Public Interest Energy Research (PIER) Program

White Paper

SOCIAL VULNERABILITY TO CLIMATE CHANGE IN CALIFORNIA

A White Paper from the California Energy Commission's California Climate Change Center

Prepared for: California Energy Commission

Prepared by: Pacific Institute

PACIFIC
INSTITUTE

JULY 2012

CEC-500-2012-013

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DISCLAIMER

ACKNOWLEDGEMENTS

Major funds for this paper were made possible through the California Energy Commission's Public Interest Energy Research (PIER) Program.

Many individuals, organizations, and agencies helped make this work possible by providing data, information, and input, as well as reviewing the final paper. First, the authors wish to thank our Project Advisory Committee, including Paul English (California Department of Public Health), Atta Stevenson (Intertribal Council), Miya Yoshitani (Asian Pacific Environmental Network), Ellen Wu (California Pan-Ethnic Health Network), Caroline Farrel (Center for Race, Poverty, and the Environment), Zoe Heller (Environmental Protection Agency, Region 9), Evelyn Rangel-Medina (Ella Baker Center), and Rachel Morello-Frosch (University of California at Berkeley). Additional input was provided by members of the Oakland Climate Action Coalition.

PREFACE

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

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- Transportation

In 2003, the California Energy Commission's PIER Program established the California Climate Change Center to document climate change research relevant to the states. This center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions.

For more information on the PIER Program, please visit the Energy Commission's website http://www.energy.ca.gov/research/index.html or contract the Energy Commission at (916) 327-1551.

ABSTRACT

The State of California faces a range of impacts from global climate change, including increases in extreme heat, wildfires, coastal flooding, and erosion. Changes are also likely to occur in air quality, water availability, and the spread of infectious diseases. To date, a great deal of research has been done to forecast the physical effects of climate change, while less attention has been given to the factors that make different populations more or less vulnerable to harm from such changes. While disaster events may not discriminate, impacts on human populations are shaped by intervening conditions that determine the human impact of the event and the specific needs for preparedness, response, and recovery.

In this study, the authors analyzed the potential impacts of climate change by using recent downscaled climate model outputs to create a variety of statistics and visualizations that show their distribution across the state. To understand how the population exposed to these impacts will be affected, social vulnerability – defined as the susceptibility of a given population to harm from exposure to a hazard, directly affecting its ability to prepare for, respond to, and recover, must be evaluated.

The researchers developed a new climate vulnerability index to indicate the social vulnerability of a region's population to climate-related harm. The index combines 19 indicators into one overall climate vulnerability score and includes factors specifically related to climate impacts, such as air conditioner ownership, childhood obesity, percentage of tree cover, pre-term births, workers in outdoor occupations, and others.

The authors present a series of maps showing where social vulnerability to climate change is greatest, and where it intersects with the most severe projected climate change impacts. The most significant risk from climate change occurs where there are large groups of people exposed to a climate-related hazard and where there is high social vulnerability.

Understanding vulnerability factors and the populations that exhibit these factors are critical for crafting effective climate change policies and response strategies. They are also important to the emerging study of climate justice, which is the concept that no group of people should disproportionately bear the burden of climate impacts or the costs of mitigation and adaptation.

Keywords: climate change, social vulnerability, economic vulnerability, social vulnerability, California, sea level rise, wildfire, extreme heat, air quality, water, energy, electricity, agriculture

Please use the following citation for this paper:

Cooley, H., E. Moore, M. Heberger, and L. Allen (Pacific Institute). 2012. ***Social Vulnerability to Climate Change in California.*** California Energy Commission. Publication Number: CEC-500-2012-013.

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SECTION 1:
Introduction

California faces a range of impacts from global climate change, including an increase in extreme heat events, wildfires, coastal flooding, and erosion. Other consequences of climate change include changes to air quality, water availability, and the spread of certain infectious diseases. A significant body of research focuses on developing projections of potential climate impacts for California. The vast majority of these studies emphasize the physical effects of climate impacts on various sectors, including water resources, ecosystems, energy, agriculture, and public health.

Studies show that social variables, such as age, race, and income, affect the ability of an individual to prepare, respond, and recover from a natural disaster or other potential climate impacts (Cutter et al. 2009, Pastor et al. 2006, Rossi et al. 1983, Hewitt 1997). Low-income communities and communities of color are especially vulnerable to natural disasters. For example, mortality rates from Hurricane Audrey, which struck the coast of Louisiana in 1957, were more than eight times higher among blacks than among whites (Bates et al. 1963, cited in Pastor et al. 2006). A study of all United States disasters between 1970 and 1980 found that white households had $2,370 less of a financial burden following a disaster than other racial groups (Rossi et al. 1983). Reports following Hurricanes Hugo and Katrina pointed to a range of problems related to a lack of understanding and appropriate preparation and response to ensure equal protection for low-income communities (Pastor et al. 2006). Thus, while extreme events may not discriminate, impacts on human populations are shaped by intervening conditions that determine the human impact of the event and the specific needs for preparedness, response, and recovery (Hewitt 1997).

This study looks specifically at social vulnerability to climate change — defined as the susceptibility of a given population to harm from exposure to a hazard, directly affecting its ability to prepare for, respond to, and recover (Cutter 2009). Social vulnerability is a function of diverse demographic and socio-economic factors that influence a community’s sensitivity to climate change. Understanding vulnerability factors and the populations that exhibit these vulnerabilities is critical for crafting effective climate change adaptation policies and disaster response strategies. This is also important to achieving climate justice, which is the concept that no group of people should disproportionately bear the burden of climate impacts or the costs of mitigation and adaptation.

SECTION 2:
Literature Review of Social Vulnerability Factors

Numerous studies have identified a wide range of socio-economic factors that increase vulnerability to various environmental and natural hazards, such as extreme heat, floods, wildfires, and poor air quality. Typically, these studies are based on a retrospective analysis of a particular event or series of events, for example, Hurricane Katrina. Here, the authors summarize the available studies in an effort to better understand social vulnerability to potential climate impacts. However, while some factors, such as poverty, have been linked to a range of hazards, others are more specific to a particular hazard.

2.1 Natural Hazards

Natural hazards are physical events that have an adverse impact on humans or the environment. These hazards consist of a broad range of phenomena, including wildfires, floods, droughts, and earthquakes. A natural hazard becomes a "natural disaster" when it impacts human systems and disrupts the social system on a material, psychological, or health basis. Adverse health impacts associated with natural disasters include death or injury during the event, as well as psychological trauma after the disaster as a result of evacuations, displacement, and property loss. Non-health related impacts include dislocation, property loss, and fracturing of the social fabric.

A significant body of research has been dedicated to identifying socio-economic factors that increase vulnerability to natural disasters (Table 1). Those with low incomes are particularly vulnerable to disasters in a number of ways, and for a variety of reasons. They are often under-insured, and more likely to have a home that is damaged in a disaster due to lower quality construction (Fothergill and Peek 2004; Bolin and Bolton 1986; Blanchard-Boehm 1997). Additionally, those with low incomes may not have the resources to evacuate when a disaster strikes (Bolin and Bolton 1986; Blanchard-Boehm 1997 cited in Heberger et al. 2009). A related risk factor that has been identified is car ownership and access to public transit; those without a vehicle are less likely to evacuate (Brodie et al. 2006). During emergency response, studies have found that the poor are one of the groups most likely to not have their needs met (Fothergill and Peek 2004). Further, those with low incomes are more likely to suffer emotional stress and other psychological impacts after a disaster (Fothergill and Peek 2004, citing Bolin and Bolton 1986 and Bolin 1993).

Besides poverty, age and other socio-economic factors are commonly associated with increased vulnerability to a disaster. Multiple studies have found people of color and ethnic minorities to be particularly vulnerable to disasters (Hajat et al. 2003; Blanchard-Boehm 1997; Perry and Mushkatel 1986; Phillips and Ephraim 1992). Women (who are disproportionately poor), the elderly (who often live on fixed incomes), and children are also vulnerable groups (Hajat et al. 2003). Those who are disabled or have a disabled family member are also more vulnerable, as disabilities can make evacuation more difficult (Hajat et al. 2003; Brodie et al. 2006).

Table 1: Factors Contributing to Social Vulnerability to Natural Hazards

Category	Vulnerability Factor(s)/Vulnerable Population	Source
Socio-economic	Low-income	Bolin and Bolton 1986; Fothergill and Peek 2004; Blanchard-Boehm 1997; Collins and Bolin 2009; Hajat et al. 2003
	People of color (ethnic minorities)	Hajat et al. 2003, Blanchard-Boehm 1997; Perry and Mushkatel 1986; Phillips and Ephraim 1992, cited in Pastor et al. 2006
	Women	Hajat et al. 2003
Age	Elderly	Hajat et al. 2003
	Children	Hajat et al. 2003
Housing conditions	Home renters	Collins and Bolin 2009
	Flammable roof, vegetation within 10 meters of home	Collins 2005 citing Foote 1994; Howard et al. 1973
Isolation	Language ability/linguistic isolation	Wang and Yasui 2008
	Isolation from public agencies or fear of interacting with public agencies	Wang and Yasui 2008
	Geographic isolation	Moser and Ekstrom 2010
Other	No health insurance	Bovbjerg and Hadley 2007
	No vehicle	Brodie et al. 2006
	Disabled (or family member disabled)	Hajat et al. 2003; Brodie et al. 2006
	Institutionalized populations	Moser and Ekstrom 2010; Caruson and MacManus 2008

Social and geographic isolation are also factors in how people are impacted by a disaster. Wang and Yasui (2008) note that “many recent disaster response crises illustrate how language barriers, isolation from public agencies, and fear of interacting with public agencies combine to increase the vulnerability of many residents.” Geographic isolation, such as living in rural areas, often results in slow emergency response times. A study of vulnerability to climate impacts in San Luis Obispo, California, found that, “response time is fast for highly populated regions yet over 20 minutes in the more isolated rural regions, creating geographic differences in response capacities, and thus in vulnerability” (Moser and Ekstrom 2010).

Finally, institutionalized populations, such as those in hospitals, nursing homes, and prisons are reliant on the preparedness and response of the facility. Many post-disaster analyses have found flaws in the disaster preparedness and evacuation planning of institutions (Moser and Ekstrom 2010; Caruson and MacManus 2008).

2.2 Extreme Heat

Extreme heat events are, by definition, a natural hazard. However, they are discussed separately due to the significant body of research dedicated to this hazard and the unique socio-economic vulnerability factors associated with these events. A large number of factors, both intrinsic and extrinsic, can contribute to different levels of risk to heat-related illness or death (Table 2). Intrinsic factors are those that are inherent to the individual, such as age or medical condition, while extrinsic factors are those that are external to the individual, such as living conditions or access to transportation. Heat-related illness and death have been studied extensively, largely through analysis of past extreme heat events. Even relatively moderate heat can cause heat-related illness or death for those who are not acclimated to heat. In a 2006 heat wave in California, for example, those in the relatively cooler Northeast part of the state and in the Pacific coast had the highest rate of emergency room visits, suggesting that people in these areas may have higher vulnerability due to lack of adaptation to heat. However, the Central Valley had the highest rate of hospitalizations (Knowlton et al. 2009).

Perhaps the most widely identified risk factor for heat related illness and death is age. Those 65 years and older are particularly vulnerable (Knowlton et al. 2009; Naughton et al. 2002; Basu and Ostro 2008; Whitman et al. 1997; Poumadere et al. 2005; Reid et al. 2009), as are children, adolescents (Knowlton et al. 2009; AAP 2000), and infants (Basu and Ostro 2008). The American Academy of Pediatrics (2000) states that, "for morphologic and physiologic reasons, exercising children do not adapt as effectively as adults when exposed to a high climatic heat stress."

Medical conditions and use of medications have also been found to increase vulnerability to extreme heat, particularly diabetes (Reid et al. 2009; Schwartz 2005), psychiatric illness (Naughton et al. 2002; Poumadere et al. 2005), and cardiovascular disease (Poumadere et al. 2005). In a 1995 heat wave in Chicago, being confined to bed was found to be the strongest risk factor for heat-related death (Semenza et al. 1996). Some medications can modify the body's thermoregulatory capacity, thus increasing vulnerability to heat-related illness (McGeehin and Mirabelli 2001). Tranquilizer use was an important risk factor for heat-stroke death in a study of St. Louis and Kansas City (Kilbourne et al. 1982).

Various living conditions are also associated with increased vulnerability to extreme heat. Those most commonly identified as vulnerable are those that live on higher floors of multistory buildings (Kilbourne et al. 1982; Semenza et al. 1996; Poumadere et al. 2005), live in homes with fewer rooms (Kalkstein 1993; Poumadere et al. 2005), lack access to air conditioning in the home (Reid et al. 2009), or do not turn on air conditioning or fans to avoid high electricity bills. Additionally, those without access to public transit or who do not own vehicles may be at increased risk because they are unable to go to cooler areas or community cooling centers (Shonkoff et al. 2009).

Neighborhood conditions can also affect vulnerability to extreme heat. Harlan et al. (2006) identified living in a neighborhood with high settlement density, sparse vegetation, and lack of open space as factors contributing to heat stress. Shonkoff et al. (2009, 2011) found a positive correlation between poverty and high amounts of impervious surfaces in a community, and a negative correlation between poverty and tree cover in four urban areas of California. Thus, suggesting that low-income populations are disproportionately exposed to the heat island effect of urban areas. The lack of electricity is a risk factor particularly for American Indians, who have a much higher rate of the absence of electricity than the general population (Houser et al. 2001). Additionally, those living in high-crime areas may be afraid to open their windows (Blum et al. 1998).

Social isolation, including lack of access to media, lack of strong community networks or social ties with neighbors, limited English language skills, living alone, and not leaving home every day have all been associated with increased risk of heat-related illness and death (Harlan et al. 2006; Poumadere et al. 2005; Naughton et al. 2002; Semenza et al. 1996). For example, during the 2003 Paris heat wave, 919 people died in their homes. Of those 919, 452 people were transported to the Institut Médico-légal for an autopsy, which noted that 92 percent of them lived alone (Poumadere et al. 2005).

In addition to these vulnerability factors, some studies have found correlations between race or ethnicity and increased risk of illness or death. African Americans (Basu and Ostro 2009; Ishigami et al. 2007; Whitman et al. 1997) and other non-white racial groups (Reid et al. 2009) were found to be particularly vulnerable to extreme heat events. In the 1995 heat wave in Chicago, mortality among African Americans was 50 percent higher than among whites (Whitman et al. 1997). In their literature review, McGeehin and Mirabelli (2001) conclude that disproportionate risk of heat-related death among African Americans is likely a result of living in inner-city neighborhoods, poverty, housing conditions, and medical conditions.

Poverty is also associated with high vulnerability (Poumadere et al. 2005; Reid et al. 2009; Harlan et al. 2006). For example in a heat wave in the Midwestern United States in 1980, many of the victims were poor and did not turn on fans which had been supplied to them through emergency relief efforts because they could not afford high utility bills (Fothergill and Peek 2004). Crop workers are particularly vulnerable to heat related death due to their high exposure rates; between 1992 and 2006, crop workers died from heat stroke at a rate nearly 20 times greater than the general population and 40 percent of these workers that died were identified as Mexican or Central American (MMWR 2008). In addition to their long work days in the sun, these workers are excluded from some labor and occupational health legal protections, which makes them particularly vulnerable (Shonkoff et al. 2009).

Table 2: Factors Related to Vulnerability to Heat-related Illness or Death

Category	**Vulnerability Factor(s)/Vulnerable Population**	**Source**
Age	Age: 65 years and older	Knowlton et al. 2009; Naughton et al. 2002; Basu and Ostro 2008; Whitman et al. 1997; Poumadere et al. 2005; Reid et al. 2009
	Children and adolescents	Knowlton et al. 2009; AAP 2000
	Infants (1 year of age or less)	Basu and Ostro 2008
Medical condition and medications	Certain medications associated with aging	McGeehin and Mirabelli 2001
	Cardiovascular disease	Poumadere et al. 2005
	Diabetes	Reid et al. 2009; Schwartz 2005
	Psychiatric illness	Naughton et al. 2002; Poumadere et al. 2005
	Using major tranquilizers	Kilbourne et al. 1982
	People with known medical problems who were confined to bed or who were unable to care for themselves	Semenza et al. 1996
	Obesity	Luber and McGeehin 2008
	Alcoholism	Kilbourne et al. 1982
Living conditions	Living on higher floors of multistory buildings	Kilbourne et al. 1982; Semenza et al. 1996; Poumadere et al. 2005
	Lack of access to air conditioned environments, no AC in home, or inability to pay high electricity bills resulting from AC use	McGeehin and Mirabelli 2001; Reid et al. 2009; Semenza et al. 1996; Kilbourne et al. 1982; Fothergill and Peek 2004
	Living spaces with fewer rooms	Kalkstein 1993; Poumadere et al. 2005
	No electricity	Houser et al. 2001
	Heat island effect (low tree cover and high percentage of impervious surfaces)	Shonkoff et al 2009
	High settlement density, sparse vegetation; having no open space in the neighborhood	Harlan et al. 2006
	Access to transit or car ownership	Shonkoff et al. 2009
	Residence in high-crime areas	McGeehin and Mirabelli 2001
Social isolation	Lack of access to media	McGeehin and Mirabelli 2001
	Lack of social and material resources to cope with extreme heat	Harlan et al. 2006
	Inadequate English language skills	McGeehin and Mirabelli 2001
	Social isolation, living alone, and/or not leaving home every day	McGeehin and Mirabelli 2001; Poumadere et al. 2005; Naughton et al. 2002; Semenza et al. 1996

Table 2: (continued)

Socio-economic factors/ other	Women	Ishigami et al. 2007; Poumadere et al. 2005
	Race other than white	Reid et al. 2009
	African Americans	Basu and Ostro 2009; Ishigami et al. 2007; Whitman et al. 1997
	Poverty	Poumadere et al. 2005; Reid et al. 2009; Harlan et al. 2006; Fothergill and Peek 2004
	Less than high school diploma	Reid et al. 2009
	Outdoor workers such as crop workers, construction workers	MMWR 2008; CDC 2010
	Lack of health insurance	
	Citizenship/legal status	Shonkoff et al. 2009

2.3 Air Quality

The literature on social vulnerability and air quality is extensive (Table 3). According to the Environmental Protection Agency people who are more vulnerable to ozone, include children, people with lung disease, those who work or play outdoors, and people with asthma. High ozone levels are associated with increased frequency of asthma attacks that require a doctor's attention or use of medication, in part because ozone makes people more sensitive to allergens that can trigger these attacks (EPA 2010; Jerrett et al. 2009). Medina-Ramon and Schwartz (2008) identified people aged 65 and older as having the largest increase in mortality with increased concentrations of ozone. Those with atrial fibrillation, or abnormal heart rhythm, were also identified as particularly vulnerable (Medina-Ramon and Schwartz 2008). Those who lack health insurance and are exposed to elevated air pollution may have more severe health impacts than those with insurance (Morello-Frosch et al. 2009).

Populations susceptible to adverse health outcomes as a result of exposure to particulate matter are similar to those that are susceptible to ozone pollution. Elevated levels of particulate matter exist in areas with high concentrations of industrial manufacturing, oil refining and combustion, and diesel vehicle traffic (Hammond et al. 2008). In agricultural areas such as the Central Valley, dust from fields also contributes to particulate matter (Fourgères 2007). These are also areas with higher rates of poverty and people of color (Keeler et al. 2002). Zeka et al. (2006) found that mortality rates (all-cause mortality) for those over 75 years of age were significantly affected by particulate matter more than other age groups. Children, infants, and those with cardiopulmonary disease are also particularly susceptible (AAP 2004; Jerrett et al. 2009). There is also evidence that elevated levels of particulate matter contribute to asthma exacerbations resulting in emergency room visits and hospitalizations (Norris et al. 1999; Lin et al. 2002; Ostro et al. 2009).

Wildfires can have significant adverse air quality impacts. Wildfire smoke can contain many different compounds, but particulate matter is the compound of greatest concern for human health (Lipsett et al. 2008). Groups sensitive to wildfire smoke, therefore, are similar to those identified as sensitive to particulate matter, i.e., the elderly, children, and those with cardiovascular disease. Additional groups that have been identified as sensitive to wildfire smoke are those with asthma and other respiratory disease, pregnant women, and smokers (Lipesett et al. 2004).

In addition to age and medical condition, some socio-economic factors can contribute to the risk of adverse health outcomes associated with air pollution. Medina-Ramon and Schwartz (2008) found an elevated risk of ozone-related death for African Americans and women. Another study found that single-mother families are overrepresented in areas with hazardous levels of air pollution (Downey and Hawkins 2008). Additionally, people of color may be disproportionately exposed to ozone. The Central Valley contains five of the nation's ten most ozone polluted counties, and farm workers in the valley are particularly vulnerable to increases in ozone levels as they work in fields along roads where ozone levels are highest (Fourgères 2007). Lack of insurance among vulnerable populations is another factor that can lead to greater health complications (Shonkoff et al. 2009; Cordova et al. 2006).

Table 3: Risk Factors and Vulnerable Populations Related to Several Air Pollutants

Pollutant	Category	Vulnerability Factor(s)/Vulnerable Population	Source
General	Age	Infants	AAP 2004
		Children	EPA 2010; AAP 2004, Bunyavanich and McMichael 2003; Lipsett et al. 2008
		People age 65 and older	Medina-Ramon and Schwartz 2008; AAP 2004; Lipsett et al. 2008
	Insurance	Lack of insurance	Morello-Frosch et al. 2009
	Socio-economic	Single-mother families	Downey and Hawkins 2008
		Low-income	Cordova et al. 2006; Health Canada 2004
Ozone	Existing medical condition	Lung disease	EPA 2010
		Cardiopulmonary disease	AAP 2004; Jerrett et al. 2009
		Asthma	EPA 2010
		Atrial fibrillation (abnormal heart rhythm)	Medina-Ramon and Schwartz 2008
	Socio-economic	African Americans	Medina-Ramon and Schwartz 2008
		Women	Medina-Ramon and Schwartz 2008
	Exposure	Those who work or play outdoors	EPA 2010
Particulate matter	Age	People age 75 and older	Zeka et al. 2006
	Socio-economic	Without high school degree	Krewski et al. 2000
		Ethnic Minorities	Keeler et al. 2002
		Low-Income	
	Existing medical condition	Cardiopulmonary disease	AAP 2004
		Diabetes	O'Neill et al. 2005
	Exposure	People who live in areas with high concentrations of industrial manufacturing, oil refining/combustion, and diesel vehicle traffic	Hammond et al. 2008
Wildfire smoke	Existing medical condition	Asthma and other respiratory disease	Lipsett et al. 2008
		Cardiovascular disease	Lipsett et al. 2008
	Other	Pregnant women	Lipsett et al. 2008
		Smokers	Lipsett et al. 2008

2.4 Environmental Infectious Disease

Studies show that several population groups, the elderly, children, and teens, are especially vulnerable to adverse health outcomes associated with environmental infectious diseases (Gerba et al. 1996; Nwachuku and Gerber 2004; Gerba et al. 1996). Socio-economic factors that increase risk are shown in Table 4. Children are more exposed to pathogens in the environment and are especially vulnerable because their digestive and immune systems are still developing (Nwachuku and Gerber 2004). Immune function degrades with age, resulting in the increased vulnerability of the elderly to infectious disease (Gerba et al. 1996). Additionally, pregnant women and immune-compromised individuals are at increased risk (Jamieson et al. 2006; Gerba et al. 1996).

