Will Climate Change Spark More Wildfire Damage?

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Summary

This report describes a geographically specific estimate of the potential effect of climate change on wildfires and the effectiveness of fire-fighting infrastructure in California, the first study of its kind. The analysis was accomplished thanks to an innovative coupling of California Department of Forestry wildfire models with the Goddard Institute for Space Sciences global climate model. The regions studied contain substantial areas of wildland/urban interface conditions on the margins of the San Francisco Bay area, the Sacramento metropolitan area, and the Redwood region's urban center of Eureka.

Global warming may increase the risk of wildfires by warming and drying out vegetation, and by stirring the winds that spread fires. As indicated by the models, in most cases climate change would lead to dramatic increases in both the land area burned by California wildfires and the number of potentially catastrophic fires—more than doubling these losses in some regions. Several important climate-wildfire interactions not currently captured by these models would amplify the expected growth in wildfires. The growth in wildfire damages would occur despite deployment of fire suppression resources at the highest current level, suggesting that climatic change could cause an increase in both fire suppression costs and economic losses due to wildfires.

An Insurance and Property Loss Perspective on Wildfire

Insurers are acutely aware that 85% of catastrophe-related payouts are due to natural disasters, with claims averaging about $10 billion per year worldwide over the past decade (Mills 1998). For a host of reasons, some better understood than others, these losses are on the rise.

A recent study by the Insurance Services Office (ISO), entitled "The Wildland/Urban Fire Hazard," spotlighted one component of this trend (ISO 1997). According to the ISO, wildfires are a pervasive insurance risk, occurring in every state in 1996. Wildfires consume an average of 5 million acres per year across the United States. Between 1985 and 1994, wildfires destroyed more than 9,000 homes in the U.S. at an average insured cost of about $300 million per year. For comparison, this was triple the number of homes lost

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during the three-decade period prior to 1985. Some of this increase is attributed to new home developments in high-risk areas.

According to ISO, of the 38 costliest U.S. wildfires between 1825 and 1995, 22 were in California, which ranks number one in terms of economic losses due to wildfire as well.

Insurers feel the effects of wildfire in several ways. Insured property is at risk, and in some cases the costs of fire-fighting or lost timber are underwritten. Wildfire-related injuries or loss of life also exact a cost from insurers. Moreover, in the aftermath of wildfire, secondary events, such as landslides, flooding, and water quality impairment can all impose additional costs. Of course, the insured damages are only a component of the total economic loss and don’t reflect the full human hardship that wildfires can cause.

The context of wildfire has taken on new dimensions as low-density residential development has expanded rapidly into areas dominated by flammable vegetation, creating a wildland/urban interface. The Oakland/Berkeley Tunnel Fire of 1991 was a poignant example of the enormous damage potential of even a single fire in this interface. The third costliest fire in U.S. history, it resulted in $2 billion in insured losses (at 1997 prices), including the destruction of 3,400 buildings and 2,000 cars (ISO 1997). Added to this were extensive losses of urban infrastructure, such as phone lines and water and road systems. The insured losses from this single fire were twice the cumulative amount experienced nationwide during the previous thirty years.

The world’s second largest reinsurance company, Swiss Re, noted that the Oakland/Berkeley fire may be "a harbinger of a new type of catastrophe that could reoccur on an even larger scale...[and] will neither be the only nor the last one of its kind" (Swiss Re 1992). They point out that the pattern of development of homes into wildlands that prevailed prior to the fire is "a prototype of many suburban areas throughout California and the rest of the U.S." In their report, which they refer to as "Fire of the Future," Swiss Re points to global climate changes as one possible factor influencing the degree of devastation wrought by this and future wildfires.

Fire suppression efforts have slashed wildfire damages over the past century. However, countervailing forces such as the accumulation of unburned litter and vegetation, increases in human populations and property values at the wildland/urban interface, pressures on fire-fighting budgets, and, possibly, global climatic change, could conspire to boost the upward trend in economic losses caused by wildfires.

