Wildfire Emission Estimates for 2023

Introduction

Fire has served natural functions in California's diverse ecosystems for millennia, such as facilitating the germination of serotinous seeds, replenishing soil nutrients, clearing dead biomass to make room for live vegetation, and reducing accumulation of fuel that leads to high-severity wildfires. However, fire also impacts human health and safety, as well as releases GHG emissions and other air pollutants, including those that contribute to ozone formation. Over the last decade, the risk for large and catastrophic wildfires has increased across California.

The California Air Resources Board (CARB) annually releases estimates of greenhouse gas (GHG) and particulate matter emissions from wildfires occurring on natural and semi-natural land (i.e. not agricultural or developed land), hereafter referred to as "wildland vegetation".[1] The fire emissions model CARB uses does not include vegetation fuel loading for urban or developed lands, therefore these land categories are excluded from analysis. Characterization of vegetation fuels for croplands in California is an area of active inquiry, therefore croplands were excluded from the analysis. Emissions are estimated using the First Order Fire Effects Model (FOFEM) (Lutes 2020, Keane and Lutes 2020) for fires reported in the California Department of Forestry and Fire Protection's (CAL FIRE) historic wildfire perimeter dataset (CAL FIRE 2024). This document summarizes estimates of statewide wildfire emissions from wildland vegetation from 2000 to 2023 for carbon dioxide (CO_2), particulate matter that are 10 microns or smaller in size (PM_{10}), and particulate matter that are 2.5 microns or smaller in size ($PM_{2.5}$).

Overview of the 2023 Fire Season

State data from CAL FIRE's historic fire perimeter dataset reported 284 wildfires in 2023 (CAL FIRE 2024), burning a total of 342,000 acres. (Note: The CAL FIRE perimeter dataset contains fires above a minimum size threshold and does not exhaustively inventory every ignited fire in California.) Of these fires, 276 occurred on wildland vegetation, burning 336,000 acres of natural and semi-natural areas (Table 1). This is slightly higher than the acreage burned in 2022. Since the year 2000, 2023 was below

[1] "Wildland vegetation" is commonly used to describe naturally vegetated ecosystems, although sometimes the definitions slightly vary. To explicitly define the term, Stewart et al. (2007) defined "wildland vegetation" as "all types of vegetative cover except those that are clearly not wild, such as urban grass, orchards, and agricultural vegetation."

the multi-decade average of burned wildland acreage, ranking 16th out of 24 years (Fig. 1). Total wildland area burned in 2023 was approximately 7% of that in 2020, the highest year on record. As in previous years, a few wildfires comprised most of the year's reported burned area. Over half of the state total burn acreage was dominated by two fires: York (93,078 acres, San Bernardino and Clark [Nevada] counties) and Kelly (87,323 acres, part of the Smith River Complex fire, Del Norte County).

Emissions Modeling Results

Total annual fire emissions correlate with the amount of fuel consumed. Similar to 2022, total estimated fuel consumption (Table 1) in 2023 was less than a tenth of the fuel consumption in the more active and recent year 2021. Total emissions of $PM_{10,}$ $PM_{2.5}$ and CO_2 in 2023 were correspondingly smaller in magnitude compared to 2021. The 2022 and 2023 fire seasons experienced similar total acreage burned (Figure 1) and similar quantities of fuel consumption and emissions (Figures 2, 3, and 4).

A wildfire's total emissions is affected by vegetation types and fuels consumed within the fire footprint. Forest and woodland vegetation typically contain greater fuel loads per unit area (typically dead wood and surface fuels) than vegetation types dominated by shrubs, herbaceous plants, or grasses. Large fires extend across a variety of vegetation types. For example, the York fire extended across 20 different fuelbed types, spanning shrubland, woodland, grasslands, and forested areas. However, 97% of the pre-fire area was dominated by just one fuelbed type: blackbrush shrubland (Fuel Characteristic Classification System Fuelbeds [FCCS] 309). Since this fuelbed's fuel loading primarily comes from shrub and herbaceous vegetation—and has very little fuel loading from litter, duff, and woody debris—it was only the 25th largest contributor to $PM_{2.5}$. On the other hand, the next largest fire, the Kelly fire, was the largest contributor to $PM_{2.5}$ emissions due to its large size and the fact that it mostly burned forested areas (98% of total area).

