2009]	Low
California	Montane hardwood-conifer	0.39	*Vaillant et al.* [2009]	Low
California	Sierran mixed conifer	18.74	*Vaillant et al.* [2009]	Low
California	Sierran mixed conifer	26.38	*Vaillant et al.* [2009]	Medium
California	PP	0.00	*Vaillant et al.* [2009]	Low
	DF	76.80	*Ryan and Amman* [1996]	Medium
	ES	94.12	*Ryan and Amman* [1996]	High
	LP	60.93	*Ryan and Amman* [1996]	Medium
	SF	100.00	*Ryan and Amman* [1996]	High
Montana	DF	53.00	*Ryan et al.* [1988]	Medium
Montana	DF	47.00	*Ryan et al.* [1988]	Medium
Oregon	SP	59.00	*Agee* [2003]	Low
Oregon	WF	52.00	*Agee* [2003]	Low
Oregon	PP	28.00	*Agee* [2003]	Low
California	WF, RF	61.00	*Keifer et al.* [2000]	Medium
California	WF, RF, CBO, SP, IC, JP	6.80	*North et al.* [2009]	Low
California	SP, PP, WF, IC, DF, CBO, T, BC, PM	48.06	*Stephens and Moghaddas* [2005]	Medium
	WP	47.20	*Keane and Parsons* [2010]	Low
	WP	88.37	*Keane and Parsons* [2010]	Medium
	WP	80.00	*Keane and Parsons* [2010]	High
	SF	58.05	*Keane and Parsons* [2010]	Low
	SF	40.83	*Keane and Parsons* [2010]	Medium
	SF	84.85	*Keane and Parsons* [2010]	High
California	WF, RF, IC, JP, PP, SP	97.00	*North and Hurteau* [2011]	High

[a]Species codes: A = Aspen; BC = Bush Chinkapin; BO = Black Oak; BS = Blue Spruce; CBO = California Black Oak; CLO = Canyon/Coast Live Oak; DF = Douglas-fir; ES = Engelmann Spruce; GF = Grand Fir; GO = Gambel Oak; IC = Incense Cedar; JP = Jeffrey Pine; LP = Lodgepole Pine; MC = Mixed Conifer; MD = Mountain Dogwood; NML = New Mexico Locust; PM = Pacific Madrone; PP = Ponderosa Pine; QA = Quaking Aspen; RF = Red Fir; RMDF = Rocky Mountain Douglas-fir; SF = Subalpine Fir; SP = Sugar Pine; T = Tanoak; WF = White Fir; WH = Western Hemlock; WL = Western Larch; WP = Whitebark Pine; WRC = Western Red Cedar; YP = Yellow Pine.

A5. Litter and Duff

[51] The reduction of duff and litter layers can be used to determine the consumption of the carbon cycle model's so-called surface pools. The CASA model has three types of surface pools, namely structural, metabolic and microbial pool. Litter is divided into fractions of structural and metabolic components in the carbon cycle model depending on the lignin to nitrogen ratio. The structural component is considered to have higher lignin to nitrogen ratio and slower turnover time than the metabolic component. The consumption of litter corresponds to the consumption of both the structural and metabolic surface pools. In contrast, the consumption of the duff corresponds to the consumption of the microbial surface pool. The consumption of surface pool transfers carbon from the surface pool to the atmosphere. The litter and duff consumption rates (%) for different fire severities compiled from the literature are presented in Table A3.

Appendix B: Area-Normalized Fire-Induced Direct Emissions and Biomass Killed

[52] Table B1 reports the area-normalized fire-induced direct emissions and biomass killed stratified by forest species groups, fire severity levels, regions and productivity

Table A3. Consumption Rates for Dead Woody, Litter and Duff Fuels for Different Species and Fire Severity Levels

State	Species[a]	Dead Woody (%)	Litter (%)	Duff (%)	Reference	Severity
California	WF, IC, T, SP, PP, DF, CBO	56.01	68.84	84.98	*Kobziar et al.* [2006][b]	Medium
California	WF, IC, T, SP, PP, DF, CBO	68.84	69.20	78.88	*Kobziar et al.* [2006][b]	Medium
California	WF, IC, T, SP, PP, DF, CBO	84.46	52.26	90.67	*Kobziar et al.* [2006][b]	Medium
Montana	PP, DF	57.15	69.00	17.00	*Kalabokidis and Wakimoto* [1992][b]	Low
Montana	PP, DF	40.32	69.00	30.00	*Kalabokidis and Wakimoto* [1992][b]	Low
California	IC, CBO, SP, PP, WF	91.00	93.00	93.00	*Stephens and Finney* [2002][b]	Medium
California	CBO, DF, IC, PP, SP, WF	51.53		61.98	*Hille and Stephens* [2005][b]	Low
California	CBO, DF, IC, PP, SP, WF	74.09	70.79	95.94	*Hille and Stephens* [2005][b]	Medium
Idaho	PP			40.00	*Armour et al.* [1984]	Low
Idaho	PP			80.00	*Armour et al.* [1984]	Medium
South Dakota	PP	80.40	91.93	97.52	*Keyser et al.* [2008][c]	High
South Dakota	PP	82.91	87.58	95.04	*Keyser et al.* [2008][c]	Medium
South Dakota	PP	74.87	68.32	88.65	*Keyser et al.* [2008][c]	Low
Oregon, California	DF, WH, BM, T, JP	77.06	100.00	99.00	*Campbell et al.* [2007][b]	High
Oregon, California	DF, WH, BM, T, JP	58.28	76.00	51.00	*Campbell et al.* [2007][b]	Medium
Oregon, California	DF, WH, BM, T, JP	58.78	75.00	54.00	*Campbell et al.* [2007][b]	Low
Arizona	SF, WF, ES, PP, QA, DF, NML	46.80		63.89	*Fulé et al.* [2004][b]	Medium
Washington	PP, DF	59.17			*Agee and Lolley* [2006][b]	Low
Arizona	PP, GO	38.90			*Fulé and Laughlin* [2007][c]	Low
Arizona	PP, WF, QA, RMDF	40.76			*Fulé and Laughlin* [2007][c]	Medium
Arizona	SF, ES, BS, RMDF, PP, QA	56.06			*Fulé and Laughlin* [2007][c]	Medium
California	Sierran mixed conifer	77.69	60.36	89.72	*Vaillant et al.* [2009][b]	Medium
California	Klamath mixed conifer	48.40	83.78	77.71	*Vaillant et al.* [2009][b]	Low
California	PP		81.48	45.88	*Vaillant et al.* [2009][b]	Low
California	JP	44.89	61.36	55.16	*Vaillant et al.* [2009][b]	Low
California	Eastside pine	54.82	32.14	61.76	*Vaillant et al.* [2009][b]	Low
California	Montane hardwood-conifer	64.36	76.74	11.38	*Vaillant et al.* [2009][b]	Low
California	Sierran mixed conifer	53.59		60.00	*Vaillant et al.* [2009][b]	Low
California	Sierran mixed conifer	28.43	64.81	76.12	*Vaillant et al.* [2009][b]	Medium
California	PP	36.88	77.69	44.81	*Vaillant et al.* [2009][b]	Low
California	PP, WF, IC	76.40	93.50	93.50	*Kauffman and Martin* [1989][b]	Medium
California	PP, WF, IC	73.49	64.20	64.20	*Kauffman and Martin* [1989][b]	Medium
California	PP, WF, IC	24.83	11.30	11.30	*Kauffman and Martin* [1989][b]	Low
California	PP, WF, IC	34.87	75.90	75.90	*Kauffman and Martin* [1989][b]	Medium
California	DF, IC, PP	85.05	94.00	94.00	*Kauffman and Martin* [1989][b]	High
California	DF, IC, PP	45.38	84.10	84.10	*Kauffman and Martin* [1989][b]	Medium
California	DF, IC, PP		70.00	70.00	*Kauffman and Martin* [1989][b]	Low
California	DF, IC, PP	57.40	92.10	92.10	*Kauffman and Martin* [1989][b]	Medium
California	JP, DF, IC	83.11	72.80	72.80	*Kauffman and Martin* [1989][b]	Medium
California	JP, DF, IC	25.63	67.60	67.60	*Kauffman and Martin* [1989][b]	Low
California	JP, DF, IC	59.26	82.50	82.50	*Kauffman and Martin* [1989][b]	Medium
California	JP, DF, IC	48.57	87.60	87.60	*Kauffman and Martin* [1989][b]	Medium
California	WF, SP, IC, RF, JP, PP, D, CBO	57.52	82.01	69.08	*Knapp et al.* [2005][b]	Low
California	WF, SP, IC, RF, JP, PP, D, CBO	78.92	94.74	92.95	*Knapp et al.* [2005][b]	Medium
California	WF, RF, CBO, SP, IC, JP,	54.33	41.00		*Knapp et al.* [2005][c]	Low
California	SP, PP, WF, IC, DF, CBO, T, BC, PM	74.57	62.43	88.44	*Stephens and Moghaddas* [2005][b]	Medium
Oregon	GF, DF, PP, LP	68.34	49.88	20.91	*Youngblood et al.* [2008][b]	Low

