FCEM

Forest Carbon and Emissions Model

IMPACTS OF CALIFORNIA WILDFIRES ON CLIMATE AND FORESTS: A Study of Seven Years of Wildfires (2001-2007)

FCEM Report No. 3

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Executive Summary

This study (FCEM Report No. 3) and the previous study (FCEM Report No. 2), use a new computer model, the Forest Carbon and Emissions Model (FCEM), to estimate greenhouse gas emissions from wildfires and insect infestations, and opportunities to recover these emissions and prevent future losses.

This report shows that the wildfires that scorched California from 2001 to 2007 seriously degraded the state's forests and contributed to global warming. Political and economic obstacles to managing forests and restoring burned forests are the root causes of the wildfire crisis.

The impact of California's wildfires on climate and forests is one of the most important issues of our time. It is imperative to take action now to prevent the annual recurrence of disastrous and costly fire seasons.

The wildfire crisis is becoming more serious each year. Fires are getting bigger, more destructive, and more expensive. In 2001, California wildfires burned one-half million acres. In 2007, 1.1 million acres burned, and an estimated 1.4 million acres burned in 2008 destroying 1,000 homes. This was the most destructive fire season in the state's history and 2009 could be worse.

From 2001 to 2007, fires burned more than 4 million acres and released an estimated 277 million tons of greenhouse gases into the atmosphere from combustion and the post-fire decay of dead trees. That is an average of 68 tons per acre. These wildfires also kill wildlife, pollute the air and water, and strip soil from hillsides. The greenhouse gases they emit are wiping out much of what is being achieved to reduce emissions from fossil fuels to battle global warming.

The emissions from only the seven years of wildfires documented in this study are equivalent to adding an estimated 50 million more cars onto California's highways for one year, each spewing tons of greenhouse gases. Stated another way, this means all 14 million cars in California would have to be locked in a garage for three and one-half years to make up for the global warming impact of these wildfires.

The catastrophic and unnatural forest fires that ravage California each year do not resemble historic fires. Frequent lightning and Indian-set fires that burned along the ground, igniting only scattered small groups of trees, kept forests open and healthy, and resistant to catastrophic fires.

Even chaparral fires in the vast brushlands of Southern California were limited in extent in past centuries. Frequent fires sustained a mosaic in which old flammable chaparral was isolated between patches of less flammable young chaparral, which kept wildfires from spreading across the landscape, regardless of strong winds. Today, old chaparral stretches across huge areas to fuel massive fires that destroy human lives and homes.

It is not realistic or acceptable for an industrialized, modern society to live with the annual recurrence of unnatural catastrophic wildfires. To protect our communities, forests, and climate, we must reduce the threat of wildfires. That means not just fighting fires, but taking action to reduce fuels to prevent them.

Although hundreds of millions of dollars are spent fighting wildfires each year, very little is spent on fuel reduction. Since forests keep growing thicker and surface fuel continues to pile up, wildfires are getting bigger and more destructive.

Some public forests in California have more than 1,000 trees per acre when 40 to 60 trees per acre would be natural. These dense forests contain small trees that can carry fire into the canopy, and heavy concentrations of woody debris lying on the ground intensify the flames. This combination of too many large trees intermixed with small trees and surface debris are responsible for the size and severity of many forest fires.

Reducing the number of all sizes of trees per acre by thinning is effective in helping prevent crown fires in forests. This was demonstrated in two California wildfires – the Cone Fire in 2002 and the Bell Fire in 2005. These crown fires dropped to the ground and became light and easily suppressed surface fires after entering thinned forests. We should use this knowledge and act quickly to prevent catastrophic wildfires before they destroy more property, lives, and forests, and further alter the global climate.

This is only part of the wildfire tragedy. During the seven years covered by this study, California wildfires deforested about 882,759 acres of public and private land and only an estimated 120,755 acres were replanted. That means about 762,004 acres of forest converted permanently to brush because no live trees remain standing to provide seed for a new forest. That is an average loss of about 109,000 acres of forest each year, or the equivalent of an area nearly four times the size of San Francisco.

Not only are wildfires causing California's forests to dwindle, but the greenhouse gases they emit will stay in the atmosphere for centuries. The estimated 134 million tons of carbon dioxide (CO_2) released by fires and the decay of dead trees from forests that were permanently converted to brush from 2001 to 2007 will continue to worsen global warming.

Harvesting dead trees to prevent them from releasing CO_2 from decay, storing the carbon they contain in long-lasting wood products, and using the money to replant a young forest that absorbs CO_2 through photosynthesis is the only way to restore deforested areas and recover this greenhouse gas from the atmosphere.

The immensity of greenhouse gas emissions from California's wildfires and the permanent loss of huge areas of forest are a warning. Clearly, we must make every effort to reduce the amount of fuel in public and private forests to prevent catastrophic wildfires. That means decreasing the number of trees of all sizes by thinning to make forests resistant to crown fires. We must also harvest fire-killed trees and replant young trees in burned forests to replace what was lost.

If we take these steps, we will restore the natural health and diversity of our forests, help the fight to reduce harmful emissions, and leave a legacy of which we can be proud.

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Introduction

This report analyzes the California wildfires that burned public and private lands from 2001-2007 using the Forest Carbon and Emissions Model (FCEM) (see Appendix A). Impacts of the disastrous 2008 fire season were not analyzed because of the lack of available data from responsible agencies. A detailed technical description of FCEM is in Bonnicksen (2008a). FCEM computes estimates using the metric system, but results in this study use the more familiar English system of measurement to improve understanding.

