Baseline Wildland Fires and Emissions for the Western United States

By Todd J. Hawbaker and Zhiliang Zhu

Chapter 3 of

Baseline and Projected Future Carbon Storage and Greenhouse-Gas Fluxes in Ecosystems of the Western United States

Edited by Zhiliang Zhu and Bradley C. Reed

Professional Paper 1797

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit http://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit http://www.usgs.gov/pubprod

To order this and other USGS information products, visit http://store.usgs.gov

Suggested citation:
Hawbaker, T.J., and Zhu, Zhiliang, 2012, Baseline wildland fires and emissions for the Western United States, chap. 3 *of* Zhu, Zhiliang, and Reed, B.C., eds., Baseline and projected future carbon storage and greenhouse-gas fluxes in ecosystems of the Western United States: U.S. Geological Survey Professional Paper 1797, 10 p. (Also available at http://pubs.usgs/gov/pp/1797.)

Contents

Figures

Tables

This page intentionally blank

Chapter 3. Baseline Wildland Fires and Emissions for the Western United States

By Todd J. Hawbaker[1] and Zhiliang Zhu[2]

3.1. Highlights

- Wildland fires burned an annual average of 13,173 km^2 between 2001 and 2008 in the Western United States.
- The interannual variability in the area that was burned between 2001 and 2008 was high; as few as 3,345 km^2 burned in 2004 and as much as 25,206 km^2 burned in 2007.
- The annual average emissions from wildland fires from 2001 to 2008 were 36.7 $TgCO_{2\text{-eq}}$/yr (10.0 TgC/yr), with a median value of 41.0 $TgCO_{2\text{-eq}}$/yr (11.2 TgC/yr), and a range from 6.8 $TgCO_{2\text{-eq}}$ (1.9 TgC/yr) in 2004 to 75.3 $TgCO_{2\text{-eq}}$ (20.6 TgC/yr) in 2007.
- The minimum, average, and maximum emissions from wildland fires in the Western United States from 2001 to 2008 were equivalent to 7.9 percent, 11.6 percent, and 87.0 percent, respectively, of the mean terrestrial carbon sequestration estimated for the Western United States in this study.
- The minimum, average, and maximum emissions from annual wildland fires in the Western United States from 2001 to 2008 were equivalent to 0.1 percent, 0.7 percent, and 1.3 percent, respectively, of the 2010 fossil-fuel emissions for the entire United States.
- The Western Cordillera ecoregion produced 77 percent of all emissions in the Western United States during the baseline period.

3.2. Introduction

The methodology for this assessment explicitly addressed ecosystem disturbances, including human- and naturally caused wildland fires, as required by the EISA legislation (U.S. Congress, 2007; Zhu and others, 2010). As indicated by figure 1.2 in chapter 1 of this report, the estimates for the baseline biomass combustion emissions from wildland fires are presented in this chapter. The projected future potential wildland fire emissions are described in chapter 8. The baseline burned areas and the projected future potential burned areas for wildland fires and their severity, described in the two chapters, were used as input into the assessment of baseline and projected future potential terrestrial carbon and greenhouse-gas fluxes (chapters 5 and 9 of this report, respectively).

Wildland fires are a critical component of the global carbon cycle because they produce an immediate release of greenhouse gases—carbon monoxide (CO), carbon dioxide (CO_2), and methane (CH_4)—when biomass is consumed through combustion (Seiler and Crutzen, 1980). Wildland fires also have long-term effects on ecosystem carbon cycling by influencing the rate of carbon sequestration after combustion, both through the decomposition of dead vegetation and through photosynthesis, which helps establish new vegetation; because of those effects, years to decades can pass before carbon stocks return to pre-fire conditions (M.G. Turner and others, 1998; Cleary and others, 2010; Hurteau and Brooks, 2011; Kashian and others, in press). If fire regimes are stable, the long-term effects of wildland fires on carbon

[1]U.S. Geological Survey, Denver, Colo.

[2]U.S. Geological Survey, Reston, Va.

cycling are typically negligible because carbon sequestration through vegetation growth and carbon loss through wildland fire emissions cancel out each other over long time periods (Balshi, McGuire, Duffy, Flanigan, Kicklighter, and Melillo, 2009; Flannigan and others, 2009). If a fire regime changes, however, the vulnerability for carbon storage is high because the amount of carbon stored in the ecosystem can be altered or lost through emissions. Substantial evidence is available to document that fire regimes are not static. For example, the frequency of wildland fires has been greatly reduced since settlement of the United States began, mainly due to land-use changes and the success of fire suppression in the last century (Cleland and others, 2004); however, the frequency of wildland fires has been increasing since the 1990s because of an increasingly earlier snowmelt (Westerling and others, 2006). Therefore, any credible assessment of carbon storage and fluxes in ecosystems through time must account for the potential changes in wildland-fire occurrence and emissions.

