IDENTIFING THE IMPACT OF THE BUILT ENVIRONMENT ON WILDFIRE PROPERTY DAMAGE IN CALIFORNIA

A Thesis

by

TAKASHI MICHAEL MAKINO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF MARINE RESOURCES MANAGEMENT

Approved by:

Chair of Committee, Samuel D. Brody
Co-Chair of Committee, Wesley E. Highfield
Committee Member, Thomas J. Cova
Head of Department, Patrick Louchouarn

May 2013

Major Subject: Marine Resources Management

ABSTRACT

Wildfires are a natural hazard that present an increasing risk to communities in fire-prone areas. This study examines the impacts of the municipal-level built environment upon fire damages in California, a particularly fire-vulnerable state. This study uses a multivariate linear regression model to isolate the effects of the human built environment upon reported monetary wildfire damages. Reported monetary losses from wildfires for the years 2007 to 2010 are examined against relevant built environment variables, while statistically controlling for biophysical and socio-economic variables.

The fully-specified regression model indicates that wildfire property damage is driven primarily by the built environment. Socioeconomic and biophysical variables contribute comparatively little explanatory power to the model. Findings from this study will be of particular interest to fire management officials, land developers, and urban planners interested in creating a more fire-resilient future for cities within California.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Brody, and my committee members, Dr. Highfield, and Dr. Cova, for their guidance and support throughout the course of this research.

I would also like to thank the current and former students of the Center for Texas Beaches and Shores, particularly Russell Blessing, Patrick Doty, Josh Gunn, Alexandra Stiles, and Morgan Wilson for providing discussion and suggestions for improvement during the writing of this thesis.

The fire damage data used in this analysis was provided by Kirsti Fong of the California All Incident Reporting System. Without her patient assistance, this analysis would not have been possible.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Wildfires are natural hazards that pose a threat to communities that are not prepared to face them. Wildfires have the potential to be very damaging, large-scale disasters. In the year 2000 alone, an estimated 8.4 million acres of land in the United States were burned in wildfires (Busenberg, 2004). An additional estimated 6.6 million acres burned in 2002. In 2003, in the state of California alone, over 739,000 acres and 3,600 households were consumed by fire (Reams et al., 2005). As time passes and more data becomes available, significant increases in areas burned by wildfire have been observed (Westerling et al., 2006). The cost of combating wildfires is only expected to rise in the future (Gude et al., 2008). In fact, despite rising fire suppression spending, wildfire property damage has increased rather than decreased (Keeley, 2002). Modern fire management practices and human expansion into wildlands have all contributed to the current level of threat from wildfires. The potential for human exposure to wildfire has never been higher.

2. PROBLEM IDENTIFICATION

As is the case with other natural hazards, wildfires become a concern for people when they come into contact with human developed or managed areas. Wildfires occur naturally and have taken place for countless millennia. Prior to the concept of private property, monetary wildfire damage did not occur. Two conditions must be met for wildfire damages to occur: (1) wildfires must be burning, and (2) human resources must exist in the same space as wildfire.

To better understand the nature of fire damages, this study examines the nature of human resources that have previously been damaged by wildfires. If patterns of the human environment that are particularly vulnerable to wildfire can be identified, such information can be used by fire managers, planners, and developers to form communities that are better prepared to face wildfire hazards.

Wildfires play important roles in many ecosystems (Haydon et al., 2000; Pianka, 1996). Human alteration of natural ecosystems has changed the way fire interacts with these environments. A growing body of evidence supports the assertion that wildfires have the potential to become even more hazardous and costly to humans than they are today (Gude et al., 2008; Westerling et al., 2006; State Board of Forestry and Fire Protection, 2010).

The state of California is particularly fire vulnerable. The southern portion of the state is prone to drought in the summer and seasonal “episodic high wind events” increasing the likelihood of wildfires (Hammer et al., 2007). The state has experienced several seasons of drought in recent years, further increasing the risk of ignition (State Board of Forestry and Fire Protection, 2010). California has 5.1 million housing units (more than any other state) in areas containing high levels of vegetative fuel (Radeloff et al., 2005). The combination of naturally occurring fire regimes, biophysical variables that increase the likelihood of a fire event, and a large human presence within areas containing fuel provide an ideal study area in which to examine the interaction of the built environment and wildfire.

3. RESEARCH QUESTION

The objective of this research is to identify relationships between the human built environment and wildfire damage. Research examining individual building survivability, building techniques, and mitigation practices has been undertaken in the past (Bhandry, 2008; Cohen, 2000; Quarles, 2010). The focus of this study is to examine the relationship between fire damage and the built environment at the municipal level. Previous studies have been undertaken at the site and individual structure level. However, an analysis such as the one conducted in this study does not readily appear in a search of the literature. This study provides information regarding property damage at the municipal level which should be particularly useful to planners who operate at the municipal level.

This study seeks to answer the following research question: what is the relationship between characteristics of the built environment and resulting property damage from fires at the local level in California? To address this question, several characteristics of the built environment will be examined, including housing density, building age, development intensity and land use mix. Other relevant variables will be statistically controlled.

4. SUMMARY OF OVERALL APPROACH

This study will generate a multivariate linear regression model to isolate the effect of the built environment on fire damage at the municipal level. Fire damage, measured in dollars, will be the dependent variable in this study. Fire damage is the loss of property due to wildfire. Therefore, no damage occurs in wildfires that do not coincide with human developed or managed areas. By using fire damage rather than other metrics of fire intensity, the relationship between the human environment and property loss to wildfire can be specifically examined. Because the goal of this research is ultimately to provide planners, developers, and stakeholders with information that can be used to reduce fire damage, using fire damage as the dependent variable provides results that can be translated into specific, directed, damage-reducing planning actions. While using a different dependent variable, such as area burned, would still be informative, it would not provide results that directly describe how the independent variables impact monetary fire damage.

5. RELEVANCE OF RESEARCH

Understanding the relationship between the built environment and fire damage should be of particular interest to planners and land managers. Such an examination has yet to be performed at the municipal level and may provide planners, land managers, and developers with practical insight into the nature of wildfire damages. Identifying patterns of development that are closely linked to fire damage, or lack of fire damage, will allow planners to make provisions to improve fire resilience and safety. Despite the best efforts of fire suppression crews and other wildland fire protection entities, it is impossible to completely control all wildland fires. Limited resources or extreme weather conditions may allow a fire to escape control and threaten human development. If development patterns facing the risk of wildland fire can be made inherently less fire vulnerable, it may be possible to reduce the loss of life and property to wildland fire.

This research is particularly timely. The state of California recognizes that wildfire represents an increasingly hazardous natural phenomenon (State Board of Forestry and Fire Protection, 2010). Compared to previous decades, recent years feature much larger areas burned within the state, particularly in conifer forests and shrub lands. From 1970 to 2000, a mean of 48,000 acres of conifer forest burned in California annually. This is in stark contrast to a mean of 193,000 conifer forest acres burned annually in the years 2000 to 2008. Between 2000 and 2008, an annual average of almost 275,000 acres of shrub burned in the state, a more than two-fold increase in mean annual burn area over the previous five decades (State Board of Forestry and Fire

Protection, 2010). There seems to be no indication that burned acreage or damage caused by fires will decrease in the future. In fact, there seems to be a general consensus among fire researchers, policy makers, and state officials that wildfire risk, damage, and burn acreage will all only increase in the future.

6. FIRE AND THE CHAPARRAL ECOSYSTEM

Many ecosystems around the planet, including ecosystems within California, are adapted to wildfires (Haydon et al., 2000; Minnich, 1983; State Board of Forestry and Fire Protection, 2010). Normally, when such fires sweep through an area they consume much of the available plant fuel. However, when natural wildfires are suppressed, the fuel they would otherwise consume continues to accumulate. This accumulation of fuel leads to abnormal fire behavior including massive high-intensity wildfires (Christiansen et al., 1989). These wildfires have the potential to severely disturb maladapted environments. In contrast, low-intensity, high-frequency wildfires tend to be relatively small scale disturbances. Frequent small wildfires create a diverse mosaic of habitats and fuel levels within an ecosystem over time, promoting biological diversity and reducing the likelihood of a large, high-intensity fire (Kilgore and Taylor, 1979; Haydon et al., 2000, Pianka, 1996). Quite frequently, fires will cease burning once they hit an area of land that has recently burned. Recently burned areas will lack the fuel necessary to propagate fire (Minnich, 1983). The policy of intentional suppression of small wildfires can promote large wildfires that are virtually immune to effects of fire suppression tactics (Minnich, 1983).

The chaparral ecosystem of Southern California and Baja California, Mexico provides an interesting case study into the effects of fire suppression on fire regimes. The United States adheres to a stricter and more intense fire suppression policy than Mexico. According to Minnich (1983), fire suppression procedures have been practiced for so long and are so widespread in Southern California that there no longer exists any land in the region that exhibits natural fire regimes. While Mexico does practice fire suppression, it does not suppress fires to nearly the same degree as the United States.

Unlike many forested ecosystems adapted to small, high-frequency fires, these shrub land ecosystems are instead adapted to small, relatively infrequent, high-intensity stand replacement fire events. Typically, in a fire event all but the largest above-ground plants within the range of the fire will be consumed in a chaparral ecosystem (Minnich, 1983). While these fires are intense, they are typically relatively small-scale events. While experts provide various estimates for the fire return interval in natural chaparral fire regimes, the estimates tend to range between 50 and 100 years (Conard and Weise, 1998; Keeley, 2002; Minnich, 1983).

Historical accounts from the late 19th century, prior to current widespread fire suppression practices, recount that chaparral fires in California often burned for months at a time, yet did not exceed 7,000 ha (Minnich, 1983). This is likely due to a mosaic of burn patches in the chaparral shrub land. Young chaparral (less than 20 years post fire) is very resistant to fire. While contested by others, some authors claim that young chaparral is so nonflammable that it will act as a fuel break even in the face of fires pushed by the powerful Santa-Ana winds (Minnich, 1983).

In the present day, Baja California experiences higher frequencies of small (< 800 ha) fires than Southern California, but lower frequencies of larger fires. This pattern of a comparatively higher frequency of small fires coupled with a comparatively lower frequency of large fires is likely to closely resemble the natural fire regime of chaparral ecosystems (Minnich, 1983). Median fire size has increased in Southern California since 1910, with a particular increase in large-scale fires after 1950 (Minnich, 1983). Presumably, if chaparral does experience a fire return interval of 50 to 100 years, this sudden increase may be due to a homogenous landscape of mature chaparral vegetation that is approaching its natural fire return interval. No such increase in fire size after 1950 is observed in Baja California (Minnich, 1983). The median fire size for the decade of 1971-1980 in Southern California was 3,500 ha. The same decade produced a median fire size of 1,600 ha in Baja California. However, Baja California experienced a higher *total* area burned for the same time - 182,800 ha in Baja California compared to 164,700 ha in Southern California (Minnich, 1983). Presumably the presence of many small area fires contribute to the higher total area burned in Baja California.

As discussed earlier, relatively high-frequency small fires will preclude large area fires due to the nonflammable nature of young chaparral vegetation. A patchwork mosaic of vegetation ages exists in the Baja Californian chaparral and precludes the existence of large chaparral fires. In contrast, a similar mosaic is "almost lacking" in Southern California, allowing fires to travel across the chaparral with little interruption (Minnich, 1983).

The suppression of natural fire regimes has been practiced in California since the early 20th century, setting the state up for large-scale, high-intensity fires that threaten human life and property (Minnich, 1983). Urban sprawl, specifically development in areas prone to high-intensity fires, is a major driving force behind suppression practices (Keeley, 2002). Major cities in Southern California are close to and sprawl into chaparral ecosystems. This increases public support for suppression policies. Chaparral fires have the potential to cause a high level of damage to property and have large impacts on air and water quality (Conard and Weise, 1998). Crown fires, such as those produced in chaparral environments, are virtually impossible to control by fire crews (Minnich, 1983). Chaparral fires thus represent a real threat to property and life for those who reside within chaparral environments.

7. HUMAN EXPANSION INTO WILDLANDS

The expansion of human development into wildland areas has accelerated in recent years and shows no signs of slowing down (State Board of Forestry and Fire Protection, 2010; Theobald and Romme, 2007). Perhaps more than any other factor, it is this expansion into wildland areas that increases property damage. It should come as no surprise that expansion into wildland areas that naturally experience wildfire can result in property loss.

The concept of the wildland-urban interface (WUI) is used extensively in wildfire literature. The WUI is defined as the area where housing units are interspersed throughout a surrounding matrix of wildland vegetation (Radeloff et al., 2005). Other authors contest that the term WUI describes only the areas where development abuts undeveloped wildland vegetation. These authors developed a separate term, the wildland-urban intermix, to describe areas where isolated structures are found surrounded by wildland vegetation (Theobald and Romme, 2007). Regardless of the specific definition used, the WUI is the area that faces the greatest risk of wildfire property damage.

Various estimates exist to describe current and projected WUI areas. Theobald and Romme (2007) report that in 2000, the WUI included 12.5 million housing units in 465,614km^2-an expansion of over 50% since the 1970s. Of these 465,613km^2 of WUI land, 302,648km^2 (65%) are in areas characterized by high-severity fire regimes. The same authors estimate that the WUI is projected to encompass no less than 513,670km^2

by the year 2030. Using a more inclusive definition, Radeloff et al. (2005) identified 719,156km² of WUI within the continental United States (US) in the year 2000. By their estimates, this area encompasses 9% of the total land area of the continental US and contains 39% of all housing units in the nation. The discrepancies in estimates between these authors likely results from the more exclusive definition of WUI that Theobald and Romme (2007) favor. Semantics aside, the WUI represents a nontrivial proportion of land area and housing units in the United States.