Table 4: Vulnerability Factors for Infectious Diseases

Disease	Vulnerability Factor(s)/Vulnerable Population	Source
Viral encephalitides	Elderly (especially Saint Louis encephalitis)	IPCC 1997
	Children under 16 years are at greatest risk of LaCrosse encephalitis.	IPCC 1997
Other Infectious Diseases	Children	Nwachuku and Gerba 2004; Gerba et al. 1996
	Teens	Nwachuku and Gerba 2004
	The elderly	Gerba et al. 1996
	Immunocompromised individuals	Gerba et al. 1996
	Pregnant women	Jamieson et al. 2006; Gerba et al. 1996

2.5 Impacts on Natural Ecosystems

While all people are dependent upon the function of natural ecosystems, the connection between the natural world and their livelihood is more direct for some groups. In particular, those dependent upon a particular natural resource, such as commercial fishermen or subsistence farmers, will be the first affected by changes in these resources. For American Indians, loss of subsistence resources can be especially devastating. Cordalis and Suagee (2008) write, "The loss of traditional cultural practices because important plants and animals are no longer available may prove to be too much for some tribal cultures to withstand on top of the external pressures they have faced during recent generations."

No research was found that focused specifically on the impacts of climate change on those with natural (non-managed) ecosystem-based livelihoods in California. Most of the research done on the impacts of climate change on native peoples in the U.S. was conducted in Alaska, where resource changes will be significant and are already being felt. For tribes in the Pacific Northwest who are traditionally dependent on salmon as a resource, decline or loss of salmon runs would cause both the loss of a healthy food source and a deep cultural loss (Hanna 2007, ITEP). Additionally, decreased coastal upwelling is expected along the coast, which would decrease coastal productivity and therefore those reliant on coastal resources (USCCSP 2008).

SECTION 3:
Approach

Climate risk is a function of exposure and vulnerability. The primary objective of the research project was to identify geographic areas within the state with heightened risk to projected climate impacts, as a guide to policymakers and affected communities on where to focus climate adaptation efforts. The methodology employed in this analysis included the following: (1) develop or obtain geographic data on the extent and severity of projected physical impacts of climate change to determine exposure to these impacts; (2) gather data on indicators of social vulnerability that relate to these impacts at an appropriate geographic scale; and (3) overlay vulnerability and exposure layers to produce a composite of exposure and vulnerability. The areas of overlap indicated locations with a heightened risk of impact by climate change as a result of exposure and social vulnerability. Each step is described in greater detail in sections 3.1 and 3.2.

Community engagement was integrated into this project in two forms. A Project Advisory Committee was established in the initial phases of the project that included eight representatives from federal, state, and regional agencies and community-based organizations. The Project Advisory Committee provided input on the analytical methods employed and the availability of quality data for the analysis. Secondly, input from a local collaborative of community leaders and advocates, the Oakland Climate Action Coalition (OCAC) was obtained. The OCAC consists of more than 30 community, environmental, labor, and other organizations that collaborate to identify and integrate community-driven priorities for climate change mitigation and adaptation in the City of Oakland. OCAC members provided input to this study on additional vulnerability factors to consider, potential limitations to the data and methods, and guidance on the outreach strategy for the results of the research. Meetings with the OCAC were held in October 2010, May 2011, July 2011, August 2011, September 2011, October 2011, and November 2011.

3.1 Climate Impacts

Climate change is expected to cause a number of changes to natural and human systems. The quantitative analysis was limited to those impacts for which sufficient data exists to assess local areas within California. These include extreme heat, wildfires, coastal flooding due to sea level rise, and air quality. For the sake of consistency, all climate impacts except air quality were evaluated under the Intergovernmental Panel on Climate Change (IPCC) A2 and B1 greenhouse gas emissions scenarios, which correspond to medium and medium-high greenhouse gas emission scenarios, respectively (see below for a description of the scenarios). These scenarios were selected to be consistent with other climate impact and vulnerability studies in California. For all climate impacts, reported data represented averages over the following time periods (with the midpoints in parentheses): 1971–2000 (1986), 2010–2039 (2025), 2040–2069 (2055), and 2070–2099 (2085). Similar data was not available for air quality. Air quality data was obtained from a modeling study covering current conditions (2000–2006) and mid-century (2047–2053) under a business-as-usual greenhouse gas emissions scenario and an extrapolation of current pollutant emissions.

3.1.1 IPCC Climate Change Scenarios

The impacts of climate change will ultimately depend on future greenhouse gas concentrations. Future greenhouse gas emissions, however, remain uncertain and are influenced by a variety of demographic, socio-economic, and technological factors. Scenarios can be a useful tool for examining how changes in these driving factors affect greenhouse gas concentrations. The IPCC produced the Special Report on Emissions Scenarios (SRES), which outlines four storylines that differ according to demographics, social, economic, environmental, and technological factors, which lead to different levels of greenhouse gas emissions. Each storyline has a number of different scenarios, referred to as a family. A total of 40 scenarios have been developed by the IPCC to guide climate research.

The four storylines are described as follows:

> The A1 storyline is characterized by "a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income" (IPCC 2000). The A1 family is further divided into three subgroups that are differentiated according to energy source: fossil intensive (A1FI), non-fossil sources (A1T), and a mix of fossil and non-fossil sources (A1B).
>
> The A2 storyline is characterized by "self-reliance and preservation of local identities" (IPCC 2000). Population is expected to continuously increase, but economic growth and technological development are expected to be slow.
>
> The B1 storyline has the same population projections as the A1 storyline but has "rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies" (IPCC 2000).
>
> The B2 storyline is characterized by "a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines" (IPCC 2000).

3.1.2 Extreme Heat

For this analysis, a downscaled climate model output of daily temperature developed by the Scripps Institution at the University of California at San Diego was used. These raster datasets have a spatial resolution of 12 kilometers (km) and contained simulated daily minimum, maximum, and average temperature for the period 1950 to 2100. Data from four climate models were averaged in order to provide a more robust estimation that is less dependent on a single model. The four models were:

- CGCM4/CanCM4 from the Canadian Centre for Climate Modeling and Analysis
- CCSM3 from the University Corporation for Atmospheric Research
- GFDL CM2.x from the Geophysical Fluid Dynamics Laboratory (GFDL)
- HadCM3 from the UK Met Office Hadley Centre for Climate Change

Summary statistics were generated from the daily files by processing with scripts written in the Python programming language, and a series of database queries in Microsoft Access. Scripts and query definitions are available by request to the authors. For additional detail about these data, see Maurer et al. (2010).

This study evaluated exposure to extreme heat. There is no standard definition of *extreme heat.* This analysis used the deviation from an average temperature over a given period of time. Using climate model output from 1971 to 2000 determined the 95th percentile daily maximum temperature for each grid cell during the summer (May 1 to October 31), which was defined as the local high-heat threshold. This approach was consistent with that used in other studies, notably Joacim et al. (2010) and the National Climate Data Center (2010), and took into account temperature acclimation, e.g., residents in San Francisco will likely suffer heat impacts when the temperature reaches the 90s, while residents in Los Angeles are more accustomed to this temperature range and may not suffer ill effects. Although heat stress is frequently determined based on apparent heat, which includes the effects of humidity, humidity forecasts were not readily available and thus the temperatures were based on temperature data alone. Therefore, the analysis might underestimate heat stress, particularly for those living in humid areas.

To determine the 95th percentile for each grid cell, the authors compiled the summer daily maximum temperature for the historical period from 1971 to 2000. Following the procedure for calculating percentiles described by Helsel and Hirsch (2002) the temperatures were sorted and assigned a non-exceedance probability, using the Weibull plotting position. Thirty years worth of summer temperatures for a region (represented by a grid cell) provided 5,490 daily values. Once these values were sorted, the 95th percentile was the 5,217th number, i.e., this was the daily maximum temperature that was exceeded less than 5 percent of the time.

By definition, the local high-heat threshold is exceeded 7.6 days each year, on average (5 percent of the 152 days from May 1 to Oct 31). Future exposure to extreme heat was divided into low, medium, and high bins based on the number of days where the exposure exceeded the local high-heat threshold. The cutoff for low exposure was defined as less than a tripling of the number of high-heat days. High exposure was set as exposure to five times the number of high-heat days. Thus, the three bins of exposure level are as follows:

Low Exposure:	< 22.8 days
Medium Exposure:	22.8 to < 38 days
High Exposure:	38 or more days

These cutoffs are arbitrary. In reality, risks related to extreme heat exposure occur along a continuum and cannot be neatly categorized. These categories, however, were useful for identifying where exposure to extreme heat was greatest.

There are a number of ways to measure the relative increase in temperature due to climate change. In developing an indicator for heat stress, the authors considered using a single statewide threshold, e.g., annual number of days above a threshold of 105ºF. However, there is also a small body of evidence, and some precedent, for the use of a more local temperature threshold for determining heat stress. This is based on the observation that populations are acclimatized to local temperatures, and will begin to suffer symptoms of heat-related illnesses as local temperatures increase relative to the historic norm. Based on this finding, a relative increase approach was chosen. The authors caution against using this as a sole indicator of heat-related climate change impacts because areas in the state with less pronounced increases in temperature relative to historic temperatures might have high absolute temperatures that should be considered in adaptation planning.

3.1.3 Wildfire Risk

Two datasets were merged to evaluate future wildfire risk. CalFire published geographic information system (GIS) shapefiles of Fire Hazard Severity Zones, which are ranked as moderate, high, and very high fire severity. This dataset was the highest-resolution geographical information available showing the current extent and severity of wildfires in California.

Climate-based projections of future wildfire risk were produced for the 2011 California Climate Change Center studies by Krawchuk and Moritz (2012). Those studies focused on changes in the distribution and frequency of fire in future climates. The fire model outputs are raster layers that show the probability of one or more fires occurring in each grid cell over the 30-year periods. For this study GIS software was used to overlay the fire frequency data with census tract boundary files from the U.S. Census. A small census tract might cover less area than a single grid cell, while large census tracts might cover dozens of cells. The authors used the ArcGIS Zonal Statistics tool to calculate the mean of grid cells within each tract. Each grid cell (or pixel) in the raster dataset contained a value from 0 to 1, representing the model of one or more fires in a 30year period in that grid cell. The zonal statistics tool averaged the values of all the cells that fall within its boundaries. The result of the calculation was the average probability of one or more fires in a 30-year period in each of California’s 7,049 census tracts.

Averages had the disadvantage of smoothing out the data somewhat, as large tracts included areas with both high and low risk. Census tracts were relatively large, and it would be desirable to perform the analysis at a smaller geographic scale. However, there was significant uncertainty associated with attempts to precisely quantify expected fire damages because fire is unpredictable and depends on a variety of factors, including future patterns of development and fire suppression policies. It was concluded that summarizing the data at the tract level preserved most, but not all, of the variance in the original dataset. Because this step made it possible to overlay climate impacts and social vulnerability datasets, we deemed it an acceptable compromise; we gave up some geographic precision in order to make the data more useful for the analysis.

The wildfire probability data was divided into three bins of low, medium, and high exposure, in order to simplify the visualization and presentation of results. The bin sizes were set at the following:

Low Exposure: < 14.2%

Medium Exposure: 14.2%–33.3%

High Exposure: > 33.3%

These cutoffs were arbitrary. In reality, risks related to wildfire exposure occur along a continuum and cannot be neatly categorized. These categories, however, were useful for identifying where exposure to wildfire was greatest.

3.1.4 Coastal Flooding from Sea Level Rise

Flood risk inundation maps for the California coast were developed by the Pacific Institute and described in Heberger et al. (2009). These maps showed the areas at risk from a 100-year flood event following a 1.0 meter (39 inches) and 1.4 meter (55 inches) rise in sea levels and corresponded to estimates under the A2 and B1 scenario, respectively, by the end of the century. The 100-year flood was chosen because it is a standard for planning, insurance, and environmental regulations. Note that these estimates include coastal flood risks only, e.g., flooding caused by rising seas along the Pacific Ocean and San Francisco Bay. Higher sea levels, however, can also worsen flooding in nearby rivers as higher water surface elevations at the downstream end of a river causes water to back up and increase upstream flooding. These impacts were not evaluated in this study.

3.1.5 Air Quality

Projected air quality conditions were analyzed using model output from Kleeman et al. (2010). An effort was made to analyze as many air quality constituents for which reliable information could be found, including ozone and particulate matter. After further discussion with other scientists, however, it became clear that there was no apparent trend in the ozone simulations. In other words, there was no evidence from the modeling that ozone concentrations were either increasing or decreasing with time under any of the scenarios they modeled. As a result, the discussion of climate change and air quality was limited to respirable, fine particulate matter ($PM_{2.5}$), for which researchers express the most confidence in their numerical models. There are a number of other air quality parameters that are important to human health, particularly ozone, for which reliable data were not as readily available.

Air quality data were based on downscaled climate model output from the National Center for Atmospheric Research Parallel Climate Model under the B06.44 business as usual scenario. Note that this scenario does not correspond to the IPCC scenarios (A2 and B1) used elsewhere in this paper. The air quality modeling was based on a projection of future emissions which extrapolates current emissions trends and does not include emissions controls. The modeling did not include the effects of new or proposed air quality regulations in California. In other words, pollution was expected to keep growing at current rates. While it seems likely that stricter regulations could affect this rate, the effect of regulation was not included. The air-quality models were run for seven-year windows in order "to account for the effects of El Niño Southern Oscillation (ENSO) events and the intra-annual variability in the climate data that would have different implications in the final air quality results" (Kleeman et al. 2010, 143).

Modeled $PM_{2.5}$ concentrations were divided into three bins of low, medium, and high exposure, in order to simplify the visualization and presentation of results. The bin sizes were set at the following:

Low Exposure: $< 6\ \mu g/m^3$
Medium Exposure: $6–12\ \mu g/m^3$
High Exposure: $> 12\ \mu g/m^3$

These bins were based on California's air quality standard for average annual ambient $PM_{2.5}$ concentration. The California standard for the average airborne concentration has been set at 12 micrograms per cubic meter ($\mu g/m^3$). The standard was adopted by the California Air Resources Board, following a scientific review mandated by the legislature under the Children's Environmental Health Protection Act (ARB 2009) and is stricter than the EPA national standard of 15 $\mu g/m^3$. The lowest bin was defined as one half of the state average annual standard concentration. Airborne concentrations greater than this, but below the standard, were defined as medium, while those areas where the average annual concentration exceeds the state standard were defined as high risk. Note that these delineations were arbitrary and not based on any scientific risk assessments.

3.2 Vulnerability to Climate Impacts

To compare social vulnerability to climate change among areas within the state, a vulnerability index that combined many vulnerability factors into one composite score was used. The methodology for the index was based on the Social Vulnerability Index (SoVI) (Cutter et al. 2003), developed to assess social vulnerability to hazards. Cutter's original formulation of SoVI included 32 factors that the literature suggested contribute to a community's ability to prepare for, respond to, and recover from hazards (Cutter et al. 2003). The SoVI index quantified social vulnerability using available data, mostly from the U.S. Census, including income, race, unemployment, and others. A custom index was developed that differs from SoVI in that it solely includes indicators specific to climate change impacts, as identified in the literature review (see Section 2).

The vulnerability index was developed based on 19 separate factors. Table 5 shows the vulnerability factors, the indicator used to represent that vulnerability, and the data sources used in the analysis. Ideally, the social vulnerability index would have included more than 19 factors, but was limited due to the availability of data on various vulnerability factors. For example, some social characteristics, such as the level of community organization in an area, will have a significant effect on the population's ability to respond to and recover from climate change. Yet an indicator for this factor was not included in the analysis because reliable data at the appropriate scale were not available.

The social vulnerability index was compiled at the census tract level. Thus, a single vulnerability value for each of the 7,049 census tracts in the state (which average 5,000 people in each) was created.[1] For much of the data collected, census tracts were the smallest geographic boundary at which the data was aggregated. Each of the 19 variables was measured and reported in its own units (e.g. number of low-income residents or percent impervious cover). In order to add these variables together, they were transformed to standard units using z-score standardization, as employed in Cutter et al. (2003). The cardinality was then adjusted to ensure that the sign of the factor represents the way the factor influences vulnerability. For example, a high percentage of low-income residents indicate higher vulnerability, giving this variable a cardinality of +1. By contrast, a higher percentage of high-school graduates indicate lower vulnerability, so this variable has a cardinality of -1. Once all of the variables were transformed, the component z-scores were averaged to generate a vulnerability score for each of the 7,049 census tracts in the state (HVRI 2011a). To compare social vulnerability among areas in the state, the index scores were grouped into terciles, with scores below the 33rd percentile considered Low Vulnerability, those between the 33rd and 66th percentile considered Medium Vulnerability, and the higher tercile comprising High Vulnerability.

In addition to a single vulnerability index, maps for each vulnerability factor are available at www.pacinst.org and can be accessed by agencies, community groups, and individuals to help inform climate adaptation efforts. It is important to note that some indicators of vulnerability are not intended to measure progress toward more resilient communities, e.g., race and age characteristics of a community will not change through efforts to build resilience. Thus, these indicators will not be useful in measuring the effect of these efforts. Separate indicators will likely be needed to track climate planning and action processes.

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[1] The census tract boundaries from the 2000 Decennial Census were used, rather than the more recent 2010 census boundaries. Much of the data used was collected from 2005–2009 and was aggregated with the year-2000 census tract boundaries. It will be several years before American Community Survey data which is grouped according to the 2010 Census boundaries become available.

Table 5: Vulnerability Factors Included in the Vulnerability Index and their Data Sources

Vulnerability Factor	**Indicator**	**Data Source**
Households with air conditioning	Households with an air conditioning unit	Roberts 2011a
Population over 25 with a diploma	People over age 25 who have a high school diploma	U.S. Census, American Community Survey (2005–2009)
Born outside the U.S.	People who were born outside the United States	U.S. Census, American Community Survey (2005–2009)
Impervious areas	Land in the area that has an impervious surface (e.g. sidewalk or roof)	EPA 2001
Residents living in institutions	Population living in "group quarters", including institutions like correctional facilities, nursing homes, and mental hospitals, college dormitories, military barracks, group homes, missions, and shelters.	U.S. Census, American Community Survey (2005–2009)
Households with limited English	Population 5 years and over who answered that they speak English less than "very well"	U.S. Census, American Community Survey (2005–2009)
Households with no vehicle	Percentage of households with no vehicle available	U.S. Census, American Community Survey (2005–2009)
People of color	People identifying as any other race or ethnicity besides white.	U.S. Census, American Community Survey (2005–2009)
Households in poverty	Households with an income that is below 200% of the official federal poverty level	U.S. Census, American Community Survey (2005–2009)
Pre-term births	Infants that were born before completing 37 weeks (about 8.5 months) of pregnancy	Roberts 2011b
Renter-occupied households	Percent of households where people are renting	U.S. Census, American Community Survey (2005–2009)
Over 65 and living alone	Percent of households occupied by someone over age 65 who lives alone	U.S. Census, American Community Survey (2005–2009)
Tree canopy cover	Land covered by tree canopy	Calculated by Jessdale et al. using data from Nat'l Land Cover Dataset, 2001
Under age 18	Population under age 18	U.S. Census, American Community Survey (2005–2009)

Table 5: (continued)

Vulnerability Factor	Indicator	Data Source
Unemployment	Population 16 years and over able to work who are unemployed	U.S. Census, American Community Survey (2005–2009)
Have jobs working outdoors	Percent of workers who work in agriculture, forestry, mining, or construction	U.S. Census, American Community Survey (2005–2009)
Pregnancy	Percentage of women 15 to 50 years old who had a birth in the past 12 months	U.S. Census, American Community Survey (2005–2009)
Food access	Access to full-service supermarkets according to Low Access Area measurement tool	The Reinvestment Fund 2010
Youth fitness	Fraction of children that are overweight or obese in tract (i.e., fraction over 85th percentile for age and gender based on the CDC growth curves.	Ortega Hinojosa 2011

3.3 Study Limitations

The index integrated the 19 factors for which local data were available for the entire state. Data were not available for a range of factors that scientists and practitioners have found to influence vulnerability to natural hazards and climate change, such as diabetes, homelessness, and citizenship status. Thus, the social vulnerability factors included in this study represented a subset of known vulnerability factors, and the resulting index scores might have under-represented the vulnerability of some areas.

The analysis summarized social vulnerability at the census tract level, obscuring any variation within tracts. The Census Bureau periodically redraws tract boundaries so that the population within each tract is relatively homogenous and ranges between 1,500 and 8,000 residents. However, population changes happen more frequently than adjustments to tract boundaries, allowing for potentially significant demographic variation within tracts and size differences between tracts.

The estimated number of people affected was based on current population figures, as reported in the U.S. Census. The total state population, however, is projected to reach 60 million by 2050, a 60 percent increase over 2000 levels (CA Department of Finance 2007). The analysis did not use population projections because these projections are not available at the census tract level. The actual rate and distribution of population growth, and social and economic change will play a key role in shaping vulnerability in the future. For example, if the trend of the shrinking middle class and intensified poverty continues, the number of people socially vulnerable to climate impacts will surpass estimates. Adequate data were not available to evaluate these changes.

SECTION 4:
Results

4.1 Social Vulnerability Index

To compare overall social vulnerability to climate change among areas within the state, a single vulnerability index that combines data from 19 vulnerability factors was used to calculate a vulnerability index for each of the 7,049 census tracts in the state. A higher score indicated the population within a tract had greater social vulnerability to climate-related disturbances. The values had an average of 0 and a standard deviation of 0.5. The minimum score was –1.99, and the maximum was +1.90 (Figure 1). The distribution was asymmetric, with a positive skew. While both the mean and the median were close to zero, there was a large cluster of index values between –1 and 0. There were very few tracts with a vulnerability score between –1 and –2, which would be indicative of very *low* vulnerability. On the positive side of the distribution, the values were more evenly spread, gradually decreasing in frequency between 0 and +2.