In the conterminous United States (CONUS), the net carbon flux in ecosystems reported by the Environmental Protection Agency (EPA) was 1,075 $TgCO_{2\text{-eq}}$/yr (293 TgC/yr) in 2010, the majority of which was sequestered within forests (EPA, 2012). The estimates of emissions from wildland fires in the United States were highly variable; after converting the reported emissions to carbon dioxide equivalent, they were as follows: (1) from 15 to 73 $TgCO_{2\text{-eq}}$/yr, (2001–2008; Global Fire Emissions Database (GFED), Oak Ridge National Laboratory Distributed Active Archive Center, 2012; see also Giglio and others, 2010; van der Werf and others, 2010); (2) from 29 to 199 $TgCO_{2\text{-eq}}$/yr (2001–2008; French and others, 2011; Michigan Tech Research Institute, 2012), and (3) from 157 to 283 $TgCO_{2\text{-eq}}$/yr (2002–2006; Wiedinmyer and Neff, 2007). When compared with the 2010 net carbon flux of ecosystems in the CONUS (EPA, 2012), the annual emissions from wildland fires were equivalent to 1 to 26 percent of the ecosystem's total annual flux. In contrast, from 2001 to 2008, the combustion of fossil fuels produced 5,642 $TgCO_{2\text{-eq}}$/yr (EPA, 2012) and flux increased at a rate of 1 percent per year (Pacala and others, 2007). Based on these rates, the annual emissions from wildland fires were equivalent to 0.3 to 5.1 percent of the emissions from fossil-fuel consumption.

The differences among the accuracy and quality of these data, their spatial and temporal resolution, and assumptions about variations in combustion efficiency were the primary sources of uncertainties in wildland-fire emissions estimates (Larkin and others, 2009; French and others, 2011). The assumptions about the proportion of aboveground biomass consumed by wildland fire, especially aboveground woody biomass in forests, can have a substantial influence on emission estimates (Campbell and others, 2007; Meigs and others, 2009). The methods used for calculating emissions relied on estimates of the area that was burned, fuel loads (available live and dead biomass for burning), combustion efficiency, and emission factors (Seiler and Crutzen, 1980; Albini and others, 1995; Wiedinmyer and Neff, 2007; Ottmar and others, 2008). For instance, the GFED (Giglio and others, 2010; van der Werf and others, 2010) estimates biomass consumption and emission at fire locations detected by MODIS (Roy and others, 2002; Giglio and others, 2003) on the basis of land-cover types, combustion completeness, soil moisture, and land-cover specific emission factors. GFED also incorporates changes in fuel loads using the Carnegie Ames Stanford Approach to characterize biomass production (Potter and others, 1993, 2012). Wiedinmyer and Neff (2007) also used active wildland fire observations from NASA's MODIS (Giglio and others, 2003), but calculated the emissions based on static land-cover types, percent land cover, and biomass at 1-km resolution. French and others (2011) used the CONSUME model (Ottmar and others, 2008), which calculated fuel consumption and emission using fuel loads derived from the Fuel Characterization Classification System (FCCS; Ottmar and others, 2007) and fuel moistures derived from weather-station data.

These existing studies provided an estimate of the effects of wildland fires on a national scale but lacked the regional detail required by this assessment. Furthermore, there were few projections of future potential wildland-fire emissions that were consistent with the existing baseline emission estimates. Therefore, a set of baseline emissions (this chapter) and projected future potential emissions (chapter 8) was developed to ensure consistency throughout this and other regional assessments. This chapter focuses on the baseline estimates of wildland-fire occurrence and emissions for the Western United States and strives to answer two primary questions: (1) What were the patterns of wildland-fire occurrence and emissions in the Western United States?, and (2) How did wildland fires vary temporally and spatially among the ecoregions of the Western United States? The results from this chapter were also used in the assessment of baseline carbon storage, sequestration, and greenhouse-gas fluxes of terrestrial ecosystems (chapter 5).

3.3. Input Data and Methods

The baseline estimates for the number of wildfires, the area burned, and emissions were derived from the Monitoring Trends in Burn Severity (MTBS) database (Eidenshink and others, 2007) and the First Order Fire Effects Model (FOFEM; Reinhardt and others, 1997) for the major GHGs: carbon dioxide (CO_2), carbon monoxide (CO), and methane (CH_4). This method was applied to each wildland fire in the region that was in the MTBS database to produce estimates of CO_2, CO, and CH_4 emissions (converted to CO_2 equivalent). The results were aggregated to produce an estimate of emissions for the Western United States as a whole and for each level II ecoregion within it.

The locations of wildland-fire scars were taken from the MTBS database, which includes information about wildland fires in the Western United States that occurred between 1984 and 2008 and that were greater than 404 ha (1,000 acres). The MTBS data were selected because of the high degree of confidence in the data (fire size and severity were derived manually). Other data sources were considered but ultimately not used, including the various versions of Federal wildland-fire databases, because of the spatial inaccuracies and duplicate records that would have introduced uncertainties (T.J. Brown and others, 2002). The MODIS active fire (Giglio and others, 2003) and burned area (Roy and others, 2002) products were also considered but not used because they contained no information about the causes of the wildland fires and had a coarse spatial resolution that complicated the calculations of emissions and the modeling of future trends.