[a]Species codes: BC = Bush Chinkapin; BM = Bigleaf Maple; BS = Blue Spruce; CBO = California Black Oak; D = Dogwood; DF = Douglas-fir; ES = Engelmann Spruce; GF = Grand Fir; GO = Gambel Oak; IC = Incense Cedar; JP = Jeffrey Pine; LP = Lodgepole Pine; NML = New Mexico Locust; PM = Pacific Madrone; PP = Ponderosa Pine; QA = Quaking Aspen; RF = Red Fir; RMDF = Rocky Mountain Douglas-fir; SF = Subalpine Fir; SP = Sugar Pine; T = Tanoak; WF = White Fir; WH = Western Hemlock.

[b]Dead woody fuels are reported as 1 h, 10 h, 100 h and 1000 h (time lag) fuels.

[c]Dead woody fuels are reported as fine woody debris and coarse woody debris.

Table B1. Area-Normalized Carbon Emissions and Biomass Killed for Combinations of Forest Species Groups, Fire Severity Levels, Regions and Productivity Classes

	Area-Normalized Carbon Emissions (kgC m^{-2})			Area-Normalized Biomass Killed (kgC m^{-2})		
	Low-Severity Fires	Medium-Severity Fires	High-Severity Fires	Low-Severity Fires	Medium-Severity Fires	High-Severity Fires
Spruce/Fir						
Pacific Northwest						
High Productivity	2.67	3.29	4.20	1.96	4.16	7.53
Low Productivity	2.67	3.29	4.20	1.96	4.16	7.53
Pacific Southwest						
High Productivity	3.10	3.79	4.82	1.96	4.16	7.53
Low Productivity	3.10	3.79	4.82	1.96	4.16	7.53
Rocky Mountain North						
High Productivity	2.33	2.90	3.69	1.88	4.01	7.29
Low Productivity	2.33	2.90	3.69	1.88	4.01	7.29
Rocky Mountain South						
High Productivity	2.27	2.83	3.60	1.92	4.09	7.42
Low Productivity	2.27	2.83	3.60	1.92	4.09	7.42
Pinyon/Juniper						
Pacific Northwest						
High Productivity	0.50	0.74	0.88	0.77	1.62	3.08
Low Productivity	0.65	0.70	0.88	0.68	1.65	2.87
Pacific Southwest						
High Productivity	3.44	4.31	5.66	2.11	4.58	8.42
Low Productivity	0.43	0.66	0.80	0.65	1.38	2.56
Rocky Mountain North						
High Productivity	0.36	0.39	0.55	0.37	0.70	1.64
Low Productivity	0.37	0.43	0.62	0.47	0.90	1.75
Rocky Mountain South						
High Productivity	0.18	0.26	0.35	0.29	0.65	1.21
Low Productivity	0.17	0.24	0.33	0.29	0.65	1.16
Douglas-Fir						
Pacific Northwest						
High Productivity	5.08	6.80	8.81	5.53	16.21	33.73
Low Productivity	1.64	2.54	3.33	3.50	10.23	20.77
Pacific Southwest						
High Productivity	6.96	9.50	12.12	6.39	18.14	38.44
Low Productivity	4.13	5.32	7.09	3.40	9.76	20.34
Rocky Mountain North						
High Productivity	1.87	2.95	3.95	4.47	12.87	27.06
Low Productivity	0.95	1.42	1.69	1.32	3.73	8.20
Rocky Mountain South						
High Productivity	0.84	1.28	1.67	1.32	3.81	7.83
Low Productivity	0.80	1.29	1.70	1.32	3.66	7.62
Ponderosa Pine						
Pacific Northwest						
High Productivity	1.17	1.64	1.92	1.89	3.89	9.90
Low Productivity	0.78	1.03	1.29	0.99	2.04	5.11
Pacific Southwest						
High Productivity	1.49	2.33	2.86	2.66	5.69	13.86
Low Productivity	1.08	1.39	1.72	1.08	2.23	5.29
Rocky Mountain North						
High Productivity	1.41	2.43	3.41	2.13	4.47	11.17
Low Productivity	0.38	0.61	0.77	0.88	1.82	4.72
Rocky Mountain South						
High Productivity	0.66	0.99	1.20	0.76	1.60	3.91
Low Productivity	0.70	0.99	1.27	0.76	1.60	4.00
Western White Pine						
Pacific Northwest						
High Productivity	2.68	3.30	4.21	3.88	7.12	6.29
Low Productivity	2.68	3.30	4.21	3.88	7.12	6.29
Pacific Southwest						
High Productivity	0.64	0.96	1.18	2.94	5.55	4.88
Low Productivity	0.65	0.94	1.22	2.96	5.45	4.98
Rocky Mountain North						
High Productivity	2.86	3.58	4.91	4.63	8.32	7.20
Low Productivity	2.86	3.58	4.91	4.63	8.32	7.20

Table B1. (continued)