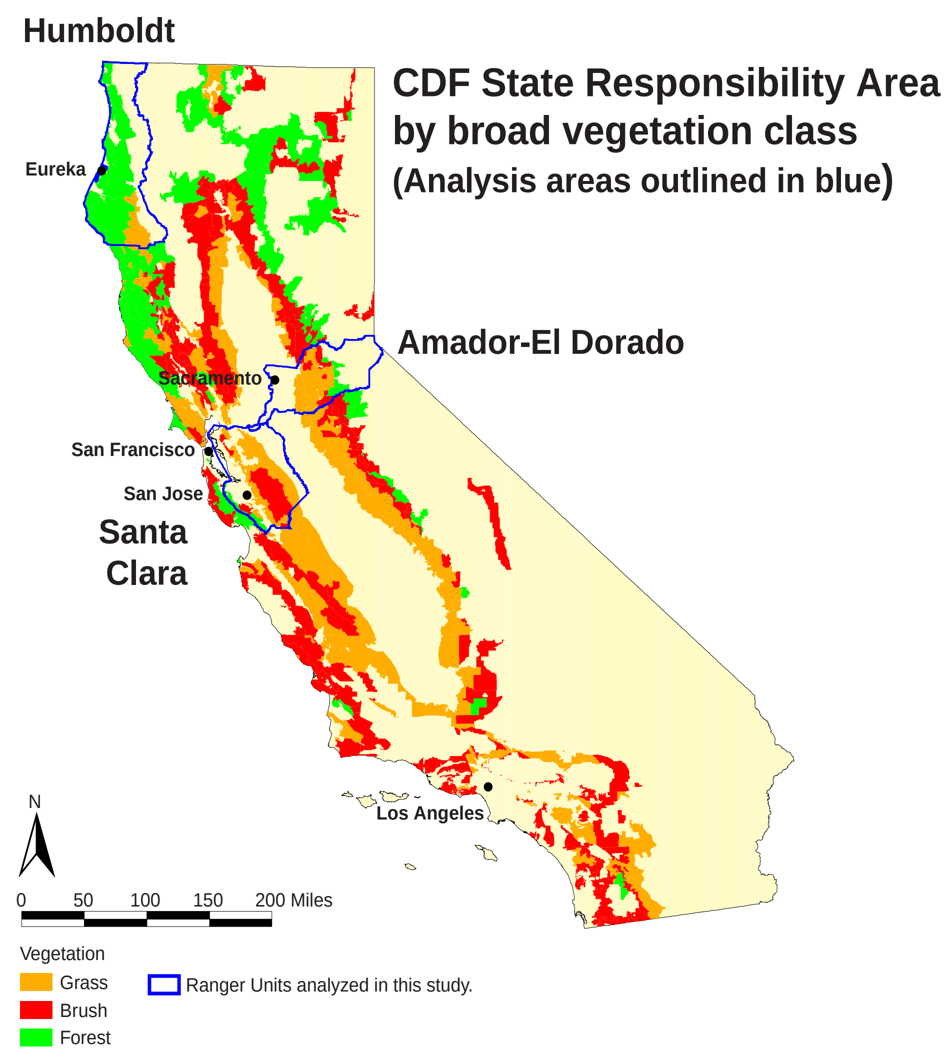
Insurers and climatologists have long known that fire danger is linked to climate, with hot, dry spells creating the highest risk. Concerns over the consequences of global warming were rekindled this year by the impacts of El Niño. The powerful impact that climatic anomalies can have on wildfire was demonstrated after droughts linked to El Niño were followed by widespread, devastating fires in Florida, Indonesia, and elsewhere. The latest predictions suggest that global warming may also create conditions that intensify wildfire danger, by warming and drying out vegetation, and by stirring the winds that spread fires. Faster fires are much harder to contain, and thus are more likely to expand and cause substantial damage to insured property.

Modeling the Behavior of Wildfire under Scenarios of Climatic Change

This study evaluates the potential of global climatic change to increase wildfire damage in California. To explore this question, we combined local weather and fire data, validated fire and fire suppression models, and state-of-the-art general circulation models (global models that simulate climate change scenarios). The analysis produced a geographically-specific estimate of the potential effect of climate change on wildfires and the effectiveness of fire-fighting infrastructure (Houghton et al. 1990, CDF 1997; Fried and Torn 1990; Torn and Fried 1992; Fried et al. 1987; Fried and Gilless 1988).

To capture some of the complexity of California's landscape, this study examined three climatically distinct regions of northern California: Santa Clara (near San Francisco Bay), Amador-El Dorado (in the Sierra foothills), and Humboldt (on the northern coast) (Figure 1). The regions studied contain substantial areas of wildland/urban interface conditions on the margins of the San Francisco Bay area, the Sacramento metropolitan area, and the Redwood region's urban center of Eureka. El Dorado is the fastest growing county in California, and Amador is the sixth-fastest growing county in the State.