Unfortunately, it is likely that this expansion will probably continue into the foreseeable future (Theobald and Romme, 2007). While combating this expansion would perhaps be the most effective method of reducing property loss to wildfire, there are other methods of fire hazard mitigation that can also be employed to reduce the threat of wildfire to human property that already exists in WUI areas.

8. MITIGATION TECHNIQUES TO REDUCE THE ADVERSE IMPACTS OF FIRE

8.1 Prescribed Burns

Prescribed burns are an often discussed and frequently contentious point among fire researchers, policy makers, and the public. The motivations for prescribed burns vary, but among them include the desire to reduce fire hazards in an area and to improve public resources (Keeley, 2002). As the focus of this proposed research is to examine fire damage, reduction of fire hazards is likely to play an important role in reducing fire damage. It is in relation to fire hazard reduction that prescribed burning will be discussed.

In theory, prescribed burns reduce fire hazard by minimizing the amount of fuel in an area. If fuel is removed by a human-controlled prescribed burn, it will not be available for fires that are out of human control: i.e. naturally occurring wildfires. Ideally, prescribed burns would mimic the natural fire regimes of an ecosystem, yet would be under the watchful eye of land managers. However, in some ecosystems, this may not be practical. As mentioned above, chaparral crown fires are very intense. Due to the sprawling presence of humans within the Southern California chaparral and the uncontrollable nature of crown fires, prescribed burns that mimic the natural fire regime in chaparral ecosystems cannot be the sole method of fuel management. The risk to human life and property is simply too high.

On the other hand, prescribed burns that are practical from a human property standpoint have the potential to be ecologically devastating. Two ecological risks are eminent: "senescence risk" and "immaturity risk" (Keeley, 2002). Senescence risk is the potential for the loss of fire-dependent biota in times of fire exclusion (Zedler, 1995). Certain organisms, including many plants, require wildfire to exist and reproduce. The exclusion of fire from these ecosystems can result in the extirpation of organisms that are dependent upon fire to reproduce. Conversely, immaturity risk is the potential for the extirpation of organisms that require fire return intervals longer than the interval between prescribed burns to reach maturity and reproduce (Zedler, 1995). Senescence risk is a potential outcome of prescribed burns that occur at a lower frequency than the natural fire return interval of an ecosystem. Immaturity risk is a potential outcome of prescribed burns that occur at a higher frequency than the natural fire return interval of an ecosystem.

Ignoring ecological impacts, Keeley (2002) identifies the three major factors of highest concern when developing a prescription burn plan:

1. Prescribed burns must be executed in a safe and controlled manner. Burns must be carried out by experienced crews and must be restricted to the area that was intended to burn.

2. The vegetation within the pre-determined area of the burn must be consumed for the burn to be successful. If the vegetation does not burn and fuel is not consumed, the burn has not performed the task it was designed for. Vegetation must be consumed by fire to decrease the fire hazard in the area.

3. Ultimately, as far as this discussion is concerned, reduction of fire hazards is the goal of prescribed burns. If hazard reduction does not occur, or if hazard risk increases, the burn is an abject failure.

These three factors are engaged in a three-way tug-of-war. Only in satisfying all three conditions does a prescribed burn become a useful method of fire hazard mitigation. Successful prescribed burn plans have been generated and employed in coniferous forests across the United States (Keeley 2002). However, the Californian chaparral provides a somewhat challenging situation for fire managers. Unlike coniferous forests that have naturally occurring *surface* fires, fires that consume fuel on the ground, chaparral fires experience *crown* fires, far more intense fires that spread above ground level by consuming elevated fuel in the tree crowns. In coniferous forests, prescribed burns are used to clear out understory vegetation much like natural fires would in these forests (Keeley, 2002). Surface fires are much more easily contained and controlled than crown fires. This difference in fire behavior between surface and crown fires makes prescribed burns a challenging undertaking in chaparral. There is no "one size fits all" model for prescribed burns.

To satisfy the requirement that fires remain under control and do not endanger human lives and property, prescribed burns in chaparral (as well as other ecosystems) must be executed within a specific range of weather conditions. Wind speed, temperature, and humidity are all factors that contribute to fire spread. Prescribed burns should only be executed during times of low wind speed, low temperature, and high humidity. Should these conditions not be met, prescribed burns can escape the control of fire crews and can endanger human property and life.

A major obstacle to prescribed burns is that weather is often unpredictable. Prescribed burns that were initiated under suitable weather conditions can rage out of control should weather conditions change (Keeley, 2002). Due to the inherent risks associated with setting fire to fire-prone land, the conditions that are acceptable for prescribed burns are very specific. Various pre-burn fuel treatments have been developed to mitigate the potential for disaster associated with prescribed burns, but they are often expensive and ecologically irresponsible (Keeley, 2002).

Due to the emphasis placed on safety and control in prescribed burning, the burns themselves often take place under conditions that are less than ideal (Keeley, 2002). While this is obviously intentional, sub-optimal conditions should reduce the likelihood of an out-of-control fire; if the conditions are too "safe," the fire will not achieve the reduction of fuel it was intended for. Under high humidity and low wind conditions, physical fuel arrangement (fuel continuity, presence of ladder fuels, presence of dead fuels, etc…) becomes the primary determinant of fire spread. Should the physical arrangement of fuel not be adequate, the fire will not spread and the fuel will not thin.

Should a successful prescribed burn take place, it is likely to only eliminate fuels that satisfy the above safety requirements. A prescribed burn is probably only going to eliminate the fuels that are going to burn in low wind, high humidity conditions. The fuels that will burn in high wind and low humidity conditions-fuels that are likely to contribute to high intensity, high damage conflagrations-will not be consumed. It is the high-intensity, uncontrollable fires that threaten human life and property, not small controllable fires (Keeley, 2002). Prescribed burning will prevent or severely limit the spread of fire that takes place under conditions similar to those in which the prescribed burn took place. Wildfires that initiate in high-risk weather conditions pose an entirely different threat. Under high wind and low humidity conditions, such as the Santa Ana winds in California, a wildfire will behave in an entirely different manner. Winds can propel fire through vegetation that did not burn in a prescribed burn and fire brands can travel for miles on the wind and ignite distant areas (Keeley, 2002; Quarles et al., 2010). Keeley (2002) states that prescribed burns are “most efficient at inhibiting the least threatening fires, and least effective in inhibiting the most threatening fires.”

Additional concerns over air quality, mechanical, manpower, and economic resources, and public perception indicate that prescription burns, while they may be one tool used in fire mitigation, should by no means be the exclusive tool for mitigating wildfire damage (Conard and Weise, 1998).

Mechanical fuel treatments alleviate the air quality concerns associated with prescribed burns. Mechanical fuel treatment operates on the same principle as prescribed burns: simply remove fuel from the environment before it has the opportunity to burn in a wildfire. Mechanical fuel treatments do not negatively impact air quality in the same way as prescribed burns, nor can they escape control and endanger lives and property. For these reasons, mechanical fuel treatments are often preferred by individuals living in WUI areas (Winter et al., 2002). Prescribed burns can be so socio-politically unpopular that they simply are not a viable option for some communities (Kalabokidis et al., 1998).

Winter et al., (2002) surveyed homeowners living in Florida, Michigan, and California about their perceptions on fuel treatments and found that beliefs about the outcome of fuel treatments were the primary concern in public perception. If homeowners felt that a fuel treatment was likely to negatively impact air quality, escape control, or be a financial burden, they were less likely to show support for that method. Mechanical fuel treatments were the method most preferred fuel treatments by WUI residents in the survey.

8.2 Mechanical Treatments

Various methods of mechanical treatments exist; each with their own set of pros and cons. Kalabokidis et al. (1998) used experimental plots of land to test three types of mechanical fuel treatment: "[vegetation] thinning with whole-tree removal; thinning with stem removal – lopping and scattering; and thinning with stem removal – hand piling and burning." All three methods were found to reduce available fuel levels and also reduced the rate of fire spread, heat (kJ/m^2), fireline intensity (kW/m), flame length, burned area, and fire perimeter. These experimental results indicate that mechanical fuel treatments represent effective methods for reducing fire hazards.

Despite being effective in an experimental setting, Kalabokidis et al. (1998) caution against the use of mechanical treatments that do no remove fuel from the environment (thinning with stem removal – lopping and scattering). The authors feel that despite the observed reduction in several metrics of fire risk, the risk associated with scattering fuels without removal is still too high to be a practical option for real-world fire mitigation. Additionally, the most effective method of mechanical treatment used in this study, vegetation thinning coupled with hand piling and burning of slash, amounts to little more than a pre-treated prescribed burn. This method requires piles of removed vegetation to be burned to remove fuel. Consequently, many of the risks and concerns associated with prescribed burns still apply to this method (Kalabokidis et al., 1998).

Despite awareness of these various mitigation techniques, both in scientific literature and government-published literature, the damage caused by wildfires has increased over time and shows no signs of decreasing. Mitigation alone does not appear to be a satisfactory response to the increasing damage caused by wildfires. If variables of the built environment that are linked to high fire damage can be identified, planners and land developers can take steps to prevent fire damage from occurring.

9. BUILT ENVIRONMENT DETERMINANTS OF FIRE DAMAGE

9.1 Density

Regions with high population and/or housing density are expected to experience increased damages compared to areas with relatively low densities. This relationship is expected because many fires are ignited, either intentionally or accidentally, by humans (Virginia Department of Forestry, 2012; National Interagency Fire Center, 2007). It is also possible that after a certain density threshold, damages may actually decrease. High levels of development should decrease available wildland fuels, decreasing the potential for fire damage (Virginia Department of Forestry, 2012).

9.2 Household Occupancy

Household occupancy data may further help to explain patterns of human/fuel interaction. Households themselves may operate as small pockets of intense fuel in a wildfire. Areas of high household occupancy may have more damages due to increased human presence and increased fuel in the form of structures. Alternatively, areas featuring households with low household occupancy may have higher damages because property may not be maintained in a manner that reduces wildfire risk. Evidence from Australia indicates that homeowner occupancy may have a roll in mitigating fire damage. Australia uses a “stay or go” policy in regards to wildfire evacuation.

Homeowners are encouraged to either evacuate well in advance of the fire or stay in place until well after the fire has passed (Handmer and Tibbits, 2005). In the event that homeowners choose to stay in place, they can actively protect their property. Obviously, vacant housing will not have occupants that have the option to remain in place and defend the structure. In this respect, increasing occupancy may decrease fire damage. Handmer and Tibbits (2005) conclude that "[the] available evidence that 'houses proect people and people protect houses' is strong…"

9.3 Building Age

Firebrands, mobile embers generated by a fire, pose a serious risk to structures in or near wildland fuel. Firebrands are one of the primary ways a fire can propagate (Quarles et al., 2010). Fire spread requires oxygen, heat, and fuel; a lack of any one ingredient will stop the spread of fire. Appropriate building codes should limit the spread of fire, and associated damage, by withholding fuel (in the form of flammable building materials) from a spreading fire. Differences in building survivability explained by building techniques are observed in both experimental and real-world settings (Cohen, 2000; Quarles et al., 2010). Presumably, modern building codes and techniques should be more resistant to fire. San Diego County claims that "homes built under recent (2001) codes have a more than three times better chance of survival" compared to older homes (San Diego County, 2010). (Building age will be used as an estimate of building code modernity.)

9.4 Percent Urban/Rural

The urban/rural composition of a municipality may contribute to the way fire damage is spread across the landscape. Differences in vegetation and development densities would be expected between urban and rural land use. Municipalities with high proportions of urban areas are expected to have lower damages, if only due to the relative scarcity of vegetative fuels in comparison to municipalities with a high proportion of rural areas. Alternatively, urban areas may experience higher damage than rural areas due to the relative abundance of man-made structures that could be consumed by fire.

9.5 Development Intensity

Differing degrees of development may influence fire damage. Development intensity may indicate different likelihoods of human-influenced ignitions or different densities of vegetative fuels. Development intensity data come from the 2006 National Land Cover Database (NLCD). The proportions of low intensity, medium intensity, high intensity, and open space development within a municipality will be examined. Increasingly extreme intensities of development are predicted to have less wildfire damage as vegetation is replaced by development.

Development intensity in the NLCD is determined by remote sensing spectral reflectivity. The reflectivity of each 30m x 30m pixel is analyzed and categorized. Open space “[includes] areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover [within each $30m^2$ pixel]. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.” Low intensity development “[includes] areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of the total cover. These areas most commonly include single-family housing units.” Medium intensity development “[includes] areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.” Finally, high intensity development “[includes] highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to 100 percent of the total cover” (Environmental Protection Agency, 2007).

10. BIOPHYSICAL DETERMINANTS OF FIRE DAMAGE

10.1 Vegetation Cover

Land cover data will also be used to examine vegetation cover. Types of vegetation will vary; different species of plants will exist in separate areas. This variability in distribution should contribute to variability in flammability (Virginia Department of Forestry, 2012).

10.2 Slope

Slope will influence fire damages. Generally speaking, wildfires travel uphill more readily than in any other direction. The heat generated by a fire rises and pre-heats vegetation, increasing the flammability of uphill vegetation (Pacific Northwest Wildfire Coordinating Group, 2001; Virginia Department of Forestry, 2012). This effect is exacerbated by steeper slopes. In addition to slope alone, the direction the slope faces will impact how vegetation burns. In the northern hemisphere, south and southwest facing slopes receive more solar energy. Solar energy increases the flammability of vegetation through dehydration (Virginia Department of Forestry, 2012). Presumably, steep south or southwestern facing slopes should be more flammable when compared to other orientations and slopes.