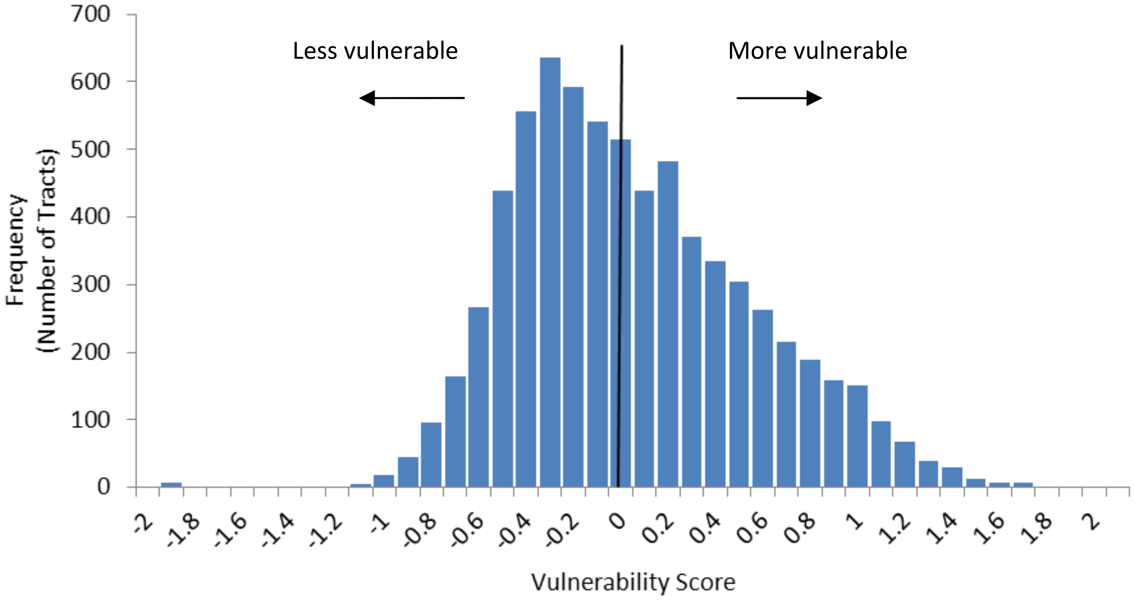

Figure 1: Distribution of Calculated Vulnerability Scores for California Census Tracts

The index scores were broken into terciles, with scores below the 33rd percentile categorized as low vulnerability, those between the 33rd and 66th percentile categorized as medium, and the higher tercile comprising high vulnerability. The low vulnerability category included tracts with a score less than –0.285. Medium vulnerability included tracts with a score between –0.285 and +0.167, and high vulnerability included tracts with a score greater than +0.167. Areas with a high vulnerability were found throughout the state but were largely concentrated within the San Joaquin Valley and in the southeastern portion of California (Figure 2).

In total, about 12.4 million Californians lived in census tracts with high social vulnerability to climate impacts (Table 6). A disproportionate number of those with high vulnerability were located in Los Angeles County (Figure 3). Approximately 27 percent of the state's population lived in Los Angeles County. Yet, more than 40 percent of those in census tracts with high social vulnerability, or about 5 million people, were located in Los Angeles County. There were also large numbers of people in high vulnerability areas in Orange, Riverside, and San Diego Counties.

In some rural counties, the total number of residents in highly vulnerable tracts was not large but represented a large fraction of the total population in the county. For example, in Imperial County, more than 90 percent of the population lived in areas with high social vulnerability. Likewise in Merced County, 70 percent of the population resided in areas with high social vulnerability to climate impacts.

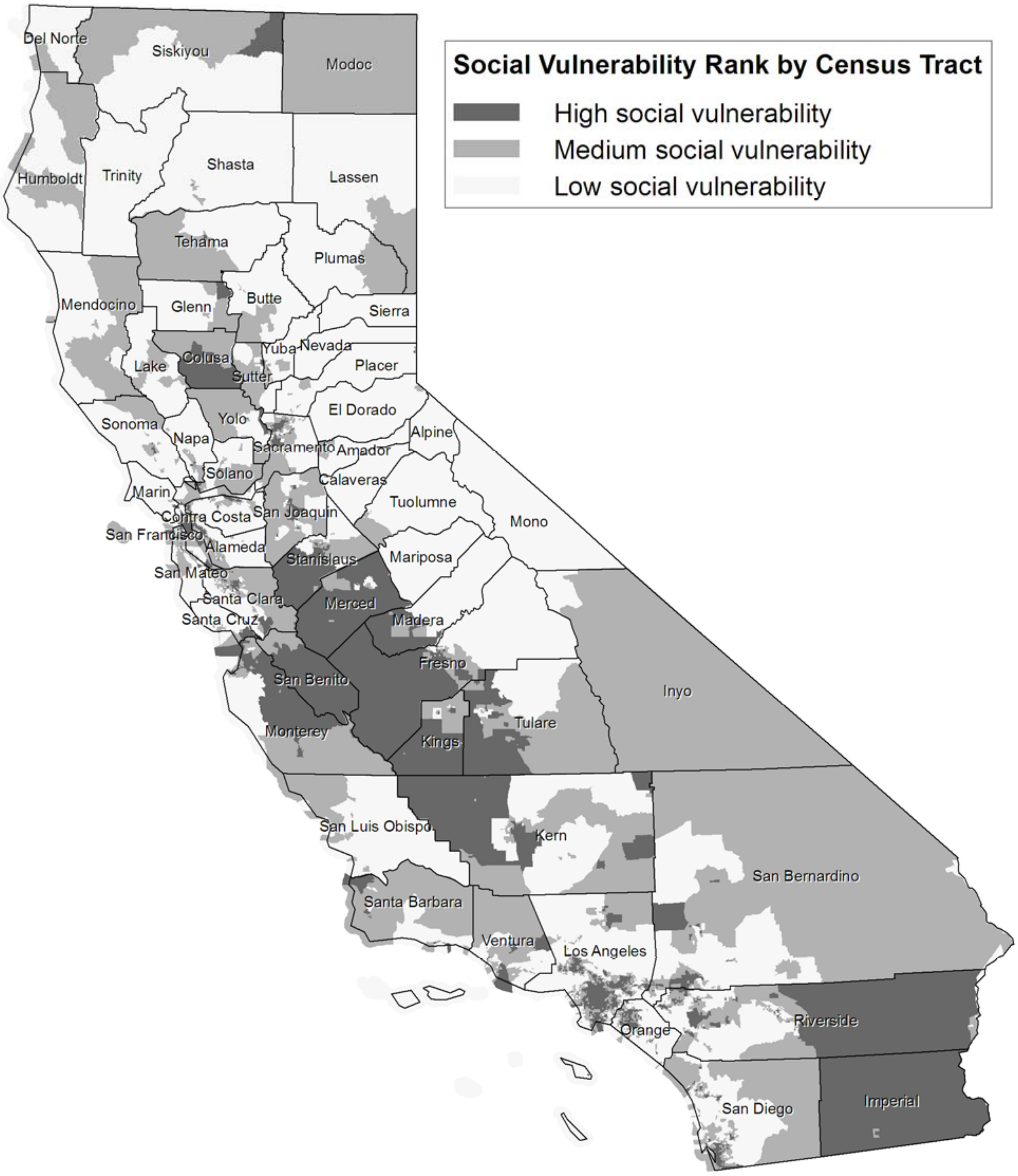

Figure 2: Social Vulnerability Index Scores, by Census Tract

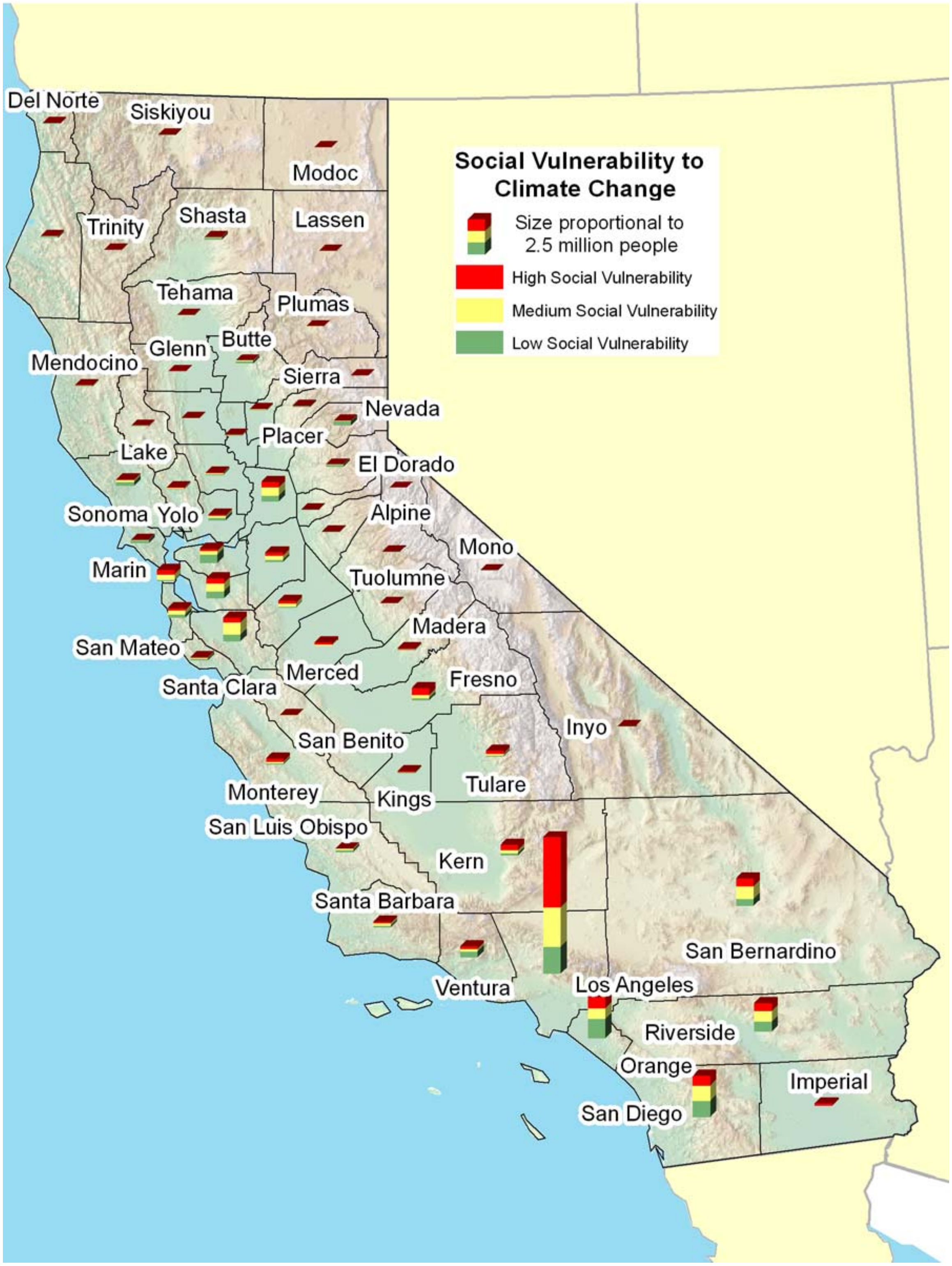

Figure 3: Social Vulnerability of California's Population, by County

Table 6: Social Vulnerability of California’s Population, by County

County	Low social vulnerability		Medium social vulnerability		High social vulnerability		Total population
Alameda	510,000	(35%)	569,000	(39%)	378,000	(26%)	1,460,000
Alpine	1,150	(100%)	0	(0%)	0	(0%)	1,150
Amador	32,200	(85%)	5,790	(15%)	0	(0%)	38,000
Butte	157,000	(72%)	61,400	(28%)	0	(0%)	218,000
Calaveras	46,500	(100%)	0	(0%)	0	(0%)	46,500
Colusa	0	(0%)	10,100	(48%)	10,900	(52%)	21,000
Contra Costa	603,000	(59%)	254,000	(25%)	159,000	(16%)	1,020,000
Del Norte	22,800	(79%)	1,340	(5%)	4,590	(16%)	28,700
El Dorado	160,000	(91%)	15,200	(9%)	357	(0%)	176,000
Fresno	183,000	(21%)	203,000	(23%)	505,000	(57%)	891,000
Glenn	1,870	(7%)	22,700	(81%)	3,350	(12%)	27,900
Humboldt	75,400	(58%)	53,600	(42%)	0	(0%)	129,000
Imperial	0	(0%)	14,600	(9%)	145,000	(91%)	160,000
Inyo	4,230	(24%)	13,200	(76%)	0	(0%)	17,400
Kern	148,000	(19%)	246,000	(31%)	387,000	(50%)	781,000
Kings	15,100	(10%)	69,400	(47%)	62,200	(42%)	147,000
Lake	38,400	(59%)	26,400	(41%)	0	(0%)	64,800
Lassen	21,200	(62%)	13,200	(38%)	0	(0%)	34,400
Los Angeles	1,950,000	(20%)	2,820,000	(29%)	5,020,000	(51%)	9,790,000
Madera	36,000	(25%)	39,800	(28%)	68,900	(48%)	145,000
Marin	212,000	(86%)	20,300	(8%)	14,700	(6%)	247,000
Mariposa	17,900	(100%)	0	(0%)	0	(0%)	17,900
Mendocino	33,300	(39%)	43,000	(50%)	9,710	(11%)	86,000
Merced	11,700	(5%)	59,800	(25%)	171,000	(70%)	242,000
Modoc	0	(0%)	9,160	(100%)	0	(0%)	9,160
Mono	12,900	(100%)	0	(0%)	0	(0%)	12,900
Monterey	68,100	(17%)	102,000	(25%)	234,000	(58%)	405,000
Napa	39,900	(30%)	68,000	(51%)	24,300	(18%)	132,000
Nevada	97,100	(100%)	0	(0%)	0	(0%)	97,100
Orange	1,380,000	(46%)	762,000	(26%)	831,000	(28%)	2,980,000
Placer	292,000	(88%)	36,200	(11%)	3,370	(1%)	332,000
Plumas	15,300	(75%)	5,210	(25%)	0	(0%)	20,600
Riverside	710,000	(35%)	755,000	(37%)	571,000	(28%)	2,040,000
Sacramento	405,000	(29%)	590,000	(43%)	381,000	(28%)	1,380,000
San Benito	0	(0%)	29,400	(54%)	25,400	(46%)	54,800
San Bernardino	503,000	(25%)	916,000	(46%)	567,000	(29%)	1,990,000
San Diego	1,160,000	(39%)	1,100,000	(37%)	727,000	(24%)	2,990,000
San Francisco	85,600	(11%)	369,000	(46%)	342,000	(43%)	797,000

Table 6: (continued)

County	Low social vulnerability		Medium social vulnerability		High social vulnerability		Total population
San Joaquin	120,000	(18%)	329,000	(49%)	216,000	(33%)	665,000
San Luis Obispo	152,000	(58%)	110,000	(42%)	0	(0%)	262,000
San Mateo	235,000	(33%)	314,000	(45%)	153,000	(22%)	702,000
Santa Barbara	112,000	(28%)	167,000	(41%)	123,000	(31%)	402,000
Santa Clara	494,000	(29%)	887,000	(51%)	348,000	(20%)	1,730,000
Santa Cruz	125,000	(50%)	66,700	(27%)	59,900	(24%)	251,000
Shasta	130,000	(72%)	48,500	(27%)	1,290	(1%)	179,000
Sierra	3,240	(100%)	0	(0%)	0	(0%)	3,240
Siskiyou	30,500	(69%)	12,500	(28%)	1,400	(3%)	44,400
Solano	174,000	(43%)	151,000	(37%)	81,500	(20%)	406,000
Sonoma	271,000	(58%)	161,000	(35%)	32,200	(7%)	464,000
Stanislaus	59,200	(12%)	235,000	(47%)	211,000	(42%)	505,000
Sutter	40,600	(45%)	26,900	(30%)	23,300	(26%)	90,700
Tehama	23,000	(38%)	30,600	(50%)	7,050	(12%)	60,600
Trinity	13,900	(100%)	0	(0%)	0	(0%)	13,900
Tulare	53,600	(13%)	135,000	(33%)	227,000	(55%)	416,000
Tuolumne	49,300	(88%)	6,460	(12%)	0	(0%)	55,800
Ventura	402,000	(51%)	210,000	(27%)	180,000	(23%)	792,000
Yolo	96,800	(50%)	62,300	(32%)	33,900	(18%)	193,000
Yuba	18,800	(26%)	37,500	(53%)	14,600	(21%)	70,900
Total	11,700,000	(32%)	12,300,000	(34%)	12,400,000	(34%)	36,300,000

Note: Population estimates represent the total number of people within a given county that are living in census tracts with low, medium, and high social vulnerability. The percent of the county population that these groups represent are shown in parentheses. Population estimates are rounded to three significant figures.

4.1.1 Contributing Factors in the Most Vulnerable Areas of the State

As described above, the vulnerability z-scores were divided into thirds and ranked as low, medium, and high vulnerability. To understand which of the 19 factors were most influential over the index scores of the most vulnerable census tracts, the average values of each factor in tracts scoring in the top 33 percent were evaluated. Figure 4 shows the average z-score value of the vulnerability factors within the tracts with high social vulnerability. The factors with higher average scores made a greater contribution to the high vulnerability scores in these tracts. Nearly all of the individual factors contributed in some way to the vulnerability scores, except for "Residents over the age of 65 living alone" and "Residents living in institutions." Four factors (lacking a high-school diploma, low-income, non-English speaking, and people of color) were the primary drivers for the most vulnerable census tracts. Each of these factors had an average z-score of around 1, indicating that their values were 1 standard deviation above the mean for the group. However, the values for individual tracts within the high vulnerability group showed considerable variation. In the 2,350 tracts that were in the top third, more than 90 percent of these had positive (more vulnerable) values for these four factors. The stem-and-whisker plots in Figure 5 show the distributions for the four most important factors.

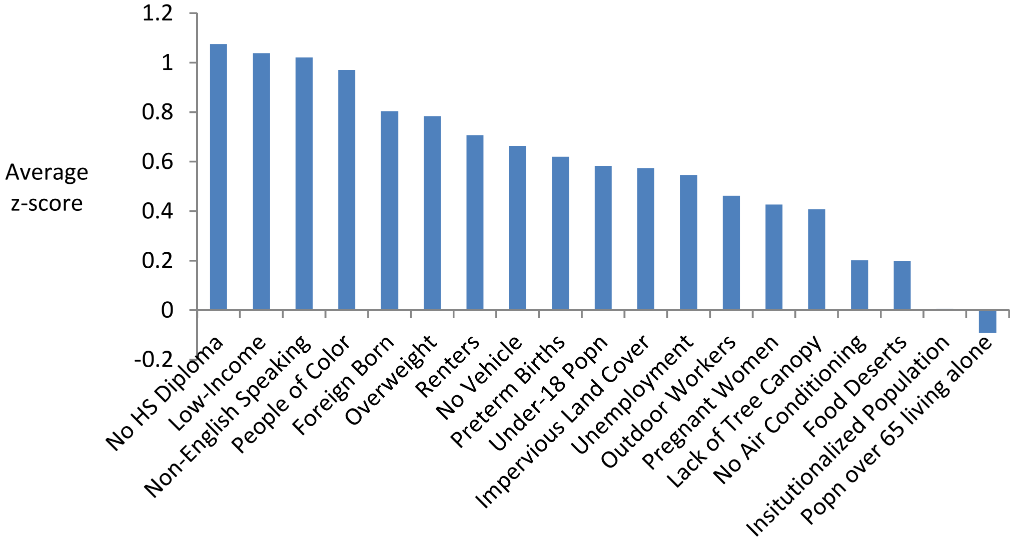

Figure 4: Average Z-Scores for Individual Vulnerability Factors for Tracts Ranked Highly Vulnerable

Note: Popn = population; HS = high school

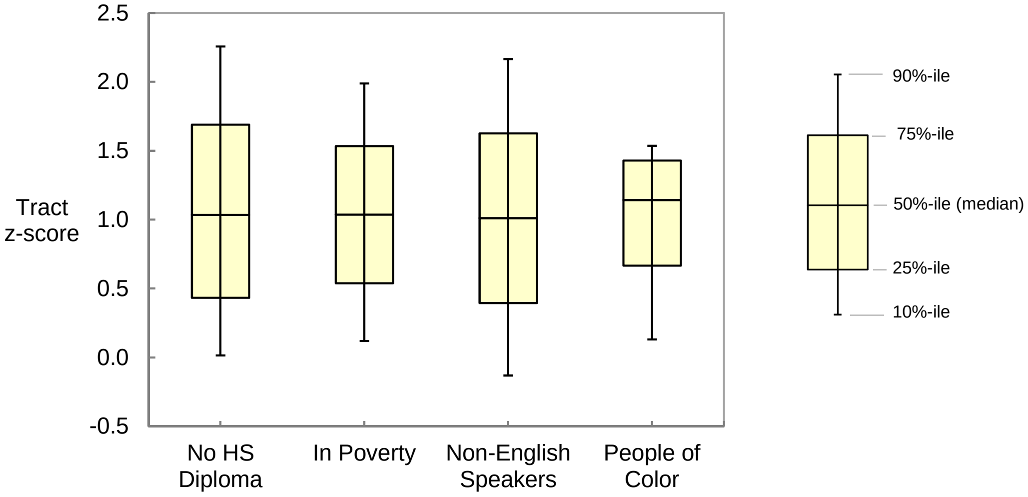

Figure 5: Stem-and-Whisker Plots Showing the Distribution of the Top 4 Vulnerability Factors for Tracts Ranked Highly Vulnerable

Note: No HS Diploma: Population over the age of 25 without a high-school diploma.
In Poverty: Households with an income that is below 200 percent of the official federal poverty level.
Non-English Speakers: Population 5 years and over who answered that they speak English less than "very well."
People of Color: People identifying as any other race or ethnicity besides white.

4.2 Climate Impact and Social Vulnerability Analysis

Climate risk is a function of exposure and vulnerability. The vulnerability index score maps were overlaid with maps of projected exposure to extreme heat, particulate matter, coastal flooding, and wildfire to identify areas with high social vulnerability and high projected exposure to climate change disturbances. The areas of overlap indicated those locations with heightened risk of being impacted by these climate changes as a result of exposure and social vulnerability. The following sections describe this overlay for each of the climate impacts.

4.2.1 Extreme Heat

The magnitude of extreme heat was measured in terms of the number of days that the daily maximum temperature exceeds the 95th percentile historical (1971–2000) local high-heat threshold during the summer months (May 1 through October 31). Results were compiled at the 1/8-degree grid cell and shown in Figures 6 through 8. Results were summarized by county in Table 7.