This report shows that the wildfire crisis is becoming more serious each year. Fires are getting bigger, more destructive, and more expensive. In 2001, California wildfires burned one-half million acres. In 2007, 1.1 million acres burned, and 1.4 million acres burned in 2008 destroying 1,000 homes. This was the most destructive fire season in the state's history and 2009 could be worse.

The purpose of this report is to document the impact of wildfires on greenhouse gas emissions and the importance of thinning forests to prevent these emissions. It also documents the tragic loss of forests due to the lack of replanting and natural regeneration after wildfires. In addition, it emphasizes the ecological significance of removing dead trees and replanting permanently deforested areas to recover carbon dioxide released into the atmosphere by wildfires.

Thinning forests to reduce fuel, harvesting fire-killed trees, and replanting will help prevent catastrophic fires, restore burned forests at minimal cost, reduce and recover greenhouse gases emitted by wildfires, protect nearby communities from wildfires, and help fight global warming.

Input Data and Simulations

FCEM requires a minimum of input data to analyze the climate impacts of wildfire. The first step is to describe the forest as it was before a wildfire. This provides the initial conditions that contribute to the size, severity, and impacts of a wildfire.

Data Sources

Data used in this report for area burned, deforestation, natural regeneration, and area replanted, come from a variety of government and other sources. They include, most importantly, the U.S. Forest Service Pacific Southwest Region Ecosystem Planning Staff, U.S. Forest Service Region 5 Silviculturalist, California Department of Forestry and Fire Protection (CAL FIRE), and the National Interagency Fire Center (NIFC).

Other sources include recently published peer-reviewed scientific and other technical papers. The latter sources include reports from universities, government agencies, and consulting firms. On-site visits to burned forests, first-person accounts, and personal communications with experts also provided valuable information.

Forest Patchiness, Density, and Biomass

The catastrophic wildfires that ravage California each year do not resemble the historic fires that took place in these forests for millennia. Natural fires set by lightning and Native people were frequent and light, burning mainly surface fuels and igniting only scattered small groups of trees (Bonnicksen 2000, Bonnicksen et al. 2000).

These light fires created a variety of young and old patches in historic forests that helped to contain hot fires. Patches of young trees, and old trees with little growing underneath did not burn well and served as fuel breaks. Thus, historic forests developed an ingenious pattern of fuel breaks that kept them immune from monster fires (Bonnicksen 2000, Bonnicksen and Stone 1981, 1982).

Many forests have lost their immunity to monster fires because as trees grow dense, there are few younger and open patches left to slow the flames. Today, wildfires are free to sweep across landscapes destroying whole forests and habitat, killing wildlife, baking soils into hardened clay that cannot absorb rainwater, and causing massive erosion and greenhouse gas emissions (Bonnicksen 2008c).

Some California forests have more than 1,000 trees per acre when 40 to 60 trees per acre would be natural. These overcrowded forests contain too many large trees as well as small trees that can carry fire into the canopy. They also contain unnaturally heavy loads of surface fuels composed of litter, duff, down dead wood, and shrubs that range from an estimated 25 to 40 tons or more per acre. This combination of too many large trees intermixed with small trees and surface debris are responsible for the size and severity of forest fires (Bonnicksen 2008b, 2008c).

Similarly, chaparral fires in the vast brushlands of Southern California were smaller in past centuries because of their patchiness. Frequent fires set by Native people and lightning sustained a mosaic in which small patches of old flammable chaparral were isolated from one another by patches of less flammable young chaparral (Lee and Bonnicksen 1978, Leiberg 1900, Lewis 1973, Minnich 2001, Timbrook et al. 1982). This kept wildfires from spreading across the landscape, regardless of strong winds (Bonnicksen 1980, Chou et al. 1993, Minnich, 2001, 2003). When a fire reached a recently burned area, it went out. In contrast, today old chaparral stretches across huge areas to fuel massive fires that destroy homes and release greenhouse gases that contribute to global warming.

Carbon Density Data

Normally, FCEM uses tree diameter and density data to compute estimates of greenhouse gas emissions using diameter-based allometric equations for each tree species. These data were not available for the 2001-2007 fire seasons. Therefore, input data required to describe pre-fire forests was changed in this version of FCEM to published Forest Service look-up tables of carbon density by vegetation type. The original FCEM model also used look-up table data for non-forest vegetation (see Appendix A for look-up table data and references).

Look-up table data provide averages of carbon density for each vegetation type. Carbon density is 50 percent of biomass. These data are very conservative because they represent a mean between extremes. Therefore, simulated estimates of greenhouse gas emissions in this report are lower than might be expected. Most modern forests and brushlands are denser and packed with more biomass than is shown in look-up table data. Biomass is the single most important variable used to compute greenhouse gas emissions (Bonnicksen 2008a).

Vegetation Types

The Forest Service provides vegetation types and proportions of each type affected by wildfires for 2001-2007 on their website (U.S. Forest Service Region 5, 2008). These proportions varied from year to year. They also analyze selected fires, including acreage deforested, and forested (regenerating naturally) by vegetation type and ownership (i.e., Forest Service and “other,” meaning private or California Department of Forestry and Fire Protection CDF responsibility areas). Finally, they document the deforested area replanted each year, but not by vegetation type. CDF (i.e., CAL FIRE) did not have similar data.