10.3 Percent Water Coverage

Bodies of water may decrease fire damages by acting as fire breaks (areas of space that fire cannot cross) and/or by increasing the moisture content of vegetative fuel, rendering it less flammable (Cardille et al., 2001). Alternatively, bodies of water may increase fire damages by promoting the growth of vegetative fuel. Past research has identified the amount of rainfall in the previous year as a predictor of the intensity of fires during the subsequent wildfire season (Swetnam and Betancourt, 1990). Precipitation in the year prior increases fire intensity by promoting the growth of the vegetation that will become wildfire fuel in the subsequent year. The presence of water bodies may promote vegetation growth in a similar manner.

11. SOCIOECONOMIC DETERMINANTS OF FIRE DAMAGE

Previous work has identified a number of variables that play a leading role in contributing to the social vulnerability of a population to natural hazards (Cutter et al., 2000; Cutter et al., 2003). Generally speaking, socially vulnerable populations are those populations that are in some way marginalized. For example, those lacking access to information, political input, and personal wealth are more socially vulnerable than other populations.

11.1 Education and Income

Education is an important component of vulnerability associated with fire hazards. Education is linked to higher earnings, and a lack of personal wealth is the number one factor contributing to social vulnerability (Cutter et al., 2003). Those individuals lacking sufficient funding cannot appropriately respond to the financial burdens of hazards. Though analysis is required to demonstrate this, there may alternatively be a positive relationship between income and fire damage. The individuals in wildfire vulnerable areas may be more affluent individuals. Due to the amenities of the WUI, including beautiful scenery, distant neighbors, and integration into nature, property costs can actually increase as fire risk increases (Donovan et al., 2007). Prior research on hazards and property values has shown that in some cases, property in otherwise high-hazard areas can command a higher price if it is associated with amenities of high value (Bin and Kruse, 2006). This may be the case in this study area.

11.2 Median Age

Previous research has investigated age as a component of social vulnerability. Cutter et al. (2003) identified children and the elderly as two populations that are particularly socially vulnerable. Children and the elderly are dependent upon others and may represent an obstacle in the movement of a population out of harm's way during a wildfire. However, Cutter et al. (2003) found that an increase in median age decreased social vulnerability. Similar effects of age upon fire damage are expected.

12. RESEARCH METHODS

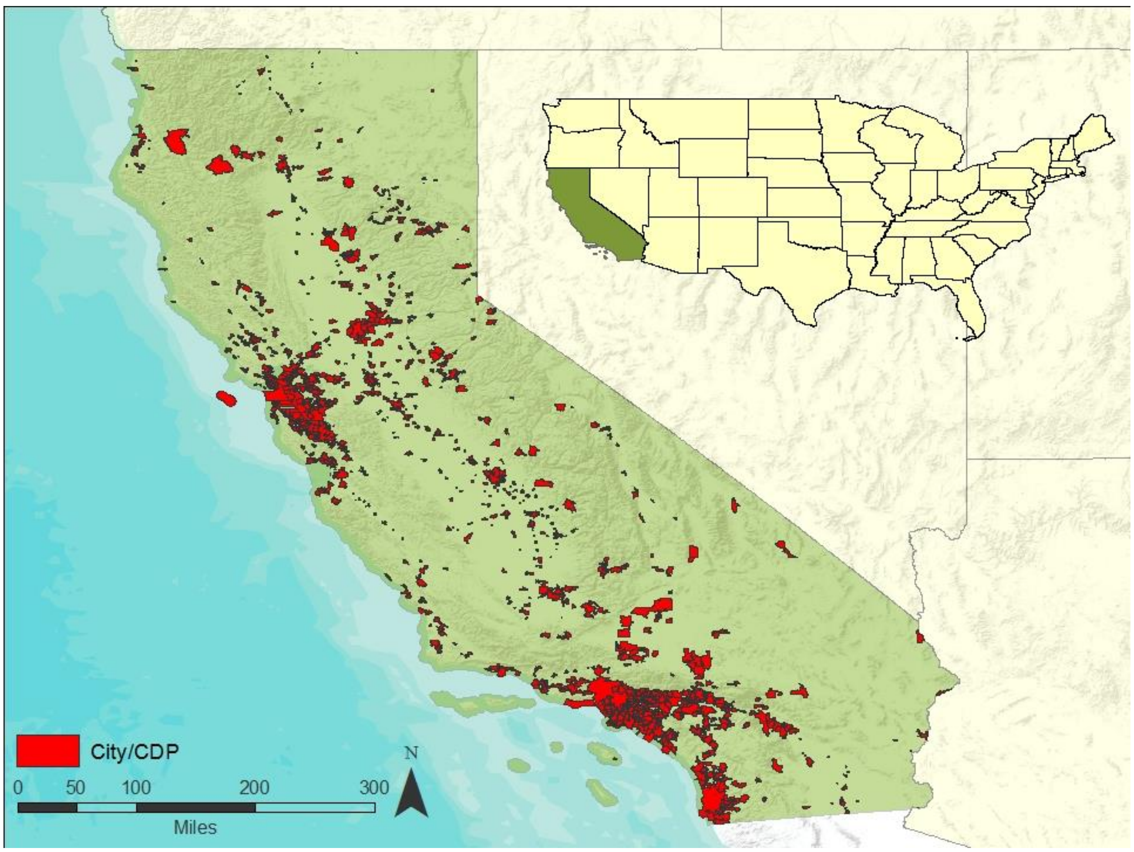
12.1 Study Area

The state of California provides an ideal study area to examine fire damage. The state frequently experiences wildfires and has a high number of housing units in areas that are vulnerable to fire. This intersection of the human built environment and a naturally fire prone environment provides an opportunity to examine how these two different realms interact.

12.2 Sample Selection

The sample used in this study is the Census Designated Places (CDP) in the state of California (see Figure 1). Nineteen municipalities were excluded from this analysis due to a lack of complete data coverage. The municipalities excluded are Almanor, Angels City, Calwa, Caribou, East Blythe, Foothill Ranch, Laguna, Laguna West-Lakeside, Moraga, Murrieta Hot Springs, Nebo Center, Newport Coast, Orosi, Portola Hills, San Joaquin Hills, South Yuba City, Storrie, Tustin Foothills, and Twentynine Palms Base. Some of these jurisdictions no longer exist due to annexation into other jurisdictions. Several other jurisdictions have populations of zero individuals. Other jurisdictions were very small and may not have been within the scope of investigation by the US Census Bureau. A total of 1,058 cities have complete data coverage for every variable and were used to develop the model used in this study.

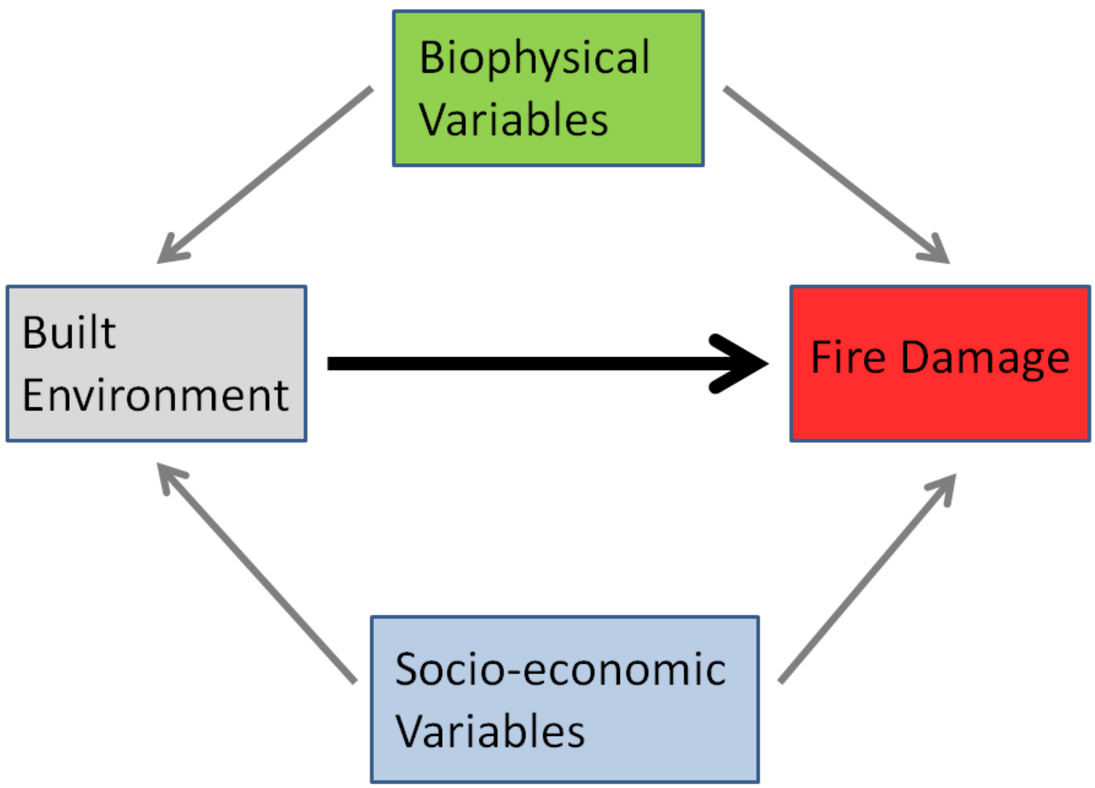
Figure 1. Study area and sample selection



13. CONCEPTUAL MODEL

Biophysical and socioeconomic factors interact at the local level to impact the amount of damage from wildfires. As shown in Figure 2, the relationship between the built environment and fire damage is the primary interest of this study. This relationship will be statistically isolated by controlling for biophysical and socio-economic variables.

Figure 2. Conceptual model



In this model, biophysical variables such as vegetation type and coverage, slope, and the presence of bodies of water are expected to impact fire damages and will be statistically controlled to isolate the effect of the built environment upon fire damage. More specifically, variables measuring patterns of vegetation growth and distribution are likely to influence fire intensity, if not also fire damage, due to the role of vegetation as the primary source of fuel in a wildland fire. Slope will influence fire behavior by heat convection. Fires will dry and pre-heat upslope vegetation, increasing the flammability of the land above it. Fire will travel faster uphill than downhill and faster on steep slopes than on flat land (Pacific Northwest Wildfire Coordinating Group, 2001). Variables of the biophysical environment should influence the built environment by constraining development. For example, building a subdivision on a lake or on a steep slope would be a poor decision for developers. Consequently development will not occur in such areas.

The socioeconomic environment also is expected to influence both fire damage and the built environment. Personal wealth may limit the areas where people may be able to live and consequently constrain development in certain areas. For example, affluent populations may have the ability to live in vulnerable areas that feature high-quality amenities while impoverished populations may be restricted to inexpensive housing in urban environments. Fire damage is also expected to be influenced by socio-economic variables. For example, wealthier jurisdictions may appear to have higher fire damage simply because they have more property value to lose while the actual threat from fire is no greater than in less wealthy communities. Additionally, wealthier individuals may have the means to live in higher hazard areas that offer high-quality amenities such as hilltop vistas and immersion in wildland landscapes. In contrast, lower income individuals may have no option other than to live in urban areas.

Intervention and mitigation is expected to moderate fire damage. Intervention actions such as firefighting should limit or prevent damage to structures or other property. Mitigation actions, including fuel treatments, defensible space, or prescribed burns, should prevent fires from occurring or modify fire behavior in a manner that decreases the likelihood of property damage due to fire.

14. CONCEPT MEASUREMENT

Table 1 – Descriptive statistics for all variables

Variable	Mean	Std. Dev.	Min	Max
Dependent Variable				
Fire Damage (Untransformed)	455100.8	7632180	0	237436100
Fire Damage (log transformed)	4.646	5.036	0	19
Built Environment Variables				
Proportion occupancy	0.889	0.136	0.195	1
Household density	1148.03	1187.514	0.584	11762.36
Median year built	1970.083	10.637	1939	1998
Total housing units	12139.73	49647.28	9	1370961
Socio-economic Variables				
Proportion urban	0.729	0.418	0	1
Proportion of population under age 5	.057	.017	0	.099
Proportion of population over age 65	0.023	.021	0	.333
Median income	49883.98	24171.84	14821	201730
Biophysical Variables				
Average slope	4.949	5.116	0	31.367
Water coverage	3.442	11.747	0	84.397
Developed open space coverage	14.324	11.505	0	73.944
Low-intensity development coverage	15.763	12.082	0	75.576
High-intensity development coverage	4.144	8.115	0	86.921
Deciduous forest coverage	0.724	2.414	0	30.051
Scrubland coverage	10.746	18.035	0	94.067
Grassland coverage	9.289	13.845	0	82.578
Woody wetland coverage	0.445	1.738	0	29.642
Herbaceous wetland coverage	0.638	2.186	0	25.743
Mixed forest coverage	1.674	4.449	0	38.746

14.1 Dependent Variable

The dependent variable for the study, fire damage, is reported for each incident in US dollars. Individual nonzero incident damages range from $1.00 to $237,401,649, with a mean incident damage of $86,141. This variable was log-transformed to approximate a normal distribution (see Table 1).