By definition, the 95th percentile high-heat threshold is the local temperature exceeded 7.6 days per year, on average, over the summer months during the historical period (1971–2000). The 95th percentile temperature fell within 80–90 degrees F in many of the coastal and northern counties, and reached over 100 degrees in much of the Central Valley and southern California (Figure 6). Climate change increased the number of extreme heat events across the state. The largest increases in the number of days exceeding the local high heat threshold were in the inland and southern parts of California. For example, in Inyo County, the number of days exceeding the local high heat threshold (101°F) increased from 7.6 days under historic conditions to 40 days under the B1 scenario and 71 days under the A2 scenario by 2070–2099. The coast experienced considerably smaller increases. In San Francisco County, for example, the number of days exceeding the local high heat threshold (79.4°F) increased from 7.6 days under historic conditions to 16 days under the B1 scenario and 27 days under the A2 scenario by 2070–2099. In the following sections, these results are used to determine the total number of people and vulnerable populations that would be affected under the A2 and B1 climate change scenarios.

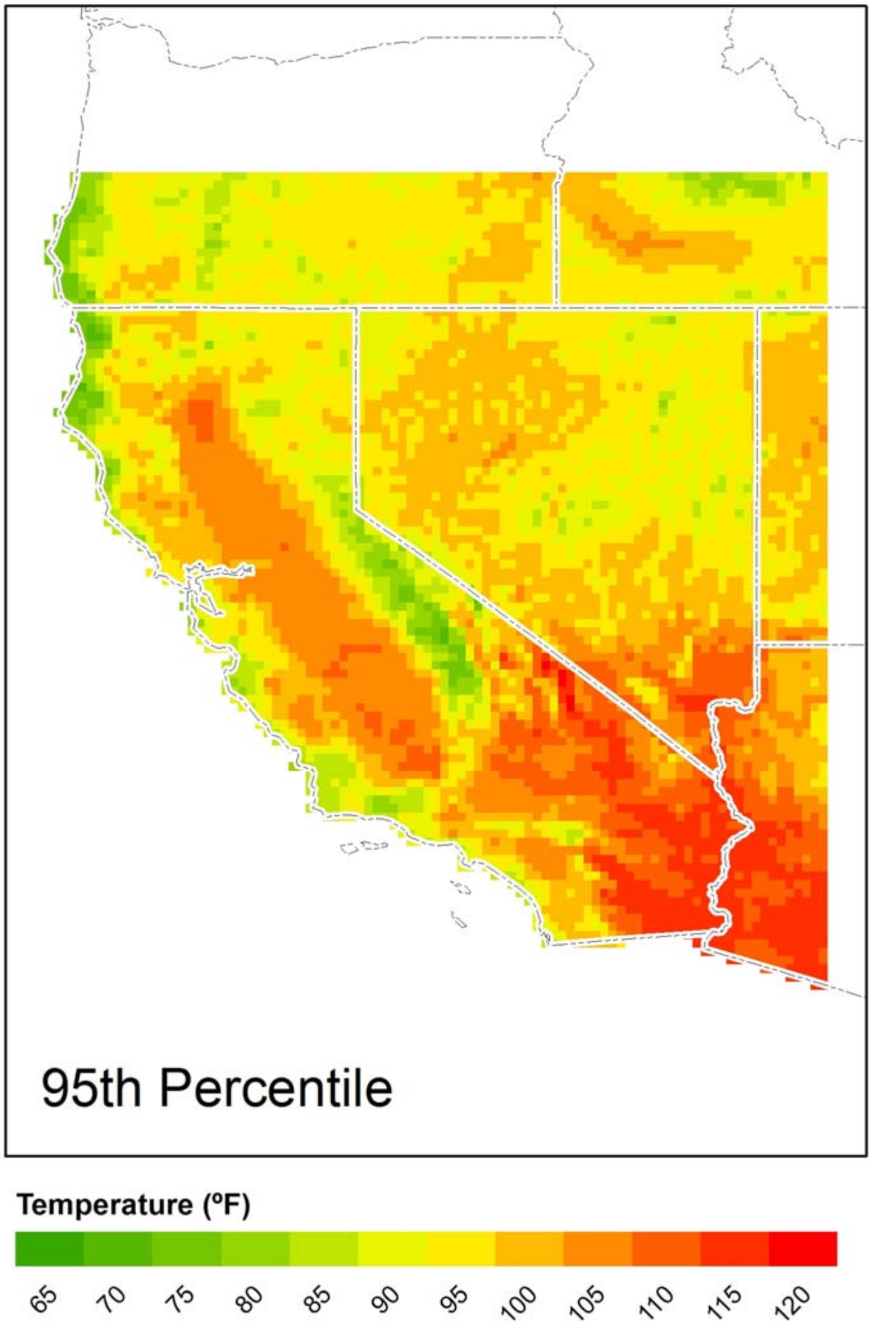

Figure 6: Historical (1971–2000) 95th Percentile Daily Maximum Temperature Over the Summer Period (May 1 to October 31)

Note: Results show the historical local high-heat threshold, defined as the temperature that is exceeded 5 percent of the time during the summer months for the period 1971 - 2000. Results are averaged from four downscaled climate models.

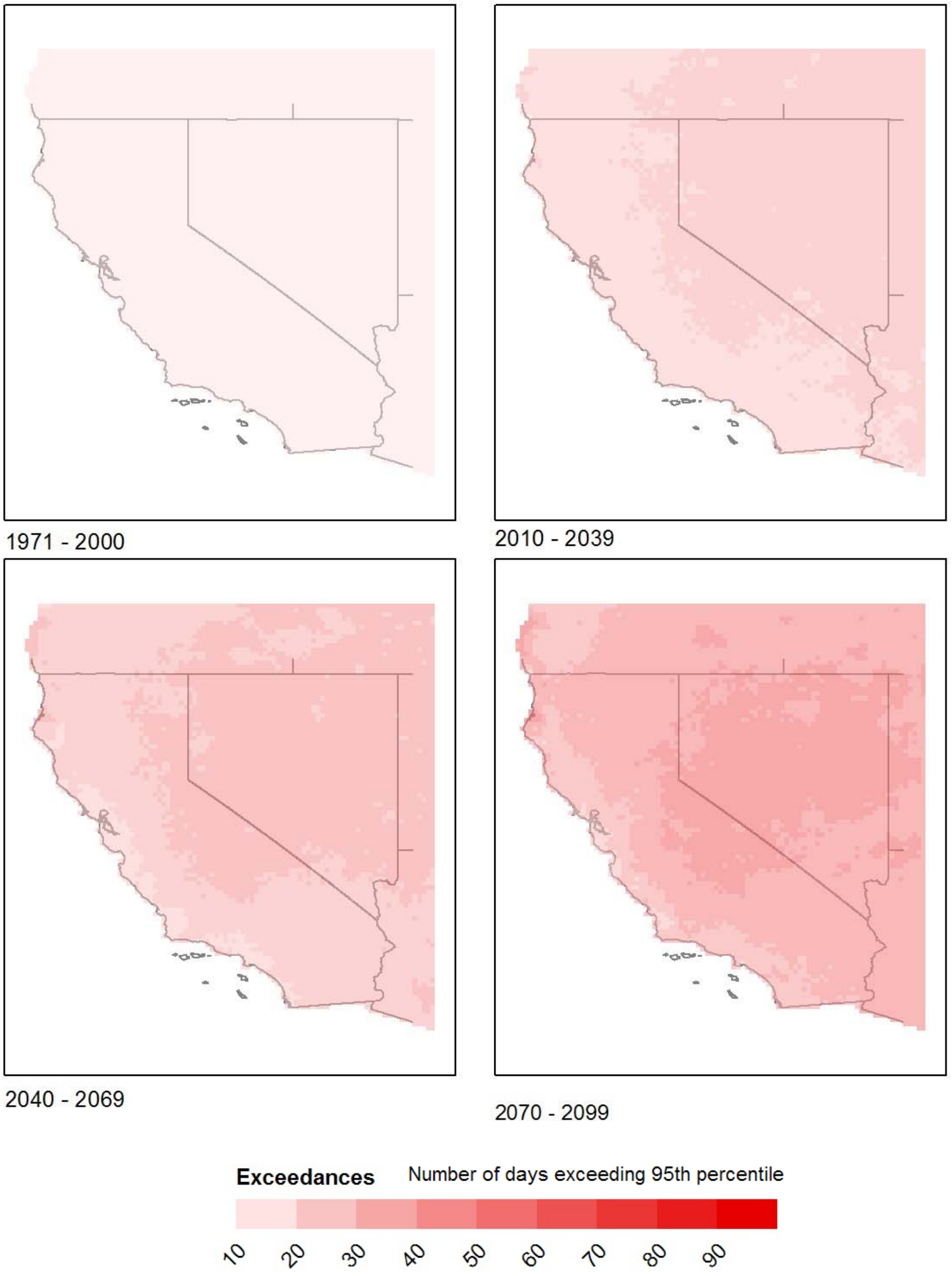

Figure 7: Number of Days Exceeding the Historical (1971–2000) 95th Percentile Daily Maximum Temperature Over the Summer Period in the B1 Scenario

Note: Figure shows the average number of days where the daily maximum temperature exceeds the local high-heat threshold from May 1 to October 31 over the analysis period. Projections are based on the B1 scenario and are averaged for four downscaled climate models.

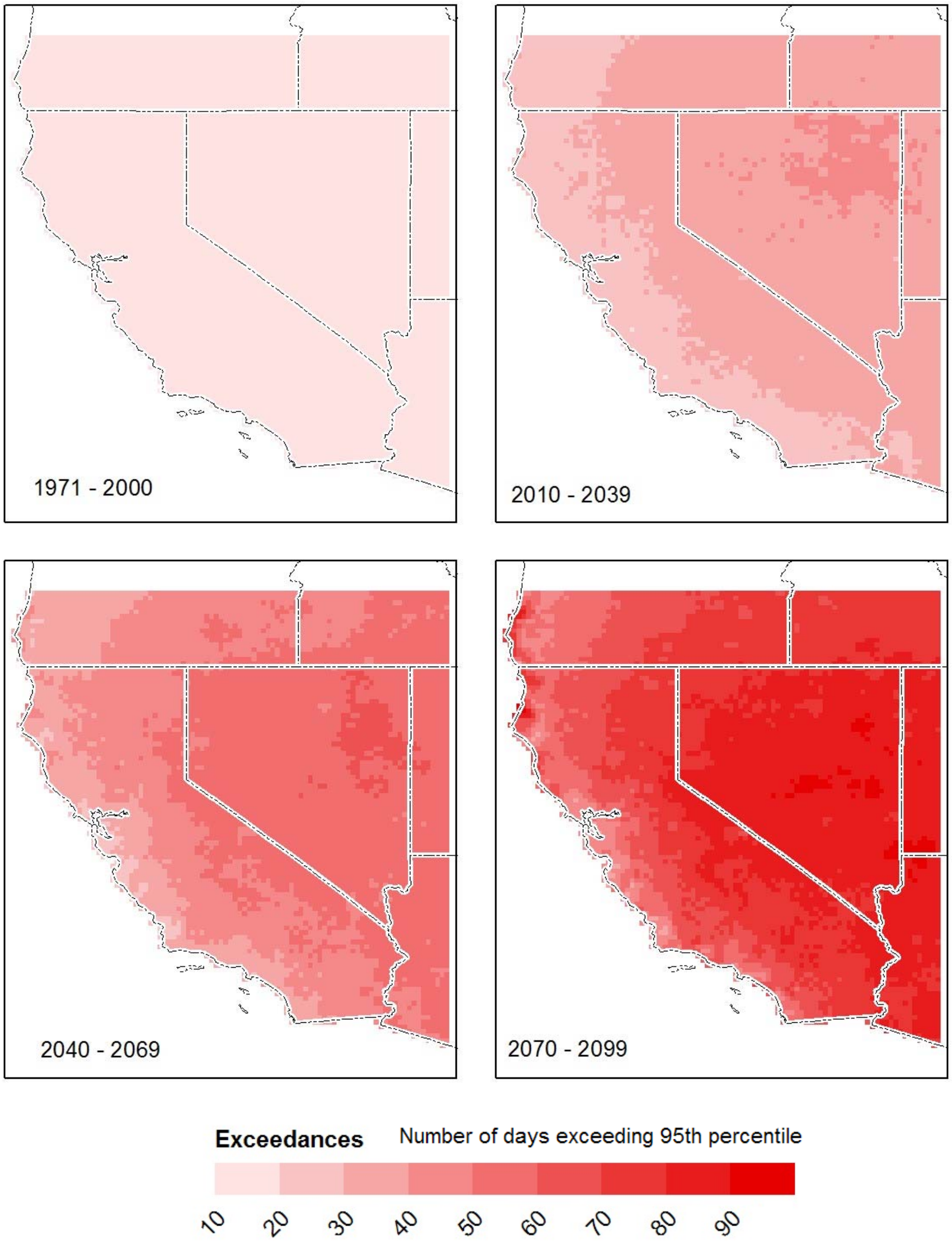

Figure 8: Number of Days Exceeding the Historical (1971–2000) 95th Percentile Daily Maximum Temperature Over the Summer Period in the A2 Scenario

Note: Figure shows the average number of days where the daily maximum temperature exceeds the local high-heat threshold from May 1 to October 31 over the analysis period. Projections are based on the A2 scenario and are averaged for four downscaled climate models.

Table 7: Number of Days Exceeding the Historical (1971–2000) 95th Percentile Daily Maximum Temperature Over the Summer Period in the A2 and B1 Scenario, by County

	B1					A2				
County	T_{95}* (°F)	1971-2000	2010-2039	2040-2069	2070-2099	T_{95}* (°F)	1971-2000	2010-2039	2040-2069	2070-2099
Alameda	93.2	7.6	13	18	22	93.3	7.6	14	21	35
Alpine	81.1	7.6	24	37	45	81.3	7.6	25	44	73
Amador	99.0	7.6	19	30	37	99.2	7.6	20	35	61
Butte	100	7.6	18	28	35	100	7.6	20	34	60
Calaveras	97.6	7.6	20	30	39	97.5	7.6	22	37	63
Colusa	101	7.6	17	26	32	101	7.6	20	32	55
Contra Costa	96.0	7.6	15	21	25	96.0	7.6	16	23	39
Del Norte	75.8	7.6	16	26	34	75.9	7.6	16	27	55
El Dorado	92.4	7.6	20	32	40	92.4	7.6	22	39	66
Fresno	94.8	7.6	20	31	40	94.8	7.6	21	36	63
Glenn	100	7.6	16	25	31	100	7.6	19	32	55
Humboldt	81.5	7.6	16	24	31	81.6	7.6	16	26	50
Imperial	112	7.6	18	25	32	112	7.6	19	36	64
Inyo	101	7.6	21	31	40	101	7.6	25	42	71
Kern	101	7.6	19	27	34	101	7.6	21	35	62
Kings	104	7.6	19	29	37	104	7.6	20	34	60
Lake	97.1	7.6	15	22	27	97.0	7.6	17	27	46
Lassen	91.0	7.6	20	31	38	91.0	7.6	24	39	65
Los Angeles	96.4	7.6	16	21	27	96.4	7.6	17	28	51
Madera	95.8	7.6	20	32	40	95.8	7.6	22	38	64
Marin	91.9	7.6	13	16	20	91.9	7.6	13	19	33
Mariposa	95.6	7.6	20	32	40	95.6	7.6	22	37	64
Mendocino	89.4	7.6	15	22	27	89.3	7.6	17	27	48
Merced	102	7.6	19	29	37	102	7.6	19	32	56
Modoc	91.6	7.6	20	30	36	91.7	7.6	23	37	62
Mono	83.8	7.6	23	35	45	83.9	7.6	25	44	73
Monterey	91.9	7.6	13	19	24	91.9	7.6	14	21	38
Napa	98.0	7.6	15	22	26	98.0	7.6	16	26	44
Nevada	92.3	7.6	20	30	38	92.3	7.6	22	38	65
Orange	89.8	7.6	15	19	24	89.8	7.6	15	24	45
Placer	91.4	7.6	19	30	38	91.3	7.6	22	38	65
Plumas	89.9	7.6	20	31	39	89.9	7.6	24	39	65
Riverside	107	7.6	18	25	32	107	7.6	20	35	63
Sacramento	102	7.6	17	26	32	102	7.6	18	31	53
San Benito	94.3	7.6	15	22	29	94.3	7.6	15	24	44
San Bernardino	106	7.6	19	27	35	106	7.6	22	39	69
San Diego	95.5	7.6	16	21	27	95.5	7.6	16	27	50
San Francisco	79.4	7.6	11	14	16	79.7	7.6	12	17	27
San Joaquin	101	7.6	16	24	30	101	7.6	17	28	50

Table 7: (continued)

	B1					A2				
County	T_{95}* (°F)	1971-2000	2010-2039	2040-2069	2070-2099	T_{95}* (°F)	1971-2000	2010-2039	2040-2069	2070-2099
San Luis Obispo	89.8	7.6	15	21	26	89.7	7.6	16	25	44
San Mateo	83.6	7.6	12	15	18	83.7	7.6	12	18	34
Santa Barbara	85.1	7.6	15	20	26	85.1	7.6	16	25	45
Santa Clara	92.5	7.6	13	19	24	92.6	7.6	14	21	38
Santa Cruz	87.1	7.6	12	17	21	87.3	7.6	13	18	34
Shasta	97.5	7.6	18	27	34	97.6	7.6	20	33	57
Sierra	88.4	7.6	21	32	40	88.4	7.6	24	41	68
Siskiyou	91.1	7.6	18	28	34	91.2	7.6	19	32	53
Solano	99.4	7.6	16	23	28	99.5	7.6	18	27	45
Sonoma	91.9	7.6	14	19	23	92.1	7.6	14	22	41
Stanislaus	101	7.6	18	27	33	101	7.6	18	30	52
Sutter	103	7.6	18	28	35	103	7.6	19	33	60
Tehama	98.8	7.6	18	27	33	98.8	7.6	20	33	56
Trinity	93.7	7.6	17	26	31	93.8	7.6	18	29	48
Tulare	93.1	7.6	21	32	41	93.1	7.6	23	40	68
Tuolumne	88.2	7.6	21	34	42	88.2	7.6	23	40	68
Ventura	87.9	7.6	15	21	26	87.8	7.6	16	28	51
Yolo	103	7.6	17	25	31	103	7.6	19	31	52
Yuba	101	7.6	20	30	38	101	7.6	21	37	63

Note: T_{95} values represent the county average 95th percentile daily maximum temperature from May 1 to October 31 over the historical period (1971–2000). Table shows the average number of days where the daily maximum temperature exceeds the local high-heat threshold from May 1 to October 31 over the analysis period. Projections are based on the A2 scenario and are averaged for four downscaled climate models.

By the end of the century, under both A2 and B1 scenarios, the number of extreme heat days during the summer months was projected to increase in every county in the state (Table 8). Under the B1 scenario, 22 million, or 59 percent, of the state’s current population resided in areas that will have 22.8 to 38 days, a medium exposure, of extreme heat during the summer months by the end of the century. About 1.7 million people, or less than 5 percent of the state’s population, lived in areas that will have more than 38 days, high exposure, of extreme heat during the summer months by the end of the century. Of those with high exposure to extreme heat, about 39 percent, or 650,000 people, also lived in areas with high social vulnerability. The remaining 61 percent of those with high exposure were evenly split among low and medium social vulnerability.

Exposure to extreme heat was much greater under the A2 scenario (Table 9) than under the B1 scenario. By the end of the century, 28 million Californians, about 76 percent of the population, would face more than 38 days of temperatures that currently occur on the hottest 7.6 days of the year. Of those with high exposure to extreme heat, about 37 percent, or 10.1 million people, also lived in areas with high social vulnerability.

Table 8: Population Vulnerability and Extreme Heat Exposure Under the B1 Scenario by the End of the Century

Exposure to extreme heat	Social Vulnerability			Total Population
	Low	Medium	High	
Low (<22.8 days)	3,520,000 (27%)	4,400,000 (34%)	5,220,000 (40%)	13,100,000
Medium (22.8–38 days)	7,630,000 (35%)	7,390,000 (34%)	6,490,000 (30%)	21,500,000
High (>38 days)	513,000 (31%)	496,000 (30%)	652,000 (39%)	1,660,000
Total	11,700,000 (32%)	12,300,000 (34%)	12,400,000 (32%)	36,300,000

Note: Population estimates represent the total number of people living in census tracts according to the tract’s social vulnerability index score and exposure to extreme heat. The percent of the population that these groups represent is shown in parentheses. Population estimates are rounded to three significant figures.

Table 9: Population Vulnerability and Extreme Heat Days Under the A2 Scenario by the End of the Century

Exposure to extreme heat	Social Vulnerability			Total
	Low	Medium	High	
Low (<22.8 days)	- (0%)	- (0%)	- (0%)	-
Medium (22.8–38 days)	2,980,000 (34%)	3,510,000 (40%)	2,260,000 (26%)	8,750,000
High (>38 days)	8,680,000 (32%)	8,780,000 (32%)	10,100,000 (37%)	27,600,000
Total	11,700,000 (32%)	12,300,000 (34%)	12,400,000 (34%)	36,300,000

Note: Population estimates represent the total number of people living in census tracts according to the tract’s social vulnerability index score and exposure to extreme heat. The percent of the population that these groups represent are shown in parentheses. Population estimates are rounded to three significant figures.

Table 6 shows the social vulnerability of population in areas with high exposure (>38 days) to extreme heat under the B1 and A2 scenarios by county. Under the B1 scenario, about 1.7 million people, or less than 5 percent of the state’s population, lived in areas with high exposure to extreme heat. Most of those with high exposure to extreme heat were concentrated in the San Joaquin Valley, with nearly 45 percent of those with high exposure, or 740,000 people, in Fresno County alone (Figure 9). In these areas, the number of extreme heat days would increase 500 percent by the end of the century. About 39 percent of those with high exposure to extreme heat, or 650,000 people, lived in census tracts with a high social vulnerability under the B1 scenario. Those that lived in areas of high exposure and high social vulnerability were concentrated in Fresno and Tulare Counties.

Under the A2 scenario, about 27.6 million people, or about 76 percent of the state's population, lived in areas with high exposure to extreme heat. The population with high heat exposure was concentrated in the Los Angeles and San Diego areas, with 64 percent living in Los Angeles, Riverside, Orange, San Bernardino, and San Diego Counties (Table 10; Figure 10). Nearly 71 percent of those living in areas with high exposure and high social vulnerability were also located in these five counties. Fresno County also had large numbers of people living in areas with high exposure and high social vulnerability. In other counties, there were fewer people in areas with high heat exposure and high social vulnerability, yet, in some cases, they comprised a high percentage of the county population. In Imperial, Monterey, and Merced Counties, for example, more than 70 percent of the population with high exposure to extreme heat also lived in census tracts with high social vulnerability.