This report covers all fires that occurred in California for the seven year period analyzed. However, Forest Service data are incomplete for federal lands since they only deal with selected fires. Likewise, they do not cover all non-federal lands nor do they include the area burned by vegetation type on these lands.

Consequently, FCEM computes estimates of greenhouse gas emissions based on Forest Service data for the proportion of different vegetation types burned in a given year, and the ratio of Forest Service to non-federal land burned. Even so, the Forest Service thoroughly analyzed the proportion of forest types burned each year on so many different areas that, for the purposes of this study, their data are considered a reliable representation of all forests burned in a given year. Likewise, the proportion of non-federal land burned in these fires is considered representative of other fires that occurred during the same year.

Table 1 shows the proportion of each vegetation type burned each year. These data do not include alpine areas or redwood because they only burned in 2008. Table 2 summarizes these data by major vegetation type.

These tables also show that the proportion of forest burned changed each year. In some years, mostly forest burned, while in other years, mostly chaparral burned. This is significant since forest fires produce more greenhouse gases than chaparral because they have more biomass to burn.

Table 1. Proportion of vegetation types in burned California forests (2001-2007).

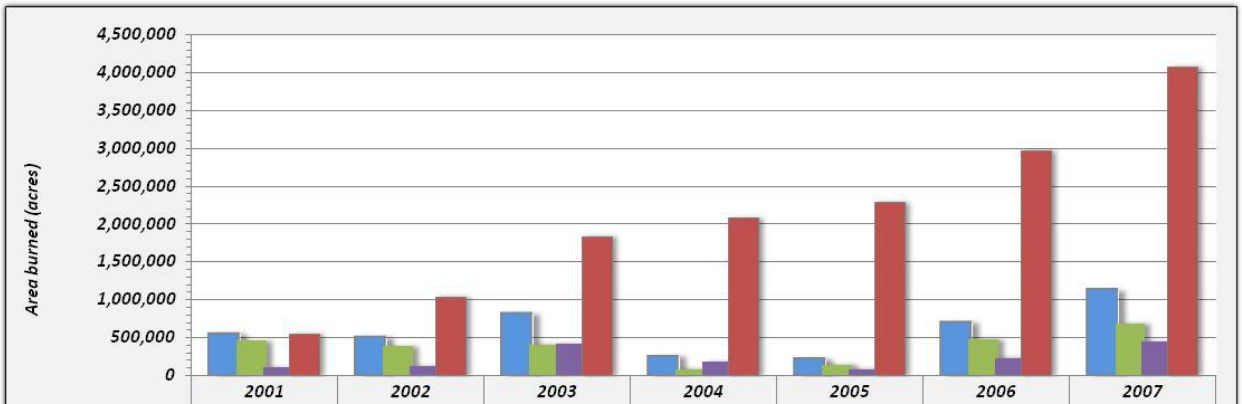
Composition of Burned Vegetation	Year 2001	2002	2003	2004	2005	2006	2007
Coast redwood	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Douglas-fir	9.2%	3.8%	7.8%	13.3%	0.0%	28.4%	5.5%
Pinyon-juniper	1.0%	0.2%	0.1%	0.0%	0.0%	6.0%	1.8%
Lodgepole pine	2.1%	2.2%	2.6%	0.5%	0.0%	0.4%	2.4%
Ponderosa/Jeffrey pine	8.9%	7.4%	1.9%	14.0%	56.1%	5.2%	4.2%
Mixed conifer	34.8%	25.9%	10.2%	37.7%	24.2%	14.5%	14.7%
True fir/hemlock	10.7%	9.8%	1.7%	0.7%	0.0%	2.6%	1.0%
Oak/tanoak/laurel	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Chaparral/knobcone-chaparral	22.1%	40.0%	66.0%	14.1%	19.7%	36.2%	61.8%
Hardwoods/western oak	11.3%	10.7%	9.7%	19.7%	0.0%	6.6%	8.6%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 2. Proportion of major vegetation types in burned California forests (2001-2007).

Vegetation Type Burned	Year 2001	2002	2003	2004	2005	2006	2007
Conifer forest	66.6%	49.3%	24.2%	66.2%	80.3%	57.2%	29.6%
Chaparral/knobcone-chaparral	22.1%	40.0%	66.0%	14.1%	19.7%	36.2%	61.8%
Hardwoods/western oak	11.3%	10.7%	9.7%	19.7%	0.0%	6.6%	8.6%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Area Burned

The only other data required for FCEM were the total acres burned in California in each of the seven years covered in this study. These data came from the National Interagency Fire Center (NIFC) (2008). They published statistics showing the total acreage burned by lightning and human causes for northern and southern California. The sum of these data provides the total acres burned by year. California Department of Forestry and Fire Protection (CDF) (2008) wildfire summaries for 2001 to 2007 provided data on the acres burned on private land. Figure 1 shows the total acres burned by ownership by year.



	2001	2002	2003	2004	2005	2006	2007
Total	537,137	488,478	799,819	242,817	204,253	687,863	1,107,976
Forest Service	446,172	375,668	395,491	74,683	130,249	464,967	673,309
Other owners	90,965	112,810	404,328	168,134	74,004	222,896	434,667
Cumulative total	537,137	1,025,615	1,825,434	2,068,251	2,272,504	2,960,367	4,068,343

Figure 1. Total acres burned in California by ownership (2001-2007).