Forests were the most commonly burned vegetation types in 2023, with fuel consumption ranging from 0.7 to 130 tons/acre, averaging 24 tons/acre. The model estimated high rates of fuel consumption, with nearly complete consumption of litter, shrubs, and 1-hr, 10-hr and 100-hr dead fuels, as well as high rates for large-diameter dead fuels. Consumption of large-diameter dead fuels and duff (a forest floor dead organic layer between litter and soil layers) is largely associated with combustion in the smoldering phase. Carbon dioxide (CO_2) emissions are associated with fuel consumption in both the flaming and smoldering phases. Table 1 is a summary of 2023 wildfire area, fuel consumption, and emissions.

Table 1. 2023 wildfire area, fuel consumption, and emissions from wildland vegetation.

Wildfire Area (million acres)	Fuel Consumed (million short tons)	PM_{10} (thousand short tons)	$PM_{2.5}$ (thousand short tons)	CO_2 (million metric tons)
0.34	6.9	114	97	9.1

The top twenty wildfires comprised approximately 91% of total area burned. Their estimated emissions are listed in Table 2. The Kelly and Mosquito fires were the largest contributors to $PM_{2.5}$ emissions in 2023, accounting for 64% of the total estimated emissions. These two fires were part of the Smith River and SRF Lightning Complex fires, which burned approximately 28% and 15% of the total area in 2023, respectively.

Table 2. Top 20 wildfires of 2023 by area of wildland vegetation burned. *Names of fire complexes, if applicable, are in parentheses.

Rank	Fire Name*	Alarm & Containment Date	Area (acres)	Fuel Consumed (thousand pounds)	CO_2 (million metric tons)	PM_{10} (thousand short tons)	$PM_{2.5}$ (thousand short tons)
1	York	7/28—8/20/2023	93,032	65	0.1	0.2	0.2
2	Kelly (Smith River)	8/15—11/14/2023	87,323	3031	3.95	53.7	45.5
3	Mosquito (SRF)	8/15—10/25/2023	34,626	1051	1.37	18.8	15.9
4	Elliot (Happy Camp)	8/15—10/23/2023	13,546	471	0.62	8.0	6.8
5	Pearch (SRF)	8/17—10/25/2023	12,588	434	0.57	7.5	6.4
6	Quarry	9/9—11/8/2023	8,499	220	0.29	3.6	3.0
7	Rabbit	7/14—7/23/2023	8,134	95	0.15	0.4	0.3
8	Ufish (Happy Camp)	8/16—9/28/2023	7,571	259	0.34	4.5	3.8
9	Head (Happy Camp)	8/15—9/7/2023	6,730	145	0.2	1.9	1.6
10	Plant	8/19—8/31/2023	5,461	54	0.08	0.3	0.3
11	Almond	8/6—8/7/2023	4,674	15	0.02	0.1	0.1
12	Deep	8/15—10/3/2023	4,110	98	0.13	1.8	1.5
13	Rabbit	9/30—10/30/2023	2,731	85	0.11	1.5	1.2
14	3-9 (South Fork)	8/16—11/2/2023	2,689	46	0.07	0.5	0.4
15	Hurdy-Gurdy (Smith River)	8/15—11/14/2023	2,624	70	0.09	1.2	1.0
16	South	12/9—12/12/2023	2,527	21	0.03	0.1	0.1
17	Highland	10/30—11/8/2023	2,344	35	0.05	0.2	0.1
18	Bonny	7/26—8/7/2023	2,290	32	0.05	0.2	0.1
19	Redwood	8/15—12/14/2023	2,241	51	0.07	0.8	0.7
20	Marlow (SRF)	8/15—10/3/2023	1,959	46	0.06	0.8	0.7

Figures 1 to 4 present annual wildfire acreages and emissions of CO_2, PM_{10}, and $PM_{2.5}$ for 2000 to 2023.[1]