	Area-Normalized Carbon Emissions (kgC m^{-2})			Area-Normalized Biomass Killed (kgC m^{-2})		
	Low-Severity Fires	Medium-Severity Fires	High-Severity Fires	Low-Severity Fires	Medium-Severity Fires	High-Severity Fires
Rocky Mountain South						
High Productivity	3.61	4.35	5.54	3.90	7.14	6.30
Low Productivity	3.61	4.35	5.54	3.90	7.14	6.30
			Fir/Spruce/Mountain Hemlock			
Pacific Northwest						
High Productivity	1.66	2.55	3.14	3.97	7.99	15.10
Low Productivity	0.83	1.27	1.53	2.25	4.48	8.48
Pacific Southwest						
High Productivity	1.87	2.98	3.49	4.33	8.69	16.26
Low Productivity	1.26	1.91	2.38	2.94	5.89	11.17
Rocky Mountain North						
High Productivity	1.29	1.93	2.54	3.11	5.97	11.22
Low Productivity	0.94	1.38	1.85	1.70	3.33	6.02
Rocky Mountain South						
High Productivity	0.71	1.05	1.23	1.40	2.77	5.20
Low Productivity	0.69	1.01	1.28	1.38	2.73	5.32
			Lodgepole Pine			
Pacific Northwest						
High Productivity	2.13	2.18	2.86	2.03	4.10	6.52
Low Productivity	1.76	2.10	2.61	1.91	3.87	5.80
Pacific Southwest						
High Productivity	2.10	2.26	2.93	2.73	5.29	7.96
Low Productivity	1.46	1.91	2.53	2.46	4.92	7.49
Rocky Mountain North						
High Productivity	4.87	6.11	7.27	4.17	8.51	11.90
Low Productivity	1.06	1.54	1.98	1.78	3.62	5.47
Rocky Mountain South						
High Productivity	1.02	1.25	1.63	1.68	3.31	4.98
Low Productivity	0.96	1.28	1.72	1.63	3.31	4.98
			Hemlock/Sitka Spruce			
Pacific Northwest						
High Productivity	4.42	4.99	6.84	6.84	14.31	21.55
Low Productivity	1.87	2.33	2.92	4.43	9.52	14.06
Pacific Southwest						
High Productivity	1.92	2.09	2.80	1.37	2.90	4.29
Low Productivity	1.92	2.09	2.80	1.37	2.90	4.29
Rocky Mountain North						
High Productivity	2.29	3.75	4.18	4.64	9.74	14.44
Low Productivity	1.25	1.69	2.38	3.62	7.45	11.22
Rocky Mountain South						
High Productivity	2.81	3.10	4.13	2.36	5.01	7.44
Low Productivity	2.81	3.10	4.13	2.36	5.01	7.44
			Western Larch			
Pacific Northwest						
High Productivity	1.32	2.15	2.58	2.82	7.26	12.56
Low Productivity	1.14	1.65	2.10	2.14	5.51	9.30
Pacific Southwest						
High Productivity	3.10	3.79	4.82	1.79	4.56	7.65
Low Productivity	3.10	3.79	4.82	1.79	4.56	7.65
Rocky Mountain North						
High Productivity	2.03	3.17	3.52	4.11	10.95	18.91
Low Productivity	1.11	1.41	1.85	1.91	4.86	8.33
Rocky Mountain South						
High Productivity	2.67	3.30	4.19	1.78	4.55	7.65
Low Productivity	2.67	3.30	4.19	1.78	4.55	7.65
			Redwood			
Pacific Northwest						
High Productivity	2.67	3.29	4.20	1.95	4.14	7.50
Low Productivity	2.67	3.29	4.20	1.95	4.14	7.50
Pacific Southwest						
High Productivity	9.35	11.66	15.58	6.81	13.90	23.18
Low Productivity	9.30	11.55	16.08	6.77	13.77	23.92

Table B1. (continued)

	Area-Normalized Carbon Emissions (kgC m^{-2})			Area-Normalized Biomass Killed (kgC m^{-2})		
	Low-Severity Fires	Medium-Severity Fires	High-Severity Fires	Low-Severity Fires	Medium-Severity Fires	High-Severity Fires
Rocky Mountain North						
High Productivity	2.47	3.07	3.91	1.94	4.13	7.49
Low Productivity	2.47	3.07	3.91	1.94	4.13	7.49
Rocky Mountain South						
High Productivity	2.67	3.30	4.19	1.94	4.13	7.50
Low Productivity	2.67	3.30	4.19	1.94	4.13	7.50
Other Western Softwoods						
Pacific Northwest						
High Productivity	0.70	0.75	0.89	2.33	4.45	3.86
Low Productivity	0.61	0.73	0.96	2.40	4.47	4.03
Pacific Southwest						
High Productivity	8.26	10.83	13.67	16.54	30.43	26.95
Low Productivity	1.99	2.32	3.15	6.33	9.62	9.34
Rocky Mountain North						
High Productivity	0.37	0.57	0.63	1.51	2.90	2.45
Low Productivity	0.52	0.64	0.75	1.60	2.99	2.66
Rocky Mountain South						
High Productivity	0.50	0.61	0.90	1.70	3.12	2.88
Low Productivity	0.52	0.63	0.86	1.73	3.13	2.81
California Mixed Conifer						
Pacific Northwest						
High Productivity	3.03	3.73	4.82	1.94	4.13	7.48
Low Productivity	3.03	3.73	4.82	1.94	4.13	7.48
Pacific Southwest						
High Productivity	1.86	2.68	3.16	2.48	5.42	9.76
Low Productivity	1.89	2.50	3.28	2.51	5.42	9.86
Rocky Mountain North						
High Productivity	2.55	3.19	4.11	1.93	4.10	7.45
Low Productivity	2.55	3.19	4.11	1.93	4.10	7.45
Rocky Mountain South						
High Productivity	3.51	4.30	5.54	1.95	4.14	7.49
Low Productivity	3.51	4.30	5.54	1.95	4.14	7.49
Oak/Pine						
Pacific Northwest						
High Productivity	2.67	3.29	4.20	2.00	4.23	7.49
Low Productivity	2.67	3.29	4.20	2.00	4.23	7.49
Pacific Southwest						
High Productivity	3.10	3.79	4.82	2.00	4.23	7.49
Low Productivity	3.10	3.79	4.82	2.00	4.23	7.49
Rocky Mountain North						
High Productivity	2.47	3.07	3.91	1.99	4.21	7.48
Low Productivity	2.47	3.07	3.91	1.99	4.21	7.48
Rocky Mountain South						
High Productivity	2.26	2.83	3.60	1.99	4.20	7.47
Low Productivity	2.26	2.83	3.60	1.99	4.20	7.47
Oak/Hickory						
Pacific Northwest						
High Productivity	2.67	3.29	4.20	0.87	2.97	4.25
Low Productivity	2.67	3.29	4.20	0.87	2.97	4.25
Pacific Southwest						
High Productivity	3.10	3.79	4.82	0.87	2.97	4.26
Low Productivity	3.10	3.79	4.82	0.87	2.97	4.26
Rocky Mountain North						
High Productivity	2.40	2.99	3.80	0.85	2.94	4.24
Low Productivity	2.40	2.99	3.80	0.85	2.94	4.24
Rocky Mountain South						
High Productivity	0.69	0.74	1.11	0.37	1.21	1.85
Low Productivity	0.66	0.79	0.97	0.39	1.28	2.00
Elm/Ash/Cottonwood						
Pacific Northwest						
High Productivity	3.02	2.94	4.10	3.76	8.07	13.76
Low Productivity	1.80	2.20	3.49	3.07	6.34	11.62

Table B1. (continued)