Table 3 shows the acreage burned by major vegetation type. Along with Figure 1, this table shows that wildfires are getting bigger (also see Bonnicksen 2008c). Inadequate data precluded using the 2008 fire season to compute estimates in this study. However, available data document that the area burned in 2008 was greater than in 2007. During the summer and early fall, 2,100 fires burned more than 1.1 million acres of forests and woodlands. The following November, wildfires burned an additional 64 square miles and destroyed 1,000 homes. A total of 1.4 million acres burned in 2008, making it the worst fire year in California's history.

Table 3. Area burned in California forests by major vegetation type (2001-2007).

	Year						
Vegetation Type Burned	2001	2002	2003	2004	2005	2006	2007
Conifer forest	357,707	240,877	193,854	160,676	164,015	393,136	327,642
Chaparral/knobcone-chaparral	118,837	195,571	528,173	34,238	40,238	249,309	684,835
Hardwoods/western oak	60,593	52,030	77,793	47,903	0	45,418	95,500
Total (acres)	537,137	488,478	799,819	242,817	204,253	687,863	1,107,976

Mortality from Wildfires

Computations for estimating greenhouse gas emissions from wildfires in FCEM simulations require specifying percent mortality for understory and overstory vegetation. Mortality means trees or shrubs killed or, for sprouting species, the loss of above ground biomass. Other factors that affect greenhouse gas emissions, such as biomass consumption by fuel component, and emission factors for each gas by fuel component are part of FCEM (Bonnicksen 2008a).

Table 4 shows the percent mortality specified in FCEM for each wildfire based on available information. Computer simulations show that these percentages are important, but that minor differences in percent mortality have little effect on estimated greenhouse gas emissions.

Table 4. Percent understory and overstory mortality for simulations.

Simulation	*Understory*	*Overstory*
Deforested	*100%*	*100%*
Forested/regenerating	*80%*	*50%*
Potentially permanently deforested	*100%*	*100%*

Vegetation Condition (deforested vs. forested)

The total acreage deforested (TD) in this study includes the percent of burned forest deforested according to Forest Service data and 15 percent of the area the Forest Service thinks will regenerate naturally but is likely to fail and become deforested (personal communication, Philip Aune). For example, for each of the seven years of the study (see Table 5 for results):

Total acres deforested (TD) = 0.15*(a + b) + c

Where:

a = acres conifer forest forested/regenerating
b = acres hardwoods/western oak forested/regenerating
c = acres deforested

The total acreage forested/regenerating (TF) in this study includes the percent of burned forest regenerating naturally less the 15 percent failure rate and the area of chaparral/knobcone-chaparral that usually regenerates without replanting. For example, for each of the seven years of the study (see Table 5 for results):

Total acres forested/regenerating (TF) = 0.85*(a + b) + c

Where:

a = acres conifer forest forested/regenerating
b = acres hardwoods/western oak forested/regenerating
c = acres chaparral/knobcone-chaparral forested/regenerating

The total acreage potentially permanently deforested (TP) in this study is the total acreage deforested less the area planted by the Forest Service and 16.5 percent of the area of non-Forest Service deforested conifer forest (California Forestry Association 2008). Industrial forest landowners routinely remove dead trees and replant after a wildfire. Since about 16.5 percent of timberlands are in private industrial ownership, this percentage of deforested private land is considered replanted and not deforested. For example, for each of the seven years of the study (see Table 5 for results):

Total acres potentially permanently deforested (TP) = TD – (a + 0.165*b)

Where:
TD = total deforested (acres)
a = acres replanted by Forest Service
b = acres private conifer forest deforested

Table 5. Acreage by vegetation condition (2001-2007).

	Year						
Vegetation Condition	2001	2002	2003	2004	2005	2006	2007
Deforested	191,588	116,733	81,750	114,846	109,371	122,203	146,266
Replanted	20,622	15,684	16,871	19,652	15,362	17,681	14,882
Potentially permanently deforested	170,966	101,050	64,879	95,194	94,009	104,522	131,384
Forested/regenerating	345,549	371,745	718,069	127,971	94,882	565,660	961,710
Total (acres)*	537,137	488,478	799,819	242,817	204,253	687,863	1,107,976

*Replanted + potentially permanently deforested + forested/regenerating

Simulations

Separate FCEM model runs or simulations were broken into three major vegetation condition categories for each of the seven years of the study. This required 21 model runs. The three major vegetation condition categories included deforested (TD), forested/regenerating (TF), and potentially permanently deforested (TP). Acreage affected, mortality, and proportion of vegetation types changed by major category and year.

Emissions

FCEM computes emissions only for forestry-related greenhouse gases (GHG) recognized by the U.S. Environmental Protection Agency (EPA) and the Intergovernmental Panel on Climate Change (IPCC) (U.S. Environmental Protection Agency 2006). These greenhouse gases include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Therefore, particulates and short-lived gases like carbon monoxide are excluded from FCEM emission estimates.

Table 6 shows greenhouse gas emissions from combustion and post-fire decay caused by the seven years of California wildfires analyzed in this report. Estimated greenhouse gas emissions for all wildfires, including CO_2, CH_4, and N_2O total nearly 277 million tons. This equals an average of 68 tons of greenhouse gases emitted per acre burned (based on the cumulative total for seven years) in all vegetation types. The average would be higher for forests because they contain so much biomass and lower for chaparral because it contains less biomass. Even so, this average may be useful in the future for calculating rough estimates of greenhouse gas emissions for the total acres burned in a given year.