This data come from the California All Incident Reporting System (CAIRS), part of the Office of the State Fire Marshall (OFSM) (see Table 2). This state program "collects, analyzes and distributes statistical information reported by the California Fire Service" (CAIRS Homepage). Reporting to OFSM is entirely voluntary but is encouraged. Annually, these records are analyzed and reported to state entities and other interested parties. Each incident report details location, total property loss, and any loss of life or injury. While fire departments report a whole host of incident types to OFSM, this study will focus exclusively upon damages sustained during natural vegetation fires, cultivated vegetation fires, and unauthorized burns. A total of 79,919 relevant incidents were reported from 2007-2010 and will be included in this study.

The vast majority of relevant fire incidents reported to OFSM, about 91%, have no dollar damage. It is not uncommon for multiple fire departments to respond to the same incident (Kirsti Fong, personal communication, 12/14/2011). In the eventuality of a mutual aid event, the assisting fire departments are instructed by OFSM to report a loss of zero dollars, leaving the incident command fire department responsible for reporting damages. This is a potential source for the high proportion of zero-damage fire incidents.

However, it seems unlikely that mutual aid events are the primary source of zero-damage wildfires. Many of these zero-damage event records may be from fire incidents that required fire department attention, yet did not cause any property damage.

The dependent variable was derived from a comprehensive dataset as reported to OFSM as of 12/14/2011. This data covers the entire geographic range of the state of California. Damages are reported to OFSM by fire departments after each individual incident. Each record details the dollar damage of the incident, injuries to civilians and fire crews, and any civilian or fire crew loss of life. Each record is reported by CAIRS as received by OFSM. CAIRS does no data processing on the reports that they distribute. Thus, the reporting fire departments are entirely responsible for determining the quality of the data available from CAIRS. Incident report submission, while encouraged, is entirely voluntary. This results in considerable variation across records. For example, some fire departments report incident street addresses (or as close as possible) while others do no more than report the city in which the incident occurred.

Many fire departments report incident zip codes, as it is a field that is required for submission (Kirsti Fong, personal communication, December 15, 2011). Unfortunately, zip codes represent a problematic unit of analysis for multiple reasons and are probably best ignored in this instance. About 98% of total incidents provide an incident city. While a finer spatial resolution would be ideal, as cities are not homogenous across their extent, cities do represent a convenient unit of analysis for this study. Damages were aggregated to the city level and summed across all years for which data existed.

14.2 Biophysical Variables

Frequently, extreme weather conditions such as drought or high winds are important variables in driving fire behavior. Because this is a cross-sectional study, it will be difficult to interpret how single extreme weather events are related to fire damage over the four years examined. Measurements of central tendency may not adequately explain how weather influences fire damage since fires starts are driven more by extreme weather conditions than typical weather conditions. Consequently, weather variables will not be examined and other non-meteorological variables will be examined instead.

Because wildland fire is fueled by vegetation, it is necessary to control for biophysical variables that might influence the distribution of fuel in space. In the fully specified model used in this study, eleven biophysical predictors of fire damage were included: *slope, water coverage, developed open space coverage, low-intensity development coverage, high-intensity development coverage, deciduous forest coverage, scrubland coverage, grassland coverage, woody wetland coverage, herbaceous wetland coverage,* and *mixed forest coverage*.

Slope is measured as the average slope of the land within the boundaries of a municipality. Digital Elevation Models from the US Geological Survey were processed in ArcMap to derive an average slope for every municipality (see Table 2). *Slope* ranged from 0 in the flat municipalities of Bombay Beach, Brawley, Calipatria, Desert Shores, El Centro, Holtville, Imperial, Mecca, Niland, Salton Sea Beach, Seeley, and

Westmorland, all located in California's Imperial Valley, to 31.3669 in the hilly municipality of Tobin, located in the Cascade Mountains.

Vegetation cover data comes from the NLCD dataset (see Table 2). All NLCD data used in this study is derived from Landsat reflectance data and has a spatial resolution of 30 meters (see Table 2). Used in this study are the classifications of *water, deciduous forest, scrubland, grassland, woody wetland, herbaceous wetland,* and *mixed forest*. All variables are measured as the percent of a municipality that is covered by that vegetation type.

Water coverage ranged from 0% coverage in 468 municipalities to 84.39% coverage in Brisbane, a city on the San Francisco Bay. Mean *water coverage* for all municipalities within California is 3.44% coverage.

Deciduous forest coverage ranged from 0% coverage in 782 municipalities to 30.05% coverage in Loma Rica, a city a few miles outside of the Tahoe National Forest. Mean *deciduous forest coverage* for all municipalities in California was 0.72% coverage.

Scrubland coverage ranged from 0% coverage in 287 municipalities to 94.07% coverage in the Mojave Desert community of Darwin. Mean *scrubland coverage* for all municipalities in California was 10.73% coverage.

Grassland coverage ranged from 0% coverage in 103 municipalities to 82.58% coverage in Chinese Camp, a former gold rush town located in the grasslands between the agricultural development in the state's Central Valley and the Sierra Nevada Mountains. Mean *grassland coverage* for all municipalities was 9.29% coverage.

Woody wetland coverage ranged from 0% coverage in 593 municipalities to 29.64% coverage in Bradley, a small municipality that sits on the Salinas River. Mean *woody wetland coverage* in all municipalities in California was 0.45% coverage.

Herbaceous wetland coverage ranged from 0% coverage in 631 municipalities to 25.74% coverage in Whitehawk, a Northern California municipality so small in area that one large alluvial field between two divergent creeks appears to account for all wetland coverage. In aggregate, municipalities in Califnoria have a mean of 0.64% *herbaceous wetland coverage*.

Development intensity data come from the 2006 NLCD dataset. The NLCD classifies developed areas as being *developed open space, low-intensity, medium-intensity,* or *high-intensity development.* While all four categories were initially selected for inclusion in the model, *medium-intensity* development was removed from analysis because it introduced high levels of multiple colinearity.

Developed open space coverage ranged from 0% coverage in Buena Vista, East Compton, Greenhorn, Johnsville, Seven Trees, Sunol-Midtown, and Walnut Park to 73.94% coverage in Atherton, an exceptionally wealthy municipality in the San Francisco Bay Area. In aggregate, municipalities in California have a mean of 14.32% *developed open space coverage*.

Low-intensity development coverage ranged from 0% in Big Bend, Bucks Lake, Greenhorn, Johnsville, Sunol-Midtown, and Walnut Park to 75.58% coverage in Niland, a small census-designated place in the south of the state. The municipalities with 0% *low-intensity development* coverage are all heavily forested municipalities, with the exception of Sunol-Midown in the heavily developed San Francisco Bay Area. In aggregate, municipalities in California have a mean of 15.76% *low-intensity development coverage*.

High-intensity development coverage ranged from 0% coverage in 266 separate municipalities, to 86.92% coverage in Vernon, part of the Los Angeles metropolitan area. Mean *high-intensity development coverage* for all municipalities was 4.14%.

14.3 Socioeconomic Variables

Several socioeconomic variables were measured for use in this analysis. *Median household income* data was taken from Geolytics Annual Estimates. The data provided by Geolytics is generated by processing US Census Data (see Table 2). The US Census Bureau defines median income as being “the amount which divides the income distribution into two equal groups, half having incomes above the median, half having incomes below the median. The medians for households, families, and unrelated individuals are based on all households, families, and unrelated individuals, respectively. The medians for people are based on people 15 years old and over with income” (US Census Bureau, 2012b). *Median household income* for the year 2007 ranged from $14,821 in Salton Sea Beach to $201,730 in Rolling Hills, a municipality composed of a single private, “ranch style/equestrian environment” gated community (Rolling Hills, CA, 2013). The mean *median household income* for all municipalities examined in this study was $49,883.98. *Education*, measured by the proportion of the population over the age of 25 with a bachelors' degree, was intended for inclusion in the analysis but was ultimately omitted due to colinearity with *median income*.

Proportion urban/rural data come from the 2000 US Census (see Table 2). This variable is measured as the proportion of a municipality that is classified as urban by the US Census Bureau. According to the US Census Bureau, to be considered urban an area "must encompass at least 2,500 people, at least 1,500 of which reside outside institutional group quarters." Anything that falls outside of that definition is considered to be "rural" (US Census Bureau, 2012a). In the 1,058 municipalities used in this study, 250 municipalities were completely rural (0.00) and 384 municipalities were completely urban (1.00). The average *proportion urban* for all municipalities was 0.73.

As in Cutter et al. (2003), three age-related variables are examined: *Proportion of the population under age 5, Proportion of the population over age 65,* and *Median age*. The *Median age* variable was excluded from analysis because it introduced multiple colinearity to the model. The other two variables, *proportion of the population under age 5* and *proportion of the population over age 65*, are intended to measure the presence of children and the elderly, respectively. All age-related measurements come from Geolytics Annual Estimates. As is the case with all data obtained from Geolytics, the estimates from the year 2007 were used.

14.4 Built Environment Variables

Household density measurements were taken from Geolytics Annual Estimates (see Table 2). In this study, *household density* was measured as the mean number of households per square mile in a municipality. *Household density* ranges from 0.58 houses per square mile in Homewood Canyon-Valley Wells in the Mojave Desert to 11,762.4 households per square mile in West Hollywood. The mean *household density* for all municipalities in California is 1,187.51 households per square mile.

Total housing unit counts were taken from Geolytics Annual Estimates (see Table 2). Quite simply, this variable is defined by the total number of housing units within the boundaries of a municipality in the year 2007. Total housing units ranged from 9 housing units in the municipalities of Prattville and Tobin, both in the Cascade Mountains to 1,370,961 housing units in the city of Los Angeles. Mean *total housing units* for all municipalities in California is 12,139.73 housing units.

Household occupancy data come from Geolytics Annual Estimates (see Table 2). *Proportion occupancy* was defined as the proportion of total households within a municipality that are occupied. *Proportion occupancy* ranged from .195 in Darrington to 1.00 in Clyde, Port Costa, and San Geronimo, with a mean of .729.

Building age data come from the 2000 US Census (see Table 2). Building age is measured as the median year of household construction within a municipality. To clarify, this variable is defined by the *year* of construction, rather than the *age* of structures. The oldest *median year built* was 1939, observed in the municipalities of

Amador City, Crockett, March Air Force Base, McCloud, Pearsonville, Piedmont, Port Costa, Randsburg, Ross, Tennant, Tomales, and Walnut Grove. The municipality of Las Flores has the youngest buildings, with a *median year built* of 1998. The mean median year built across all municipalities was 1970.

Table 2. Concept measurement

Variable name	Variable operation	Expected Sign	Data source
Dependent variable			
Fire damage	The total reported property damage within a municipality as reported by OFSM for years 2007-2010		California All Incident Reporting System, 2007-2010
Built environment variables			
Density	The mean household density within a municipality, measured in households per square mile	+/-	Geolytics Annual Estimates, 2007
Household occupancy	The proportion of total households within a municipality that are occupied	+/-	Geolytics Annual Estimates, 2007
Building age	The mean structure year built within a municipality	-	US Census Bureau, 2000
Biophysical variables			
Development intensity	The proportion of a municipality occupied by open space, low-intensity development, medium-intensity development, and high-intensity development	-	NLCD, 2006
Vegetation cover	The percentage of a municipality covered by deciduous forest, evergreen forest, mixed forest, shrub/scrub, or grassland/herbaceous vegetation coverage	+	NLCD, 2006
Slope	The average slope of a municipality	+	USGS
Water area	The percentage of a municipality covered by open water, woody wetland, or herbaceous wetlands	+/-	NLCD, 2006
Socioeconomic variables			
Income	The median household income within a municipality	+	Geolytics Annual Estimates, 2007
Education	The proportion of the population over the age of 25 in a municipality with a bachelor's degree	+	Geolytics Annual Estimates, 2007
Median age	The median age of the population within a municipality	-	Geolytics Annual Estimates, 2007
Children	The proportion of the population in a municipality under the age of 5	+	Geolytics Annual Estimates, 2007
Elderly	The proportion of the population in a municipality over the age of 65	+	Geolytics Annual Estimates, 2007
Percent urban	The percentage of a municipality classified as urban by the US Census Bureau	+/-	US Census Bureau, 2000

15. HYPOTHESES

Based on the conceptual model outlined in Figure 2, my research empirically tests the following hypotheses (Table 2):

H1. Increasing household density in a municipality will significantly increase the reported dollar loss from wildland fire within that municipality.

H2. Increasing development intensity in a municipality will significantly decrease the reported dollar loss from wildfire within that municipality.

H3. Increasing the proportion of rural area in a municipality will significantly increase the reported dollar loss from wildland fire within that municipality.

H4. Increasing the average building age in a municipality will significantly decrease the reported dollar loss from wildfire within that municipality.

H5. Increasing the median household income of a municipality will significantly increase the reported dollar loss from wildland fire within that municipality.

H6. Increasing the proportion of vacant households in a municipality will significantly increase the reported dollar loss from wildland fire within that municipality.

15.1 Expected Results

It is expected that a higher municipal household density will be related to higher reported damages. This is expected for two reasons: (1) humans have been indicated as a source of wildfire ignition and (2) private property, public property, and infrastructure that does not exist cannot be damaged. It is also possible that beyond a certain density level, damages will decrease due to development replacing vegetation in the landscape.

It is expected that areas classified as high- or medium-intensity development in the NLCD dataset will exhibit lower fire damage. These areas are expected to be so intensely developed that the presence of flammable fuels is not possible.

It is expected that areas of more extreme development intensity will exhibit lower fire damage. More extreme levels of development are expected to have low levels of vegetation, whereas open spaces and areas of lower development intensities are expected to have higher levels of vegetation. For the same reason, rural areas are expected to exhibit higher damage reports. Rural areas are expected to have higher levels of flammable fuels.

Municipalities with younger average building ages are expected to have lower reported damages. Younger buildings are assumed to have been built with more advanced building codes and practices that should reduce the likelihood of a building igniting or propagating fire.