Most of the vegetation fuel types found in the American West are represented in the three regions, including grass, brush (scrub or chaparral), oak savanna, and mixed conifer and redwood forests. Modeling was undertaken for the state "Ranger Unit" in each region. These comprise the area under California Department of Forestry and Fire Protection (CDF) responsibility, i.e., all private and state-owned land in the regions not under the protection of municipal fire departments. These are predominantly rural unincorporated areas with significant suburban encroachment.



Notes: Map created by Jeremy Fried on 22 October, 1998 using Fire Management Analysis Zone boundary and attribute data prepared for use with the California Fire Economics Simulator, version 1, in the early 1990s. The authors gratefully acknowledge the provision of this data by James Spero of the California Department of Forestry and Fire Protection's Fire and Resource Assessment Program.

Figure 1. Map of vegetation types and three regions analyzed in this study

Climate Change Scenarios

The relative certainty that elevated concentrations of greenhouse gases will lead to climatic changes was underscored by the most recent reports of the IPCC. The report, representing the consensus of over 2,500 scientists, concluded that detectable, human-induced global warming is already taking place (Houghton et al. 1996). While temperatures will increase over most of the globe, changes in other climate attributes will be more complex: some areas will become wetter and others drier; some areas will experience more cloud cover and others less. Such variation is evident within California alone. To understand the implications for wildfire necessitates the use of sophisticated climate and wildfire models that incorporate wind speed and humidity as well as temperature and precipitation.

Climate simulation studies performed by general circulation models (GCMs) provide standard scenarios for climate change impact assessments used by government and university scientists around the world, including the IPCC. To facilitate comparisons among such studies, analyses are generally standardized to the warming that corresponds to carbon dioxide (CO_2) levels double those that prevailed in the mid-1900s. Barring large changes in global energy use and forest management, atmospheric CO_2 levels will double by the middle of the 21st century.

We applied two GCMs in all three regions: the Goddard Institute for Space Sciences model (GISS) and Princeton University's Geophysical Fluid Dynamics Laboratory model (GFDL). The GISS model yielded less dramatic increases in wildfire and was the one selected for this study.

The GISS model predicts that under a double-CO2 climate the Santa Clara and Amador-El Dorado regions would become warmer, windier and somewhat drier, while Humboldt will become warmer but less windy, more humid, and have more rainfall. Therefore the effect of climatic change on wildfire severity can be expected to vary from region to region.

Creating climate change scenarios for wildfire is complicated by differences in scale. Fire behavior is affected by daily or even hourly weather conditions, but readily available GCM output yields only a monthly average value for each climate variable (temperature, precipitation, wind speed, and humidity). In addition, GCM output represents a comparatively large geographic area in which there is a great deal of local variation in weather and fire danger. To bridge scales, we used the difference in GCM output for present and future (double CO_2) climates to create scaling factors for each month. The scaling factors were used to adjust historical weather data from local weather stations, thereby generating weather data that reflects the predicted changes in climate while retaining the rich temporal and spatial information of historical records.

Modeling Approach

The attributes of wildfires that make them hard to contain are the rate at which they spread and their burning intensity (an index linked to temperature and flame height). By warming and drying vegetation, and by stirring the winds that spread fires, global warming may exacerbate both attributes.

In addition to weather, wildfire behavior depends on slope, vegetation and many other characteristics of a site. In this modeling approach, approximately 700 actual, historical fires were simulated representing a typical fire year in California. Each fire's spread rate and temperature were modeled with the historical weather data for that day and then in a second run with the climate change "weather." (The day, time, slope, vegetation, location, and number of fires were the same in both runs. The effect of climatic change on fire starts is not critical because over 90% of California's wildfires are started by people.)

Based on six years of historical weather and fire records, statistically representative fires were used as input to the California Fire

Economics Simulator (CFES). CFES is a deterministic model of initial attack on wildfire used by CDF as a tool to evaluate decisions involving the deployment and positioning of fire fighting equipment and personnel. CFES simulates fire growth and fire suppression by CDF forces until the fire is brought under control or exceeds fire size or burn-time limits (e.g., 300 acres or two hours in grass), in which case it is classified as an "escape".