	Area-Normalized Carbon Emissions (kgC m^{-2})			Area-Normalized Biomass Killed (kgC m^{-2})		
	Low-Severity Fires	Medium-Severity Fires	High-Severity Fires	Low-Severity Fires	Medium-Severity Fires	High-Severity Fires
Pacific Southwest						
High Productivity	3.22	3.86	4.76	2.15	4.48	7.93
Low Productivity	3.22	3.86	4.76	2.15	4.48	7.93
Rocky Mountain North						
High Productivity	0.58	0.71	0.91	1.44	2.79	4.93
Low Productivity	0.60	0.78	0.97	1.41	2.58	4.93
Rocky Mountain South						
High Productivity	0.49	0.74	0.85	1.38	2.78	5.14
Low Productivity	0.45	0.72	0.84	1.30	2.95	5.11
Maple/Beech/Birch						
Pacific Northwest						
High Productivity	2.67	3.29	4.20	2.00	4.23	7.49
Low Productivity	2.67	3.29	4.20	2.00	4.23	7.49
Pacific Southwest						
High Productivity	3.10	3.79	4.82	2.00	4.23	7.49
Low Productivity	3.10	3.79	4.82	2.00	4.23	7.49
Rocky Mountain North						
High Productivity	2.47	3.07	3.91	1.99	4.21	7.48
Low Productivity	2.47	3.07	3.91	1.99	4.21	7.48
Rocky Mountain South						
High Productivity	2.84	3.49	4.42	1.98	4.20	7.47
Low Productivity	2.84	3.49	4.42	1.98	4.20	7.47
Aspen/Birch						
Pacific Northwest						
High Productivity	0.79	1.21	1.33	1.94	4.16	7.40
Low Productivity	0.63	1.05	1.39	1.33	2.85	4.99
Pacific Southwest						
High Productivity	2.70	3.49	4.39	4.11	8.69	15.54
Low Productivity	0.90	1.29	1.34	1.17	2.48	4.30
Rocky Mountain North						
High Productivity	0.58	0.78	0.86	1.28	2.87	4.64
Low Productivity	0.53	0.75	1.01	1.22	2.85	5.09
Rocky Mountain South						
High Productivity	0.71	0.99	1.25	1.57	3.36	6.15
Low Productivity	0.73	0.98	1.23	1.57	3.29	6.06
Alder/Maple						
Pacific Northwest						
High Productivity	4.43	4.45	6.32	3.69	7.44	13.55
Low Productivity	2.24	2.68	3.32	3.46	7.58	12.82
Pacific Southwest						
High Productivity	2.11	3.13	3.51	3.65	7.11	12.87
Low Productivity	2.01	2.31	4.13	3.69	7.42	12.72
Rocky Mountain North						
High Productivity	2.67	2.89	3.86	2.07	4.36	7.79
Low Productivity	2.67	2.89	3.86	2.07	4.36	7.79
Rocky Mountain South						
High Productivity	2.88	3.10	4.13	2.08	4.36	7.79
Low Productivity	2.88	3.10	4.13	2.08	4.36	7.79
Western Oak						
Pacific Northwest						
High Productivity	2.42	2.84	3.84	1.06	3.46	5.29
Low Productivity	1.30	1.72	2.05	0.97	3.55	5.04
Pacific Southwest						
High Productivity	1.27	1.76	2.12	1.10	4.24	5.84
Low Productivity	1.34	1.87	2.25	1.12	4.33	5.92
Rocky Mountain North						
High Productivity	2.68	3.41	4.18	1.09	4.12	5.68
Low Productivity	2.68	3.41	4.18	1.09	4.12	5.68
Rocky Mountain South						
High Productivity	0.55	0.75	0.89	0.52	1.92	2.78
Low Productivity	0.56	0.79	0.91	0.50	1.97	2.70

Table B1. (continued)

	Area-Normalized Carbon Emissions (kgC m^{-2})			Area-Normalized Biomass Killed (kgC m^{-2})		
	Low-Severity Fires	Medium-Severity Fires	High-Severity Fires	Low-Severity Fires	Medium-Severity Fires	High-Severity Fires
			Tanoak/Laurel			
Pacific Northwest						
High Productivity	2.11	3.18	3.74	5.11	10.89	19.48
Low Productivity	1.69	2.32	3.30	3.55	7.54	14.08
Pacific Southwest						
High Productivity	6.23	7.30	9.58	4.48	9.06	14.58
Low Productivity	5.46	6.58	8.80	5.03	10.24	17.10
Rocky Mountain North						
High Productivity	2.60	3.14	3.86	1.95	4.13	7.33
Low Productivity	2.60	3.14	3.86	1.95	4.13	7.33
Rocky Mountain South						
High Productivity	2.81	3.37	4.13	1.95	4.13	7.34
Low Productivity	2.81	3.37	4.13	1.95	4.13	7.34
			Other Western Hardwoods			
Pacific Northwest						
High Productivity	5.21	6.65	8.47	4.08	8.81	15.59
Low Productivity	1.12	1.50	1.96	1.49	3.37	5.29
Pacific Southwest						
High Productivity	2.50	2.98	3.98	2.50	5.30	9.54
Low Productivity	1.76	2.20	2.78	1.48	3.03	5.53
Rocky Mountain North						
High Productivity	2.89	3.55	4.48	2.16	4.50	7.97
Low Productivity	2.89	3.55	4.48	2.16	4.50	7.97
Rocky Mountain South						
High Productivity	0.37	0.47	0.60	0.47	1.04	1.71
Low Productivity	0.35	0.48	0.62	0.47	0.98	1.80
			Exotic Hardwoods			
Pacific Northwest						
High Productivity	2.67	3.29	4.20	2.00	4.23	7.49
Low Productivity	2.67	3.29	4.20	2.00	4.23	7.49
Pacific Southwest						
High Productivity	2.89	3.54	4.51	1.99	4.21	7.47
Low Productivity	2.89	3.54	4.51	1.99	4.21	7.47
Rocky Mountain North						
High Productivity	2.47	3.07	3.91	1.99	4.21	7.48
Low Productivity	2.47	3.07	3.91	1.99	4.21	7.48
Rocky Mountain South						
High Productivity	2.67	3.30	4.19	1.99	4.22	7.49
Low Productivity	2.67	3.30	4.19	1.99	4.22	7.49

Table C1. Pre-fire Pool Sizes of Leaf, Stem, Root, Dead Woody and Surface Pools for Combinations of Forest Species Groups, Fire Severity Levels, Regions and Productivity Classes

	Pre-fire Leaf Pool (kgC m^{-2})			Pre-fire Stem Pool (kgC m^{-2})			Pre-fire Root Pool (kgC m^{-2})			Pre-fire Dead Woody Pool (kgC m^{-2})			Pre-fire Surface Pool (kgC m^{-2})		
	LS[a] Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires
								Spruce/Fir							
Pacific Northwest															
High Productivity	0.24	0.24	0.24	8.22	8.22	8.22	0.25	0.25	0.25	2.91	2.91	2.91	1.20	1.20	1.20
Low Productivity	0.24	0.24	0.24	8.22	8.22	8.22	0.25	0.25	0.25	2.91	2.91	2.91	1.20	1.20	1.20
Pacific Southwest															
High Productivity	0.25	0.25	0.25	8.22	8.22	8.22	0.25	0.25	0.25	3.74	3.74	3.74	1.15	1.15	1.15
Low Productivity	0.25	0.25	0.25	8.22	8.22	8.22	0.25	0.25	0.25	3.74	3.74	3.74	1.15	1.15	1.15
Rocky Mountain North															
High Productivity	0.20	0.20	0.20	7.99	7.99	7.99	0.23	0.23	0.23	2.72	2.72	2.72	0.87	0.87	0.87
Low Productivity	0.20	0.20	0.20	7.99	7.99	7.99	0.23	0.23	0.23	2.72	2.72	2.72	0.87	0.87	0.87
Rocky Mountain South															
High Productivity	0.20	0.20	0.20	8.14	8.14	8.14	0.23	0.23	0.23	2.62	2.62	2.62	0.86	0.86	0.86
Low Productivity	0.20	0.20	0.20	8.14	8.14	8.14	0.23	0.23	0.23	2.62	2.62	2.62	0.86	0.86	0.86

Table C1. (continued)