Table 6. Greenhouse gas emissions (2001-2007).

	Year						
Emissions (tons)	2001	2002	2003	2004	2005	2006	2007
Carbon dioxide CO_2 (combustion)	18,922,036	11,703,619	8,789,133	9,025,086	5,875,029	17,043,037	13,706,977
Methane CH_4 (combustion)	50,987	32,008	25,202	25,013	15,285	45,329	38,634
Nitrous oxide N_2O (combustion)	2,411	1,492	1,122	1,151	747	2,170	1,749
Total emissions (combustion)	18,975,434	11,737,119	8,815,457	9,051,250	5,891,062	17,090,536	13,747,360
Carbon dioxide CO_2 (post-fire decay)	44,480,446	26,333,849	16,951,929	19,523,258	15,749,020	40,590,338	27,830,056
Total emissions (all sources)	63,455,880	38,070,968	25,767,386	28,574,508	21,640,082	57,680,874	41,577,416
Cumulative total emissions (all sources)	63,455,880	101,526,848	127,294,234	155,868,743	177,508,825	235,189,698	276,767,115

Combustion emissions occur during a wildfire, but dead trees and shrubs release 2-3 times as much CO_2 as combustion when they decay. Therefore, combining combustion and decay emissions provides a more complete picture of the impact of wildfires on global warming.

Dead trees generally decompose within about 100 years, with most of the decay occurring in the first 50 years. FCEM considers dead biomass left after a fire as carbon that will decay in 100 years and computes the amount of CO_2 released accordingly.

As shown in Table 6 and Figure 2, greenhouse gas emissions from decay are larger than combustion emissions. The reason is that 3.67 times the carbon content of biomass is released as CO_2 during decomposition. Therefore, forests emit more CO_2 when they decay than when they burn because large quantities of biomass remain after combustion. However, brush like chaparral burns more completely than trees, so combustion emissions of CO_2 usually exceed decay emissions in this vegetation type.

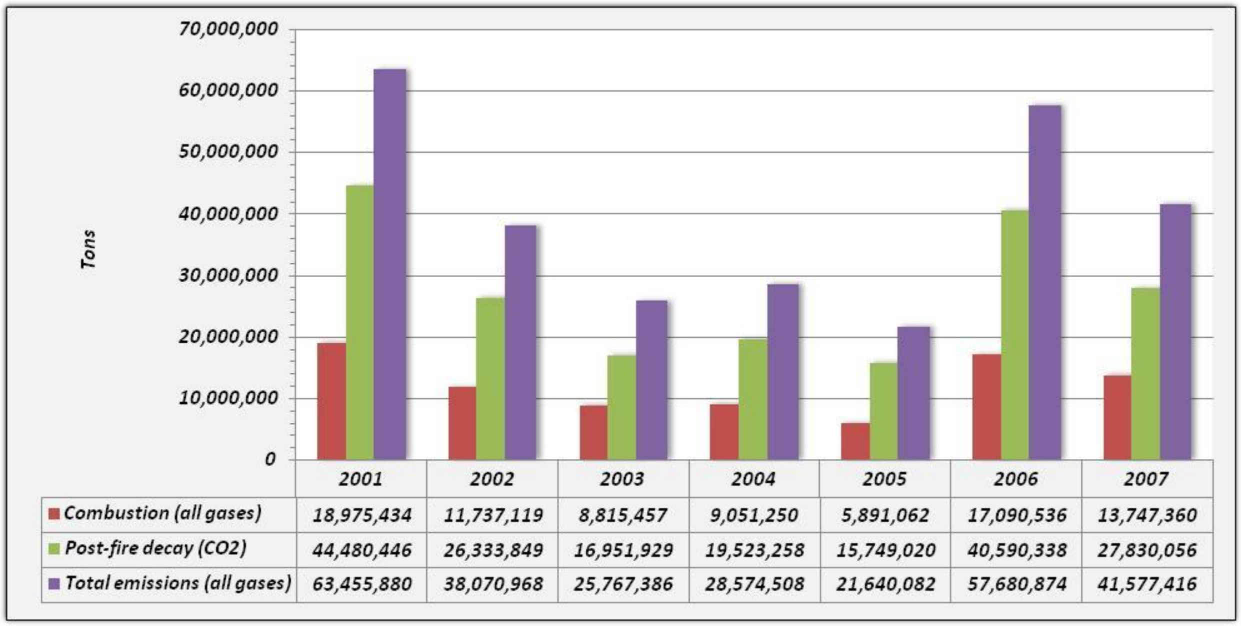


Figure 2. Greenhouse gas emissions from California wildfires (2001-2007).

Automobile Equivalents

It is difficult to interpret greenhouse gas emissions in tons without a comparison. Therefore, Table 7 shows how many cars would be added to California's highways for one year, each spewing several tons of greenhouse gases, and the percent of all cars on the road in California that would equal these emissions. The cumulative total for the seven years is nearly 50 million cars (see Bonnicksen 2008a for formulas).

Table 7. Greenhouse gas emissions and one-year automobile equivalents (2001-2007).