Sixteen counties in the state have a historical 95th percentile heat threshold that was 100°F degrees or higher. In these counties, the number of days of extreme heat was projected to increase by an average of 26 days under the B1 scenario and an average of 51 days under the A2 scenario. This was a four- to eight-fold increase in the number of summer days with temperatures exceeding 100°F. While the population in these counties might be more accustomed to high temperatures, the increases in number of high heat days in these areas could pose a greater challenge than increases in areas where the heat threshold is lower.

Table 10: Social Vulnerability of Population in Areas with High Exposure (>38 Days) to Extreme Heat Under the B1 and A2 Scenarios by the End of the Century, by County

	Population Affected Under B1 Scenario				Population Affected Under A2 Scenario			
	Social Vulnerability				Social Vulnerability			
COUNTY	Low	Medium	High	Total	Low	Medium	High	Total
Alameda	0	0	0	0	41,800	9,880	2,100	53,800
Alpine	1,150	0	0	1,150	1,150	0	0	1,150
Amador	6,190	0	0	6,190	32,200	5,790	0	38,000
Butte	0	0	0	0	157,000	61,400	0	218,000
Calaveras	19,500	0	0	19,500	46,500	0	0	46,500
Colusa	0	0	0	0	0	10,100	10,900	21,000
Contra Costa	0	0	0	0	223,000	203,000	134,000	560,000
Del Norte	0	0	0	0	22,800	1,340	4,590	28,700
El Dorado	23,700	15,200	357	39,300	160,000	15,200	357	176,000
Fresno	183,000	203,000	358,000	744,000	183,000	203,000	505,000	891,000
Glenn	0	0	0	0	1,870	22,700	3,350	27,900
Humboldt	54,500	32,200	0	86,700	69,500	53,600	0	123,000
Imperial	0	0	0	0	0	14,600	145,000	160,000
Inyo	4,230	13,200	0	17,400	4,230	13,200	0	17,400
Kern	0	0	0	0	148,000	246,000	387,000	781,000
Kings	15,100	49,300	29,100	93,500	15,100	69,400	62,200	147,000

Table 10: (continued)

	Population Affected Under B1 Scenario				**Population Affected Under A2 Scenario**			
	Social Vulnerability				**Social Vulnerability**			
COUNTY	**Low**	**Medium**	**High**	**Total**	**Low**	**Medium**	**High**	**Total**
Lake	0	0	0	0	38,400	26,400	0	64,800
Lassen	3,350	13,200	0	16,500	21,200	13,200	0	34,400
Los Angeles	0	0	0	0	1,520,000	2,210,000	4,510,000	8,240,000
Madera	36,000	14,500	23,300	73,800	36,000	39,800	68,900	145,000
Mariposa	17,900	0	0	17,900	17,900	0	0	17,900
Mendocino	0	0	0	0	33,300	43,000	9,710	86,000
Merced	7,470	26,200	57,800	91,400	11,700	59,800	171,000	242,000
Modoc	0	0	0	0	0	9,160	0	9,160
Mono	12,900	0	0	12,900	12,900	0	0	12,900
Monterey	0	0	0	0	0	13,800	37,400	51,200
Napa	0	0	0	0	21,500	10,800	0	32,300
Nevada	19,400	0	0	19,400	97,100	0	0	97,100
Orange	0	0	0	0	1,310,000	656,000	795,000	2,760,000
Placer	17,100	0	3,370	20,400	292,000	36,200	3,370	332,000
Plumas	5,790	5,210	0	11,000	15,300	5,200	0	20,600
Riverside	0	0	0	0	710,000	755,000	571,000	2,040,000
Sacramento	0	0	0	0	405,000	590,000	381,000	1,380,000
San Benito	0	0	0	0	0	5,190	6,760	12,000
San Bernardino	19	0	0	19	503,000	916,000	567,000	1,990,000
San Diego	0	0	0	0	1,090,000	988,000	681,000	2,760,000
San Joaquin	0	0	0	0	120,000	329,000	216,000	665,000
San Luis Obispo	0	0	0	0	67,600	39,700	0	107,000
San Mateo	0	0	0	0	0	9,950	0	9,950
Santa Barbara	0	0	0	0	90,600	125,000	47,400	263,000
Santa Clara	0	0	0	0	29,900	679	8,790	39,400
Santa Cruz	0	0	0	0	21,820	4,010	0	25,800
Shasta	0	0	0	0	130,000	48,500	1,290	179,000
Sierra	3,240	0	0	3,240	3,240	0	0	3,240
Siskiyou	0	0	0	0	30,500	12,500	1,400	44,400
Solano	0	0	0	0	174,000	147,000	67,700	389,000
Sonoma	0	0	0	0	13,800	14,500	0	28,300
Stanislaus	0	5,490	0	5,490	59,200	235,000	211,000	505,000
Sutter	0	0	0	0	40,600	26,900	23,300	90,700

Table 10: (continued)

	Population Affected Under B1 Scenario				**Population Affected Under A2 Scenario**			
	Social Vulnerability				**Social Vulnerability**			
COUNTY	**Low**	**Medium**	**High**	**Total**	**Low**	**Medium**	**High**	**Total**
Tehama	0	0	0	0	23,000	30,600	7,050	60,600
Trinity	0	0	0	0	13,900	0	0	13,900
Tulare	28,100	112,000	180,000	321,000	53,600	135,000	227,000	416,000
Tuolumne	49,300	6,460	0	55,800	49,300	6,460	0	55,800
Ventura	0	0	0	0	402,000	210,000	180,000	792,000
Yolo	0	0	0	0	96,800	62,300	33,900	193,000
Yuba	4,590	0	0	4,590	18,800	37,500	14,600	70,900
Total	**513,000**	**496,000**	**652,000**	**1,660,000**	**8,680,000**	**8,780,000**	**10,100,000**	**27,600,000**

Note: Population estimates represent the total number of people living in census tracts with high exposure to extreme heat according to the tract’s social vulnerability index score. Population estimates are rounded to three significant figures.

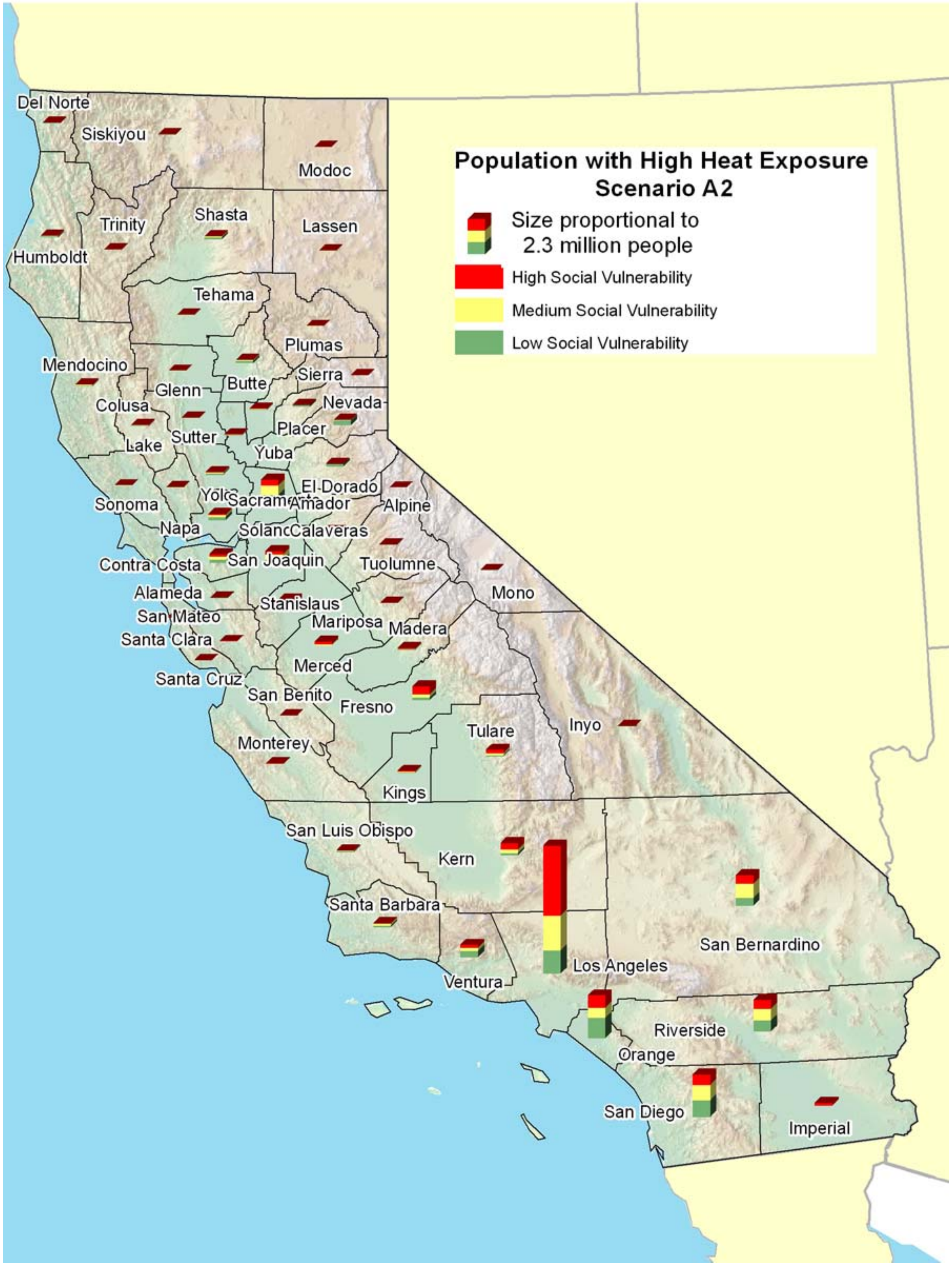

Figure 9: Social Vulnerability of Population in Areas with High Exposure (>38 Days) to Extreme Heat Under the B1 Scenario by the End of the Century, by County

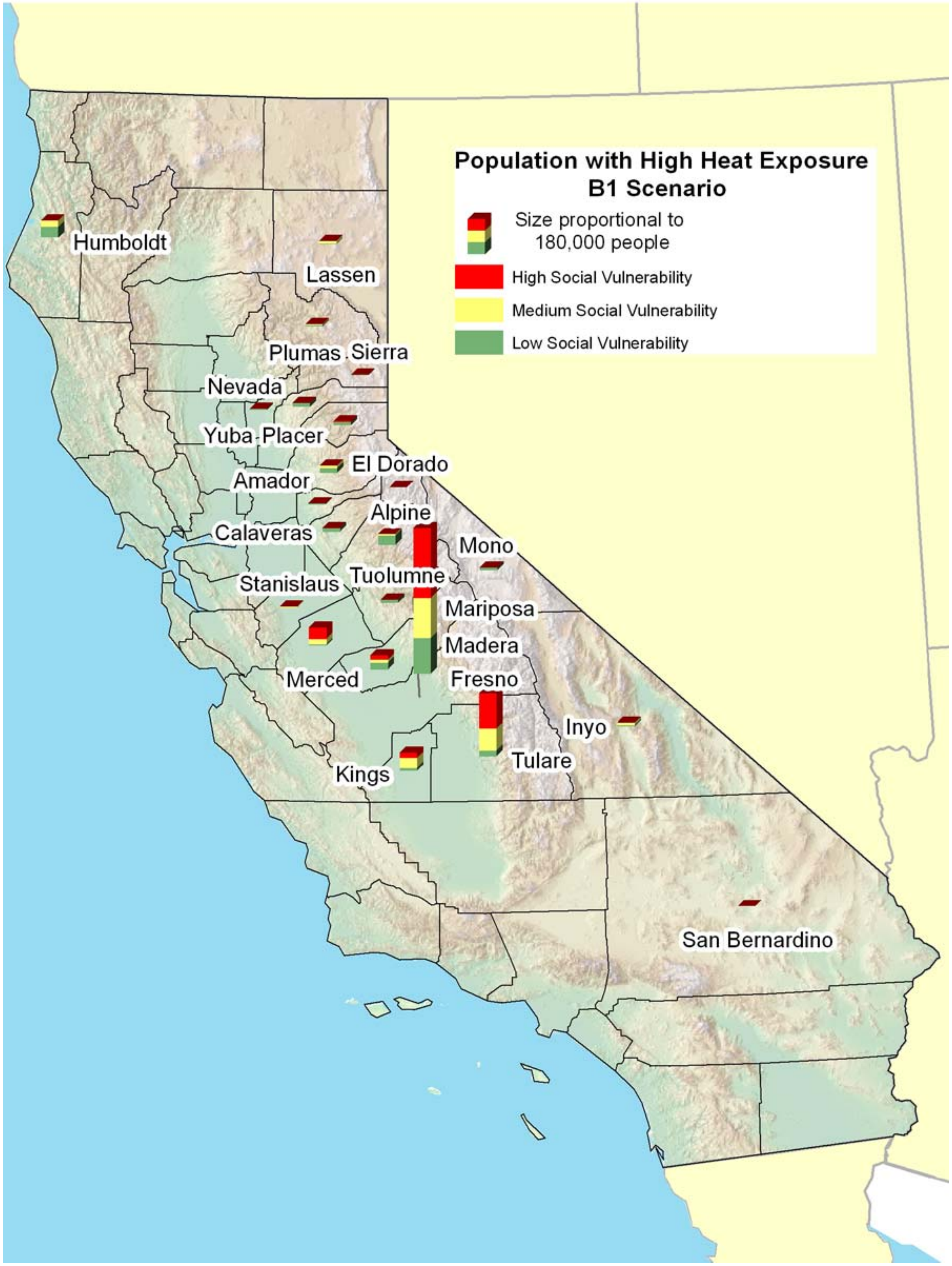

Figure 10: Social Vulnerability of Population in Areas with High Exposure (>38 Days) to Extreme Heat Under the A2 Scenario by the End of the Century, by County

4.2.2 Coastal Flooding

Table 11 shows the social vulnerability of the population with increased exposure to coastal flooding under the B1 and A2 scenarios. These data are presented in graphical form in Figures 11 and 12.

Under the B1 scenario, with a 1.0 meter (m) rise in sea levels, nearly 420,000 people were exposed to coastal flood risk by the end of the century. Under the A2 scenario with a 1.4 m rise in sea levels, more than 480,000 people along the California coast were exposed to coastal flood risk by the end of the century. Under both the A2 and B1 scenarios, about 18 percent of those exposed to coastal flooding lived in areas with high social vulnerability. San Mateo County had a large number of people living in areas with high social vulnerability, as did Marin, Monterey, Orange, and Ventura Counties. About 43 percent of those exposed to flooding from sea level rise lived in areas with a medium social vulnerability. The remainder lived in areas with low social vulnerability.

Sea level rise and social vulnerability showed strong regional trends. Impacts from sea level rise were largely clustered in the San Francisco Bay area and the Los Angeles region, especially Orange County. Social vulnerability, however, was generally low in the Los Angeles region, with the exception of Ventura County, where more than half of those impacted lived in census tracts with high social vulnerability. The San Francisco Bay Area had large numbers of people living in areas with high social vulnerability. The discrepancy between the San Francisco and Los Angeles regions reflect the economic geography of the region. In Los Angeles, the most valuable properties tend to be located along the ocean; in San Francisco, by contrast, the most valuable properties are in the hills overlooking the San Francisco Bay.

Table 11: Social Vulnerability of Population Exposed to Coastal Flooding by the End of Century Under the A2 and B1 Scenario, by County

	B1 Scenario				A2 Scenario			
	Social Vulnerability				Social Vulnerability			
County	Low	Medium	High	**Total**	Low	Medium	High	**Total**
Alameda	7,380	36,700	3,390	**47,500**	11,200	49,700	5,100	**66,000**
Contra Costa	236	1,870	2,220	**4,330**	299	2,470	3,030	**5,800**
Del Norte	1,960	143	289	**2,390**	2,110	162	341	**2,610**
Humboldt	4,560	1,890	0	**6,450**	5,190	2,570	0	**7,760**
Los Angeles	5,990	2,670	1,240	**9,900**	8,200	3,570	1,890	**13,700**
Marin	19,600	4,240	12,100	**35,900**	21,600	4,780	12,900	**39,200**
Mendocino	358	54	204	**616**	379	57	212	**649**
Monterey	816	4,550	10,200	**15,600**	884	2,870	10,500	**14,300**
Napa	545	370	191	**1,110**	569	467	475	**1,510**
Orange	76,600	16,800	7,190	**101,000**	85,400	18,400	7,550	**111,000**
San Diego	1,680	4,580	308	**6,570**	2,030	6,790	483	**9,310**
San Francisco	123	2,480	5,360	**7,960**	359	4,020	5,920	**10,300**
San Luis Obispo	784	278	0	**1,060**	1,020	306	0	**1,320**
San Mateo	21,800	66,300	18,200	**106,000**	22,400	69,400	21,500	**113,000**
Santa Barbara	293	5,030	447	**5,770**	337	5,640	677	**6,660**
Santa Clara	9,810	15,400	157	**25,400**	11,000	19,800	374	**31,200**
Santa Cruz	2,320	7,930	4,210	**14,500**	2,620	8,620	4,780	**16,000**
Solano	1,030	5,870	3,710	**10,600**	1,100	6,900	4,270	**12,300**
Sonoma	971	233	0	**1,200**	975	266	0	**1,240**
Ventura	4,500	1,540	7,470	**13,500**	5,760	1,870	8,670	**16,300**
Total	161,000	179,000	76,900	**417,000**	**184,000**	**209,000**	**88,700**	**481,000**

Note: Population estimates represent the total number of people living in census tracts exposed to coastal flooding according to the tract’s social vulnerability index score. Population estimates are rounded to three significant figures.

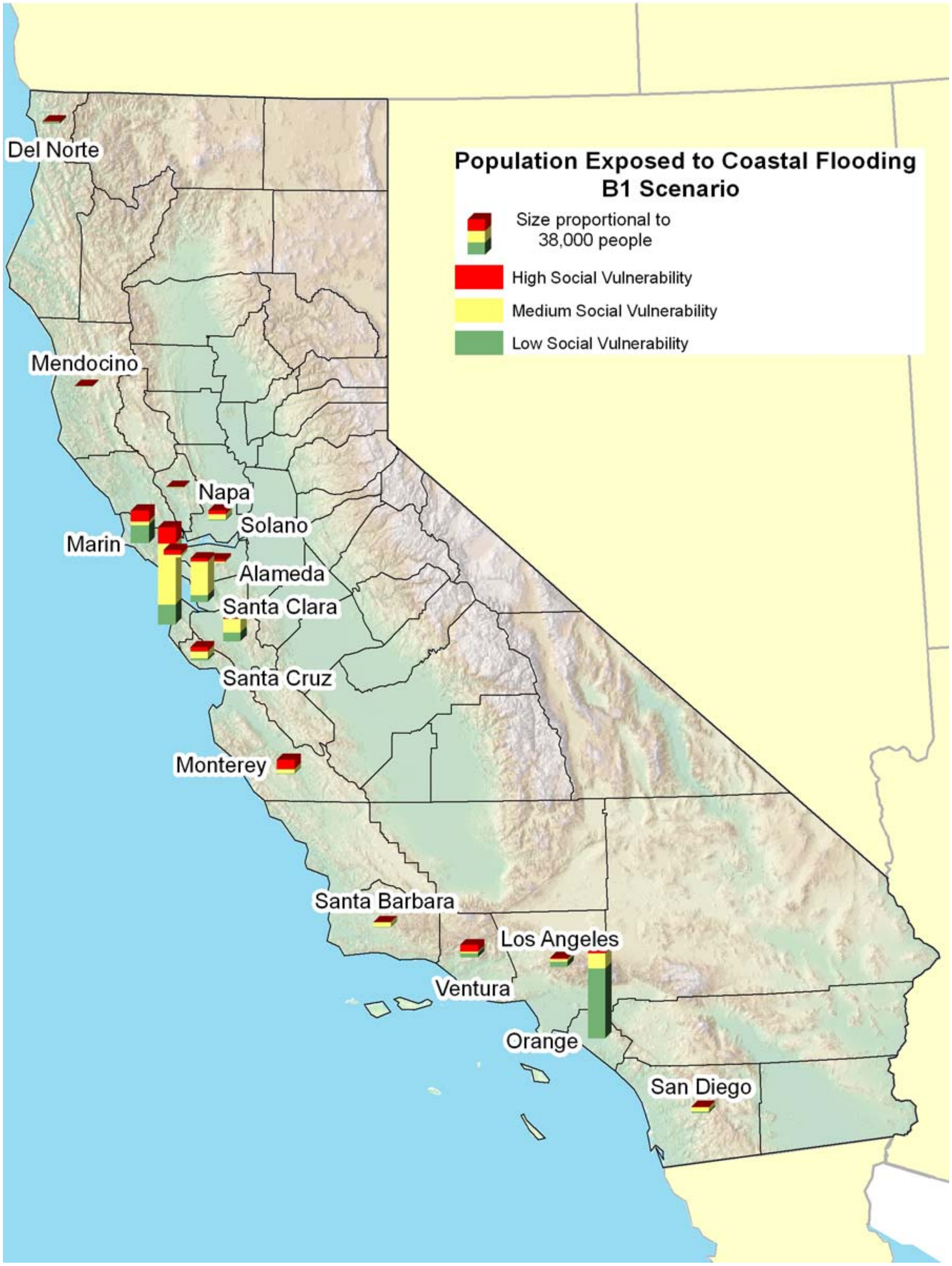

Figure 11: Social Vulnerability of Population Exposed to Coastal Flooding Under the B1 Scenario by the End of the Century, by County