Wildland-fire emissions were calculated for each burned pixel in the MTBS database using the FOFEM, which used fuel loads along with fuel moistures to estimate the amount of forest litter and downed deadwood that was consumed (Albini and others, 1995; Albini and Reinhardt, 1995, 1997). The consumption of duff (decaying forest litter), trees, plants, and shrubs was estimated as a function of the region, season, fuel moistures, and fuel loads. Canopy fuel consumption was estimated as a function of the burn severity provided by the MTBS data. The emissions of CO_2, CO, and CH_4 were then calculated on the basis of the amount of fuel consumed, the organic-matter content of the fuel, and how efficiently it burned. The required input data for the FOFEM included fuel loads, burn severity, and dead and live fuel moistures (fig. 3.1).

Fuel-load data provided an estimate of the amount of biomass that was available for consumption and were derived from the LANDFIRE project's Fuel Loading Models data layer (FLM; Lutes and others, 2009). These fuel-load data were categorized by 1-, 10-, 100-, and 1,000-hour fuel classes (Lutes and others, 2009) for dead biomass, decaying biomass (duff and forest litter), and live biomass (grass, shrubs, and tree canopy). In the FOFEM, the amount of tree canopy that was consumed was a direct function of burn-severity values from the MTBS data. The amount of canopy foliage that was consumed in the high, moderate, and low burn-severity categories was assumed to be 100, 60, and 20 percent, respectively. Similarly, the consumption of the canopy's branch wood was set at 50, 30, and 10 percent for the high, moderate, and low burn-severity categories, respectively. These values were based on previously published estimates (Spracklen and others, 2009; Zhu and others, 2010) and on a comparison of the FOFEM emissions with previously published results for selected wildland fires. Prior to processing with the FOFEM, the LANDFIRE FLM and MTBS raster data were aggregated to 250 m resolution using a nearest-neighbor method to match the resolution of other

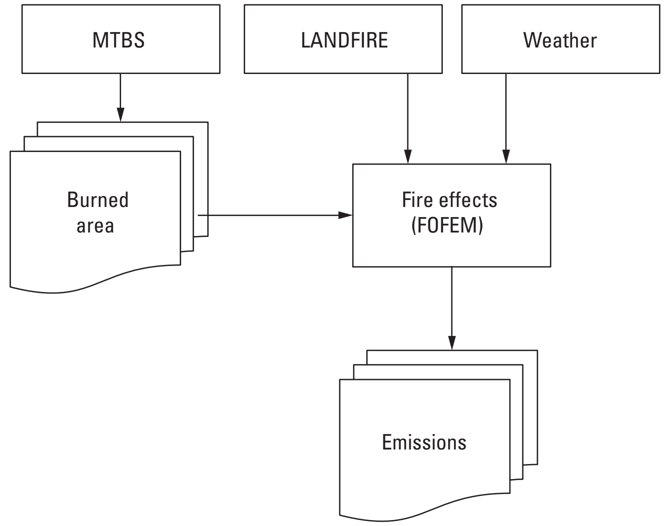

Figure 3.1. Flowchart showing the process for calculating baseline estimates of greenhouse-gas emissions from wildland fires.

raster data being used in this assessment. The emissions were calculated for wildland fires occurring between 2001 and 2008, which is the baseline time period for this component of the assessment. Wildland fires before 2001 were excluded because the LANDFIRE fuels data were derived from circa 2001 Landsat imagery. The year-to-year variability in the amount of burned area was high. Therefore, data on all wildland fires that occurred after 2001 were included to help reduce the influence of extreme wildland fire years (either high or low occurrence) on the baseline statistics.

Fuel moistures were estimated by applying the National Fire Danger Rating System (NFDRS; Bradshaw and others, 1983) algorithms to a 1/8° gridded daily weather dataset that spanned the conterminous United States (Maurer and others, 2002). These data spanned 1950 to 2010 and included the minimum and maximum daily temperature and daily precipitation. The Mountain Climate Simulator (MT–CLIM) algorithms (Glassy and Running, 1994) were used to calculate relative humidity based on minimum and afternoon daily temperatures (Kimball and others, 1997). Dead and live fuel moistures were calculated by using the NFDRS (Deeming and others, 1977; Bradshaw and others, 1983; Burgan, 1988). The NFDRS algorithms required information about the beginning of both spring ("green-up") and fall ("brown-down") to estimate live fuel moistures. To generate the green-up and brown-down dates, a technique was implemented that determined the dates of seasonal changes in live fuel on the basis of the daily amount of exposure to light, minimum temperature, and the vapor-pressure deficit (Jolly and others, 2005).