	Year						
Emissions (tons) and Cars	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*
Total emissions (all sources)	*63,455,880*	*38,070,968*	*25,767,386*	*28,574,508*	*21,640,082*	*57,680,874*	*41,577,416*
Emissions equivalent in cars (1 yr)	*11,444,577*	*6,866,284*	*4,647,274*	*5,153,552*	*3,902,894*	*10,403,026*	*7,498,690*
Pct. of California annual car emissions	*81.7%*	*49.0%*	*33.2%*	*36.8%*	*27.9%*	*74.3%*	*53.6%*
Cumulative total emissions (all sources)	*63,455,880*	*101,526,848*	*127,294,234*	*155,868,743*	*177,508,825*	*235,189,698*	*276,767,115*
Cumulative emissions equivalent in cars	*11,444,577*	*18,310,861*	*22,958,135*	*28,111,687*	*32,014,581*	*42,417,607*	*49,916,297*
Pct. of California annual car emissions	*81.7%*	*130.8%*	*164.0%*	*200.8%*	*228.7%*	*303.0%*	*356.5%*

Seen another way, this number represents how many cars would have to be taken off the road and locked in a garage for one year to make up for the global warming impact of these wildfires. In this case, the number is too large in a given year because there were only 14 million passenger cars on California's highways in 2005 (California Air Resources Board 2006). That means all 14 million cars would have to be locked in a garage for 3 1/2 years to make up for the global warming impact of the 2001-2007 California wildfires.

Global Warming Potential (GWP)

Total greenhouse gas emissions are worse than it may appear. Each greenhouse gas has a Global Warming Potential (GWP). GWP is the ratio of global warming radiative forcing from one kilogram of a greenhouse gas to one kilogram of carbon dioxide over 100 years. CO_2 has a GWP of 1, CH_4 has 21 times the impact on global warming as CO_2, and N_2O has 310 times the impact of CO_2 (Houghton et al. 1996, U.S. Environmental Protection Agency 2002). Therefore, the estimated global warming potential of emissions of CO_2 equivalent (CO_2e) from seven years of California wildfires is:

$$
\begin{aligned}
\text{GWP } (CO_2e) &= 276{,}523{,}813 \text{ tons } CO_2 + 21*232{,}459 \text{ tons } CH_4 + 310*10{,}842 \text{ tons } N_2O \\
&= 284{,}766{,}472 \text{ tons}
\end{aligned}
$$

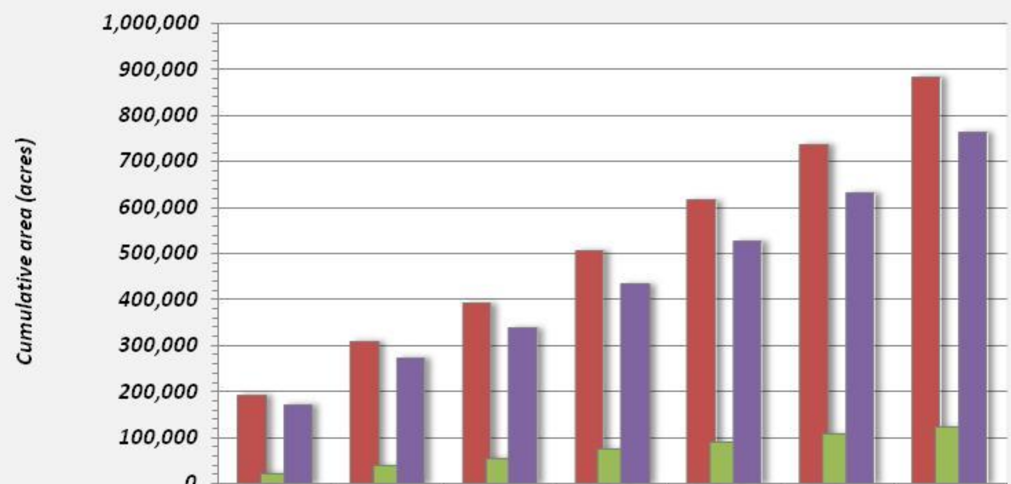
The immensity of greenhouse gas emissions illustrated in Tables 6 and 7 and Figure 2, and the even greater GWP of these emissions, is a serious warning. Clearly, it is not enough to fight wildfires when it is too late to do anything else. To help prevent catastrophic wildfires, we must make every effort to reduce the amount of excess biomass in public and private forests and brushlands. That means thinning trees to restore the natural health and diversity of forests and to make them resistant to crown fire. It also means breaking up old chaparral to keep wildfires from spreading across landscapes.

There is no question that thinning is effective in helping to prevent crown fires. This was documented in two California wildfires – the Cone Fire in 2002 and the Bell Fire in 2005. These crown fires dropped to the ground and became light and easily suppressed surface fires after entering thinned forests (Moghaddas 2006, Skinner, et al. 2004). We should use this knowledge and act quickly to prevent catastrophic wildfires before they destroy more property, lives, forests, and the global climate.

Potentially Permanently Deforested Land

Table 5 on page 13 shows the annual acreage of potentially permanently deforested land. That is, burned forests that cannot regenerate naturally because no live trees still stand to provide seed for new forests and the land remains unplanted. The accumulation of permanently deforested land in California illustrates the long-term destruction caused by wildfires. California's forests are disappearing, and the greenhouse gases they emitted from combustion and decay will stay in the atmosphere for centuries.