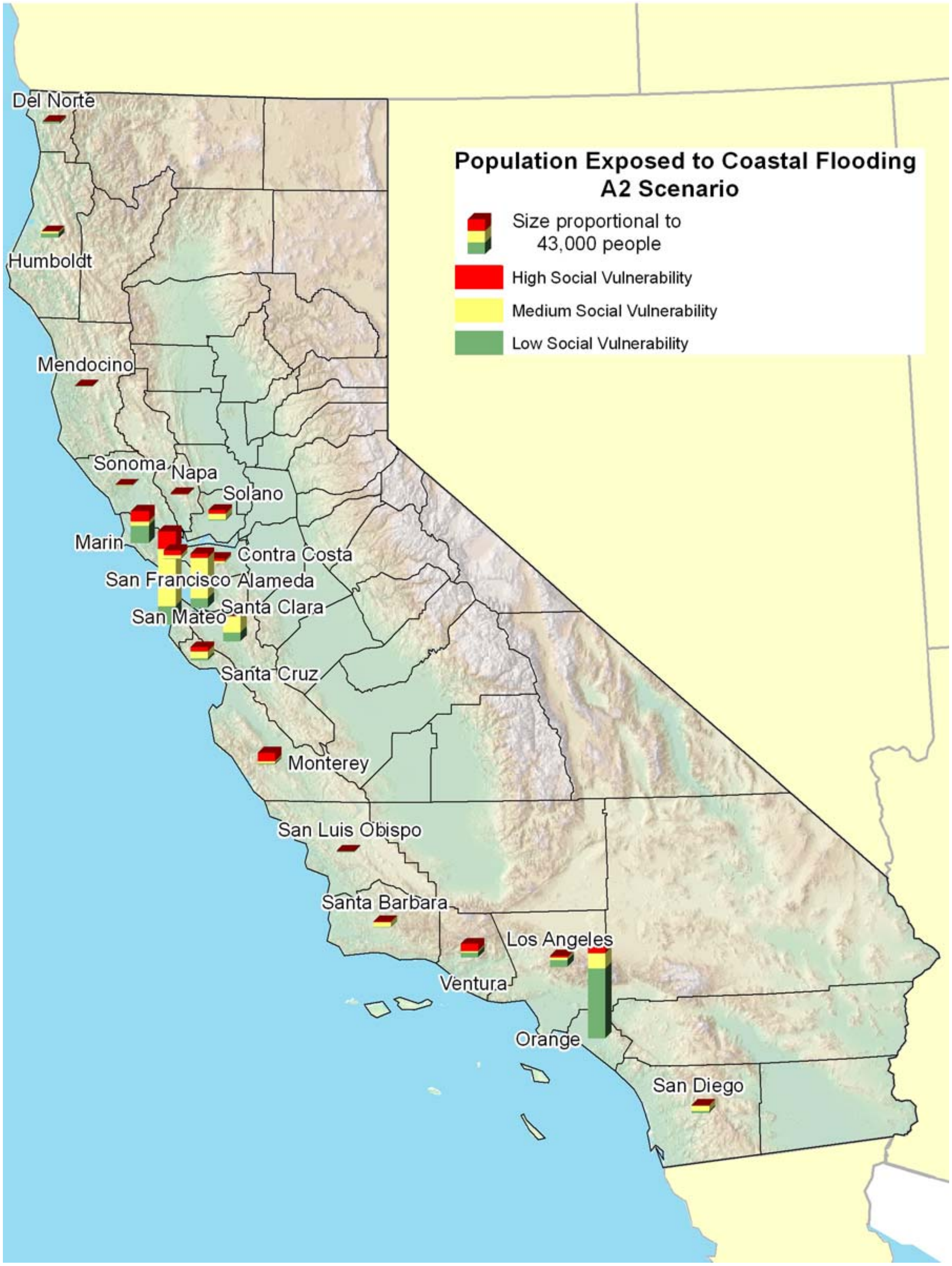

Figure 12: Social Vulnerability of Population Exposed to Coastal Flooding Under the A2 Scenario by the End of the Century, by County

4.2.3 Wildfire

Figures 13 and 14 show the probability of one or more fires over a thirty-year period under historic conditions and as modeled for the B1 and A2 scenarios. The modeled probability of future wildfires was highest in the Sierra foothills and along the coast, especially in Southern California. Under the A2 and B1 scenarios, the probability of wildfire was projected to increase across California through the end of the century. Larger increases were projected for the A2 scenario compared to the B1 scenario. By the end of the century, the probability of a wildfire over large swaths of Southern California was projected to be 45 percent or higher for the A2 scenario.

The number of Californians exposed to wildfires and their social vulnerability are shown in Tables 12 and 13. Under the B1 scenario, approximately 8.4 million people lived in areas with a wildfire risk in excess of 33 percent by the end of the century, which was categorized as high exposure. All of those living in areas with a high exposure to wildfire were in southern California (Table 14; Figure 15). Of those living in areas with high exposure to wildfire, about one-third were also living in areas with high social vulnerability. Los Angeles County had large numbers of people living in areas with both high exposure and high vulnerability, as did San Diego, San Bernardino, and Orange Counties (Table 14).

Table 12: Social Vulnerability of Population with Increased Probability of Wildfire Under the B1 Scenario, 2070–2099

	Social Vulnerability			
Wildfire Exposure	**Low**	**Medium**	**High**	**Total**
Low (<14.2%)	3,690,000	4,990,000	4,030,000	12,700,000
Medium (14.2 to 33.3%)	5,010,000	4,660,000	5,540,000	15,200,000
High (>33.3%)	2,950,000	2,640,000	2,780,000	8,380,000
Total	11,700,000	12,300,000	12,400,000	36,300,000

Note: Population estimates represent the total number of people living in census tracts according to the tract's social vulnerability index score and exposure to wildfire. Population estimates are rounded to three significant figures.

While exposure to wildfire was greater under the A2 scenario, both scenarios showed similar statewide trends. More than 11 million people lived in areas with a high exposure to wildfire by the end of the century under the A2 scenario, or 34 percent more people than under the B1 scenario (Table 13). Of those living in areas with high exposure to wildfires, nearly 4.4 million people, or 39 percent, also lived in areas with high social vulnerability. Many of those living in areas with both high exposure and high social vulnerability were in Los Angeles County (Table 14; Figure 16). Large numbers of people living in areas with high exposure and high social vulnerability were also found in San Diego, San Bernardino, and Orange Counties (Table 14).

Table 13: Social Vulnerability of Population Exposed to Wildfire Under the A2 Scenario, 2070–2099

	Social vulnerability			
Wildfire Exposure	**Low**	**Medium**	**High**	**Total**
Low (<14.2%)	3,540,000	4,840,000	3,980,000	12,400,000
Medium (14.2 to 33.3%)	4,490,000	4,280,000	3,990,000	12,800,000
High (>33.3%)	3,630,000	3,180,000	4,380,000	11,200,000
Total	11,700,000	12,300,000	12,400,000	36,300,000

Note: Population estimates represent the total number of people living in census tracts according to the tract's social vulnerability index score and exposure to wildfire. Population estimates are rounded to three significant figures.

Table 1: Social Vulnerability of Population in Areas with High Exposure to Wildfire by County, 2070–2099

	Population with High (>33.3%) Probability Under B1 Scenario				**Population with High (>33.3%) Risk Under A2 Scenario**			
	Social Vulnerability				**Social vulnerability**			
COUNTY	**Low**	**Medium**	**High**	**Total**	**Low**	**Medium**	**High**	Total
Los Angeles	1,180,000	1,540,000	2,170,000	4,890,000	1,480,000	2,010,000	3,720,000	7,210,000
Orange	589,000	72,800	34,900	697,000	830,000	236,000	129,000	1,190,000
Riverside	12,800	3,520	5,290	21,600	67,700	8,630	9,300	85,700
San Bernardino	266,000	427,000	256,000	949,000	280,000	491,000	362,000	1,130,000
San Diego	666,000	560,000	304,000	1,530,000	593,000	320,000	132,000	1,040,000
San Luis Obispo	0	0	0	0	15,200	18,000	0	33,200
Santa Barbara	30,200	0	0	30,200	67,800	18,200	3,400	89,400
Ventura	214,000	39,200	9,160	263,000	301,000	72,600	24,200	398,000
Total	**2,950,000**	**2,640,000**	**2,780,000**	**8,380,000**	**3,630,000**	**3,180,000**	**4,380,000**	**11,200,000**

Note: Population estimates represent the total number of people living in census tracts with high exposure to wildfire according to their social vulnerability index score. Population estimates are rounded to three significant figures.

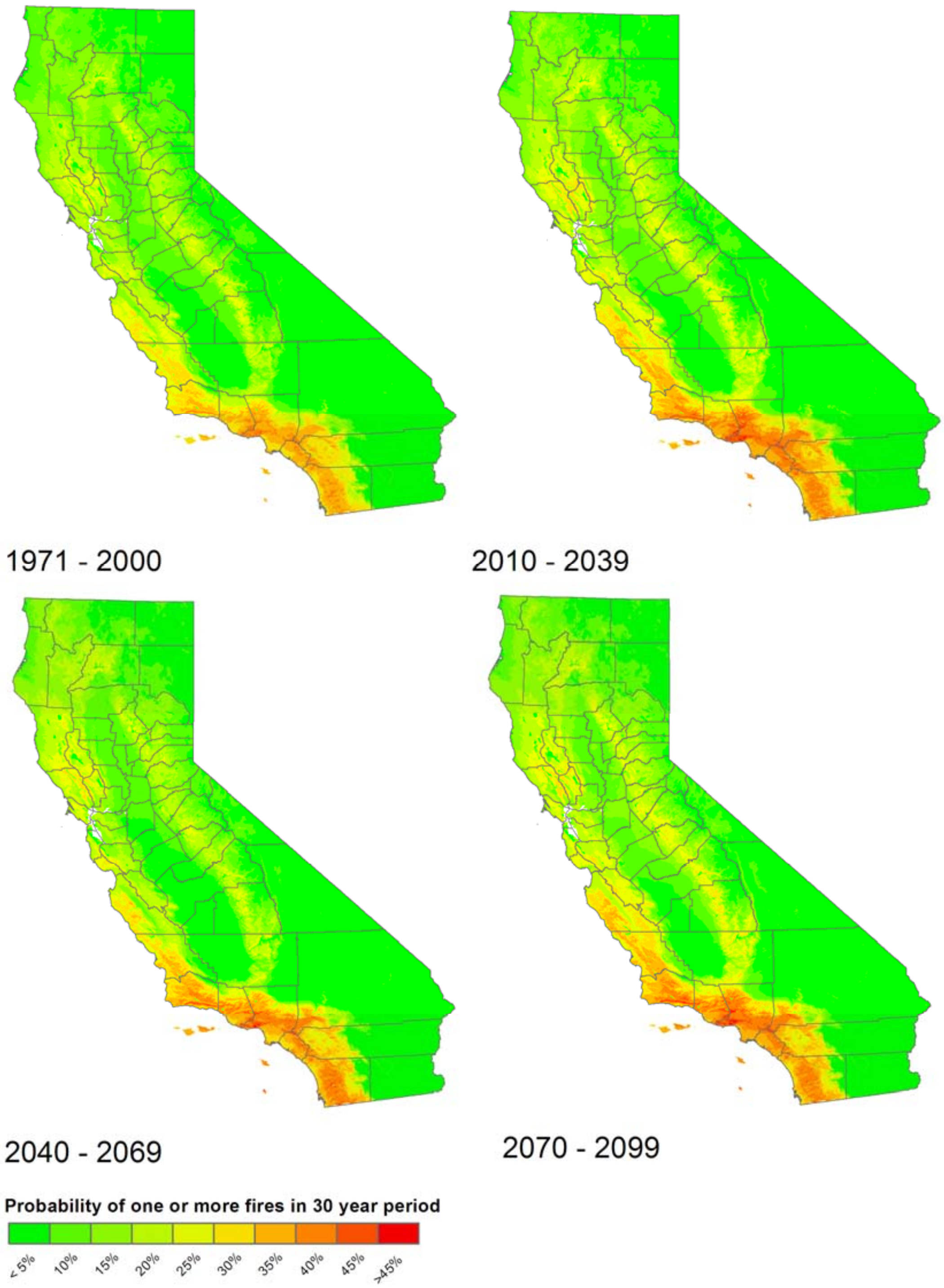

Figure 13: Probability of One or More Fires over the 30-year Analysis Periods Under the B1 Scenario

Note: Data are from Krawchuk and Moritz (2012) and are based on GFDL Model and UPlan Base-Case Growth Scenario.

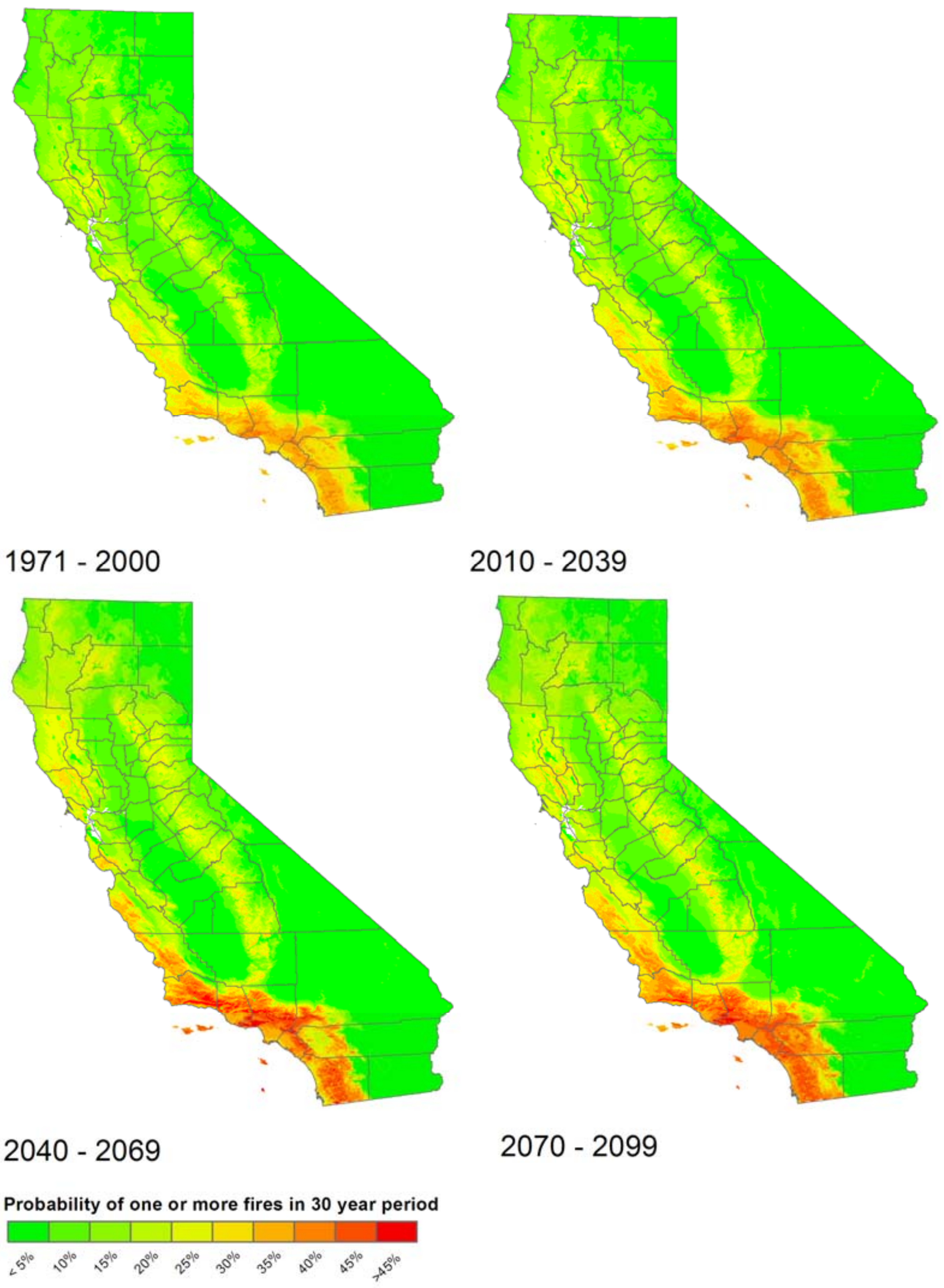

Figure 14: Probability of One or More Fires over the 30-year Analysis Periods Under the A2 Scenario

Note: Data are from Krawchuk and Moritz (2012) and are based on GFDL Model and UPlan Base-Case Growth Scenario.

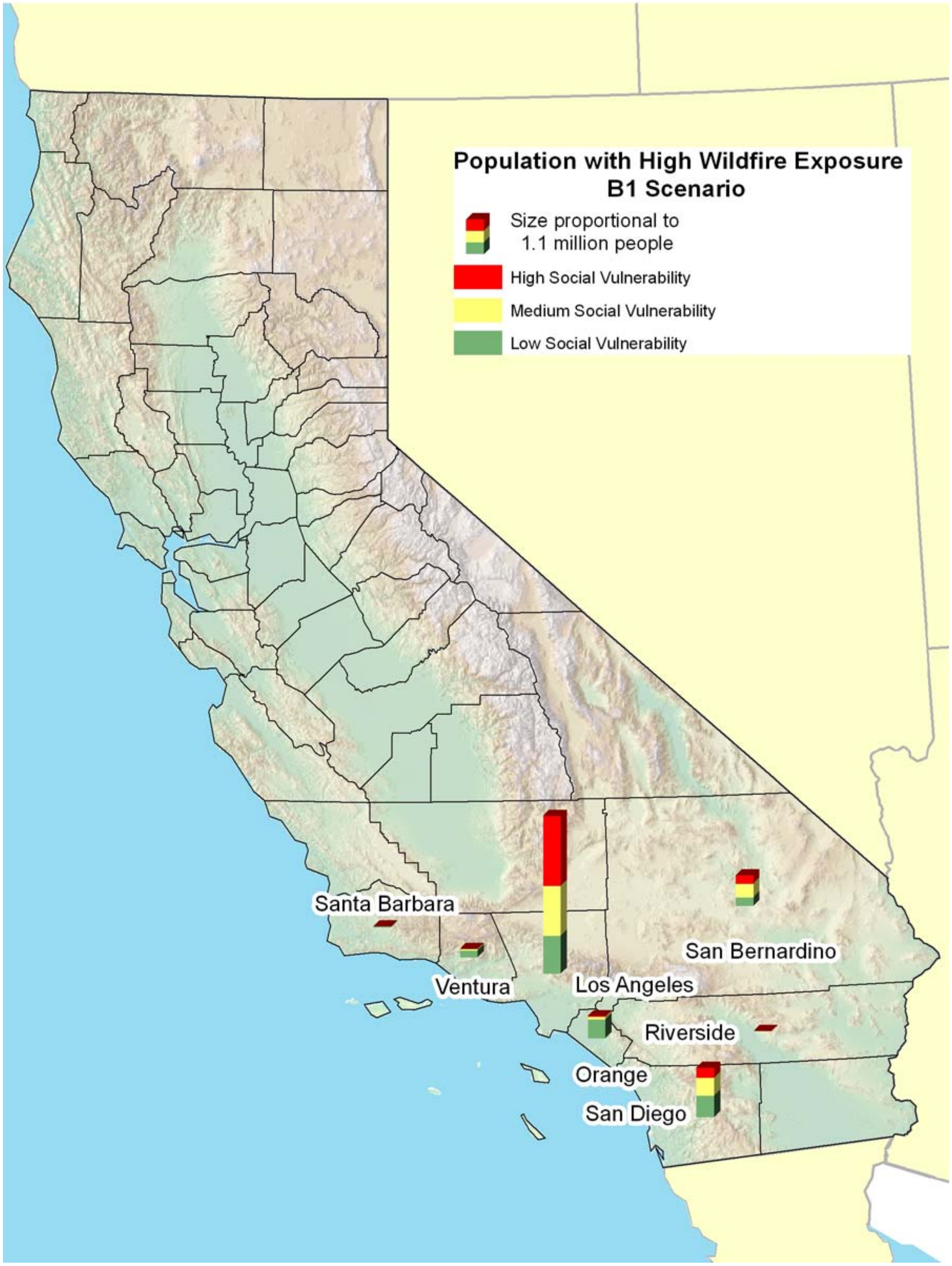

Figure 15: Social Vulnerability of Population with High Wildfire Exposure Under the B1 Scenario by the End of the Century, by County

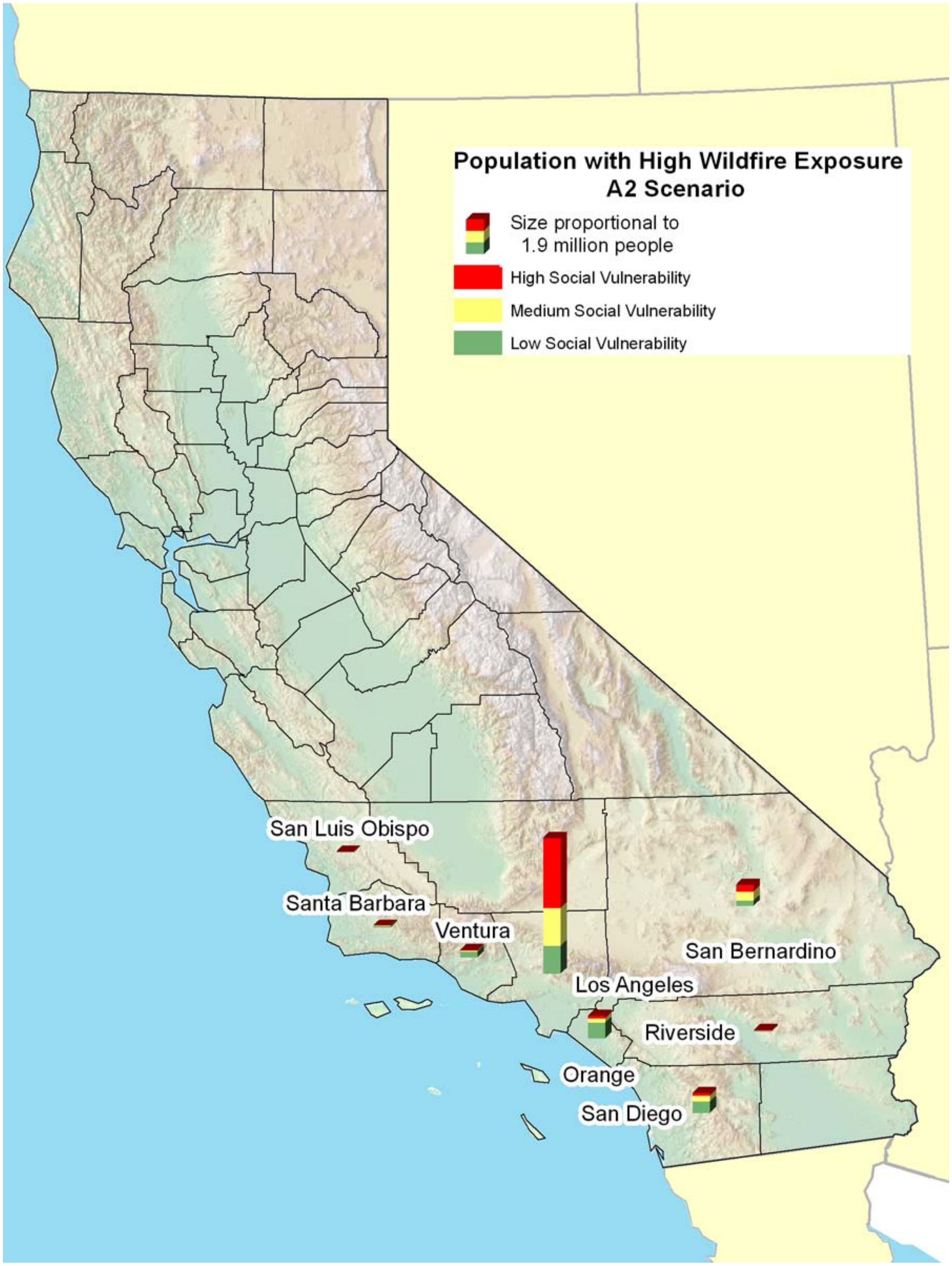

Figure 16: Social Vulnerability of Population with High Exposure to Wildfire Under the A2 Scenario by the End of the Century, by County

4.2.4 Air Quality

Figure 17 shows average particulate matter concentration under present (2000–2006) conditions and by mid-century, using data from Kleeman et al. (2010). Under historic climate conditions, an estimated 10.9 million Californians lived in census tracts with $PM_{2.5}$ levels above the California standard. By 2050, this number is projected to increase. By 2050, an estimated 14 million residents lived in census tracts with $PM_{2.5}$ levels projected to be above the California standard in 2050, which is categorized as high exposure (Table 15). About half of those with high exposure also lived in areas with high social vulnerability. Those in areas with high social vulnerability and high $PM_{2.5}$ concentration were largely concentrated in southern California (4.2 million) and along the San Francisco Bay (Figure 18). Those in areas with high exposure and high vulnerability are especially high in Los Angeles County, with significant numbers also in Orange, Santa Clara, San Francisco, Imperial, and Alameda counties (Table 16).