	Pre-fire Leaf Pool (kgC m^{-2})			Pre-fire Stem Pool (kgC m^{-2})			Pre-fire Root Pool (kgC m^{-2})			Pre-fire Dead Woody Pool (kgC m^{-2})			Pre-fire Surface Pool (kgC m^{-2})		
	LS[a] Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires
Pinyon/Juniper															
Pacific Northwest															
High Productivity	0.04	0.04	0.04	3.46	3.35	3.48	0.04	0.05	0.04	0.53	0.62	0.55	0.17	0.20	0.18
Low Productivity	0.05	0.04	0.04	3.00	3.43	3.24	0.05	0.04	0.04	0.76	0.56	0.57	0.23	0.18	0.18
Pacific Southwest															
High Productivity	0.27	0.28	0.28	8.98	9.13	9.27	0.28	0.28	0.29	4.26	4.34	4.40	1.31	1.33	1.35
Low Productivity	0.04	0.04	0.04	2.89	2.84	2.88	0.04	0.04	0.04	0.45	0.54	0.50	0.17	0.20	0.19
Rocky Mountain North															
High Productivity	0.03	0.02	0.02	1.62	1.44	1.85	0.03	0.02	0.02	0.43	0.36	0.38	0.12	0.10	0.11
Low Productivity	0.03	0.02	0.03	2.07	1.88	1.96	0.03	0.02	0.03	0.43	0.37	0.43	0.13	0.11	0.13
Rocky Mountain South															
High Productivity	0.02	0.02	0.02	1.29	1.34	1.36	0.02	0.02	0.02	0.18	0.19	0.21	0.07	0.07	0.08
Low Productivity	0.02	0.02	0.02	1.31	1.34	1.30	0.02	0.02	0.02	0.17	0.16	0.19	0.07	0.07	0.07
Douglas-Fir															
Pacific Northwest															
High Productivity	0.44	0.44	0.43	36.77	37.44	37.15	0.46	0.46	0.45	5.09	5.00	4.98	2.08	2.06	2.05
Low Productivity	0.15	0.15	0.16	23.79	23.96	23.04	0.16	0.15	0.16	1.15	1.12	1.30	0.61	0.60	0.65
Pacific Southwest															
High Productivity	0.57	0.59	0.57	42.26	41.68	42.24	0.57	0.60	0.58	7.30	7.77	7.43	2.92	3.09	2.97
Low Productivity	0.34	0.34	0.34	22.33	22.37	22.30	0.34	0.34	0.35	4.44	4.43	4.50	1.76	1.75	1.78
Rocky Mountain North															
High Productivity	0.17	0.16	0.17	30.47	30.20	30.04	0.18	0.18	0.19	1.32	1.22	1.49	0.59	0.55	0.63
Low Productivity	0.08	0.08	0.08	8.90	8.65	9.07	0.09	0.09	0.08	0.95	1.06	0.91	0.32	0.35	0.31
Rocky Mountain South															
High Productivity	0.06	0.07	0.07	8.96	8.88	8.67	0.07	0.07	0.07	0.80	0.86	0.91	0.29	0.30	0.31
Low Productivity	0.06	0.07	0.07	8.93	8.53	8.43	0.07	0.07	0.08	0.73	0.91	0.96	0.27	0.31	0.32
Ponderosa Pine															
Pacific Northwest															
High Productivity	0.14	0.13	0.13	10.73	10.51	10.73	0.15	0.14	0.13	1.13	1.01	0.89	0.48	0.44	0.41
Low Productivity	0.09	0.08	0.08	5.58	5.47	5.51	0.09	0.09	0.09	0.83	0.72	0.73	0.31	0.28	0.28
Pacific Southwest															
High Productivity	0.18	0.18	0.18	15.16	15.40	15.02	0.18	0.18	0.18	1.35	1.39	1.39	0.61	0.63	0.62
Low Productivity	0.12	0.11	0.11	5.98	5.95	5.68	0.12	0.11	0.11	1.24	1.10	1.08	0.44	0.40	0.39
Rocky Mountain North															
High Productivity	0.17	0.19	0.21	12.08	11.95	12.00	0.18	0.21	0.23	1.40	1.79	2.11	0.58	0.68	0.76
Low Productivity	0.05	0.05	0.05	5.04	4.94	5.13	0.05	0.05	0.05	0.29	0.29	0.30	0.16	0.16	0.16
Rocky Mountain South															
High Productivity	0.07	0.07	0.07	4.24	4.26	4.20	0.07	0.08	0.07	0.72	0.77	0.73	0.27	0.29	0.28
Low Productivity	0.07	0.07	0.08	4.23	4.27	4.31	0.08	0.08	0.08	0.79	0.78	0.79	0.29	0.29	0.29
Western White Pine															
Pacific Northwest															
High Productivity	0.23	0.23	0.23	8.22	8.22	8.22	0.25	0.25	0.25	2.92	2.92	2.92	1.21	1.21	1.21
Low Productivity	0.23	0.23	0.23	8.22	8.22	8.22	0.25	0.25	0.25	2.92	2.92	2.92	1.21	1.21	1.21
Pacific Southwest															
High Productivity	0.06	0.06	0.06	6.46	6.63	6.57	0.06	0.06	0.06	0.50	0.51	0.51	0.29	0.30	0.30
Low Productivity	0.06	0.06	0.06	6.50	6.50	6.70	0.06	0.06	0.06	0.50	0.50	0.54	0.29	0.29	0.31
Rocky Mountain North															
High Productivity	1.08	1.08	1.08	8.22	8.22	8.22	1.08	1.08	1.08	2.74	2.74	2.74	1.49	1.49	1.49
Low Productivity	1.08	1.08	1.08	8.22	8.22	8.22	1.08	1.08	1.08	2.74	2.74	2.74	1.49	1.49	1.49
Rocky Mountain South															
High Productivity	0.25	0.25	0.25	8.23	8.23	8.23	0.25	0.25	0.25	3.81	3.81	3.81	1.84	1.84	1.84
Low Productivity	0.25	0.25	0.25	8.23	8.23	8.23	0.25	0.25	0.25	3.81	3.81	3.81	1.84	1.84	1.84
Fir/Spruce/Mountain Hemlock															
Pacific Northwest															
High Productivity	0.21	0.22	0.22	16.87	17.06	16.97	0.23	0.23	0.24	1.35	1.36	1.39	0.85	0.86	0.87
Low Productivity	0.11	0.11	0.10	9.59	9.60	9.55	0.12	0.12	0.11	0.62	0.59	0.59	0.42	0.41	0.41
Pacific Southwest															
High Productivity	0.22	0.23	0.22	18.45	18.56	18.30	0.23	0.24	0.23	1.75	1.90	1.79	0.80	0.85	0.81
Low Productivity	0.15	0.15	0.15	12.53	12.61	12.57	0.15	0.15	0.16	1.17	1.17	1.22	0.53	0.53	0.55
Rocky Mountain North															
High Productivity	0.61	0.60	0.60	11.90	11.72	12.00	0.62	0.61	0.60	0.90	0.87	0.85	0.77	0.76	0.75
Low Productivity	0.42	0.43	0.43	6.27	6.33	6.28	0.42	0.43	0.44	0.78	0.79	0.81	0.56	0.56	0.57

Table C1. (continued)