Vacancy status may either decrease or increase fire damage. Vacant properties may increase damages if they are poorly maintained. Conversely, high occupancy may increase damages by having a greater human presence; humans have been demonstrated to be a source of fire ignition. Occupancy may also decrease fire damages if occupants are actively taking measures to protect their home, either in acts of pre-fire mitigation or in active firefighting.

Wealthier municipalities are expected to experience higher reported damages. This may be due to two factors: (1) wealthier municipalities may simply have more property value to be lost in a fire, and (2) wealthier individuals may have the option to live in high-cost, high-amenity areas, such as WUI areas. Lower income individuals may be restricted to urban centers.

Municipalities with higher proportions of children and/or elderly are expected to have higher fire damages. Children and elderly individuals are expected to impede the ability to move people and property out of the way of a fire; children and the elderly may be less mobile than people of intermediate age and may require assistance. Municipalities with a higher median age are expected to have lower fire damages. Increasing median age is expected to be associated with lower social vulnerability. Three age related variables will be examined: (1) median age, (2) the proportion of the population under age 5, and (3) the proportion of the population over the age of 65.

16. DATA ANALYSIS

A multiple regression model was generated to estimate the effects that the built environment and several control variables on fire damage in the state of California.

Due to the large sample size used in this model, the data are assumed to be normally distributed. Because the dependent variable, fire damage, is measured in dollars it was log transformed to approximate a normal distribution. Using the Breusch-Pagan test, the data were found to be heteroskedastic; therefore the regression model was run with robust standard errors.

A quadratic household density function was initially included in the model to test for an inflection point in the relationship between damage and household density. No such inflection point was found. The quadratic household density term was subsequently removed from the model.

Several variables that were initially selected for analysis, such as median age, education, and evergreen forest coverage were dropped from the model. Variance Inflation Factor (VIF) was calculated for all variables used in the model. Variables that exhibited strong multicollinearity were identified by VIF scores and then examined in pairwise correlation. Correlations that were statistically significant and exhibited high correlation coefficients were identified as candidates for removal from the model. This process was repeated until VIF scores were brought down to a suitable level.

For example, education and income variables exhibited strong colinearity. Consequently, the education variable was removed from analysis. Several land cover variables, including developed open space and medium intensity development, also exhibited colinearity.

The Arc suite of GIS software developed by ESRI was used extensively for data processing. ArcGIS was used to map damage data onto municipal boundaries. All biophysical, built environment and socio-economic data were imported into ArcGIS for processing prior to statistical analyses. STATA 12 statistical software was used for statistical analysis. Census data estimates were taken from Geolytics and the US Census Bureau.

17. RESULTS

Between the years of 2007 and 2010, a total of 79,919 individual incident reports ranging from $0.00 to $237,401,649.00 in damage were submitted to OFSM, totaling $603,838,301.00 in damage. Due to the high number of incidents in which no damage was reported, about 91%, the average damage per incident was only $7,556.00. The average damager per incident for non-zero damage incidents was $86,141.00. The city of Ramona sustained the most fire damage, $237,436,100.00, over the course of the four years studied.

As a group, built environment variables explain the greatest amount (just over 10%) of variation in fire damage between municipalities (see Table 3). All built environment variables are statistically significant at the .01 level.

When examining only the effect of built environment variables on fire damage, the proportion of occupied housing units within a municipality is the strongest predictor of fire damage. In order of declining contribution to the model, the median year of housing unit construction, total number of housing units, and household density are all significant predictors of fire damage. Both total housing units and more recent years of construction are positively related to higher damages. Household density is negatively related to damages (see Table 3).

After the addition of socioeconomic variables into the model, all built environment variables remain significant at the $p<.01$ level. The addition of socioeconomic variables only explains an additional 1.5% of the variation in reported

Table 3. Nested regression models predicting property damage from wildfires in California

	Unstandardized coefficient	Beta	Unstandardized coefficient	Beta	Unstandardized coefficient	Beta
Built environment variables						
Proportion occupancy	7.4068** (0.8731)	0.2003	8.0906** (1.0735)	0.2188	5.8969** (1.2033)	0.1595
Household density	-0.0005** (0.0001)	-0.1067	-0.0006** (0.0001)	-0.1336	-0.0005** (0.0001)	-0.1088
Median year built	0.0881** (0.0134)	0.1861	0.0875** (0.0135)	0.1849	0.0797** (0.0138)	0.1684
Total housing units (in 1000s)	0.0180** (0.0064)	0.1770	0.0178** (0.0066)	0.1757	0.0183** (0.0068)	0.1805
Socioeconomic variables						
Proportion urban			0.4815 (0.4808)	0.0400	0.9496† (0.5197)	0.0789
Proportion of population under age 5			-0.1300 (12.8963)	-0.0004	9.4750 (13.9679)	0.0319
Proportion of population over age 65			-5.2690 (5.8934)	-0.0220	-1.2052 (5.9393)	-0.0050
Median income (log transformed)			-1.7170** (0.4407)	-0.1393	-1.3279** (0.4676)	-0.1077
Biophysical variables						
Average slope					-0.0508 (0.0368)	-0.0516
Water coverage					0.0018 (0.0151)	0.0042
Developed open space coverage					-0.0184 (0.0157)	-0.0421
Low-intensity development coverage					-0.0226 (0.0150)	-0.0543
High-intensity development coverage					-0.0439* (0.0201)	-0.0707
Deciduous forest coverage					0.1424* (0.0647)	0.0682
Scrubland coverage					-0.0193* (0.0085)	-0.0690
Grassland coverage					0.0229† (0.0128)	0.0629
Woody wetland coverage					-0.0760 (0.1257)	-0.0262
Herbaceous wetland coverage					-0.1611* (0.0527)	-0.0699
Mixed forest coverage					0.0476 (0.0393)	0.0420
Constant	-175.1990 (26.4787)		-156.3594 (27.0480)		-143.2876 (27.4399)	
N	1058		1058		1058	
F	32.03		20.65		10.98	
Probability > F	0.0000		0.0001		0.0001	
Adjusted R-squared	0.1020		0.1170		0.1344	

Note: Robust standard errors are in parentheses
Null test of coefficient equal to zero
†p<.10
*p<.05
**p<.01

fire damage. The natural log transformation of the median income of a municipality is the only statistically significant socioeconomic predictor of fire damage in a municipality ($p<.01$).

The inclusion of biophysical variables, along with socioeconomic variables in the fully specified model, allows for the explanation of approximately 13.5% of the variation in fire property damage (see Table 3). This indicates that the four built environment variables in this model account for about 76% of the explained variation in reported fire damage. In the fully-specified model, all of the previously significant predictors of fire damage remain significant at the .01 level. The percentage of urban area in a municipality becomes significant at the .1 level after the inclusion of biophysical variables. Deciduous forest and grassland coverage both increase fire damage ($p<.05$ and $p<.1$, respectively). High intensity development, scrubland, and herbaceous wetland coverage all decrease fire damage ($p<.05$, $p<.05$, and $p<.01$, respectively).

Despite the addition of several statistically significant biophysical predictors of fire damage, the built environment variables continue to have the greatest influence on fire damage. The natural log of median household income has a relatively high degree of influence upon the dependent variable, but still remains less influential than the least effective built environment predictor of fire damage ($\beta = -.1077$) (see Table 3).

Within the fully specified model, the socioeconomic variables of proportion of population under age 5 and proportion of the population over age 65 remain statistically insignificant. Perhaps related to colinearity with another variable, the direction of the coefficient for proportion of the population under age 5 changes from negative to positive once the biophysical variables are added. However, as the variable is not statistically significant this change is no more than a curiosity.

The biophysical land coverage variables of slope, water coverage, developed open space, low-intensity development coverage, woody wetland, and mixed forest coverage are all not statistically significant in the fully specified model (see Table 3). The general lack of contribution to the model that biophysical variables, particularly slope, provided was unexpected. As discussed later, the level of analysis or categorization of data in the landcover dataset may explain why these variables performed as they did in the model.

By examining standardized betas, the relative contribution of each variable to the model can be identified. Perhaps most noteworthy is that none of the biophysical variables have betas anywhere near as high (absolute value) as any of the built environment variables. The built environment variable with the *lowest* beta score in the fully specified model, household density, has a beta of -0.1088. The biophysical variable with the *highest* beta score, high intensity development, has a beta of -0.0707. Arguably, high-intensity development coverage is not truly a biophysical variable, but a variable that describes the built environment. This further underscores the high level of explanatory power that built environment variables contribute to the fully specified model. However, because the high density development coverage data comes from the same land cover map as all other land cover variables, it was treated as a biophysical variable in this instance.

Only one socioeconomic variable is found to be statistically significant, median income ($p<.01$), the beta for median income is -0.1077, slightly lower than any of the built environment variables, but well above the betas for any of the biophysical variables, again emphasizing the relative lack of contribution to the model that the biophysical variables provide (see Table 3).

18. DISCUSSION

The overwhelming degree of statistical influence of the built environment variables in the fully specified model indicates that fire property damage is not solely a natural environment phenomenon, but one also driven by the human built environment. Ignoring the built environment variables, the next best predictor of fire damage is a socioeconomic variable, income, again indicating that fire property damage is not primarily influenced by natural processes.

The median income of a municipality is the only statistically significant socioeconomic predictor of fire damage. It was initially suspected that higher income would be related to higher damages for two reasons. First, because fire damage is measured in dollars, rather than in acres burned or some other nonmonetary metric of damage, those with greater property value have the potential for more loss. Second, it was suspected that properties in areas that are biophysically vulnerable to wildfire command high prices because of high-quality amenities available in the area. Previous research has indicated that even in high-hazard areas, property values can be driven by high-value amenities rather than hazard risk (Bin and Kruse, 2005). However, the model indicates that lower income is tied to greater property loss.

At least in the case of this study, the assumption that high-risk rural locales are areas of relative prosperity appears to be in error. In this study, income and urbanization are positively correlated ($r=.2618$, $p<0.01$). As the proportion of a municipality classified as rural by the US Census Bureau increases, the median income of that municipality decreases. According to Lynn (2003), areas most vulnerable to fire are frequently populated by the rural poor.

Research identifies social factors as being important components of hazard vulnerability (Cutter, 2003; Lynn, 2003). Income, or lack thereof, is indicated as being one of the most important components of social vulnerability (Cutter, 2003). Wealth allows populations to recover more rapidly from hazard losses. Communities that lack wealth may lack the financial resources required to recover from hazard losses and may lack the ability to avoid or prepare for hazards in the first place (Cutter, 2003; Lynn, 2003). While the work published by Cutter (2003) discusses social vulnerability without a focus on anyone specific hazard type, Lynn (2003) claims that “wildfires intensify rural poverty because they hit hardest those communities least able to protect themselves,” indicating that social relationships similar to those observed in relation to other hazards also exist for wildfire hazards.

The creation of defensible space, areas of land cleared of highly flammable vegetation around the home, is consistently one of the most cited methods of household- and community-level wildfire mitigation (Cohen, 2000; Dennis, 2003). The impoverished may lack access to resources and information that are necessary for the preparation of adequate defensible space (Lynn, 2003). Defensible space takes time, resources, and upkeep to be effective. Even if awareness of the need for defensible space preparation exists, it may not be feasible to create defensible space due to a lack of human-hours or resources needed to clear vegetation. Even if these populations are aware of the need for defensible space, they may not know how to effectively prepare a particular site. Living in high-hazard areas coupled with substandard or nonexistent defensible space preparation, puts these populations at great risk. The vulnerability to fire posed by firebrands and low-quality defensible space can be a serious issue for any homeowner, but should be of particular concern to the impoverished. Consistent with previous research, relatively low income municipalities are predicted to experience higher damages ($p<.01$).

Beyond defensible space mitigation, income may play a role in building materials or construction practices. Cohen (1999) reports that housing units can be more flammable than the vegetation that surrounds them, and recounts case studies in which houses surrounded by non-burning vegetation were ignited by firebrands from over a kilometer away. Additionally, if structures have nonflammable roofing (effectively excluding the direct influence of firebrands), case studies indicate that as little at 10 meters of defensible space is sufficient to yield a structure survival rate up to 95 percent (Cohen, 1999). Experimental data indicate that 10 meters of vegetation clearance is sufficient to prevent experimental wooden walls from igniting from exposure to radiant heat generated by crown fires (Cohen, 1999). Non-flammable roofing materials such as Spanish tile, aluminum, or slate, are expensive and may be too costly for relatively impoverished homeowners in the WUI. Homeowners using flammable roofing materials will likely not observe the high survivability reported by researchers using flame resistant materials. Consistent with existing literature, this study finds that increasing median income is a statistically significant ($p<.01$) predictor of decreasing damage.

The proportion of occupied housing units and total housing units are two of the variables that heavily influence the model. Both variables predict higher damages. The positive relationship between housing unit occupancy and damage suggests that the fires causing property damage may be started by humans. Additionally, occupied habitation may tend to be of higher value than vacant housing, thus being capable of generating more loss.

Data from the National Interagency Fire Center reveal that the vast majority of fires, about 86% from 2001 to 2011 in California, are set by humans (National Interagency Fire Center, 2007). Over the same time and area, about 72% of burned land area was caused by human-started fires.

Genton et al. (2006) found arson wildfires to be spatially clustered. Arson fire, the single most frequent cause of fire in their study, was found to be clustered around cities. Additionally, fires caused by railroads were also very strongly spatially clustered.