Figure 1. Acreage of Burned Wildland Vegetation Area

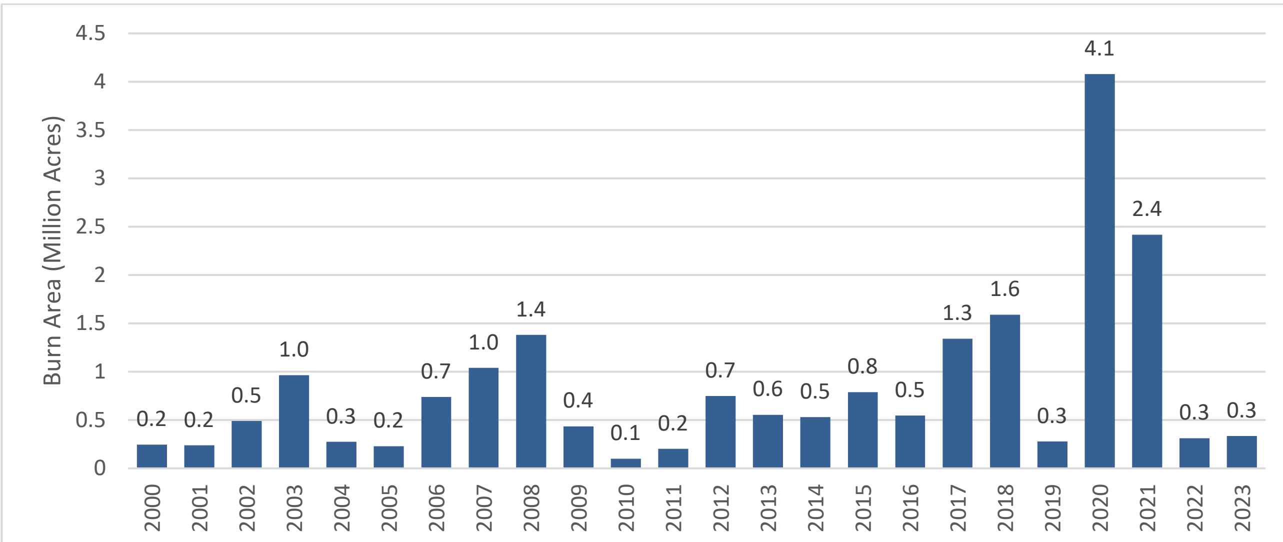
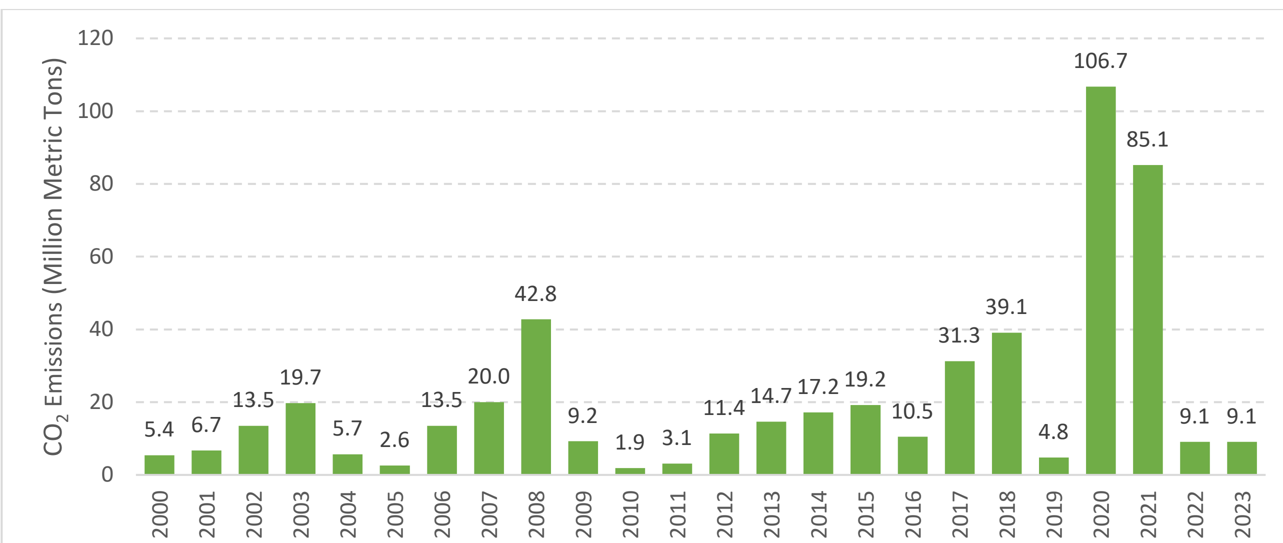


Figure 2. Estimates of Wildfire CO_2 Emissions



[1] The wildfire emissions in Figures 1 to 4 include all fire events in the CAL FIRE database (CAL FIRE 2024), including those labeled as "Wildland Fire Use (WFU)." WFU refers to fires that are managed to accomplish specific pre-stated resource management objectives in predefined geographic areas outlined in fire management plan.