	Pre-fire Leaf Pool (kgC m^{-2})			Pre-fire Stem Pool (kgC m^{-2})			Pre-fire Root Pool (kgC m^{-2})			Pre-fire Dead Woody Pool (kgC m^{-2})			Pre-fire Surface Pool (kgC m^{-2})		
	LS[a] Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires
Rocky Mountain South															
High Productivity	0.06	0.06	0.06	5.96	5.93	5.86	0.07	0.07	0.07	0.71	0.73	0.69	0.31	0.31	0.30
Low Productivity	0.06	0.06	0.06	5.92	5.86	5.99	0.07	0.07	0.07	0.68	0.69	0.72	0.30	0.30	0.31
Lodgepole Pine															
Pacific Northwest															
High Productivity	0.19	0.16	0.16	7.17	7.32	7.79	0.19	0.16	0.16	2.09	1.63	1.68	1.05	0.86	0.89
Low Productivity	0.16	0.15	0.15	6.78	6.90	6.93	0.16	0.16	0.15	1.68	1.58	1.53	0.88	0.83	0.82
Pacific Southwest															
High Productivity	0.15	0.13	0.13	9.89	9.59	9.60	0.16	0.13	0.14	2.17	1.73	1.82	0.77	0.64	0.66
Low Productivity	0.11	0.11	0.11	8.99	8.95	9.05	0.12	0.11	0.12	1.42	1.40	1.52	0.54	0.53	0.57
Rocky Mountain North															
High Productivity	0.40	0.41	0.38	14.65	14.99	14.06	0.44	0.45	0.42	5.37	5.49	5.15	1.72	1.76	1.65
Low Productivity	0.10	0.11	0.11	6.45	6.51	6.55	0.11	0.12	0.12	1.03	1.17	1.21	0.40	0.44	0.45
Rocky Mountain South															
High Productivity	0.09	0.08	0.08	6.08	6.00	6.00	0.10	0.09	0.09	0.99	0.89	0.95	0.39	0.36	0.38
Low Productivity	0.08	0.08	0.09	5.94	5.99	5.99	0.09	0.09	0.10	0.92	0.93	1.03	0.37	0.37	0.40
Hemlock/Sitka Spruce															
Pacific Northwest															
High Productivity	0.47	0.45	0.46	24.41	23.97	24.17	0.48	0.46	0.47	3.98	3.68	3.91	1.93	1.82	1.90
Low Productivity	0.22	0.22	0.21	16.04	16.11	15.90	0.23	0.22	0.21	1.40	1.28	1.22	0.84	0.80	0.78
Pacific Southwest															
High Productivity	0.15	0.15	0.15	4.74	4.74	4.74	0.14	0.14	0.14	2.25	2.25	2.25	0.65	0.65	0.65
Low Productivity	0.15	0.15	0.15	4.74	4.74	4.74	0.14	0.14	0.14	2.25	2.25	2.25	0.65	0.65	0.65
Rocky Mountain North															
High Productivity	0.95	1.21	0.99	14.87	14.46	15.24	0.96	1.22	0.99	1.63	2.53	1.68	1.17	1.58	1.21
Low Productivity	0.57	0.57	0.57	12.05	11.79	12.11	0.57	0.57	0.58	0.69	0.69	0.70	0.65	0.64	0.65
Rocky Mountain South															
High Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.25	0.25	0.25	3.17	3.17	3.17	1.00	1.00	1.00
Low Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.25	0.25	0.25	3.17	3.17	3.17	1.00	1.00	1.00
Western Larch															
Pacific Northwest															
High Productivity	0.14	0.15	0.15	13.78	13.59	13.85	0.15	0.17	0.16	0.95	1.20	1.09	0.64	0.73	0.70
Low Productivity	0.12	0.12	0.12	10.39	10.31	10.23	0.13	0.13	0.13	0.89	0.94	0.97	0.55	0.56	0.57
Pacific Southwest															
High Productivity	0.25	0.25	0.25	8.22	8.22	8.22	0.25	0.25	0.25	3.74	3.74	3.74	1.15	1.15	1.15
Low Productivity	0.25	0.25	0.25	8.22	8.22	8.22	0.25	0.25	0.25	3.74	3.74	3.74	1.15	1.15	1.15
Rocky Mountain North															
High Productivity	0.23	0.25	0.23	19.94	20.42	20.83	0.27	0.29	0.26	1.71	1.95	1.51	0.82	0.90	0.78
Low Productivity	0.12	0.11	0.12	9.23	9.06	9.15	0.14	0.13	0.13	1.01	0.87	0.94	0.44	0.40	0.42
Rocky Mountain South															
High Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.25	0.25	0.25	3.17	3.17	3.17	1.00	1.00	1.00
Low Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.25	0.25	0.25	3.17	3.17	3.17	1.00	1.00	1.00
Redwood															
Pacific Northwest															
High Productivity	0.24	0.24	0.24	8.22	8.22	8.22	0.25	0.25	0.25	2.91	2.91	2.91	1.20	1.20	1.20
Low Productivity	0.24	0.24	0.24	8.22	8.22	8.22	0.25	0.25	0.25	2.91	2.91	2.91	1.20	1.20	1.20
Pacific Southwest															
High Productivity	2.97	3.01	2.97	22.34	22.65	22.31	2.97	3.02	2.97	9.11	9.24	9.10	5.00	5.07	4.99
Low Productivity	2.96	2.98	3.06	22.22	22.43	23.02	2.96	2.99	3.07	9.06	9.15	9.39	4.97	5.02	5.16
Rocky Mountain North															
High Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.24	0.24	0.24	2.90	2.90	2.90	0.92	0.92	0.92
Low Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.24	0.24	0.24	2.90	2.90	2.90	0.92	0.92	0.92
Rocky Mountain South															
High Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.25	0.25	0.25	3.17	3.17	3.17	1.00	1.00	1.00
Low Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.25	0.25	0.25	3.17	3.17	3.17	1.00	1.00	1.00
Other Western Softwoods															
Pacific Northwest															
High Productivity	0.05	0.04	0.04	5.10	5.32	5.20	0.06	0.05	0.04	0.70	0.45	0.43	0.26	0.19	0.18
Low Productivity	0.05	0.04	0.04	5.28	5.34	5.43	0.05	0.05	0.05	0.58	0.42	0.47	0.23	0.18	0.20
Pacific Southwest															
High Productivity	0.64	0.66	0.66	35.68	35.70	35.74	0.69	0.71	0.71	9.11	9.48	9.46	3.29	3.39	3.38
Low Productivity	0.14	0.12	0.13	13.88	11.44	12.54	0.15	0.13	0.14	1.98	1.75	1.90	0.78	0.67	0.73

Table C1. (continued)