Due to their fixed nature, the clustering of arson and railroad generated fires is not surprising. In both cases the cause of fire has limited mobility. An arsonist, while mobile, is still somewhat restricted in the extent of their activities. Railroad lines, on the other hand, are fixed in space. Presumably fires from both sources would be started in areas in or near cities where the total number of housing units and the occupancy of those housing units are both high.

The relationship between total housing units and damage should not be surprising. Housing units that do not exist cannot be damaged. The total housing unit count and total area of the jurisdiction are highly correlated ($r=0.8092$, $p=0.0000$).

Simply put, larger cities can fit a larger number of housing units. Obviously, without taking the relative size of jurisdictions into consideration, it will appear that larger cities are more prone to damage. While it may not seem particularly informative to examine the effect of housing unit counts on fire damage without in some way controlling for the size of the municipality, the results from the fully specified model indicate that each additional housing unit adds, on average, an extra $138.00 in damage. If fire damage from increased development can be predicted, actions could be taken to ensure that any proposed development will have the capacity to address any fire damage that additional housing units will generate.

Fire property damage decreases as household density increases. No threshold in density caused a sign change in the relationship between damage and density as was suspected. It is possible that the municipal level of analysis does not provide adequate resolution to observe this relationship. Perhaps at a different level of analysis this relationship will be observed. This relationship between increasing density and decreasing fire damage is likely because high-density development crowds out vegetation that could become fuel in a wildfire.

Housing age is the second most powerful predictor of fire damage in the fully specified model after total housing unit count. Surprisingly, as the average age of the buildings within a municipality increase, fire damage decreases. This trend is significant at the .01 level. This trend is unexpected. It was predicted that younger municipalities would experience less fire damage. This was expected because newer buildings would be built to modern, and presumably more fire-resistant, building codes. Modern housing codes have been reported to be a factor that improves building survivability (San Diego County, 2009). An alternative hypothesis that deserves additional research attention is that younger buildings may be sprawling out into high fire hazard wildland areas.

The correlation between housing age and household density is statistically significant at the .01 level ($r=0.2228$, $p=0.0000$). As the median age of structures within a municipality increases, the average density of the municipality increases. Both municipalities with relatively young structures and municipalities with relatively low-density development are positively related with damage. These relationships suggest that relatively recent sprawling development into wildlands is responsible for the damage associated with young municipalities and low-density development.

As discussed earlier, many researchers feel that expansion into the WUI is one of the most pressing concerns in fire management. Countless authors express concern over fire hazard risks in the WUI. Cardille et al. (2001) claim that the WUI is the area in which human-caused fires are most frequent. Radeloff et al. (2005) find that the state of California has 5.1 million housing units in the WUI. Radeloff et al. (2005) also remark that the chaparral environment of southern California is "perhaps the [area] most prone to fire of all WUI areas in the United States." Alarmingly, Theobald and Romme (2007) find that 95% of the land area of California's WUI is classified as either "high severity" or "[currently] high (historically low or variable)" fire severity areas. The consensus appears to be that the sprawl of cities into surrounding wildland vegetation puts people and property in areas that are prone to fire. Curbing the development of these areas will be critical in limiting fire damages. Enacting policies that combat urban sprawl may be one of the most powerful tools available to planners to reduce fire damage.

Unexpectedly, land cover variables account for a relatively low amount of the explained variation in fire damage in the fully specified model. Land cover contributes less than 2% of the 13.4% of variation in the dependent variable that the model accounts for. This is surprising because fire behavior is heavily dictated by biophysical characteristics such as vegetation type, slope, and weather and climate (Franklin, 1995; Pacific Northwest Wildfire Coordinating Group, 2001). Perhaps because this study examined fire damage rather than number of ignitions, area burned, or other nonmonetary ways of measuring the impact of fire, variations in land cover are comparatively poor predictors of fire damage.

The negative relationship between high-intensity development coverage and fire damage is expected. Much like household density, high-intensity development is expected to out-compete vegetation for space. High-intensity development provides the largest contribution to the model out of all the land cover variables used in the fully specified model.

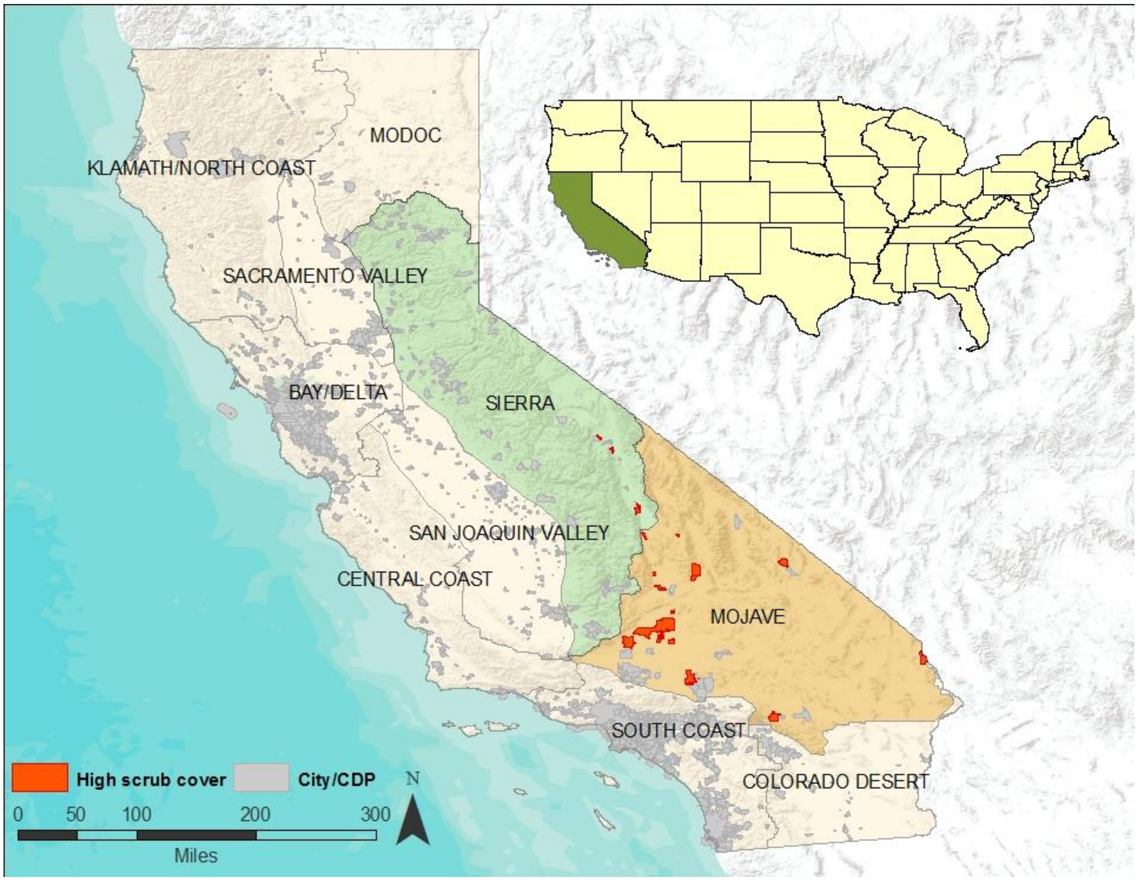
Only four other land cover variables are statistically significant. Deciduous forest, scrubland, and herbaceous wetland coverage are all statistically significant at the .05 level. Grassland coverage is statistically significant at the .1 level. Increasing both grassland coverage and deciduous forest coverage increases the degree of fire damage. Scrubland and herbaceous wetland coverage both decrease fire damage ($p<.05$).

Deciduous forest coverage likely increases damage by providing fuel in the form of leaves that have fallen from trees in the winter months. Herbaceous wetlands likely lack the accumulation of vegetative fuel that is required to support property-damaging wildfires. Grasslands likely provide flammable kindling in hot, dry summer months. However, the relationship between fire damage and scrubland coverage is somewhat confusing.

The relationship between scrubland and fire damage is the opposite of expected. Scrubland coverage was expected to increase fire damage. The Chaparral scrubland of the Southern California coast is very flammable. As discussed above, Chaparral environments are adapted to fire, and were assumed to be related to damages. However, the model generated in this study indicates otherwise. This may be due to the way that NLCD data are classified.

While the flammable Chaparral is part of the NLCD scrubland classification, it is not the only type of scrubland cover in California. Much of the scrubland in the NLCD map is found outside of the range of Chaparral ecosystems. Much of the scrubland coverage in California is located in the southeastern portion of the state, near the border with Arizona and Nevada. The twenty municipalities with the highest scrubland coverage are all found in the Mojave Desert and Sierra Nevada bioregions of California (see Figure 3). While these municipalities do have high proportions of scrubland coverage (>75%), the scrubland they contain is not the highly flammable Chaparral scrubland found closer to the coast. The NLCD dataset makes no distinction between highly flammable Chaparral scrubland and desert scrubland.

Figure 3. High scrubland coverage in cities and bioregions



The NLCD dataset is a generalized dataset for the entire nation. Only sixteen classifications are used to describe the entire range of land cover types in the coterminous United States. This classification system may be too generalized to be particularly informative. This may be the reason why land cover variables contributed so little to the model as a whole. Perhaps with a less generalized land cover map, land cover would explain a greater amount of the variation in reported fire damage.

The level of analysis may also explain why biophysical variables contribute so little to the model. The city level may be too high a level of aggregation to capture some of the relationships between fire damage and biophysical variables. For instance, average slope may not play a role in influencing fire damage at the municipal level, but may play a very important role in influencing damage at a neighborhood or individual structure level.

19. POLICY IMPLICATIONS

Unfortunately, not all of the results from this analysis can directly influence policy decisions that could help to reduce fire damage in the future. Housing unit occupancy level is one of the strongest predictor of fire damage. However, policy makers cannot possibly be expected to enact policies that support the vacation of housing units or the construction of housing units that are not intended for occupancy.

If it is the case, as it appears to be, that sprawl into a wildland areas is a driver of damages, combating sprawl directly should be a powerful way to reduce damage from wildfires. Fortunately, there exist several policy tools that are used to reduce sprawl and encourage spatially defined, dense development.

Urban growth boundaries (UGB) are a tool used to combat sprawl. A UGB is a boundary that sits on the outskirts of a city outside of which development is prohibited (Brueckner, 2000). While UGBs have the potential to effectively reduce sprawl, detractors claim that UGBs can have the unintended consequences of driving up property costs within the boundary and encouraging low-density development outside of the boundary (Brueckner, 2000; Nelson and Moore, 1993)

The city of Portland, Oregon is a frequently examined case study into UGBs. Despite being so well documented, there is no consensus on the efficacy of Portland's UGB in combating sprawl outside the boundary and increasing density within the boundary. Jun (2004) finds that Portland's UGB was ineffective in promoting residential growth within the boundary. The UGB seems to have encouraged development in nearby

Clark County, Washington. Clark Country has the distinction of being the sole county in the Portland Primary Metropolitan Statistical Area that is neither part of the UGB nor part of Oregon (Jun, 2004). Nelson and Moore (1993) report that "rural residential development has occurred immediately outside UGBs…[resulting] in a low-density residential ring around much of the UGB in metropolitan Portland."

The transferring of development rights is a tool used by urban planners to combat urban sprawl. Traditionally, transfer of development rights (TDRs) have been used to protect natural resources or habitats. TDRs work by transferring the rights to development from an area in which development is undesirable to an area where development is desired (Johnston and Madison, 1997). Typically, development rights are transferred from rural areas to urban areas.

The same principle could be applied to prevent development in areas of high fire hazard vulnerability. Rather than preventing development to protect natural resources from human development, in this case preventing development would protect humans from natural resources. Development rights would be transferred from high fire hazard areas to areas of low fire hazard, preferably urban areas.

TDRs can require cooperation between multiple counties, cities, and other jurisdictions to function correctly. As an example, the case study of Portland, Oregon indicates that sprawl reduction policies may not operate as intended if coordination between jurisdictions is poor.

Conservation easements are a planning tool used to prohibit development in ecologically sensitive regions. In a conservation easement, a landowner gives up development rights to their land to a third party, often a nonprofit conservation group or a government body, in exchange for a tax incentive. Perhaps specialized tax incentives could be used to encourage landowners to grant easements on high fire hazard land. For a more detailed description of conservation easements, and the steps needed to take to create an easement, see Wright (1993).

A zoning bonus is "…an incentive to a developer to include explicit public benefits in a real estate investment" (Seyfried, 1991). Density bonus incentives allow developers to build at higher than normally permitted levels of density in exchange for public benefit. Typically, zoning bonuses come from building housing intended for low- to moderate-income residents (Fox and Davis, 1976). Local governments require developers to sell an allotment of units below market value. In turn, developers are allowed to exceed normally permitted levels of density (Fox and Davis, 1976). If much of the damage if California comes from relatively low income WUI areas, this may be a very powerful tool to direct development away from hazardous areas.

Any policy that discourages development in high hazard wildland areas will be a useful policy in reducing fire damages. Incentivizing development in high-density urban areas will draw development away from high fire hazard WUI areas.

Because wildfire damage appears to be greater for relatively poor areas, it is worth considering public outreach programs that would inform vulnerable populations of the risks they face and educate them on the means to mitigate damages and protect their property from wildfire. Cortner et al. (1990), in their review of public fire opinion through time, document an increasing awareness of the role of different fire management policies and practices. However, awareness does not always equate to action. Gardner et al. (1985) found that homeowners show low support for policies that place the burden of action on homeowners or impact where or what can be built. Zoning and density requirements were found to be unpopular. Despite in aggregate ranking vegetation clearing being a preferable policy for reducing fire hazard, few homeowners actually follow through and clear vegetation. Great improvement in homeowner perceptions must be made if the appropriate land use policies are to receive popular support.