Figure 3. Estimates of Wildfire PM_{10} Emissions

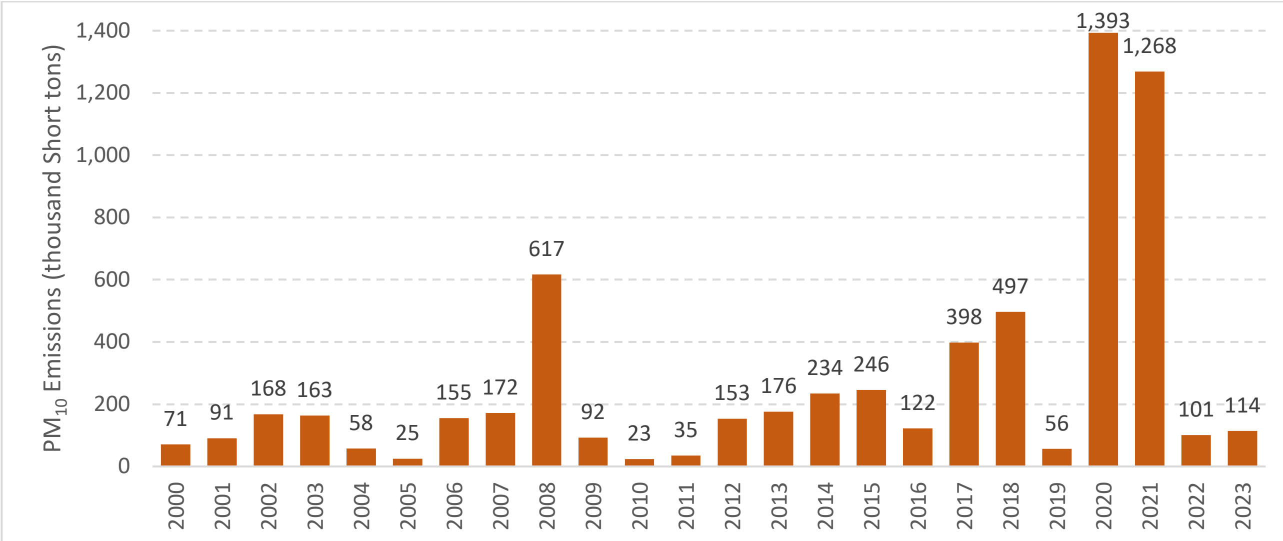
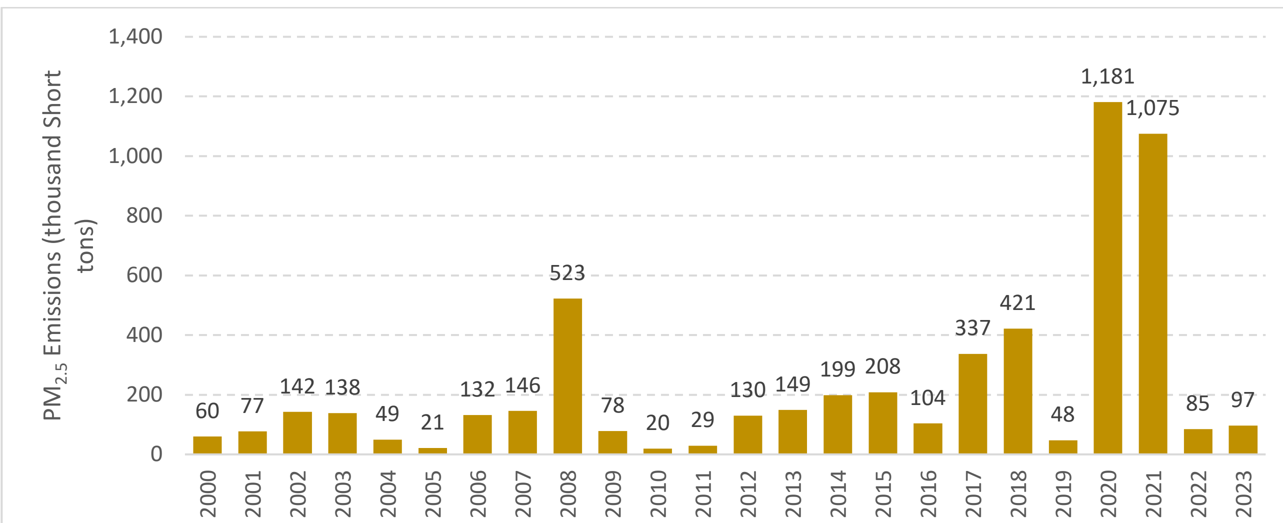