	Pre-fire Leaf Pool ($kgC\ m^{-2}$)			Pre-fire Stem Pool ($kgC\ m^{-2}$)			Pre-fire Root Pool ($kgC\ m^{-2}$)			Pre-fire Dead Woody Pool ($kgC\ m^{-2}$)			Pre-fire Surface Pool ($kgC\ m^{-2}$)		
	LS[a] Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires
Rocky Mountain North															
High Productivity	0.03	0.04	0.03	3.32	3.44	3.28	0.04	0.04	0.04	0.32	0.37	0.31	0.15	0.16	0.15
Low Productivity	0.05	0.04	0.04	3.49	3.55	3.56	0.05	0.05	0.05	0.51	0.44	0.40	0.20	0.19	0.17
Rocky Mountain South															
High Productivity	0.04	0.04	0.04	3.72	3.72	3.86	0.05	0.04	0.05	0.48	0.40	0.51	0.20	0.17	0.21
Low Productivity	0.04	0.04	0.04	3.79	3.72	3.77	0.05	0.04	0.05	0.51	0.42	0.49	0.21	0.18	0.20
California Mixed Conifer															
Pacific Northwest															
High Productivity	0.24	0.24	0.24	8.21	8.21	8.21	0.25	0.25	0.25	3.73	3.73	3.73	1.14	1.14	1.14
Low Productivity	0.24	0.24	0.24	8.21	8.21	8.21	0.25	0.25	0.25	3.73	3.73	3.73	1.14	1.14	1.14
Pacific Southwest															
High Productivity	0.18	0.20	0.18	10.88	11.06	10.91	0.18	0.20	0.18	1.60	1.78	1.59	1.06	1.15	1.06
Low Productivity	0.18	0.18	0.19	11.01	11.10	11.02	0.18	0.18	0.19	1.63	1.60	1.68	1.07	1.06	1.10
Rocky Mountain North															
High Productivity	0.22	0.22	0.22	8.19	8.19	8.19	0.24	0.24	0.24	3.11	3.11	3.11	0.94	0.94	0.94
Low Productivity	0.22	0.22	0.22	8.19	8.19	8.19	0.24	0.24	0.24	3.11	3.11	3.11	0.94	0.94	0.94
Rocky Mountain South															
High Productivity	0.25	0.25	0.25	8.22	8.22	8.22	0.25	0.25	0.25	3.80	3.80	3.80	1.83	1.83	1.83
Low Productivity	0.25	0.25	0.25	8.22	8.22	8.22	0.25	0.25	0.25	3.80	3.80	3.80	1.83	1.83	1.83
Oak/Pine															
Pacific Northwest															
High Productivity	0.24	0.24	0.24	8.22	8.22	8.22	0.25	0.25	0.25	2.91	2.91	2.91	1.20	1.20	1.20
Low Productivity	0.24	0.24	0.24	8.22	8.22	8.22	0.25	0.25	0.25	2.91	2.91	2.91	1.20	1.20	1.20
Pacific Southwest															
High Productivity	0.25	0.25	0.25	8.22	8.22	8.22	0.25	0.25	0.25	3.74	3.74	3.74	1.15	1.15	1.15
Low Productivity	0.25	0.25	0.25	8.22	8.22	8.22	0.25	0.25	0.25	3.74	3.74	3.74	1.15	1.15	1.15
Rocky Mountain North															
High Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.24	0.24	0.24	2.90	2.90	2.90	0.92	0.92	0.92
Low Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.24	0.24	0.24	2.90	2.90	2.90	0.92	0.92	0.92
Rocky Mountain South															
High Productivity	0.21	0.21	0.21	8.22	8.22	8.22	0.24	0.24	0.24	2.63	2.63	2.63	0.83	0.83	0.83
Low Productivity	0.21	0.21	0.21	8.22	8.22	8.22	0.24	0.24	0.24	2.63	2.63	2.63	0.83	0.83	0.83
Oak/Hickory															
Pacific Northwest															
High Productivity	0.24	0.24	0.24	8.22	8.22	8.22	0.25	0.25	0.25	2.91	2.91	2.91	1.20	1.20	1.20
Low Productivity	0.24	0.24	0.24	8.22	8.22	8.22	0.25	0.25	0.25	2.91	2.91	2.91	1.20	1.20	1.20
Pacific Southwest															
High Productivity	0.25	0.25	0.25	8.22	8.22	8.22	0.25	0.25	0.25	3.74	3.74	3.74	1.15	1.15	1.15
Low Productivity	0.25	0.25	0.25	8.22	8.22	8.22	0.25	0.25	0.25	3.74	3.74	3.74	1.15	1.15	1.15
Rocky Mountain North															
High Productivity	0.20	0.20	0.20	8.23	8.23	8.23	0.24	0.24	0.24	2.80	2.80	2.80	0.90	0.90	0.90
Low Productivity	0.20	0.20	0.20	8.23	8.23	8.23	0.24	0.24	0.24	2.80	2.80	2.80	0.90	0.90	0.90
Rocky Mountain South															
High Productivity	0.08	0.06	0.07	3.68	3.44	3.62	0.08	0.07	0.08	0.74	0.58	0.72	0.26	0.21	0.25
Low Productivity	0.07	0.07	0.07	3.87	3.65	3.94	0.08	0.07	0.07	0.70	0.62	0.57	0.25	0.23	0.22
Elm/Ash/Cottonwood															
Pacific Northwest															
High Productivity	0.29	0.23	0.25	14.77	15.26	14.49	0.31	0.24	0.27	3.16	2.09	2.60	1.10	0.83	0.95
Low Productivity	0.18	0.17	0.21	12.22	12.01	12.24	0.19	0.18	0.23	1.72	1.52	2.23	0.67	0.61	0.81
Pacific Southwest															
High Productivity	0.25	0.25	0.25	8.22	8.22	8.22	0.25	0.25	0.25	3.74	3.74	3.74	1.15	1.15	1.15
Low Productivity	0.25	0.25	0.25	8.22	8.22	8.22	0.25	0.25	0.25	3.74	3.74	3.74	1.15	1.15	1.15
Rocky Mountain North															
High Productivity	0.06	0.05	0.05	5.80	5.33	5.24	0.07	0.06	0.06	0.46	0.38	0.41	0.22	0.19	0.20
Low Productivity	0.06	0.05	0.06	5.65	4.91	5.24	0.07	0.06	0.07	0.50	0.48	0.47	0.23	0.21	0.22
Rocky Mountain South															
High Productivity	0.05	0.05	0.05	5.58	5.32	5.47	0.06	0.06	0.06	0.36	0.40	0.34	0.19	0.20	0.18
Low Productivity	0.05	0.05	0.05	5.23	5.65	5.45	0.06	0.06	0.06	0.33	0.36	0.34	0.17	0.19	0.18
Maple/Beech/Birch															
Pacific Northwest															
High Productivity	0.24	0.24	0.24	8.22	8.22	8.22	0.25	0.25	0.25	2.91	2.91	2.91	1.20	1.20	1.20
Low Productivity	0.24	0.24	0.24	8.22	8.22	8.22	0.25	0.25	0.25	2.91	2.91	2.91	1.20	1.20	1.20

Table C1. (continued)