3.4. Results

In the five ecoregions of this assessment, the number of wildland fires between 2001 and 2008 averaged 303 per year, but was as high as 467 in 2006 and as low as 131 in 2004 (table 3.1 and fig. 3.2). The area burned by wildland fires averaged 13,173 km^2/yr or 0.49 percent of the Western United States, which has a total area of approximately 2.66 million km^2. The area burned ranged from 3,345 km^2 (0.13 percent of total area) in 2004 to 25,206 km^2 (0.94 percent of total area) in 2007. The emissions from wildland fires and their interannual variability followed the patterns of the burned area and averaged 36.7 $TgCO_{2\text{-eq}}$/yr, ranging from 6.8 $TgCO_{2\text{-eq}}$ in 2004 to 75.3 $TgCO_{2\text{-eq}}$ in 2007. When normalized for the area burned, the annual emissions averaged 2.9 $kgCO_{2\text{-eq}}/m^2/yr$, but ranged from 1.7 to 3.9 $kgCO_{2\text{-eq}}/m^2/yr$ (or 0.8 $kgC/m^2/yr$, ranging from 0.4 to 1.1 $kgC/m^2/yr$).

The Western Cordillera ecoregion had the most wildland fires and the highest emissions among all the Western United States ecoregions (table 3.1 and fig. 3.3*A*). The number of wildland fires between 2001 and 2008 averaged 123/yr and ranged from 61 in 2004 to 173 in 2003. The burned area and the emissions averaged 5,708 km^2/yr and 28.2 $TgCO_{2\text{-eq}}$/yr, respectively. The interannual variability was high and the area burned and the emissions ranged between 1,856 km^2 and 4.7 $TgCO_{2\text{-eq}}$ in 2004 and 10,449 km^2 and 64.1 $TgCO_{2\text{-eq}}$ in 2007, respectively. The Western Cordillera covers approximately 872,000 km^2. After normalizing the area burned and the emissions for the ecoregion's area, the annual area burned ranged between 0.21 and 1.20 percent and the annual emissions ranged between 2.6 and 6.2 $kgCO_{2\text{-eq}}/m^2/yr$ for the entire Western Cordillera.

Table 3.1. Summary statistics for the number of wildland fires, area burned, and emissions, by EPA level II ecoregion and for the entire Western United States region between 2001 and 2008.

[km^2, square kilometers; $TgCO_{2\text{-eq}}$, teragrams of carbon dioxide equivalent]

	Western Cordillera	Marine West Coast Forest	Cold Deserts	Warm Deserts	Mediterranean California	Western United States
Number of wildfires per year						
Mean	123	5	121	25	31	303
Standard deviation	34.1	5.5	72.4	20.0	7.8	97.1
Minimum	61	1	36	7	15	131
Median	117	3	115	19	32	290
95th quantile	168	12	225	57	39	434
Maximum	173	13	245	66	39	467
Area burned per year (km^2)						
Mean	5,708	79	5,056	785	1,585	13,173
Standard deviation	2,966	87	4,212	702	1,198	6,736
Minimum	1,856	9	583	198	301	3,345
Median	5,371	58	3,962	544	1,220	12,136
95th quantile	9,926	178	10,926	1,920	3,292	23,261
Maximum	10,449	191	11,237	2,217	3,304	25,206
Emissions per year ($TgCO_{2\text{-eq}}$)						
Mean	28.2	0.3	4.1	2.4	1.8	36.7
Standard deviation	18.9	0.3	2.6	2.2	1.4	21.3
Minimum	4.7	0.0	0.8	0.5	0.3	6.8
Median	28.8	0.2	4.0	2.1	1.3	41.0
95th quantile	54.7	0.6	7.1	6.0	3.6	65.0
Maximum	64.1	0.7	7.1	7.4	3.7	75.3