Figure 3 shows that during the seven years covered by this study, California wildfires deforested about 882,759 acres of public and private land, and only an estimated 120,755 acres were replanted. That means about 762,004 acres of forest permanently converted to brush, which invades and dominates deforested land. That is a loss of about 109,000 acres of forest each year.



	2001	2002	2003	2004	2005	2006	2007
Deforested	191,588	308,322	390,072	504,918	614,289	736,492	882,759
Replanted	20,622	36,306	53,177	72,829	88,191	105,873	120,755
Potentially permanently deforested	170,966	272,016	336,895	432,089	526,098	630,620	762,004

Figure 3. Cumulative area deforested, replanted, and potentially permanently deforested by California wildfires (2001-2007).

There is no federal law requiring the Forest Service to replant after a wildfire nor is there a California law that requires private forest landowners to replant after a wildfire. As a result, the Forest Service only replants what it can, as do small private non-industrial forest landowners. However, private timber companies typically replant or, in the case of redwood, sprouting regenerates burned forests.

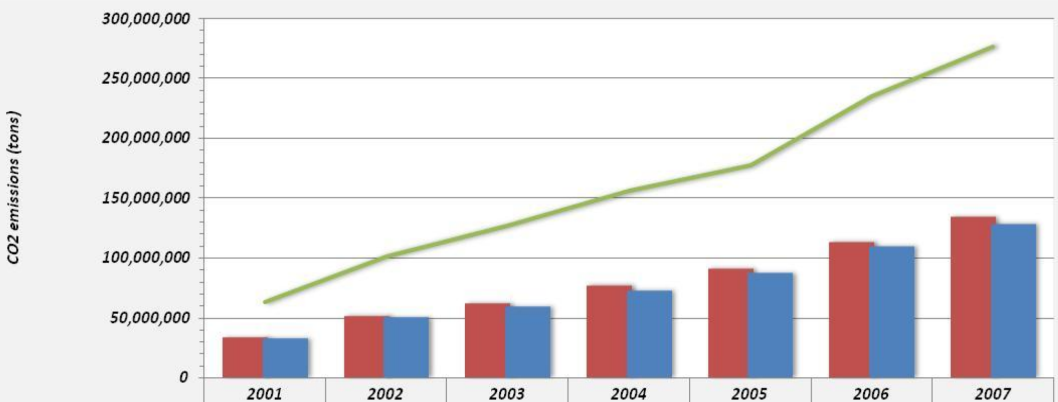
The estimated 134 million tons of CO_2 released by fires and the decay of dead trees from forests that were permanently converted to brush from 2001 to 2007 will stay in the atmosphere to worsen global warming. Many future fires will permanently deforest more land and add even more CO_2 to the atmosphere.

Recovering Emissions

Many burned forests and brushlands will recover naturally after a wildfire, especially chaparral and knobcone-chaparral. The problem is that it will take 40 to 100 years. In the meantime, the CO_2 released by wildfire and post-fire decay will remain in the atmosphere. This further increases the impact of greenhouse gases on climate change during a period when we are working hard to reduce them.

Replanting a young forest to replace one killed by wildfire so that growing trees absorb CO_2 through photosynthesis is essential for recovering this greenhouse gas after a wildfire. Removing dead trees and using the wood to manufacture solid wood products that store carbon also helps to prevent CO_2 from escaping into the atmosphere from post-fire decay. Harvesting dead trees and replanting can remove most of the CO_2 lost to the atmosphere from wildfires. Furthermore, CO_2 absorbed from the atmosphere by replanting can make up for emissions from decomposition of biomass left on the ground after harvest.

Figure 4 documents the effectiveness of harvesting dead trees and replanting. The cumulative recovery of CO_2 by harvesting and replanting is just slightly less than emissions from combustion and decay from potentially permanent deforestation. Recovery of CO_2 will take about 100 years to complete. The remaining CO_2 emissions, which are the difference between the total loss and the potential recovery from planting conifers, represent oak woodlands that may not regenerate naturally. Even so, failing to act will ensure that 134 million tons of CO_2 will stay in the atmosphere and that these forests will remain brush fields. Many future wildfires will destroy more forest and add even more CO_2 to the atmosphere.



	2001	2002	2003	2004	2005	2006	2007
Cumulative potential permanent loss	33,136,647	51,565,187	62,024,091	77,239,082	91,131,749	113,554,706	134,343,107
Cumulative potential recovery	32,434,384	50,009,637	59,028,500	72,739,157	87,372,762	109,814,803	128,528,350
Cumulative total loss	63,402,482	101,439,950	127,181,012	155,729,356	177,353,406	234,986,781	276,523,813

Figure 4. Cumulative CO_2 emissions from California wildfires (2001-2007) and the potential for recovery by replanting and removing dead trees and converting them into wood products that store carbon.

An added benefit of harvesting fire-killed trees before they decay too much (usually within two years), is earning enough money from wood products to help pay for replanting. Industrial forest landowners do this routinely after a wildfire. However, most public and many private forest landowners face political and funding limitations that constrain their efforts to restore burned forests. This is the primary cause of permanent deforestation.

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Appendix A: The Forest Carbon and Emissions Model (FCEM)

Only recently has it been possible to estimate greenhouse gas emissions from wildfires and insect infestations. The Forest Carbon and Emissions Model (FCEM) used in this study is at the forefront of making these estimates (Bonnicksen 2008a, 2008b). FCEM is a Rapid Estimation Model (REM) that requires a minimum of input data. It fills the need for quickly estimating forest carbon storage, sequestration, and greenhouse gas (GHG) emissions.