Here, the CDF model was put to a different use, evaluating the comparative success of fire-fighting efforts against fires burning under present and future climate scenarios. It yielded the prediction of either the area burned if the fire was contained or, alternatively, the prediction that the fire escaped containment efforts. Unfortunately, the area burned by escaped wildfires cannot be modeled or accurately predicted, because of the variability in terrain and burning conditions encountered by fires that exceed the escape size or time limit. The number of escaped wildfires is a crucial measure of severity, because these fires, having overwhelmed initial fire suppression efforts, are considerably more likely to become large, damaging fires.

Under current climate conditions, escapes are comparatively rare: between 1961 and 1997, only 0.03 to 0.5% of California's wildfires "escaped" (depending on the county). However, likelihood of damage from an escape is large. One out of every 10 escapes leads to injury or the loss of structures. Moreover, losses generated by some escapes are so large that this category of fire accounted for over half of the fires where structural damage or loss of life occurred, and well over half of the property value lost to fire in California over the past four decades. While forests tend to be less prone to wildfire, those that do occur and escape can be among the most destructive. Increasing concentrations of real estate in forested areas—exemplified by developments in much of the Amador-El Dorado region—represent the potential for enormous wildfire losses.

Results

Fire Behavior

According to our analyses, climatic change would cause fires to spread faster and burn more intensely in most vegetation types (Table 1). The biggest impacts were seen in grassland, where the fastest spread rates already occur. In forests, where fires move much more slowly, impacts would be less severe. The reason that faster fuels respond more is that fire behavior in these fuels is more sensitive to wind speed and elevated wind speed during fire season was a striking feature of the changed climate weather data. The response of chaparral and oak woodlands fell between that of grass and forest. Integrating over all vegetation types, each region has more fast fires and fewer slow fires due to global-warming conditions (Figure 2).

Future changes in fuel moisture and wind speeds also cause modeled fires to burn with greater intensity, triggering more intensive suppression efforts, also referred to as "dispatch levels" (Figure 3). The utilization of extra fire suppression resources, such as air tankers and bulldozers, can lead to significant increases in suppression costs. Even with higher dispatch of the available fire-fighting equipment and personnel, the number of acres burned and the number of 'escape' fires increased in most cases. In densely populated areas, climatic change caused less impact than it did in the more sparsely populated regions—testimony to the effectiveness of heightened suppression where more lives and property are at risk (Table 2). Rural areas, or regions with fewer resources for fire suppression, are thus at greater risk of having very large fires due to climatic change. In Humboldt, predictions of slower winds and more humidity offset the effects of increased temperatures; there was virtually no change in predicted fire danger in the forests and a decrease in spread rates in the grassland.

	Number of Escaped Fires			Acres Burned by Contained Fires			Total Number of Fires*
	Present	Future	Change	Present	Future	Change	
Santa Clara							
Grass	4.5	6.9	53%	2318	3278	41%	168.1
Brush	0.3	0.4	21%	10	13	34%	22.7
Tall Brush	0.0	0.0	0%	2	4	100%	11.6
Redwood	0.0	0.0	0%	2	2	7%	23.0
Overall	4.8	7.3	51%	2332	3298	41%	225
Amador—El Dorado							
Grass	1.2	2.8	143%	1709	2189	28%	58.5
Brush	5.0	11.1	121%	221	462	109%	62.9
Oak Savanna	0.0	0.0	0%	292	481	65%	152.8
Mixed Conifer	0.0	0.0	0%	26	37	43%	29.0
Overall	6.2	13.9	125%	2248	3169	41%	303
Humboldt —Del Norte							
Grass	0.0	0.0	0%	38	28	-27%	15.1
Redwood	0.6	0.6	0%	207	198	-4%	158.9
Overall	0.6	0.6	0%	245	226	-8%	174

* Approximately 700 wildfires occur in these regions in an average year.

Table 1. Average annual fire outcomes by region and vegetation under present and future (double CO_2) climate scenarios.

Area Burned and Potentially Catastrophic Fires

Climatic change increased the extent of fire damage and the number of potentially catastrophic fires in two out of three regions (Figure 4). The faster, hotter fires caused by climatic change outran fire suppression and many more acres were burned than in the current climate scenario. In the Santa Clara region, for example, contained fires in grass and brush burned 41% and 34% more area, respectively, under climate change than they did in the present climate. The number of escaped wildfires increased by 53% and 21% in grass and brush. For redwood forests, which grow in moist, foggy areas, there was a small change in fire damage although there were enhanced fire-fighting efforts (triggered by more intense fires) and higher suppression expenses.