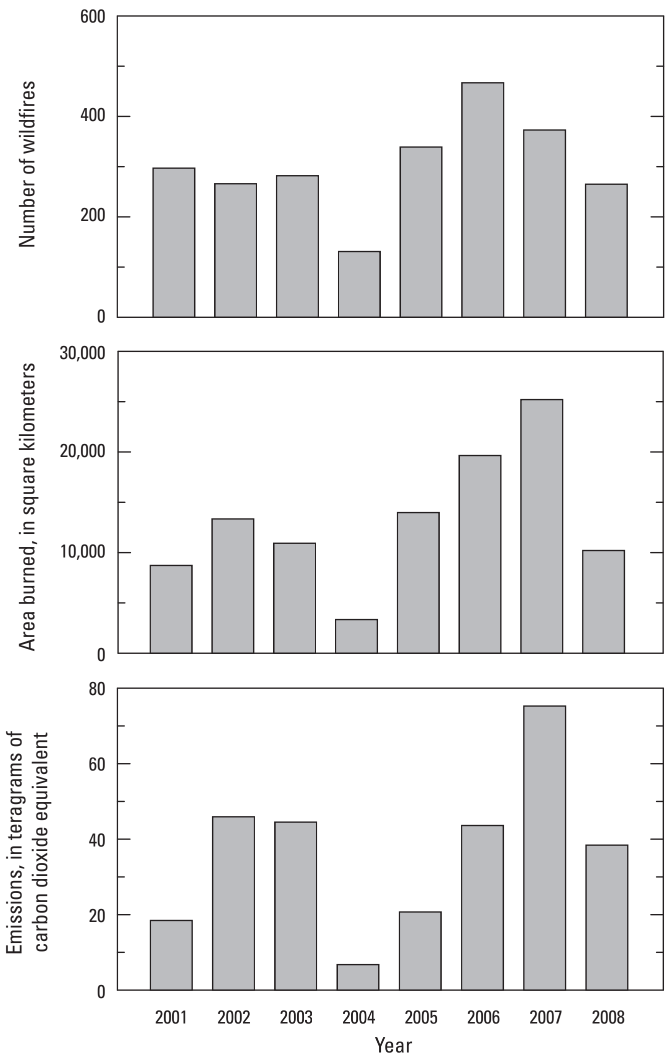

Figure 3.2. Graphs showing the annual number of wildland fires, area burned, and emissions for the baseline time period (2001–2008) in the Western United States.

Of all the ecoregions in the Western United States, the Marine West Coast Forest ecoregion had the fewest wildland fires, the smallest area burned, and the lowest emissions (table 3.1 and fig. 3.3*B*). The number of wildland fires averaged 5/yr and ranged from 1 to 13. The area burned ranged from 9 to 200 km^2 and averaged 79 km^2/yr. The emissions from the Marine West Coast Forest ranged from 0 to 0.7 $TgCO_{2\text{-eq}}$ /yr and averaged 0.3 $TgCO_{2\text{-eq}}$/yr. The area of the Marine West Coast Forest ecoregion is approximately 98,000 km^2. After normalizing the wildland-fire-occurrence statistics for area, from 0.01 to 0.13 percent of the ecoregion burned each year and emissions ranged from 2.6 to 4.8 $kgCO_{2\text{-eq}}/m^2$/yr.

The Cold Deserts ecoregion is the largest ecoregion in the Western United States at 1 million km^2 and had nearly as much wildland-fire activity as the Western Cordillera (table 3.1 and fig. 3.3*C*). On average, there were 121 wildland fires per year, but the interannual variability was high; as few as 36 wildland fires were observed in 2004 and as many as 245 were observed in 2006. The amount of area burned each year in the Cold Deserts ecoregion was similar to that of the Western Cordillera and averaged 5,056 km^2/yr, ranging from 583 km^2 in 2004 to 11,237 km^2 in 2007. This range is equivalent to 0.06 to 1.07 percent of the area of entire ecoregion; however, because the vegetation in the Cold Deserts is predominantly grass and shrubs, emissions were lower, averaging only 4.1 $TgCO_{2\text{-eq}}$/yr and ranging from 0.8 to 7.1 $TgCO_{2\text{-eq}}$ in 2004 and 2007, respectively.

In the Warm Deserts ecoregion, wildland fires were infrequent with an average of 25 wildfires per year, but as many as 66 in 2005 and as few as 7 in 2004 (table 3.1 and fig. 3.3*D*). The amount of area burned was also small and ranged from 198 km^2 in 2004 to 2,217 km^2 in 2005 with an average of 785 km^2/yr. This range equated to 0.16 to 0.46 percent of the ecoregion area, which was 478,000 km^2. The emissions were generally low, with an average of 2.4 $TgCO_{2\text{-eq}}$/yr; the variability in emissions was high, however, and varied from 0.5 $TgCO_{2\text{-eq}}$ in 2004 to 7.4 $TgCO_{2\text{-eq}}$ in 2008. When normalized for the area burned, the emissions ranged from 1.0 to 3.5 $kgCO_{2\text{-eq}}/m^2$/yr.

The Mediterranean California ecoregion is the smallest in the Western United States (173,000 km^2) but still had a substantial amount of wildland-fire activity. On average, there were 31 wildland fires per year with a range from 15 to 39 (table 3.1 and fig. 3.3*E*). The area burned averaged 1,585 km^2/yr and had a range of 301 to 3,304 km^2 in 2001 and 2003, respectively. The emissions averaged 1.8 $TgCO_{2\text{-eq}}$/yr but ranged from 0.3 to 3.7 $TgCO_{2\text{-eq}}$ in 2005 and 2008, respectively. The amount of area burned and emissions were large relative to the total area of the ecoregion. The area burned ranged from 0.17 to 1.91 percent of the entire ecoregion (the highest percent area in the Western United States), and the emissions ranged from 0.6 to 1.2 $kgCO_{2\text{-eq}}/m^2$/yr.