Figure 4. Estimates of Wildfire $PM_{2.5}$ Emissions



Data Sources and Methods

Emissions are estimated using GIS format data on fire perimeters (CAL FIRE 2024), alarm and containment dates, natural vegetation fuel type (fuel component size class), fuel loads (tons/acre), and fuel moistures. The geospatial data are used to develop inputs to a wildland fire emission model (FOFEM version 6.7, Lutes 2020, Keane and Lutes 2020). Modeled emissions in flaming and smoldering phases (lbs/acre) by fuel type are integrated over the areas of each vegetation fuel type associated with each wildfire. Flaming and smoldering emissions are summed for reporting and include every fire reported and mapped for the calendar year. Pollutant emissions of PM_{10}

and $PM_{2.5}$ are primarily associated with fuel consumption in the smoldering phase, whereas CO_2 largely originates in the flaming phase.

The magnitudes of emissions are proportional to the amount of fuel consumed, and various pollutants are generated in the flaming and smoldering phases of combustion. Fuel moisture influences the proportions of fuel consumed in flaming versus smoldering phases. 1000-hour fuel moistures are obtained from gridMET (Abatzoglou 2013). Vegetation fuel maps based on the Fuel Characteristic Classification System (FCCS) are developed for specific years by LANDFIRE (Ottmar et al. 2007, LANDFIRE 2013). LANDFIRE releases FCCS products every 2-5 years and reprojects ("remaps") vegetation post-disturbance in order to update fuel loads with time. For 2023, we used the most recent LANDFIRE FCCS product, *LF 2020 Remap ver. 2022*. For all other years (except 2001, which used LANDFIRE), CARB staff used FCCS-based vegetation fuel maps developed by researchers at the University of California at Berkeley (UC Berkeley 2019). Fuel loads for FCCS vegetation types are defined in FOFEM.

Uncertainty

Uncertainties associated with mapped vegetation fuel types, fuel loading (tons/acre by fuel size category) (Collins et al. 2016, McKenzie et al. 2007, Riccardi et al. 2007, Sikkink and Keane 2008), fuel moisture, burned area, modeled fuel consumption in flaming and smoldering phases, and emission factors (EFs, mass of pollutant species per unit mass fuel consumed) contribute to large uncertainties in emission estimates reported by CARB. EFs are derived from chemical analysis of air samples during biomass burn events. Derived EFs vary with fuel type, fuel component size class, texture, arrangement, moisture content, combustion conditions (wildfire vs. prescribed burn, flaming vs. smoldering, wind speed), and methods (laboratory versus field studies). For some pollutants, EF uncertainty approaches a factor of two (Urbanski 2014, Prichard et al. 2020). Fuel loading is an especially large source of uncertainty: across vegetation types and entire landscapes, fuel loading can vary by up to an order of magnitude. A 2011 study (Urbanski et al. 2011) estimated wildfire emissions across the western U.S. for 2003 through 2008 using a geospatially and temporally explicit fire emission model utilizing remotely sensed vegetation fuel, wildfire activity, and weather data. The study found that uncertainties were approximately a factor of two at spatial (kilometers) and temporal scales (daily) relevant to air quality modeling (4-km grid).

Note on the Previous Edition of this Report

The *Wildfire Emission Estimates for 2022* report was initially published on August 24, 2023, and later updated on September 23, 2024, to correct a data transcription error in Table 2, a canopy mortality rate assumption that had led to minor differences in emissions and fuel quality, and include an additional fire (the Lost Lake Fire) that has been added to CAL FIRE's database since the initial publication of this report. These updates are described in more detail in errata footnotes in the July 2024 update of the *Wildfire Emission Estimates for 2022* report. They do not affect any other past or current editions of the report.

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