The model is unique among available carbon models because of its simplicity and relevance to forest management. Even so, there is no accepted standard model for greenhouse gas emissions and carbon sequestration.

FCEM is a deterministic biomass-based model that uses an Excel spreadsheet to compute estimates. The model calculates estimates by systematically linking existing equations, ratios, and conversion and emission factors from a variety of recently published peer-reviewed scientific and other technical sources. The latter sources include non-peer-reviewed reports from universities, government agencies, and consulting firms.

In particular, FCEM computes above ground tree biomass using generalized allometric equations approved by the California Climate Action Registry (2007) as shown in FCEM Report 1 (Bonnicksen 2008) and reports cited by California Climate Action Registry (Brown et al. 2004a, 2004b, 2004c). FCEM computes estimates based on formulas and data from specific areas.

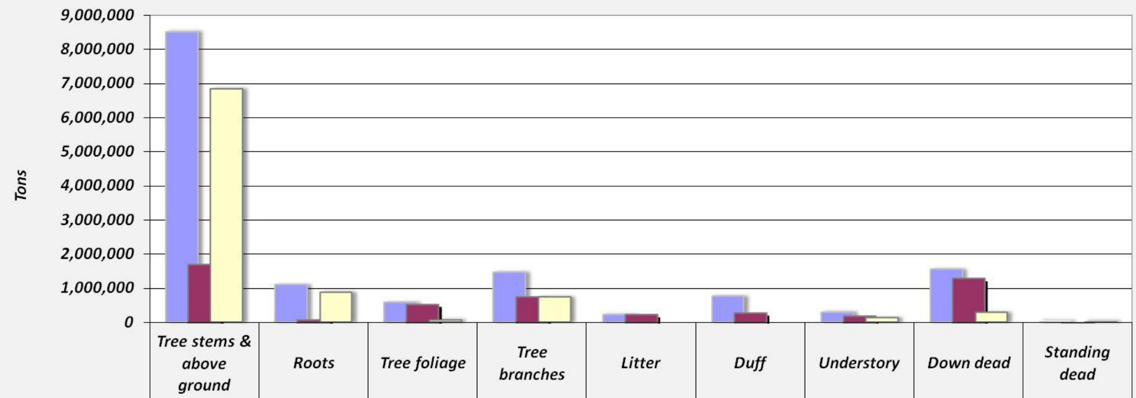
However, FCEM was modified for this study to use published look-up tables of carbon density for various forest types in California as well as other reliable information sources (Table 8). This was necessary because tree diameter data by species were not available for burned forests. Therefore, allometric equations could not be used to calculate biomass and carbon density.

Table 8. Average carbon density and biomass by vegetation type.

Vegetation Type	*Average Biomass (t/ha)*	*Average Carbon (tC /ha)*
Coast redwood	*400.8*	*200.4*
Douglas-fir	*313.6*	*156.8*
Pinyon-juniper	*51.2*	*25.6*
Lodgepole pine	*189.6*	*94.8*
Ponderosa/Jeffrey pine	*103.8*	*51.9*
Mixed conifer	*233.4*	*116.7*
True fir/hemlock	*327.2*	*163.6*
Oak/tanoak/laurel	*251.4*	*125.7*
Shrubs	*30.0*	*15.0*
Chaparral/knobcone-chaparral	*35.0*	*17.5*
Hardwoods/western oak	*134.2*	*67.1*

Sources: Birdsey (1992), Martin et al. (1981), U.S. Environmental Protection Agency (2002, 2006).

FCEM also includes ratios and other factors to convert above ground biomass into stem, branch, foliage, root, litter, duff, understory, down dead, and standing dead biomass. However, soil carbon comes from look-up tables. Computations of fuel consumption and emissions require this breakdown of fuel types (see Figure 5 for an example; blanks under litter and duff indicate zero).



	Tree stems & above ground	Roots	Tree foliage	Tree branches	Litter	Duff	Understory	Down dead	Standing dead
Pre-fire biomass	8,508,207	1,081,395	564,282	1,453,453	203,701	746,562	285,901	1,533,825	33,370
Biomass consumed by fire	1,675,630	54,070	507,854	726,727	203,701	253,831	171,541	1,257,737	2,503
Biomass consumed by decay	6,832,577	866,165	56,428	726,727			114,360	276,089	30,867

Figure 5. Proportionate contribution of forest components to pre-fire biomass, and biomass consumed by fire and decay, for the 2007 deforested simulation.

FCEM is a tool for conducting preliminary inventories of forest biomass, carbon, and CO_2 stored in a particular forest, now or in the future, including tree stems, roots, foliage, branches, litter, duff, understory, down dead, standing dead, and soil. Other more comprehensive models should be used for scientific investigations and carbon accounting.

FCEM also includes four scenarios for estimating the impacts of fire and insect infestations, the benefits of removing dead trees and converting them into solid wood products, thinning, and planting. The model also estimates the relative impacts of wildfire and prescribed fire on emissions, before and after thinning, and thinning with and without prescribed fire. FCEM compares impacts and benefits in terms of greenhouse gas emissions and carbon sequestration and storage.

The goal of the Forest Carbon and Emissions Model (FCEM) is to create an awareness of the impact of wildfire and insect infestations on greenhouse gas emissions and opportunities to prevent and recover from these disasters.