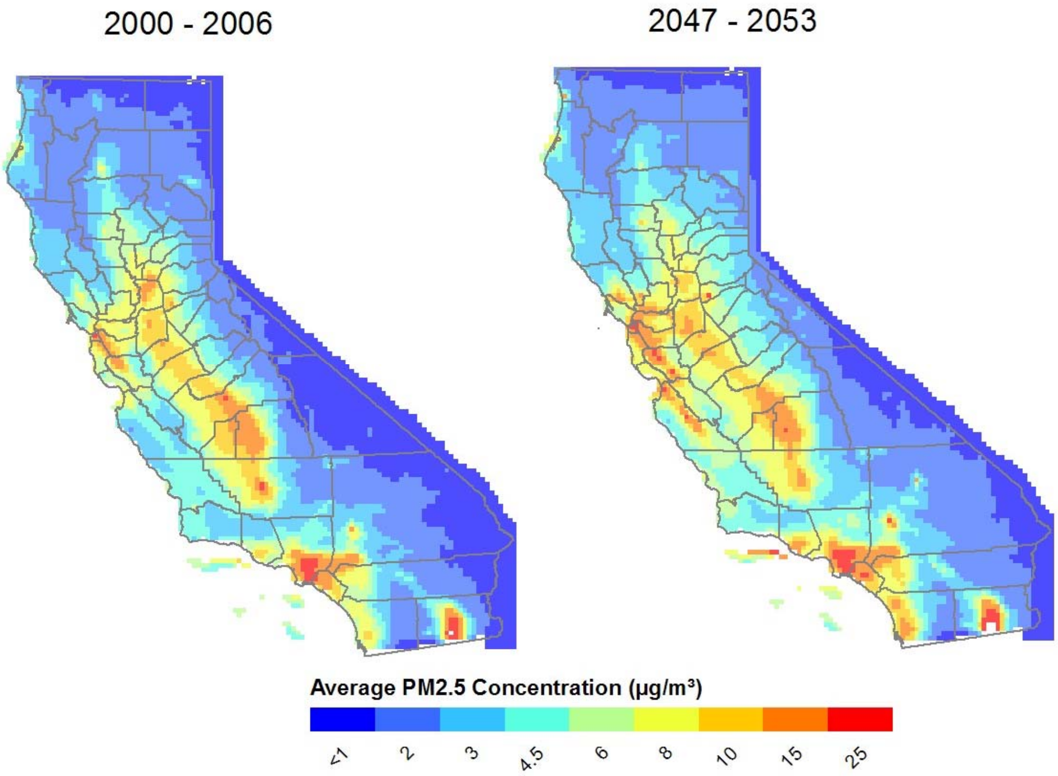

Figure 17: Average Particulate Matter ($PM_{2.5}$) Concentration Under Present (7-yr Average 2000–2006) and Projected Future Conditions (2047–2053)

Note: Projections are based on the NCAR B06.44 “Business as Usual” emissions scenario.

Table 2: Social Vulnerability of Population Exposed to $PM_{2.5}$ Concentrations, 2047–2053

	Social Vulnerability			
Exposure to $PM_{2.5}$	**Low**	**Medium**	**High**	**Total**
Low (<6 µg/m³)	1,970,000	1,390,000	596,000	3,950,000
Medium (6-12 µg/m³)	7,310,000	6,350,000	4,660,000	18,300,000
High (>12 µg/m³)	2,380,000	4,560,000	7,100,000	14,000,000
Total	11,700,000	12,300,000	12,400,000	36,300,000

Note: Population estimates represent the total number of people living in census tracts according to the tract's social vulnerability index score and exposure to particulate matter. Population estimates are rounded to three significant figures.

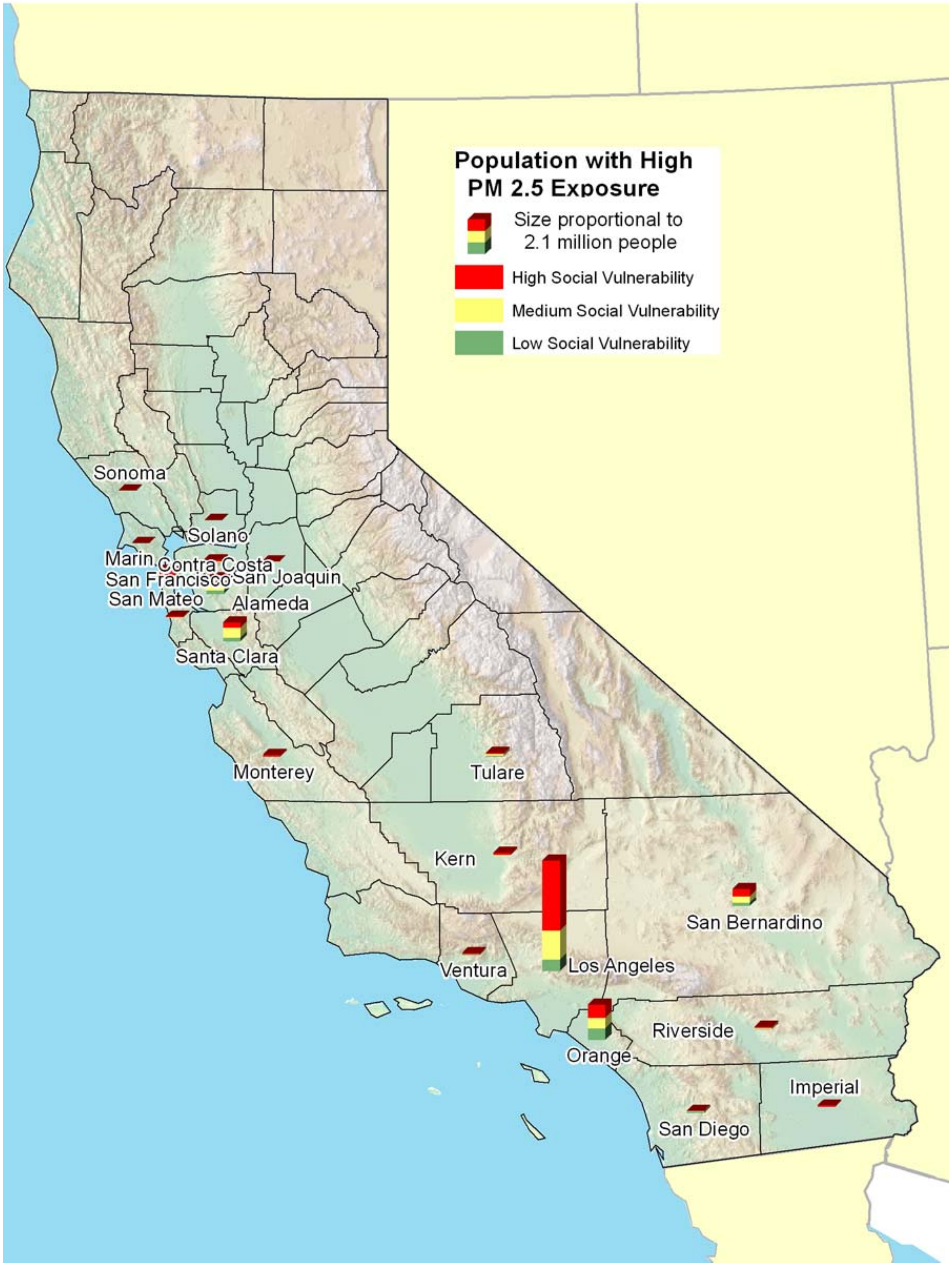

Figure 18: Social Vulnerability of Population in Census Tracts with High Exposure to PM$_{2.5}$ Concentration, 2047–2053

Table 3: Social Vulnerability of Population in Tracts with High Exposure to $PM_{2.5}$ Concentrations, 2047–2053

	Social Vulnerability			
County	Low	Medium	High	County Total
Alameda	202,000	426,000	321,000	949,000
Contra Costa	41,200	55,200	89,600	186,000
Imperial	0	11,100	79,200	90,300
Kern	0	33,800	142,000	176,000
Los Angeles	693,000	1,720,000	4,190,000	6,610,000
Marin	7,470	0	0	7,470
Monterey	1,140	12,600	99,600	113,000
Orange	700,000	645,000	776,000	2,120,000
Riverside	48,000	57,400	63,900	169,000
San Bernardino	184,000	399,000	433,000	1,020,000
San Diego	68,700	43,700	0	112,000
San Francisco	65,800	234,000	313,000	612,000
San Joaquin	0	20,700	0	20,700
San Mateo	21,100	21,000	52,000	94,000
Santa Clara	217,000	615,000	309,000	1,140,000
Solano	26,400	15,900	0	42,400
Sonoma	15,300	19,800	0	35,200
Tulare	49,100	83,000	82,700	215,000
Ventura	14,200	33,800	76,100	124,000
Total	**2,350,000**	**4,450,000**	**7,030,000**	**13,800,000**

Note: Population estimates represent the total number of people living in census tracts with high exposure to particulate matter concentrations according to the tract’s social vulnerability index score. Population estimates are rounded to three significant figures.

SECTION 5:
Discussion

5.1 Climate Impacts and Social Vulnerability

The State of California faces a range of impacts from global climate change, including increases in extreme heat, wildfires, and coastal flooding, and erosion. Changes are also likely to occur in air quality, water availability, and the spread of infectious diseases. A significant body of research has focused on understanding the physical impacts of climate change. It has become increasingly clear that any analysis of those affected by climate change must include a broader discussion of social vulnerability to these impacts. Social vulnerability is defined as the susceptibility of a given population to harm from exposure to a hazard, directly affecting its ability to prepare for, respond to, and recover. Vulnerabilities, like lack of access to a vehicle or other means of transportation, are shaped by intervening conditions that are not tied to a specific hazard but will greatly determine the human impact of the disaster and the specific needs for preparedness, response, and recovery (Hewitt 1997).

In this study, we analyzed the potential impacts of climate change by using recent downscaled climate model outputs, creating a variety of statistics and visualizations to show their distribution across the state. To understand how the population exposed to these impacts would be affected, we looked at social vulnerability.

Our main findings include the following:

- By the end of the century, under both A2 and B1 scenarios, the number of extreme heat days during the summer months is projected to at least double and in some areas increase by 500 percent. Impacts are largest in the A2 scenario and in inland and southern parts of California. More than 20 million Californians (59 percent) live in areas that will have three times as many extreme heat days per year under the more conservative scenario B1, and more than three quarters of the state population will experience a five-fold increase in extreme heat days under the A2 scenario. Of this latter population, about 37 percent, or 10.1 million people, also live in areas with high social vulnerability.

- Sixteen counties in the state have a 95th percentile heat threshold that is 100 degrees or higher. In these counties, the number of days of extreme heat is projected to increase by an average of 26 days under the B1 scenario and an average of 51 days under the A2 scenario. But while warmer temperatures will affect all Californians, it will be especially problematic for those with heightened vulnerabilities. Large numbers of socially vulnerable populations can be found throughout California but are concentrated in Los Angeles, Orange, San Diego, and San Bernardino counties. Additionally, some counties have smaller numbers of highly vulnerable populations but a much larger percent of their total population are highly vulnerable.

- Mean sea level along the California coast is projected to rise from 1.0 to 1.4 m by the end of the century under the B1 and A2 scenarios, respectively. It is estimated that a 1.0 m and a 1.4 m rise in sea levels will expose 420,000 people and 480,000 people, respectively, to a 100-year flood event. Sea level rise induced coastal flooding is largely centered on the San Francisco Bay Area and the Los Angeles region, especially Orange County. Social vulnerability, however, is generally low in the Los Angeles region, with the exception of Ventura County, where more than half of those impacted exhibit a high social vulnerability. The San Francisco Bay Area has large numbers of highly vulnerable populations, with more than half of the population at risk of inundation in Contra Costa, San Francisco, and Monterey counties scoring in the top tercile for social vulnerability. The discrepancy between vulnerability in the San Francisco and Los Angeles regions reflects the economic geography of the region. In Los Angeles, the most valuable properties tend to be located along the ocean, while in San Francisco the wealthier communities are in the hills.
- The likelihood of wildfire is projected to increase across California through the end of the century under both the A2 and B1 scenarios. Larger increases are projected for the A2 scenario compared to the B1 scenario. Southern California has an especially high probability of wildfire. By the end of the century, the probability of a fire over large swaths of southern California is projected to be 45 percent or higher. Approximately 8.4 million people live in areas with a wildfire probability in excess of 33 percent under the B1 scenario, which was categorized as high exposure; 2.8 million of these people live in census tracts with high social vulnerability. An estimated 11.2 million people live in areas with high exposure to wildfire by the end of the century under the A2 scenario, or 34 percent more people than under the B1 scenario. Of those living in areas with high exposure to wildfires, 4.4 million people, or 39 percent, also live in areas with high social vulnerability.
- Particulate matter levels above the current California standard are a major health threat that contributes to asthma, heart disease, cancer and other ailments. Currently, 15 percent of the California's population has $PM_{2.5}$ levels exceeding this threshold, and by 2050 there will be a projected increase to 39 percent. An estimated 14 million current residents live in these highly impacted areas, half of whom also live in areas with high social vulnerability. The large number of highly impacted and highly vulnerable residents in Los Angeles County represents a profound geographic concentration of potential air quality effects. Projecting air quality changes due to climate change is a rapidly developing scientific field, and the current science serves to highlight areas of concern and raise questions, but is also limited by factors such as wind currents and changing local land use and transportation patterns.

Note that the climate impacts evaluated here represent only a subset of potential impacts. California will also likely experience a range of other direct and indirect impacts, including changes in ozone concentrations, the frequency and intensity of droughts, the frequency and intensity of riverine floods, etc. These impacts were not evaluated in this analysis because data were not yet available to evaluate these impacts geographically.

Furthermore, impacts associated with the medium to medium-high greenhouse gas emissions scenarios from the IPCC are evaluated. As a result, this study does not provide the full range of possible future emissions scenarios and does not reflect the worst case climate change impacts that could occur. It is of note that current greenhouse gas emissions are exceeding those of even the high emissions scenarios. These analyses should be updated as more and better data become available.

Finally, the population estimates in this analysis are based on current population figures, as reported in the U.S. Census. The total state population, however, is projected to reach 60 million by 2050, a 60 percent increase over 2000 levels (CA Department of Finance 2007). Our analysis does not use population projections because these projections are not available at the census tract level. The actual rate and distribution of population growth, and social and economic change will play a key role in shaping vulnerability in the future and should be evaluated in future studies.

5.2 Value of a Social Vulnerability Analysis

Within the hazards literature, it is widely accepted that risk is a function of exposure and vulnerability to that impact. Much of the early literature on climate change focuses on modeling climate impacts, reflecting exposure to a particular hazard. Although still limited, there is growing interest in understanding and evaluating social vulnerability to climate change in recent years. For example, Heberger et al. (2009) found that a 1.4 meter rise in sea levels will put 480,000 people at risk of a 100-year flood event along the California coast, given year 2000 population levels. A demographic analysis revealed large numbers of people at risk with heightened vulnerability, including some regions with disproportionate numbers of low-income households and communities of color. Furthermore, they noted that given the high cost and the likelihood that individuals and state and local agencies will not protect everything, adaptation raised additional environmental justice concerns in decisions about who and what to prioritize in adaptation planning (Heberger et al. 2009). Likewise, Oxfam America (2009) published a research report that examined social vulnerability to four climate hazards (drought, flooding, hurricane force winds, and sea level rise) in the 13-state U.S. Southeast. The Oxfam study used a social vulnerability index to identify hot spots that are at particularly high risk to climate impacts. Additionally, the NOAA Coastal Services Center and University of South Carolina Hazards and Vulnerability Research Institute published data and maps of the Social Vulnerability Index to assist coastal communities with integrating social vulnerability analyses into planning (HVRI 2011b). Like previous studies, the results of this analysis show that some communities are at greater risk to climate impacts as a result of high exposure and high social vulnerability.

The creation of an index is useful for assessing overall vulnerability and comparing areas within the state. An index-based approach allows analysis across the state and within counties to identify areas where efforts are especially needed to build community resilience. Strategies for building community resilience to climate change, however, will benefit from being tailored to the projected climate change impacts in a given area, and the social groups who have heightened vulnerability within that area. Both the results of the index scoring and the results for each individual vulnerability factor included in the index would be valuable in assessing social vulnerability to climate change.[2]

Understanding vulnerability factors and the populations that exhibit these factors is critical for crafting effective climate change adaptation policies and response strategies. For example, a vulnerability analysis can highlight geographic areas where targeted assistance is needed, and be used to guide discussions about how to distribute climate adaptation funds. Additionally, it can be useful for identifying which adaptation strategies would be most effective in a particular area. For example, efforts to encourage residents to install air conditioners may not be effective among some highly vulnerable populations that may not be able to afford higher energy bills that result from using these devices.

Vulnerability indicators, however, simplify complex relationships and do not account for contexts in which the relationship between the social characteristic and vulnerability may be reversed. For example, not having an adult household member who speaks English has been found to increase vulnerability, households with this characteristic may actually be less vulnerable in a community where information is shared through social networks communicated in a language other than English. In other words, some conditions are strengths at times, vulnerabilities at others.

It is important to note that there may be highly vulnerable people within a low vulnerability tract. The common geographic denominator for most of the data analyzed was the census tract, of which there were 7,049 in California in 2000. For a state of 36 million people, this means that the average tract contains about 7,000 people. Whenever a population's characteristics are averaged across large areas, smoothing is inevitable and local variation within that area is lost. A census tract with a relatively low social vulnerability score, indicates a populace that is above average in terms of health and income. Within that same tract, however, there may be families living in poverty, senior citizens, or disabled persons that are more vulnerable and likely to require assistance in responding to and recovering from a natural disaster or other disturbances.

Additionally, one must use caution when comparing urban and rural areas. Densely populated areas tend to have a much larger number of highly vulnerable populations compared to less-populated rural areas. In some of the rural areas, however, a larger percentage of the population is characterized by high social vulnerability. This has implications for adaptation planning and implementation, much of which will occur at the local level. For example, highly impacted areas with small populations have a much smaller population base on which to spread the costs of adaptation. As a result, additional support for adaptation planning and implementation might be needed in these rural areas.

Finally, some indicators of vulnerability are not intended to measure progress toward more resilient communities, e.g., race and age characteristics of a community will not change through efforts to build resilience. Thus, these indicators will not be useful in measuring the effect of

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[2] We provide maps showing vulnerability factors across the state at www.pacinst.org. These maps can be accessed by agencies, community groups, and individuals to help inform climate adaptation efforts.

these efforts. Separate indicators will likely be needed to track climate planning and action processes.

5.3 Study Limitations

A vulnerability index that integrates vulnerabilities with multiple projected climate impacts was constructed, rather than a separate index for each distinct type of impact (flooding, extreme heat, etc.). This allows the index to estimate relative social vulnerability to climate change overall, but also provides a limited estimate of vulnerability to the particular impacts projected in an area. In areas where one climate change impact is highly unlikely, the vulnerability score still includes factors that are unique to this impact. For example, in an area with very low projected increases in extreme heat the vulnerability score still includes consideration of the percentage of households with air conditioning – a factor only relevant to vulnerability to extreme heat.

The Census Bureau's smallest measurement area is the block. In cities, the description is fitting, as they are often precisely a city block, while they tend to be much larger in rural areas. With more than 530,000 blocks in California, data aggregated at this scale can show a great deal more detail. Certain demographic variables are published at the block level, such as population and race. However, much of the data used to compile an indicator of social vulnerability is simply not available at this scale, including data from public health surveillance such as numbers of pregnant women or obese youth.

Our social vulnerability index provides a score for an area based on a measure of vulnerability to all climate change impacts, even though only one impact may affect that given area. For instance, a coastal neighborhood may be at high risk of coastal flooding and very low risk of other impacts, yet the vulnerability index takes into consideration the population's vulnerability to all impacts, including those unlikely to occur in that area. In this case, the community may have a low percentage of households with air conditioners, which would lower their vulnerability score, but that condition is unlikely to have much effect on the impact of climate change because they are at low risk of extreme heat events.

SECTION 6:
Conclusions and Recommendations

6.1 Conclusions

The State of California faces a range of impacts from climate change, including increases in extreme heat, wildfires, and coastal flooding and erosion. Changes are also likely to occur in air quality, water availability, and the spread of infectious diseases. To date, a great deal of research has been done to forecast the physical effects of climate change, while less attention has been given to the factors that make different populations more or less vulnerable to harm from such changes. While disaster events may not discriminate, impacts on human populations are shaped by intervening conditions that determine the human impact of the event and the specific needs for preparedness, response, and recovery.

Climate risk is a function of exposure and vulnerability. To compare overall social vulnerability to climate change among areas within the state, a single vulnerability index that combines data from 19 vulnerability factors was used. The authors calculated a vulnerability index for each of the 7,049 census tracts in the state. The vulnerability index score maps were overlaid with maps of projected exposure to extreme heat, particulate matter, coastal flooding, and wildfire to identify areas with high social vulnerability and high projected exposure to climate change disturbances. The areas of overlap indicated those areas with heightened risk of being impacted by these climate changes as a result of exposure and social vulnerability.