20. THREATS TO VALIDITY

There are several threats to the research validity of this study that are important to note. The damage data used in this analysis, provided by CAIRS, is submitted on an entirely voluntary basis. Currently, there are 1,167 unique fire departments in California recognized by OFSM. The number of fire departments that report to OFSM is far lower. In 2010 only 515 unique fire departments reported incidents to OFSM. Obviously, this introduces a selection bias to the study, but there is no readily available alternative source for fire damage data in the state of California.

CAIRS recognizes that the data they provide is far from perfect. In personal communication with Kirsti Fong (12/24/2011), the National Fire Incident Reporting System (NFIRS) Program Coordinator for the OFSM, it was made clear that there is no standard methodology for determining incident loss values. NFIRS does provide a property damage loss calculator on their website. However, this tool has yet to achieve widespread use across all fire departments. Additionally, incident loss values are not a required field for submission. This means that there is the potential for unreported property loss.

There is the potential for overlap in some reported loss values. It is not uncommon for multiple fire departments to respond to the same incident. Should this occur, fire departments are instructed to indicate whether they are the incident command fire department or a fire department providing assistance. In the case of a mutual aid fire, it is the responsibility of the incident command department to report damages. Assisting departments are instructed not to report damages. Unfortunately, it is "common for each of those fire departments to incorrectly report if their department was the incident command or the assisting department" (Kirsti Fong, personal communication, 12/14/2011). In this eventuality, fire damage is likely to be reported twice, as it would be unlikely that an incident command department would incorrectly indicate that they were providing aid, rather than receiving aid. It seems far more likely that a department providing assistance may mistakenly indicate that they were the incident command department and provide a duplicate damage estimate. Additionally, a fire department may incorrectly report that they did not provide mutual aid, when in fact they did, because "they don't fully understand the purpose of the reporting system or they don't understand the Aid Given field" (Kirsti Fong, personal communication, 12/14/2011).

This analysis does not include an examination into how fire mitigation and intervention influence fire damage. Mitigation, e.g. fuel breaks and defensible space, and intervention (firefighting) should moderate fire damage. Perhaps with the inclusion of intervention and mitigation data, the model would explain more of the variability in the dependent variable. Statistically speaking, these missing sets of variables have the potential to be just as impactful on the model as any of the independent variables examined in this research. Presumably, the inclusion of these sets of variables would increase the explanatory power of the model. Obviously, the exclusion of this data is a glaring omission.

The model used in this analysis fails the Ramsey RESET test. However, in practice this is not unexpected or indicative of a poorly specified model. The near infinite numbers of potential variables present in a real world analysis such as this one make it almost impossible to accept the null hypothesis of the Ramsey RESET test.

Nineteen jurisdictions were not included in this regression analysis. This is such a small proportion of the total study area that the missing jurisdictions probably do not represent a serious threat to the validity of this study. Additionally, many of these missing jurisdictions have populations of zero or other very small populations. One might argue that a city without residents is not a city at all and thus not within the scope of this study.

Finally, the damage data covers the four year span from 2007 to 2010. However, many of the other variables used in the study do not have the same temporal ranges. For example, the US Census Bureau makes data from the two latest censuses readily available online. However, the data is available for only two years, 2000 and 2010. The oldest data used is from the 2000 US Census.

21. FUTURE RESEARCH

To investigate in further detail the role that income plays in fire damage, it may be useful to classify personal wealth differently. Rather than using median income, perhaps using a measurement that picks up *poverty* explicitly, such as percentage of the population under the poverty level, would provide some greater detail. Additionally, using a different dependent variable, such as days of disrupted employment after a fire, number of households displaced, or some other "community impact" variable could give better insight into social factors related wildfire hazards.

The omission of the role of mitigation and intervention in this study is by far the biggest threat to validity. Mitigation and intervention practices should moderate fire damage. Including mitigation and suppression variables into the model should improve the accuracy of the model. It would be interesting to compare mitigation and suppression practices between two municipalities to examine how specific mitigation and suppression practices influence fire damage while controlling for other relevant variables.

Including some weather and climate data into the model may be a worthwhile avenue of investigation. Climate and extreme weather events in particular are influential in fire starts and fire behavior. While policy makers are not able to modify weather and climate conditions to reduce fire behavior, by identifying weather and climate factors that are related to damage the most dangerous conditions can be identified. If dangerous conditions are identified, measures can be taken to protect lives and property.

Classifying fire damage in some other way could provide additional insight into the interaction between the built environment and wildfire. For example, it would be possible to use a measurement of burned acreage or number of fire starts rather than monetary damage as a dependent variable. As discussed, a dependent variable that in some way accounts for the impact of fire on a community would be a very interesting way to examine how fires and social vulnerability interact.

Attention deserves to be given to the advance of low-density development into neighboring wildlands. Actively demonstrating sprawl should be relatively straightforward. If it can be demonstrated by remote sensing or other means that the footprint of development outpaces population growth then the presence of sprawl has been confirmed.

Additionally, there may be further signals that can be uncovered by focusing inquiry into specific density levels. Downtown Los Angeles is unlikely to have a wildland fire. Surrounding development that reaches up into nearby foothills is far more likely to be at risk of wildland fire. An analysis that excludes high-density areas and examines the areas that have density levels that appear to be at risk of wildland fire may provide some insight into how damage is related to the built environment in low-density, fire-prone areas.

An analysis at a different level of aggregation may be one of the most informative potential avenues for future research. Some variables may show different relationships depending upon the level of analysis. Unfortunately, this would require an entirely new dataset. With the appropriate dataset, a clustering analysis much like

Genton et al. (2006) could be undertaken. The possibilities that a very "high-resolution" dataset provides are near endless. Ultimately, the quality of the available data will constrain experimental design.

22. CONCLUSION

The results revealed by this analysis indicate that fire damage is not entirely driven by biophysical factors, but instead is driven in large part by the human built environment. At least in the case of this study, it is clear that not all development is made equal; at least as far as predicted fire damage is concerned. Knowledge of the patterns of development that predicted high fire damage in the years 2007-2010 can be used by those who can influence the development of the built environment to reduce fire damages in the future. Municipalities, planners, and developers, among others, have the ability to influence how development takes place. Armed with foresight and an understanding of the way the built environment influences fire damage, these entities have the potential to guide development in a fire resilient manner.

REFERENCES

Bhandry, U. (2007). *Vulnerability to natural hazards: A study of wildfire-burned subdivisions in the wildland-urban interface using IKONOS imagery and GIS data*. (Ph.D. dissertation). University of Colorado at Denver

Bin, O., & Kruse, J. (2006). Real estate market response to coastal flood hazards. *Natural Hazards Review*, *7*(4), 137-144.

Brueckner, J. K. (2000). Urban sprawl: Diagnosis and remedies. *International Regional Science Review*, *23*(2), 160-171.

Busenberg, G. (2004). Wildfire management in the United States: The evolution of a policy failure. *Review of Policy Research*, *21*(2), 145-156.

Cardille, J. A., Ventura, S. J., & Turner, M. G. (2001). Environmental and social factors influencing wildfire in the upper Midwest, United States. *Ecological Applications*, *11*(1), 111-127.

Christensen, N. L., Agee, J. K., Brussard, P. F., Hugest, J., Knight, D. H., Minshall, G. W., Peek, J. M., Pyne, S. J., Swanson, F. J., Thomas, J. W., Wells, S., Williams, S. E., & Wright, H. A. (1989). Interpreting the Yellowstone fires of 1988. *BioScience*, *39*(10), 678-685.

Cohen, J. D. (2000). Preventing disaster: Home ignitability in the wildland-urban interface. *Journal of Forestry*, *98*(3), 15-21.

Cohen , J. D. (1999, April). Reducing the wildland fire threat to homes: Where and how much?. Paper presented at the Symposium on Fire Economics, Planning and Policy, San Diego, California. Retrieved from: http://www.arcfuels.org/maggie/AGER 2011 maggie Copy.Data/PDF/Alvarado probability model 1999-1160096256/Alvarado probability model 1999.pdf

Conard, S. G., & Weise, D. R. (1998). Management of fire regime, fuels, and fire effects in Southern California chaparral: lessons from the past and thoughts for the future. Paper presented at the Tall Timbers Fire Ecology Conference, Tallahassee, FL. Retrieved from: http://www.fs.fed.us/psw/publications/weise/psw_1998_weise(conard)001.pdf

Cortner, H. J., Gardner, P. D., & Taylor, J. G. (1990). Fire hazards at the urban-wildland interface: What the public expects. *Environmental Management*, *14*(1), 57-62.

County of San Diego. Wildland-Urban Interface Building Division, Department of Planning and Land Use. (2009). *County fire and building code requirement*. Retrieved from website: http://www.sdcounty.ca.gov/pds/docs/pds664.pdf Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly* , *84*(2), 242-261.

Cutter, S. J., Boruff, B. J., & Shirley , W. L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly*, *84*(2), 242-261.

Cutter, S. L., Mitchell, J. T., & Scott, M. S. (2000). Revealing the vulnerability of people and places: A case study of Georgetown county, South Carolina. *Annals of the Association of American Geographers*, *90*(4), 713-737.

Dennis, F. C. (2003). Creating wildfire-defensible zones. *Colorado State University Cooperative Extension Natural Resources Series*, *6.302*,

Donovan, G. H., & Brown, T. C. (2007). Be careful what you wish for: The legacy of Smokey Bear. *Frontiers in Ecology and the Environment*, *5*(2), 73-79.

Fox, G. M., & Davis , B. R. (1975). Density bonus zoning to provide low and moderate cost housing. *Hastings Constitutional Law Quarterly*, 1015-1071.

Franklin, S. E. (1995). Fuel management, fire behavior and prescribed burning. In J. E. Keeley & T. Scott (Eds.), *Brushfires in California Wildlands: Ecology and Resource Management* (1 ed., pp. 29-33). Missoula, MT: International Association of Wildland Fire.

Genton, M. G., Butry, D. T., Gumperts, M. L., & Prestemon, J. P. (2006). Spatio-temporal analysis of wildfire ignition in the St John's River Water Management District, Florida. *International Journal of Wildland Fire*, *15*, 87-97.

Gude, P., Raster, R., & Van den Noort, J. (2008). Potential for future development on fire-prone lands. *Journal of Forestry*, *106*(4), 198-205.

Hammer, R. B., Radeloff, V. C., Fried, J. S., & Stewart, S. I. (2007). Wildland-urban interface housing growth during the 1990's in California, Oregon, and Washington. *International Journal of Wildland Fire*, *16*, 255-265.

Handmer, J., & Tibbits, A. (2005). Is staying at home the safest option during brushfires? Historical evidence for an Australian approach. *Environmental Hazards*, *6*(2), 81-91.

Haydon, D. T., Friar, J. K., & Pianka, E. R. (2000). Fire-driven dynamics mosaics in the Great Victoria Desert, Australia. *Landscape Ecology*, *15*, 373-381.

Johnston, R. A., & Madison, M. E. (1997). From landmarks to landscapes: A review of current practices in the transfer of development rights. *Journal of the American Planning Association*, *63*(3), 365-378.

Jun, M. J. (2004). The effects of Portland's urban growth boundary on urban development patterns and commuting. *Urban Studies*, *41*(7), 1333-1348.

Kalabokidis, K. D., & Omi, P. N. (1998). Reduction of fire hazard through thinning/residue disposal in the urban interface. *International Journal of Wildland Fire*, *8*(1), 29-35.

Keeley, J. E. (2002). Fire management of california shrubland landscapes. *Environmental Management*, *29*(3), 395-408.

Lynn, K. (2003). Wildfire and rural poverty: Disasterous connections. *Natural Hazards Observer*, *29*(2), 10-11.

Minnich, R. A. (1983). Fire mosaics in Southern California and northern Baja California. *Science*, *219*(4590), 1287-1294.

National Interagency Fire Center. (2012). *Statistics*. Retrieved from http://www.nifc.gov/fireInfo/fireInfo_statistics.html

Nelson, A. C., & Moore, T. (1993). Assessing urban growth management. *Land Use Policy*, *10*(4), 293-302.

NLCD 2001 land cover class definitions. (2007, August 30). Retrieved from http://www.epa.gov/mrlc/definitions.html

Pacific Northwest Wildfire Coordinating Group, US Department of Agriculture. (2001). *Living with fire: A guide for the homeowner*. Retrieved from USDA website: http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5300241.pdf

Pianka, E. R. (1996). Long-term changes in lizard assemblages in the Great Victoria Desert: Dynamic habitat mosaics in response to wildfires. In M. L. Cody & J. A. Smallwood (Eds.), *Long-Term Studies of Vertebrate Communities* (pp. 191-215). San Diego, California: Academic Press, Inc.

Quarles, S. L., Valachovic, Y., Nakamura, G. M., Nader, G. A., & De Lazaux, M. J. University of California, Agriculture and Natural Resources. (2010). *Home survival in wildfire-prone areas: Building materials and design considerations* (ANR Publication 8393). Retrieved from: http://www.wildfirezone.org/assets/images/resource_docs/homesurvivalwildfireareas.pdf

Radeloff, V. C., Hammer, R. B., Stewart, S. I., Fried, J. S., Holcomb, S. S., & McKeefry, J. F. (2005). The wildland-urban interface in the United States. *Ecological Applications*, *15*(3), 799-805.