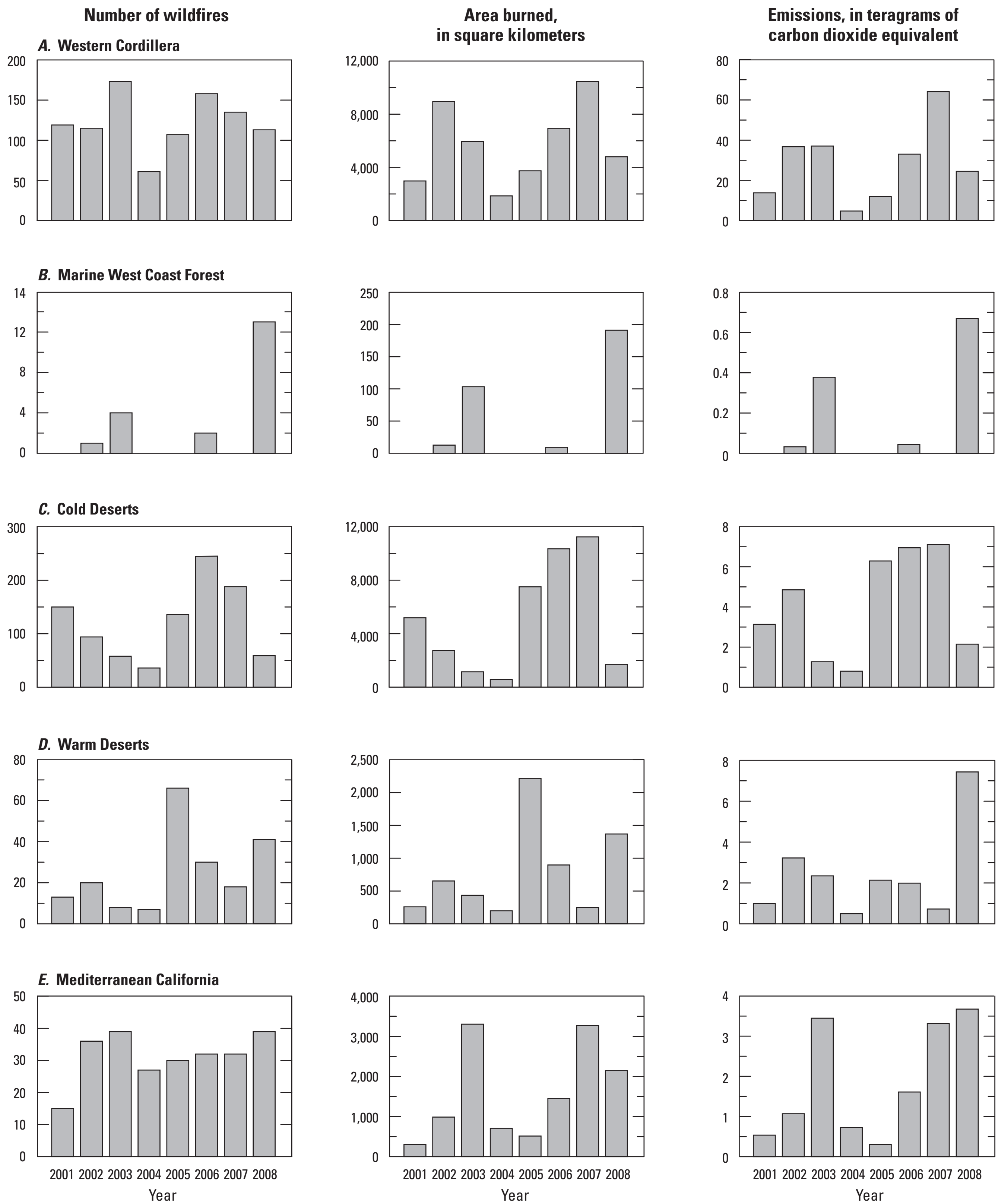

Figure 3.3. Graphs showing the annual number of wildland fires, area burned, and emissions for the baseline time period (2001–2008) for level II ecoregions in the Western United States (EPA, 1999). The vertical scales are not constant among ecoregions.

3.5. Discussion

From 2001 to 2008, wildland-fire activity in the Western United States was substantial; large wildland fires numbered between 131 and 467 per year and burned from 3,345 to 25,206 km^2 each year. These western wildland fires represented 58 percent of all the wildland fires that occurred nationwide from 2001 to 2008 and are mapped in the MTBS database, and accounted for 75 percent of the all area burned. The annual emissions averaged 36.7 $TgCO_{2\text{-eq}}$/yr, which was equivalent to 0.7 percent of the nationwide fossil-fuel emissions in 2010 (5,594 $TgCO_{2\text{-eq}}$/yr; EPA, 2012). The interannual variability in emissions was high and ranged from 6.8 to 75.3 $TgCO_{2\text{-eq}}$ in the Western United States, which was equivalent to 0.1 to 1.3 percent of the nationwide fossil-fuel emissions, respectively. Thus, the relative contribution of wildland fires of the Western United States to nationwide greenhouse-gas emissions was small when compared to the contribution of anthropogenically generated emissions.