In the Sierra foothills, the effect of climatic change was even more severe. Here, the number of potentially catastrophic (escaped) fires predicted went up dramatically—143% more each year in grassland and 121% more in brush. With the number of escaped wildfires more than doubling, climatic change could lead to a significant jump in fire damage in this region. The area burned by smaller fires, i.e., those that were contained by initial suppression, also saw large increases in all four vegetation zones. The area of brush burned more than doubled, and there was a 65% increase in oak savanna burned.

Climate change had little impact in California's Humboldt redwood region, thanks to comparatively slow fires, effective fire suppression and GISS predictions of a wetter, less windy climate. Like the redwood forests of Santa Clara, those in Humboldt

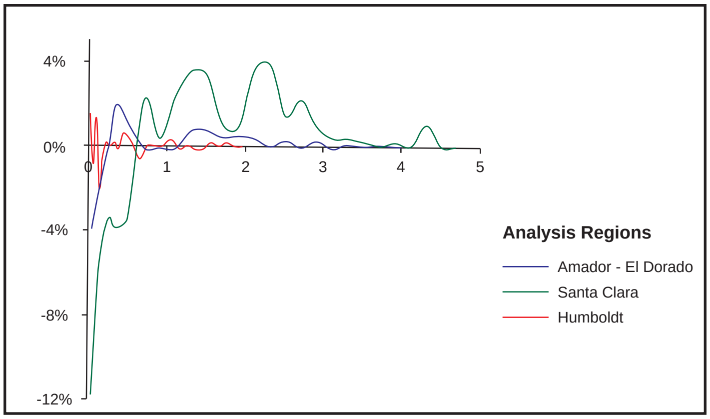


Figure 2. Change in frequency of fires by spread rate (percentage points).

showed almost no change in escapes or area burned. The small area of grassland did experience a decrease in burned area and suppression efforts. In this case, the choice of GCM made a significant difference; under GFDL predictions, Humboldt showed faster fires and more acres burned in grass due to climate change.

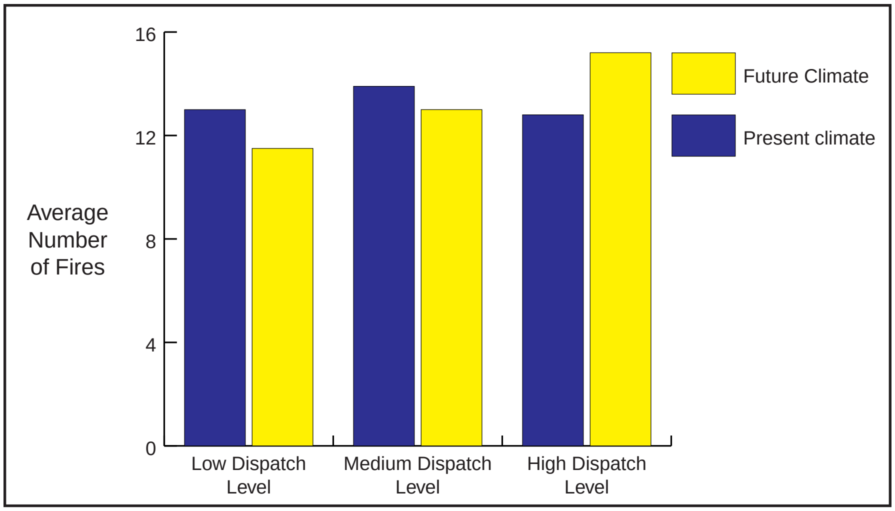


Figure 3. Annual average number of fires in each fire dispatch level for present and future (double CO_2) climate scenarios, shown for a selected region, population density, and vegetation type: Amador-El Dorado, grass, low-population-density analysis zone.

Factors That Could Cause More Severe Wildfire Losses

Wildfire behavior is controlled by both the moisture content of vegetation and its density. This study addressed the direct effects of climate change on fire behavior (such as moisture content of fuels and wind speeds). It did not consider the indirect effects of climate change on rates of plant growth or vegetation distribution because they are more difficult to quantify. As predicted by climate modelers (and as seen from this year’s El Niño), increased wintertime rainfall means a higher base of flammable fuels during fire season.