Reams, M. A., Haines, T. K., Renner, C. R., Wascom, M. W., & Kingre, H. (2005). Goals, obstacles and effective strategies of wildfire mitigation programs in the wildland-urban interface. *Forest Policy and Economics*, *7*(5), 818-826.

Seyfried, W. R. (1991). Measuring the feasibility of a zoning bonus. *Journal of the American Planning Association*, *57*(3), 348-356.

State Board of Forestry and Fire Protection, California Department of Forestry and Fire Protection. (2010). *2010 Strategic fire plan for California*. Retrieved from: http://cdfdata.fire.ca.gov/pub/fireplan/fpupload/fpppdf668.pdf

Sudhira, H. S., Ramachandra, T. V., & Jagadish, K. S. (2004). Urban sprawl: metrics, dynamics and modelling using GIS. *International Journal of Applied Earth Observation*, *5*(1), 29-39.

Swetnam, T. W., & Betancourt, J. L. (1990). Fire-southern oscillation relations in the Southwestern United States . *Science*, *249*, 1017-1020.

The City of Rolling Hills California. (n.d.). Retrieved from http://www.rolling-hills.org/

Theobald, D. M., & Romme, W. H. (2007). Expansion of the us wildland-urban interface. *Landscape and Urban Planning*, *83*(4), 340-354.

US Census Bureau. (n.d.). *2010 urban and rural classification - geography*. Retrieved from http://www.census.gov/geo/reference/ua/urban-rural-2010.html

US Census Bureau. (n.d.). *Cps definitions - people and housholds*. Retrieved from http://www.census.gov/cps/about/cpsdef.html

Virginia Department of Forestry. (n.d.). *GIS FAQs: Statewide wildfire risk assessment*. Retrieved from http://www.dof.virginia.gov/gis/dwnld-Statewide-faq.shtml

Westerling, A. L., Hidalgo, H. G., Cayan, D. R., & Swetnam, T. W. (2006). Warming and earlier spring increase Western U.S. forest wildfire activity. *Science*, *313*(5789), 940-943.

Winter, G. J., Vogt, C., & Fried, J. S. (2002). Fuel treatments at the wildland-urban interface. *Journal of Forestry*, *100*(1), 15-21.

Wright, J. B. (1993). Conservation easements: An analysis of donated development rights. *Journal of the American Planning Association*, *59*(4), 487-493.

Zedler, P. H., Gautier, C. R., & McMaster, G. S. (1983). Vegetation change in response to extreme events: The effect of a short interval between fires in California chaparral and coastal scrub. *Ecology*, *64*(4), 809-818.

APPENDIX A

CORRELATION MATRIX FOR ALL VARIABLES

	Damage (log transformed)	Proportion Occupied Housing Units	Household Density	Median Year Built	Total Housing Units	Proportion Urban	Proportion of Population Under Age 5
Fire Damage (log transformed)	1						
Proportion Occupied Housing Units	0.1635	1					
	0						
Household Density	-0.0542	0.3615	1				
	0.0781	0					
Median Year Built	0.1895	-0.081	-0.2228	1			
	0	0.0084	0				
Total Housing Units	0.1787	0.0946	0.1215	-0.0231	1		
	0	0.0021	0.0001	0.452			
Proportion Urban	0.0972	0.5486	0.4293	0.0112	0.1387	1	
	0.0015	0	0	0.7152	0		
Proportion of Population Under Age 5	0.1341	0.4372	0.3419	0.0148	0.0791	0.3824	1
	0	0	0	0.6307	0.0101	0	
Proportion of Population Over Age 65	-0.0973	-0.2715	-0.1714	-0.1208	-0.0437	-0.2129	-0.5173
	0.0015	0	0	0.0001	0.1556	0	0
Median Income (log transformed)	-0.059	0.2618	0.0048	0.0462	0.0262	0.2618	-0.2957
	0.055	0	0.8766	0.1332	0.3952	0	0
Average Slope	-0.091	-0.3287	-0.3477	0.0114	-0.045	-0.2987	-0.5482
	0.0031	0	0	0.7113	0.1437	0	0
Percentage Water Coverage	0.0098	0.0012	-0.0552	-0.0943	0.0929	0.1119	-0.0793
	0.7502	0.9682	0.0727	0.0021	0.0025	0.0003	0.0099
Percentage Open Space	-0.027	0.132	-0.124	-0.008	-0.0363	0.206	-0.1546
	0.3801	0	0.0001	0.7957	0.2377	0	0

Coverage							
Percentage Low-intensity Development Coverage	-0.0148	0.3399	0.3136	-0.048	0.0468	0.4319	0.1782
	0.6295	0	0	0.1186	0.1282	0	0
Percentage High-Intensity Development Coverage	-0.03	0.2517	0.4992	-0.1972	0.1223	0.3044	0.2982
	0.3298	0	0	0	0.0001	0	0
Percentage Deciduous Forest Coverage	0.097	-0.016	-0.1616	0.0621	-0.0511	-0.1806	-0.2528
	0.0016	0.6029	0	0.0433	0.0967	0	0
Percentage Scrubland Coverage	-0.077	-0.3831	-0.3646	0.146	-0.0416	-0.3335	-0.2459
	0.0122	0	0	0	0.1765	0	0
Percentage Grassland Coverage	0.1293	-0.0114	-0.3064	0.1781	-0.0592	-0.2318	-0.179
	0	0.711	0	0	0.0541	0	0
Percentage Woody Wetland Coverage	-0.017	-0.0354	-0.0901	0.0162	-0.0258	-0.0913	-0.0041
	0.5798	0.2498	0.0034	0.5995	0.4024	0.0029	0.893
Percentage Herbaceous Wetland Coverage	-0.0747	-0.0913	-0.0887	0.0146	-0.017	-0.0926	-0.0839
	0.0151	0.003	0.0039	0.6342	0.5803	0.0026	0.0063
Percentage Mixed Forest Coverage	0.012	0.0557	-0.1586	-0.0658	-0.0294	-0.0412	-0.235
	0.6955	0.0699	0	0.0322	0.3387	0.1807	0

	Proportion of Population Over Age 65	Median Income (log transformed)	Average Slope	Percentage Water Coverage	Percentage Open Space Coverage	Percentage Low-intensity Development Coverage	Percentage High-Intensity Development Coverage
Proportion of Population Over Age 65	1						
Median Income (log transformed)	0.0034	1					
	0.9111						
Average Slope	0.2122	0.2343	1				
	0	0					
Percentage Water Coverage	0.0287	0.1239	-0.1129	1			
	0.3518	0.0001	0.0002				
Percentage Open Space	0.0715	0.3967	0.1753	-0.1571	1		
	0.02	0	0	0			

Coverage							
Percentage Low-intensity Development Coverage	-0.0465	0.2014	-0.2551	-0.1257	0.2963	1	
	0.1309	0	0	0	0		
Percentage High-Intensity Development Coverage	-0.1468	-0.0703	-0.3035	0.0186	-0.283	-0.0696	1
	0	0.0222	0	0.5454	0	0.0236	
Percentage Deciduous Forest Coverage	0.082	-0.0391	0.2394	-0.0443	-0.0486	-0.1734	-0.1239
	0.0076	0.2035	0	0.1503	0.1143	0	0.0001
Percentage Scrubland Coverage	0.1372	-0.1092	0.3834	-0.1162	-0.1318	-0.2676	-0.2511
	0	0.0004	0	0.0002	0	0	0
Percentage Grassland Coverage	0.0282	-0.0401	0.1248	-0.115	0.0798	-0.2061	-0.2301
	0.3591	0.1927	0	0.0002	0.0094	0	0
Percentage Woody Wetland Coverage	0.009	-0.0687	-0.0715	-0.0116	0.0091	-0.0513	-0.0779
	0.7712	0.0254	0.02	0.7057	0.7667	0.0952	0.0113
Percentage Herbaceous Wetland Coverage	0.0551	-0.0222	-0.0622	0.1254	-0.088	-0.0952	-0.0321
	0.0733	0.4711	0.0433	0	0.0042	0.0019	0.2975
Percentage Mixed Forest Coverage	0.0325	0.2928	0.4141	-0.0377	0.221	-0.1439	-0.143
	0.2902	0	0	0.2206	0	0	0

	Percentage Deciduous Forest Coverage	Percentage Scrubland Coverage	Percentage Grassland Coverage	Percentage Woody Wetland Coverage	Percentage Herbaceous Wetland Coverage	Percentage Mixed Forest Coverage
Percentage Deciduous Forest Coverage	1					
Percentage Scrubland Coverage	0.0201	1				
	0.5147					
Percentage Grassland Coverage	0.2689	0.0091	1			
	0	0.7675				
Percentage Woody Wetland Coverage	0.017	0.0325	0.1037	1		
	0.5817	0.2902	0.0007			
Percentage	-0.0311	-0.0143	-0.0078	0.1446	1	

Herbaceous Wetland Coverage	0.3126	0.6419	0.8008	0			
Percentage Mixed Forest Coverage	0.1457	-0.0044	0.0644	0.002	-0.0197	1	
	0	0.8871	0.0361	0.9472	0.5216		
Damage (log transformed)	1						
Proportion Occupied Housing Units	0.1635	1					
	0						
Household Density	-0.0542	0.3615	1				
	0.0781	0					
Median Year Built	0.1895	-0.081	-0.2228	1			
	0	0.0084	0				
Total Housing Units	0.1787	0.0946	0.1215	-0.0231	1		
	0	0.0021	0.0001	0.452			
Proportion Urban	0.0972	0.5486	0.4293	0.0112	0.1387	1	
	0.0015	0	0	0.7152	0		
Proportion of Population Under Age 5	0.1341	0.4372	0.3419	0.0148	0.0791	0.3824	1
	0	0	0	0.6307	0.0101	0	
Proportion of Population Over Age 65	-0.0973	-0.2715	-0.1714	-0.1208	-0.0437	-0.2129	-0.5173
	0.0015	0	0	0.0001	0.1556	0	0
Median Income (log transformed)	-0.059	0.2618	0.0048	0.0462	0.0262	0.2618	-0.2957
	0.055	0	0.8766	0.1332	0.3952	0	0
Average Slope	-0.091	-0.3287	-0.3477	0.0114	-0.045	-0.2987	-0.5482
	0.0031	0	0	0.7113	0.1437	0	0
Percentage Water Coverage	0.0098	0.0012	-0.0552	-0.0943	0.0929	0.1119	-0.0793
	0.7502	0.9682	0.0727	0.0021	0.0025	0.0003	0.0099
Percentage Open Space Coverage	-0.027	0.132	-0.124	-0.008	-0.0363	0.206	-0.1546
	0.3801	0	0.0001	0.7957	0.2377	0	0
Percentage Low-intensity Development Coverage	-0.0148	0.3399	0.3136	-0.048	0.0468	0.4319	0.1782
	0.6295	0	0	0.1186	0.1282	0	0
Percentage High-Intensity Development	-0.03	0.2517	0.4992	-0.1972	0.1223	0.3044	0.2982
	0.3298	0	0	0	0.0001	0	0

22. CONCLUSION

The results revealed by this analysis indicate that fire damage is not entirely driven by biophysical factors, but instead is driven in large part by the human built environment. At least in the case of this study, it is clear that not all development is made equal; at least as far as predicted fire damage is concerned. Knowledge of the patterns of development that predicted high fire damage in the years 2007-2010 can be used by those who can influence the development of the built environment to reduce fire damages in the future. Municipalities, planners, and developers, among others, have the ability to influence how development takes place. Armed with foresight and an understanding of the way the built environment influences fire damage, these entities have the potential to guide development in a fire resilient manner.

Coverage							
Percentage Deciduous Forest	0.082	-0.0391	0.2394	-0.0443	-0.0486	-0.1734	-0.1239
Coverage	0.0076	0.2035	0	0.1503	0.1143	0	0.0001
Percentage Scrubland	0.1372	-0.1092	0.3834	-0.1162	-0.1318	-0.2676	-0.2511
Coverage	0	0.0004	0	0.0002	0	0	0
Percentage Grassland	0.0282	-0.0401	0.1248	-0.115	0.0798	-0.2061	-0.2301
Coverage	0.3591	0.1927	0	0.0002	0.0094	0	0
Percentage Woody Wetland	0.009	-0.0687	-0.0715	-0.0116	0.0091	-0.0513	-0.0779
Coverage	0.7712	0.0254	0.02	0.7057	0.7667	0.0952	0.0113
Percentage Herbaceous Wetland	0.0551	-0.0222	-0.0622	0.1254	-0.088	-0.0952	-0.0321
Coverage	0.0733	0.4711	0.0433	0	0.0042	0.0019	0.2975
Percentage Mixed Forest	0.0325	0.2928	0.4141	-0.0377	0.221	-0.1439	-0.143
Coverage	0.2902	0	0	0.2206	0	0	0

	Percentage Deciduous Forest Coverage	Percentage Scrubland Coverage	Percentage Grassland Coverage	Percentage Woody Wetland Coverage	Percentage Herbaceous Wetland Coverage	Percentage Mixed Forest Coverage
Percentage Deciduous Forest Coverage	1					
Percentage Scrubland	0.0201	1				
Coverage	0.5147					
Percentage Grassland	0.2689	0.0091	1			
Coverage	0	0.7675				
Percentage Woody Wetland	0.017	0.0325	0.1037	1		
Coverage	0.5817	0.2902	0.0007			
Percentage Herbaceous Wetland	-0.0311	-0.0143	-0.0078	0.1446	1	
Coverage	0.3126	0.6419	0.8008	0		
Percentage Mixed Forest	0.1457	-0.0044	0.0644	0.002	-0.0197	1
Coverage	0	0.8871	0.0361	0.9472	0.5216	