There was a large amount of year-to-year variability in wildland-fire occurrences, area burned, and emissions among the five ecoregions in the Western United States (table 3.1 and fig. 3.3), which was related to differences in vegetation and fire regimes. The Marine West Coast Forest and Western Cordillera ecoregions are dominated by coniferous forests, but have quite different fire regimes. Precipitation is high in the Marine West Coasts Forest, which results in highly productive vegetation, but the infrequent wildland fires can be severe (Agee, 1993). The forests in the Western Cordillera tend to exist in a drier climate with more frequent wildland fires, but the severity is mixed and depends on drought and vegetation conditions (Schoennagel and others, 2004). In both the Marine West Coast Forest and Western Cordillera ecoregions, wildland-fire emissions can be high under severe conditions because large amounts of canopy fuels can be consumed by a crown fire. The Marine West Coast Forest did not produce a substantial amount of emissions in this analysis, but that may be in part because the wildland-fire frequency was low in this ecoregion and the 25-year span covered by the MTBS did not include a sizeable amount of fire activity there. The results of this assessment, however, do highlight the importance of wildland-fire emissions in the Western Cordillera at both a regional and national scale because this ecoregion produced 77 percent of all emissions in the Western United States during the baseline period.

In contrast to the Marine West Coast Forest and the Western Cordillera, the Cold Deserts, Warm Deserts, and Mediterranean California ecoregions are dominated by the grasslands/shrublands ecosystem and other ecosystems (primarily deserts). Wildland fires were frequent in all three ecoregions but were more common in the Cold Deserts and Mediterranean California than in the Warm Deserts. The fire regimes in the desert ecoregions were related to vegetation productivity and climate (Mensing and others, 2006; Brooks and Chambers, 2011). These same drivers influenced wildland fires in the Mediterranean California ecoregion, but human influences and extreme winds also played a large role (Syphard and others, 2007; Moritz and others, 2010). Invasive species were also present in all three ecoregions, often displacing native vegetation and thus increasing wildland-fire frequency (D'Antonio and Vitousek, 1992; Brooks and others, 2004; Keeley, 2006). These results suggest that an extensive amount of area can burn in these regions, but the emissions are generally lower than those of the forested ecoregions simply because of the difference in the amount of available fuel.

3.6. Limitations and Uncertainties

The MTBS data used in this assessment did not include small wildland fires, but they still captured the majority of the area burned because they included the largest wildland fires which contributed most to the amount of area burned (Strauss and others, 1989; Stocks and others, 2002). A comparison of the MTBS data with the Federal wildland-fire-occurrence database (U.S Department of the Interior, 2012) showed that the MTBS listed only 2 percent of all wildland fires but that 2 percent accounted for 80 percent of the area burned in the five ecoregions covered by this assessment. Therefore, the results of this assessment captured the general patterns and trends of western wildland fires, but provided a slight underestimate of wildland-fire emissions.

In this assessment, the estimates of area burned and of emissions also did not include the influence of prescribed and agricultural fires (for example, burning crop residues); however, the emissions produced by those types of fires were suspected to be low relative to the wildland-fire emissions. The influence of prescribed fires on emissions was difficult to assess because the data characterizing prescribed fires were generally poor based on inconsistent reporting about them across the country. The existing estimates of emissions from prescribed fires suggested that they produced only 10 percent of the emissions from wildland fires (Y. Liu, 2004), in part because prescribed fires usually burn under less extreme meteorological conditions than wildland fires. The influence of agricultural fires was also estimated to be about 10 percent of the wildland-fire emissions in the GFED database. In the Western United States, the relative amount of emissions produced by prescribed and agricultural fires was likely to be even lower, because agricultural fires were more common in the Great Plains and the Eastern United States (Korontzi and others, 2006; Tulbure and others, 2011) and prescribed fires in the Western United States only accounted for 22 percent of the area burned by prescribed fires nationwide (National Interagency Fire Center, 2012).

The emissions results generated for this assessment differed and were generally lower than past estimates of emissions for the Western United States. The highest emissions estimates were from Wiedinmyer and Neff (2007), who used the active wildland fire data from the MODIS from 2002 to 2006 and estimated the mean and standard deviation of annual emissions at 105.0 and 42.0 $TgCO_{2\text{-eq}}$, respectively, for the following States: Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, Washington, and Wyoming; the five ecoregions in this assessment do not cover the exact same area. French and others (2011) calculated emissions using the MTBS data and CONSUME model (Ottmar and others, 2008) for wildland fires occurring from 2001 to 2008; their results are available online as ecoregion-level summaries (Michigan Tech Research Institute, 2012). When their results were summarized across the Western United States, the average and standard deviation of annual emissions was 78.4 and 43.3 $TgCO_{2\text{-eq}}$, respectively, which is nearly twice the amount of the emissions estimated in this assessment. The emission estimates from both of these analyses were substantially greater than the estimates generated for this assessment. The differences are most likely due to differences in methods, data, and the resolution of the data used. Wiedinmyer and Neff (2007) relied on 1-km resolution, active-wildland-fire data from MODIS and fuels data from the Fuels Characterization Classification System (FCCS; USDA Forest Service, 2012d). They also assumed that all of the available biomass could potentially burn, and that is often not the case, especially for woody fuels (Campbell and others 2007; Meigs and others, 2009). French and others (2011) also used the 1-km-resolution FCCS fuels data and aggregated 1-km-resolution MTBS data. The fuels data in their report differed from the data layer used in this assessment both in terms of information and resolution. The methods used in this assessment made use of fuel moistures, which are based on gridded daily weather data. The methods used by French and others (2011) also made use of fuel moistures, but recommended 10 percent levels for 1,000-hour availability and duff moistures, which are very favorable conditions for combustion. The full effects of the differences in fuel maps and moisture levels on this assessment were difficult to assess, but these comparisons suggest that the results in this assessment are more conservative than previously published estimates of wildland-fire emissions.