In a feedback with potentially alarming consequences, wildfires may create conditions that set the stage for subsequent wildfires. Among the six vegetation types considered, fires in earlier successional stages (grass and brush) tended to have faster spread rates and showed much more response to changes in climate. Wildfire acts to reset the successional clock, with newly burned areas colonized first by grass, later succeeded by chaparral and then forests. More frequent or extensive fires would mean more land area covered by grass and shrub vegetation. These ecosystems show the greatest susceptibility to fire, and also the greatest response to climatic change. Consequently, the effect of global warming on wildfire may be more severe than our models predict due to fire-induced alteration of ecosystem distribution.

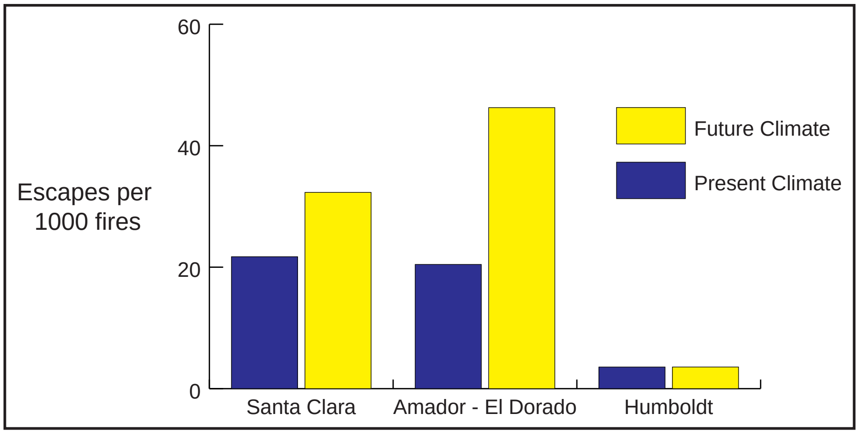


Figure 4. Average frequency of escaped wildfires under present and future (double CO_2) climate scenarios, by region.

Other important synergies exist. In California, patterns of development are superimposed on patterns of vegetation in ways that may amplify the economic consequences of wildfire. In the Sierras, for example, population growth and density are often much higher in

	Number of Escaped Fires			Acres Burned by Contained Fires		
	Present	Future	Change	Present	Future	Change
Santa Clara, Grass						
Low Population	2.6	4.7	80%	12.0	16.0	33%
Moderate Population	1.9	2.2	16%	16.4	24.8	52%
Amador — El Dorado, Chaparral						
Low Population	2.4	8.2	242%	5.9	15.5	161%
High Population	2.6	2.9	11%	1.3	2.1	65%

Table 2. Annual fire outcomes under present and future (double CO_2) climate: effect of population, density. Shown with the analysis zones demonstrating the greatest impact of climate change.

the grass, chaparral, and oak woodlands common at low elevations than at higher, forested elevations. Moreover, population is strongly concentrated in the warmer regions of the state, regions that this analysis suggests would be most affected by climatic change. These results indicate that homes and insured property are concentrated in the zones likely to experience the largest response to climate change.

Lastly, as noted above, we performed the analysis using two distinct climate models and reported here the results of the more conservative results (i.e. those with the lower wildfire damages).

Conclusions

Damages and insurance claims due to wildfire are on the rise. While this analysis was not designed to evaluate whether or not this is a result of current, human-caused global warming trends, it does provide a view of what the future may hold. There are mechanistic links between climatic change and wildfire damage, and as humanity continues to elevate the levels of greenhouse gases, we can expect an increase in wildfire danger.

Understanding and quantifying the important linkages between natural disasters and climate change calls for integration of many kinds of expertise. For example, while models of climate and wildfire focus on natural processes and underlying extreme events, the actuarially based models are focused on the economic impacts of these events. The Reinsurance Association of America has noted the opportunity and imperative for integrated assessments of climate change impacts, stating to the insurance community that "it is incumbent upon us to assimilate our knowledge of the natural sciences with the actuarial sciences -- in our own self interest and in the public interest." (Nutter 1996).

As experience has shown, any upward trend in wildfires would likely have serious consequences for the residents of California and their property. To combat these trends in the near term, local planning officials and individual homeowners need to revisit issues of fire suppression, development patterns, and vulnerability of structures (through building codes, vehicle access, brush control around buildings, and so on). Communities can also invest in more fire fighting resources. But in the longer term, this will not be enough. The broader national and international issues of climate change itself and its relation to wildfire must ultimately be addressed.

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Acknowledgments

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