	Pre-fire Leaf Pool (kgC m^{-2})			Pre-fire Stem Pool (kgC m^{-2})			Pre-fire Root Pool (kgC m^{-2})			Pre-fire Dead Woody Pool (kgC m^{-2})			Pre-fire Surface Pool (kgC m^{-2})		
	LS[a] Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires
Pacific Southwest															
High Productivity	0.25	0.25	0.25	8.22	8.22	8.22	0.25	0.25	0.25	3.74	3.74	3.74	1.15	1.15	1.15
Low Productivity	0.25	0.25	0.25	8.22	8.22	8.22	0.25	0.25	0.25	3.74	3.74	3.74	1.15	1.15	1.15
Rocky Mountain North															
High Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.24	0.24	0.24	2.90	2.90	2.90	0.92	0.92	0.92
Low Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.24	0.24	0.24	2.90	2.90	2.90	0.92	0.92	0.92
Rocky Mountain South															
High Productivity	0.20	0.20	0.20	8.23	8.23	8.23	0.23	0.23	0.23	3.38	3.38	3.38	1.08	1.08	1.08
Low Productivity	0.20	0.20	0.20	8.23	8.23	8.23	0.23	0.23	0.23	3.38	3.38	3.38	1.08	1.08	1.08
Aspen/Birch															
Pacific Northwest															
High Productivity	0.10	0.11	0.09	7.94	8.04	7.96	0.10	0.11	0.10	0.67	0.81	0.60	0.40	0.45	0.37
Low Productivity	0.07	0.09	0.10	5.45	5.45	5.32	0.08	0.10	0.10	0.58	0.86	0.91	0.32	0.42	0.43
Pacific Southwest															
High Productivity	0.22	0.22	0.22	16.81	16.78	16.67	0.24	0.24	0.24	3.17	3.21	3.18	1.25	1.26	1.25
Low Productivity	0.06	0.07	0.06	4.79	4.78	4.61	0.07	0.08	0.06	1.16	1.39	1.07	0.38	0.45	0.35
Rocky Mountain North															
High Productivity	0.06	0.06	0.05	5.28	5.59	5.00	0.07	0.07	0.06	0.60	0.55	0.47	0.26	0.25	0.22
Low Productivity	0.05	0.05	0.06	5.03	5.54	5.47	0.06	0.06	0.07	0.53	0.51	0.59	0.23	0.24	0.26
Rocky Mountain South															
High Productivity	0.06	0.06	0.06	6.47	6.54	6.63	0.07	0.07	0.07	0.74	0.75	0.75	0.32	0.32	0.32
Low Productivity	0.06	0.06	0.06	6.46	6.41	6.53	0.07	0.07	0.07	0.76	0.75	0.74	0.32	0.32	0.32
Alder/Maple															
Pacific Northwest															
High Productivity	0.45	0.41	0.43	14.49	14.00	14.28	0.46	0.42	0.45	4.40	3.98	4.29	1.82	1.66	1.77
Low Productivity	0.26	0.26	0.24	14.06	14.62	13.74	0.26	0.26	0.25	1.92	1.85	1.76	0.94	0.93	0.89
Pacific Southwest															
High Productivity	0.75	0.89	0.73	13.46	12.30	13.13	0.75	0.89	0.73	1.47	2.11	1.43	1.07	1.34	1.04
Low Productivity	0.73	0.67	0.84	13.69	13.39	12.80	0.73	0.67	0.85	1.36	1.19	1.89	1.03	0.94	1.26
Rocky Mountain North															
High Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.24	0.24	0.24	2.90	2.90	2.90	0.92	0.92	0.92
Low Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.24	0.24	0.24	2.90	2.90	2.90	0.92	0.92	0.92
Rocky Mountain South															
High Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.25	0.25	0.25	3.17	3.17	3.17	1.00	1.00	1.00
Low Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.25	0.25	0.25	3.17	3.17	3.17	1.00	1.00	1.00
Western Oak															
Pacific Northwest															
High Productivity	0.21	0.19	0.21	7.96	6.88	7.64	0.22	0.20	0.22	2.80	2.62	2.86	0.88	0.81	0.89
Low Productivity	0.12	0.12	0.12	7.59	7.23	7.42	0.13	0.13	0.12	1.35	1.35	1.28	0.48	0.47	0.45
Pacific Southwest															
High Productivity	0.13	0.13	0.13	8.66	8.67	8.61	0.13	0.13	0.13	1.22	1.24	1.21	0.49	0.50	0.49
Low Productivity	0.14	0.14	0.13	8.77	8.84	8.72	0.14	0.14	0.14	1.31	1.35	1.32	0.52	0.52	0.52
Rocky Mountain North															
High Productivity	0.20	0.20	0.20	8.22	8.22	8.22	0.24	0.24	0.24	3.12	3.12	3.12	0.99	0.99	0.99
Low Productivity	0.20	0.20	0.20	8.22	8.22	8.22	0.24	0.24	0.24	3.12	3.12	3.12	0.99	0.99	0.99
Rocky Mountain South															
High Productivity	0.05	0.05	0.04	4.12	3.95	4.12	0.05	0.05	0.05	0.51	0.50	0.48	0.22	0.21	0.20
Low Productivity	0.05	0.05	0.05	4.01	4.04	4.00	0.05	0.05	0.05	0.54	0.55	0.50	0.22	0.22	0.21
Tanoak/Laurel															
Pacific Northwest															
High Productivity	0.27	0.29	0.27	22.55	22.44	22.37	0.27	0.29	0.28	1.36	1.61	1.40	0.97	1.05	0.98
Low Productivity	0.21	0.21	0.23	15.59	15.52	16.11	0.21	0.21	0.23	1.23	1.25	1.54	0.76	0.76	0.88
Pacific Southwest															
High Productivity	1.94	1.96	1.90	14.64	14.76	14.34	1.94	1.96	1.90	5.71	5.75	5.59	3.13	3.15	3.06
Low Productivity	1.80	1.83	1.81	17.54	17.56	17.41	1.80	1.83	1.81	4.74	4.83	4.75	2.77	2.82	2.78
Rocky Mountain North															
High Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.24	0.24	0.24	2.90	2.90	2.90	0.92	0.92	0.92
Low Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.24	0.24	0.24	2.90	2.90	2.90	0.92	0.92	0.92
Rocky Mountain South															
High Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.25	0.25	0.25	3.17	3.17	3.17	1.00	1.00	1.00
Low Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.25	0.25	0.25	3.17	3.17	3.17	1.00	1.00	1.00

Table C1. (continued)

	Pre-fire Leaf Pool (kgC m^{-2})			Pre-fire Stem Pool (kgC m^{-2})			Pre-fire Root Pool (kgC m^{-2})			Pre-fire Dead Woody Pool (kgC m^{-2})			Pre-fire Surface Pool (kgC m^{-2})		
	LS[a] Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires	LS Fires	MS Fires	HS Fires
Other Western Hardwoods															
Pacific Northwest															
High Productivity	0.47	0.49	0.49	15.40	15.97	16.02	0.48	0.50	0.50	5.34	5.54	5.55	2.20	2.29	2.29
Low Productivity	0.11	0.11	0.12	5.77	6.27	5.51	0.12	0.12	0.12	1.04	1.05	1.16	0.49	0.50	0.52
Pacific Southwest															
High Productivity	0.22	0.21	0.22	9.63	9.80	9.92	0.22	0.21	0.22	2.45	2.27	2.43	1.09	1.03	1.09
Low Productivity	0.15	0.15	0.15	5.63	5.54	5.72	0.15	0.15	0.15	1.78	1.81	1.79	0.76	0.77	0.76
Rocky Mountain North															
High Productivity	0.21	0.21	0.21	8.22	8.22	8.22	0.24	0.24	0.24	3.17	3.17	3.17	1.00	1.00	1.00
Low Productivity	0.21	0.21	0.21	8.22	8.22	8.22	0.24	0.24	0.24	3.17	3.17	3.17	1.00	1.00	1.00
Rocky Mountain South															
High Productivity	0.03	0.03	0.03	1.86	1.94	1.79	0.03	0.03	0.03	0.33	0.32	0.33	0.19	0.18	0.19
Low Productivity	0.03	0.03	0.03	1.85	1.83	1.88	0.03	0.03	0.03	0.31	0.33	0.35	0.17	0.19	0.19
Exotic Hardwoods															
Pacific Northwest															
High Productivity	0.24	0.24	0.24	8.22	8.22	8.22	0.25	0.25	0.25	2.91	2.91	2.91	1.20	1.20	1.20
Low Productivity	0.24	0.24	0.24	8.22	8.22	8.22	0.25	0.25	0.25	2.91	2.91	2.91	1.20	1.20	1.20
Pacific Southwest															
High Productivity	0.23	0.23	0.23	8.20	8.20	8.20	0.25	0.25	0.25	3.20	3.20	3.20	1.29	1.29	1.29
Low Productivity	0.23	0.23	0.23	8.20	8.20	8.20	0.25	0.25	0.25	3.20	3.20	3.20	1.29	1.29	1.29
Rocky Mountain North															
High Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.24	0.24	0.24	2.90	2.90	2.90	0.92	0.92	0.92
Low Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.24	0.24	0.24	2.90	2.90	2.90	0.92	0.92	0.92
Rocky Mountain South															
High Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.25	0.25	0.25	3.17	3.17	3.17	1.00	1.00	1.00
Low Productivity	0.22	0.22	0.22	8.23	8.23	8.23	0.25	0.25	0.25	3.17	3.17	3.17	1.00	1.00	1.00

[a]LS, MS and HS refer to low-, medium- and high-severity fires, respectively.

classes. These normalized fire-induced emissions are consistent with those reported by *French et al.* [2011].

Appendix C: Pre-fire Pool Sizes

[53] Table C1 reports the pre-fire pool sizes of leaf, stem, root, dead woody and surface pools stratified by forest species groups, fire severity levels, regions and productivity classes.

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