3.7. Implications for Management and Mitigation

For this assessment, the effects of different strategies for wildland-fire management and mitigation on fire emmissions were not explicitly addressed, but there is a growing body of literature from which to draw some conclusions. Increasing the effectiveness of fire suppression (which includes firefighting, prevention, and education) is a popular first choice but unlikely to work to reduce fire emmissions given that fire suppression over the past 100 years has had mixed success (Rollins and others, 2001; Keane and others, 2002; Stephens and Ruth, 2005). In some ecoregions, reducing the area that could potentially be burned may be possible and critical to maintain ecosystem health, especially in areas where wildland-fire frequency is suspected to be unnaturally high because of the increase in human influence due to arson, accidental ignitions, or the accidental or deliberate introduction of invasive species, such as in Southern California (Keeley and others, 1999) and in the grasslands, shrublands, and deserts of the Southwestern United States where fire-adapted invasive species are altering wildland-fire cycles (D’Antonio and Vitousek, 1992; Brooks and others, 2004; Keeley, 2006).

A more effective way to reduce wildland-fire emissions from forests may be to implement management strategies designed to reduce wildland-fire severity, which is directly related to the amount of biomass consumed. In many parts of the Western United States, fire suppression has resulted in unnaturally high fuel loads producing wildland fires that are of uncharacteristically high severity (Stephens, 1998; Keane and others, 2002; Agee, 2003; Stephens and Ruth, 2005). Fuel treatments, including mechanical forest thinning and prescribed fires, are designed to reduce fuel loads so that wildland fires are less intense and easier to manage if they do occur (Agee and Skinner, 2005; Reinhardt and others, 2008). Most of the evidence suggests that fuel treatments can reduce carbon loss through wildland-fire emissions over the long term even though there is a short-term loss in carbon storage due to biomass removal (Stephens and others, 2009; Reinhardt and Holsinger, 2010; Wiedinmyer and Hurteau, 2010; North and Hurteau, 2011). Such treatments are most effective in forests where fuel loads are uncharacteristically high and may not be ecologically appropriate in other forest and vegetation types (Sibold and others, 2006; Mitchell and others, 2009). To produce a noticeable effect at a regional scale, between 20 and 40 percent of the Western United States' forests need to be treated (Finney, 2001, 2007). The potency of fuel treatments can be short-lived, on the order of 10 to 20 years (Collins and others, 2011); therefore, 1 to 4 percent of the forested landscape would need to be treated annually (Finney and others, 2007). Given that wildland fires are rare events, the proportion of the landscape that must be treated is much larger than the proportion of the landscape that burns and because of that relation, the amount of carbon removed from biomass pools in fuel treatments may be greater than the amount of carbon protected from fire (Campbell and others, 2012).

In some nonforested ecosystems in the Western United States (especially southern California, the Great Basin, and the Sonoran and Mojave Deserts), the frequencies of wildland fires are uncharacteristically high and are driven by human ignition of some fires and by invasive species which provide extra fuel (D'Antonio and Vitousek, 1992; Keeley and others, 1999; Brooks and others, 2004; Keeley, 2006). Wildland-fire emissions in these nonforested ecosystems are likely to be greater and carbon stocks lower than in historic time because native woody vegetation has been replaced by invasive grasses (Bradley and others, 2006). Even though wildland-fire emissions from these nonforested ecosystems are low relative to those from forested ecosystems, reducing the wildland-fire frequency to the historical range of variability may result in only slightly reduced overall wildland-fire emissions. In other nonforested ecosystems in the Western United States (such as grasslands/shrublands), the opposite has happened. Grazing pressure has reduced the grass cover and the frequency of wildland fires, thus allowing woody vegetation to expand its range and increase in cover (Van Auken, 2000). The expansion of woody vegetation usually results in an increase in carbon stocks (Asner and others, 2003); however, it is uncertain if the increased carbon stocks will persist over long time periods given changes in climate and fire regimes (Barger and others, 2011).

Much uncertainty remains about the short- and long-term effects of wildland-fire management on carbon budgets in many ecosystems in the Western United States. Any carbon-management strategy focused on increasing ecological carbon stocks or sequestration rates should carefully consider the benefits and risks of wildland-fire management over both short and long time periods, as well as the effects on other ecosystem characteristics and services (Jackson and others, 2005; McKinley and others, 2011; Olander and others, 2012).

This page intentionally left blank.