Understanding vulnerability factors and the populations that exhibit these factors is critical for crafting effective climate change adaptation policies and response strategies. For example, a vulnerability analysis can highlight geographic areas where targeted assistance is needed and be used to guide discussions about how to distribute climate adaptation funds. Additionally, it can be useful for identifying which adaptation strategies would be most effective in a particular area. For example, efforts to encourage residents to install air conditioners may not be effective among some highly vulnerable populations that may not be able to afford higher energy bills that result from using these devices.

6.2 Recommendations

Climate changes are inevitable, and adaptation to unavoidable impacts must be evaluated, tested, and implemented.

Local, regional, and state climate analyses have emphasized climate impacts and mitigation strategies. Yet, some degree of climate change is now unavoidable. Communities must begin developing and implementing adaptation plans.

Local governments or regional planning agencies should conduct detailed studies to better understand the potential impacts of climate change on their communities.

The analysis presented here is an initial estimate of the impacts of climate change for California using the best research available at a statewide level. More detailed assessments of local impacts and potential responses are needed.

Climate analyses should include an evaluation of social vulnerability.

A significant body of research has focused on understanding the physical impacts of climate change. Social vulnerability is often poorly understood and rarely integrated into climate assessments. Additional work is needed to integrate social vulnerability into climate adaptation and response strategies.

Local planning processes need to involve communities most vulnerable to harm when developing appropriate preparation and adaption strategies.

The particular needs of vulnerable communities, and appropriate adaptation policies, are best identified and developed through processes in which the affected communities are at the center of decision making. The complex intersection of diverse factors of vulnerability, such as access to transportation, legal residency, income, and language abilities, produces a context in which the people living in these communities can best elaborate how to take proactive measures to prevent disproportionate harm.

6.2.1 Research Needs

Further research is needed to develop geographically disaggregated population projections.

Population projections are available from a number of sources, such as the U.S. Census Bureau, the California Department of Finance, and the Public Policy Institute of California. Generally, the smallest geographical aggregation for these data is the county level. With 58 counties in California, this paints the future population with a broad brush. Other research has focused on where future growth is likely to occur. The outputs from these projects are future land use, and they do not report population at scales smaller than the county. It would have been simple to say that all the areas in a county will grow at an equal rate – the simplest way to disaggregate geographic data is to do so uniformly. However, this would be unrealistic, as certain areas are nearly built out or at capacity, while growth is taking place in many formerly unpopulated areas.

Additional research is needed to develop improved air quality projections for a variety of parameters, especially ozone.

Analysis of climate change and air quality was limited to particulate matter with a diameter < 2.5 μm ($PM_{2.5}$) because it was among the only dataset currently available. There are a number of other air quality parameters, however, that are important to human health, particularly ozone, for which reliable data are not as readily available. Additional research is needed in this area.

References

American Academy of Pediatrics (AAP). 2004. “Ambient Air Pollution: Health Hazards to Children.” *Pediatrics* 114:1699 –1707.

American Academy of Pediatrics. 2000. “Climatic Heat Stress and the Exercising Child and Adolescent.” Committee on Sports Medicine and Fitness. *Pediatrics* 106 (1 Pt 1):158–159.

Basu, R., and B. D. Ostro. 2008. “A Multicounty Analysis Identifying the Populations Vulnerable to Mortality Associated with High Ambient Temperature in California.” *American Journal of Epidemiology* 168 (6): 632–637.

Blanchard-Boehm, D. 1997. *Risk Communication in Southern California: Ethnic and Gender Response to 1995 Revised, Upgraded Earthquake Probabilities*. Research Report. Bolder, Colorado: Natural Hazards Research and Applications Information Center.

Blum et al. 1998. “Heat-Related Illness During Extreme Weather Emergencies.” *JAMA* 279 (19): 1514.

Bolin, R., and P. Bolton. 1986. *Race Religion and Ethnicity in Disaster Recovery*. Monograph No. 42. Boulder: University of Colorado, Institute of Behavioral Science.

Bovbjerg, R., and J. Hadley. 2007. “Why Health Insurance is Important.” *Health Policy Briefs*. The Urban Institute. Washington, D.C.

Brodie, M., E. Weltzien, D. Altman, R. Benson, and J. Benson. 2006. “Experiences of Hurricane Katrina Evacuees in Houston Shelters: Implications for Future Planning.” *American Journal of Public Health* 95 (5): 1402–1408.

Bunyavanich, S., C. P. Landrigan, A. J. Mc- Michael, and P. R. Epstein. 2003. “The Impact of Climate Change on Child Health.” *Ambulatory Pediatrics* 3:44–52.

California Air Resources Board (ARB). 2009. *History of California's Ambient Air Quality Standards*. http://www.arb.ca.gov/research/aaqs/caaqs/hist1/hist1.htm.

California Department of Finance. 2007. *Population Projections by Race / Ethnicity, Gender and Age for California and Its Counties 2000–2050.*

Caruson, K., and S. A. MacManus. 2008. “Disaster Vulnerabilities: How Strong a Push Toward Regionalism and Intergovernmental Cooperation?” *The American Review of Public Administration* 38 (3): 286–306. http://arp.sagepub.com/content/38/3/286.full.pdf+html.

Center for Disease Control (CDC). 2010. “NIOSH Workplace Safety and Health Topics: Heat Stress.” http://www.cdc.gov/niosh/topics/heatstress/. Accessed on October 22, 2010.

Collins, T. W. 2005. “Households, Forests, and Fire Hazard Vulnerability in the American West: A Case Study of a California Community.” *Environmental Hazards* 6:23–37.

Collins, T. W., and B. Bolin. 2009. "Situating Hazard Vulnerability: People's Negotiations with Wildfire Environments in the U.S. Southwest." *Environmental Management* 44:441–455.

Confalonieri, U., B. Menne, R. Akhtar, K. L. Ebi, M. Hauengue, R. S. Kovats, B. Revich, and A. Woodward. 2007. "Human Health." *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to T. W. Collins and B. Bolin. 2009. "Situating Hazard Vulnerability: People's Negotiations with Wildfire Environments in the U.S. Southwest."

Cordalis, D., and D. Suagee. 2008. *Natural Resources & Environment* 22 (3): 45–49. http://www.abanet.org/environ/pubs/nre/winter08/effects_climatechange.pdf.

Cordova, R., M. Gelobter, A. Hoerner, J. R. Love, A. Miller, C. Saenger, and D. Zaidi. 2006. *Climate Change in California: Health, Economic, and Equity Impacts. Redefining Progress*.

Cutter, S. L., B. J. Boruff, and W. L. Shirley. 2003. "Social Vulnerability to Environmental Hazards." *Social Science Quarterly* 84 (2).

Cutter, S. L., C. T. Emrich, J. J. Webb, and D. Morath. 2009 *Social Vulnerability to Climate Variability Hazards: A Review of the Literature.* http://adapt.oxfamamerica.org/?utm_source=redirect&utm_medium=web&utm_campaign=USROSVM.

Downey, L., and B. Hawkins. 2008. *Single-Mother Families and Air Pollution: A National Study*. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2664989/. Accessed October 21, 2010.

Ebi, K. L., and G. McGregor. 2008. "Climate Change, Tropospheric Ozone and Particulate Matter, and Health Impacts." *Environmental Health Perspectives* 116 (11): 1449–1455.

Environmental Protection Agency (EPA). 2010. "Ground-level Ozone Standards Designations." http://www.epa.gov/ozonedesignations/faq.htm#3.

Environmental Protection Agency (EPA). 2001. *National Land Cover Data*. Multi-Resolution Land Characteristics Consortium. Washington, D.C.

Fothergill, A., and L. Peek. 2004. "Poverty and Disasters in the United States: A Review of Recent Sociological Findings." *Natural Hazards* 32:89–110.

Fourgères, D. 2007. *Climate Change, Environmental Justice, and Human Rights in California's Central Valley: A Case Study*. http://www.ciel.org/Publications/Climate/CaseStudy_CentralValleyCA_Nov07.pdf. Accessed October 22, 2010.

Gerba, C. P., J. B. Rose, and C. N. Haas. 1996. "Sensitive Populations: Who is at the Greatest Risk?" *Int J Food Microbiol* 30:113–123.

Hajat, S., K. L. Ebi, R. S. Kovats, B. Menne, S. Edwards, and A. Haines. 2003. "The Human Health Consequences of Flooding in Europe: A Review." *Health San Francisco* 30: 185–196.

Hammond, D. M., J. T. Dvonch, G. J. Keeler, E. A. Parker, A. S. Kamal, J. A. Barres, F. Y. Yip, and W. Brakefield-Caldwell. 2008. "Sources of Ambient Fine Particulate Matter at Two Community Sites in Detroit, Michigan." *Atmospheric Environment* 42 (4): 720–732.

Hanna, J. M. 2007. *Native Communities and Climate Change: Legal and Policy Approaches to Protect Tribal Legal Rights*. Natural Resources Law Center. University of Colorado School of Law.

Harlan, S. L., A. J. Brazel, L. Prashad, W. L. Stefanov, and L. Larsen. 2006. "Neighborhood Microclimates and Vulnerability to Heat Stress." *Social Science and Medicine* 63:2847–2863.

Hazards and Vulnerability Research Institute (HVRI). 2011a. *SoVI Recipe*. University of South Carolina. Columbia, South Carolina. http://webra.cas.sc.edu/hvri/docs/sovi_32_recipe.pdf. Accessed on March 25, 2011.

Hazards and Vulnerability Research Institute (HVRI). 2011b. *Social Vulnerability Index for the United States*. University of South Carolina. Columbia, South Carolina. http://webra.cas.sc.edu/hvri/products/sovi.aspx. Accessed on February 13, 2012.

Health Canada. 2004. *Human Health Effects of Fine Particulate Matter: Update in Support of the Canada-Wide Standards for Particulate Matter and Ozone*. http://www.ccme.ca/assets/pdf/prrvw_pm_fine_rvsd_e.pdf.

Heberger, M., H. Cooley, P. Herrera, P. H. Gleick, and E. Moore. 2009. *The Impacts of Sea-level Rise on the California Coast.* Prepared by the Pacific Institute for the California Climate Change Center.

Helsel, D. R., and R. M. Hirsch. 2002. *Statistical Methods in Water Resources Techniques of Water Resources Investigations*. Book 4, chapter A3. U.S. Geological Survey. 522 pages.

Hewitt, K. 1997. *Regions of Risk: A Geographical Introduction to Disasters*. London: Addison Wesley Longman.

Houser, S., V. Teller, M. MacCracken, R. Gough, and P. Spears. 2001. "Potential Consequences of Climate Variability and Change for Native Peoples and Homelands." Chapter 12 in *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change.* Houser, S., V. Teller, M. MacCracken, R. Gough, and P. Spears. U.S. Climate Change Science Program, Washington, D.C.

Howard, R. A., D. W. North, F. L. Offensend, and C. N. Smart. 1973. *Decision Analysis of Fire Protection Strategy for the Santa Monica Mountains: An Initial Assessment*. Menlo Park, California: Stanford Research Institute.

Intergovernmental Panel on Climate Change. 2000. *Special Report on Emissions Scenarios.* Cambridge University Press, UK. 570 pp.

Intergovernmental Panel on Climate Change. 1997. R. T.Watson, M. C. Zinyowera, and R. H. Moss (Eds). *The Regional Impacts of Climate Change: An Assessment of Vulnerability.* Cambridge University Press, UK.

Ishigami, A., S. Hajat, S. Kovats, P. Wilkinson, and B. Armstrong. 2007. "Geographical Determinants of Mortality During the 2003 Heat Wave in England and Wales." *Epidemiology* 18 (5) S156.

Jamieson, D. J., R. N.Theiler, and S. A. Rasmussen. 2006. "Emerging Infections and Pregnancy." *Emerging Infectious Diseases* 12:1638–1643.

Jerrett, M., R. T. Burnett, et al. 2009. "Long-term Ozone Exposure and Mortality." *New England Journal of Medicine* 360 (11): 1085–95.

Jesdale, Bill. 2011. Personnel communication. Post-Doctoral Scholar, Department of Environmental Science, Policy and Management at the University of California at Berkeley.

Joacim, R., E. Kristie, and F. Bertil. 2010. "Mortality Related to Temperature and Persistent Extreme Temperatures: A Study of Cause-Specific and Age-Stratified Mortality." *Occupational and Environmental Medicine*.

Kalkstein, L. S. 1993. "Health and Climate Change - Direct Impacts in Cities." *The Lancet* 342:1397–1399.

Keeler G. J., J. T. Dvonch, F. Y. Yip, E. A. Parker, B. A. Israel, F. J. Marsik, et al. 2002. "Assessment of Personal and Community-level Exposures to Particulate Matter Among Children with Asthma in Detroit, Michigan, as Part of Community Action Against Asthma (CAAA)." *Environ Health Perspectives* 110:173–181.

Kilbourne, E. M, K.Choi, S. Jones, and S. B Thacker. "Risk Factors for Heatstroke: A Case-Control Study." *Journal of the American Medical Association* 247 (24): 3332–3336.

Kleeman, M. J., S. Chen, and R. A. Harley. 2010. *Climate Change Impact on Air Quality in California*. Report to the California Air Resources Board. Sacramento, California.

Knowlton, K., M. Rotkin-Ellman, G. King, H. G. Margolis, D. Smith, G. Solomon, R. Trent, and P. English. 2009. "The 2006 California Heat Wave: Impacts on Hospitalizations and Emergency Department Visits." *Environmental Health Perspective* 117 (1): 61–67.

Krawchuk, M. A. and M. A. Moritz (Simon Fraser University; University of California, Berkeley). 2012. *Fire and Climate Change in California.* California Energy Commission. Publication Number: CEC-500-2012-026.

Krewski, D., R. T. Burnett, et al. 2000. *Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study of Particulate Air Pollution and Mortality*. Boston, Massachusetts: Health Effects Institute.

Lin M., Y. Chen, R. T. Burnett, P. J. Villeneuve, and D. Krewski. 2002. "The Influence of Ambient Coarse Particulate Matter on Asthma Hospitalization in Children: Case-crossover and Time-series Analyses." *Environmental Health Perspectives* 110:575–581.

Lipsett, M., B. Materna, S. L. Stone, S. Therriault, R. Blaisdell, and J. Cook. 2008. *Wildfire Smoke: A Guide for Public Health Officials.* http://www.arb.ca.gov/smp/progdev/pubeduc/wfgv8.pdf. Accessed August 31, 2010.

Luber, G., and M. McGeehin. 2008. "Climate Change and Extreme Heat Events." *American Journal of Preventative Medicine* 35 (5): 429–435.

Maurer, E. P., H. G. Hidalgo, T. Das, M. D. Dettinger, and D. R. Cayan. 2010. "The Utility of Daily Large-Scale Climate Data in the Assessment of Climate Change Impacts on Daily Streamflow in California." *Hydrology and Earth System Sciences* 14:1125–1138.

McGeehin, M. A., and M. Mirabelli. 2001. "The Potential Impacts of Climate Variability and Change on Temperature-Related Morbidity and Mortality in the United States." *Environmental Health Perspectives* 109 (2): 185–189.

Medina-Ramon, M., and J. Schwartz. 2008. "Who is More Vulnerable to Die From Ozone Air Pollution?" *Epidemiology* 19:672–679.

Morbidity and Mortality Weekly Report (MMWR). 2008. "Heat-Related Deaths Among Crop Workers - United States, 1992–2006." *MMWR* 57 (24): 649–653.

Morello-Frosh R., M. Pastor, J. Sadd, and S. Shonkoff. 2009. *The Climate Gap: Inequalities in How Climate Change Hurts Americans & How to Close the Gap.* http://college.usc.edu/pere/documents/The_Climate_Gap_Full_Report_FINAL.pdf. Accessed on October 21, 2010.

Moser, S., and J. Ekstrom. 2010. *Developing Adaptation Strategies for San Luis Obispo County: Preliminary Climate Change Vulnerability Assessment for Social Systems.* Technical Report Prepared for the Local Government Commission and the San Luis Obispo Stakeholder Workshop on May 20, 2010.

Naughton, M. P., A. Henderson, M. C. Mirabelli, R. Kaiser, J. L. Wilhelm, S. M. Kieszak, C. H. Rubin, and M. A. McGeehin. 2002. "Heat-Related Mortality During a 1999 Heat Wave in Chicago." *American Journal of Preventive Medicine* 22 (4): 221–227.

NCDC (National Climatic Data Center). 2010. *U.S. Heat Stress Index*. National Oceanic and Atmospheric Administration. http://www.ncdc.noaa.gov/temp-and-precip/heat-stress.html#data. Accessed October 21, 2010.

Norris G., S. N. YoungPong, J. Q. Koenig, T. V. Larson, L. Sheppard, and J. W. Stout. 1999. "An Association Between Fine Particles and Asthma Emergency Department Visits for Children in Seattle." *Environmental Health Perspectives* 107:489–493.

Nwachuku, N., and C. P. Gerba. 2004. "Microbial Risk Assessment: Don't Forget the Children." *Current Opinion in Microbiology* 7:206–209.

O'Neill, M. S., A. Veves, A. Zanobetti, J. A. Sarnat, D. R. Gold, P. A. Economides, E. S. Horton, et al. 2005. "Diabetes Enhances Vulnerability to Particulate Air Pollution-Associated

Impairment in Vascular Reactivity and Endothelial Function." *Circulation* 111: 2913–2920. http://circ.ahajournals.org/cgi/content/full/111/22/2913.

Ortega Hinojosa, A. M. 2011. Personnel communication. Doctoral Candidate, UC Berkeley School of Public Health, Division Environmental Health Sciences.

Ostro B., L. Roth, B. Malig, and M. Marty. 2009. "The Effects of Fine Particle Components on Respiratory Hospital Admissions in Children." *Environmental Health Perspectives* 117:475–480.

Oxfam America. 2009. *Exposed: Social Vulnerability and Climate Change in the U.S. Southeast*. Boston, Massachusetts.

Pastor, M., R. Bullard, J. Boyce, A. Fothergill, R. Morello-Frosch, and B. Wright. 2006. *In the Wake of the Storm: Environment, Disaster and Race After Katrina.* New York: Russell Sage Foundation.

Perry, R., and A. H. Mushkatel. 1986. *Minority Citizens in Disasters.* Athens: University of Georgia Press.

Phillips, B., and M. Ephraim. 1992. "Living in the Aftermath: Blaming Processes in the Loma Prieta Earthquake." Working Paper No. 80. IBS. Boulder: University of Colorado, Natural Hazards Research and Applications Information Center.

Poumadere, M., C. Mays, S. Le Mer, and R. Blong. 2005. "The 2003 heat wave in France: Dangerous climate change here and now." *Risk Analysis* 25 (6): 1483–1494.

Reid, C. E., M. S. O'Neill, C. J. Gronlund, S. J. Brines, D. G. Brown, A. V. Diez-Roux, and J. Schwartz. 2009. "Mapping Community Determinants of Heat Vulnerability." *Environmental Health Perspectives* 117 (11): 1730–1736.

Roberts, E. 2011a. *Analysis of California Energy Commission Survey of California Household Air Conditioning Unit*. Personnel Communication, Research Manager, California Environmental Health Tracking Program, California Department of Public Health.

Roberts, E. 2011b. 2006. *Preterm birth rates by Census Tract for California*. Personnel Communication. Research Manager, California Environmental Health Tracking Program, California Department of Public Health.

Rossi, P. H., J. Wright, E. Weber-Burdin, and J. Pereira. 1983. *Victims of the Environment: Loss from Natural Hazards in the United State, 1970–1980.* New York: Plenum Press.

Samet, J. 2009. *Adapting to Climate Change. Resources for the Future.*

Schwartz J. 2005. "Who is Sensitive to Extremes of Temperature? A Case-Only Analysis." *Epidemiology* 16:67–72.

Semenza, J. C., C. H. Rubin, K. H. Falter, J. D. Selanikio, W. D. Flanders, H. L. Howe, and J. L. Wilhelm. 1996. "Heat-Related Deaths During the July 1995 Heat Wave in Chicago." *New England Journal of Medicine* 335:84–90.

Shonkoff, S., R. Morello-Frosch, et al. 2011. "The Climate Gap: Environmental Health and Equity Implications of Climate Change and Mitigation Policies in California—A Review of the Literature." *Climatic Change* Published online: 1–19.

Shonkoff, S., R. Morello-Frosch, et al. 2009. "Minding the Climate Gap: Environmental Health and Equity Implications of Climate Change Mitigation Policies in California." *Environmental Justice* 2 (4): 173–177.

The Reinvestment Fund. 2010. *TRF Supermarket Study of Low Access Areas.* Philadelphia, Pennsylvania. http://www.trfund.com/TRF-food-access.html. Accessed July 2011.

U.S. Climate Change Science Program (USCCSP). 2008. *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States.* U.S. Climate Change Science Program Synthesis and Assessment Product 4.3.

Wang, T., and L. Yasui. 2008. *Integrating Immigrant Families in Emergency Response, Relief, and Rebuilding Efforts*. Baltimore, Maryland: Annie E. Casey Foundation.

Whitman, S., G. Good, E. R. Donoghue, N. Benbow, W. Shou, and S. Mou. 1997. "Mortality in Chicago Attributed to the July 1995 Heat Wave." *American Journal of Public Health* 87:1515–1518.

Zeka, A., A. Zanobetti, and J. Schwartz. 2006. "Individual-level Modifiers of the Effects of Particulate Matter on Daily Mortality." *American Journal of Epidemiology* 163:849–859.

Glossary

AAP	American Academy of Pediatrics
ACS	American Community Survey
CalFire	California Department of Forestry and Fire Protection
ARB	California Air Resources Board
CDC	United States Centers for Disease Control and Prevention
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Agency
GFDL	Geophysical Fluid Dynamics Laboratory
GIS	Geographic Information System
HVRI	Hazards and Vulnerability Research Institute
IPCC	Intergovernmental Panel on Climate Change
ITEP	Institute for Tribal Environmental Professionals
JAMA	Journal of the American Medical Association
MMWR	Morbidity and Mortality Weekly Report
NCAR	National Center for Atmospheric Research
NIOSH	National Institute for Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration
OCAC	Oakland Climate Action Coalition
PIER	Public Interest Energy Research
PCM	Parallel Climate Model
$PM_{2.5}$	Fine particulate matter
RD&D	Research, development, and demonstration
SRES	Special Report on Emissions Scenarios
SoVI	Social Vulnerability Index
USCCSP	US Climate Change Science Program