TEMPORAL CHANGES TO FIRE RISK IN DISPARATE WILDLAND URBAN INTERFACE COMMUNITIES

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ABSTRACT

Temporal Changes to Fire Risk in Disparate Wildland Urban Interface Communities

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Since 1990, thirteen fires over 100,000 acres in size have burned in California seven of which were recorded to be some of the most destructive wildfires of all time (California Department of Forestry & Fire Protection 2013). To aid the development of policy that reduces the destruction caused by wildfires, it is important to evaluate how risk changes through time in communities that are expanding into fire-prone areas. The objective of this study is to discover how the likelihood of structural loss is changing in WUI as newer; more fire resilient structures replace older structures on the edges of the WUI.

Geographical Information Systems and remote sensing techniques were used to observe changes in urbanization, structural materials, housing density and defensible space over time in the communities of Rancho Santa Fe, Ramona and Julian in San Diego County. Fire Risk ratings were calculated using the equation *Fire Risk= Hazard – Mitigation*. Mitigation scores for each structure were informed using a binary logistic regression of variables influencing home loss in the Witch Creek Fire. Fire Risk Ratings were given to the 11,747 structures in the three communities for the years 2005, 2009, 2010 and 2012.

The study found that the initial 0-1.5m zone around the home is the most critical for defensible space. In this zone, increased tree cover increases the odds of structure loss by over double that of grass cover.

In Rancho Santa Fe and Julian, the majority of very high risk homes were located in high income communities despite moderate mitigation due to very high fire hazard levels. In Ramona most very high fire risk homes were located in lower income areas due to poor mitigation levels. Rancho Santa Fe and Julian decreased their fire risk over the 7 year study period with improved mitigation, Rancho Santa Fe improved the most (1.7% decrease in Very High and High risk homes). The proportion of very high fire risk homes increased in Ramona by .5% over the 7 year study period.

Development on the outskirts of the WUI could increase the risk of the overall community if proper construction standards are not met and defensible space is not implemented. If fire resistant communities are constructed and maintained to high standards of defensible space, they could potentially provide a buffer for older high fire risk homes.

Keywords: Wildland Urban Interface, Fire risk, Structures, Remote Sensing, Geographical Information Systems, Risk Classification, Roof Type, Development

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Nicola C. Leyshon

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1.0 Project Overview

1.1 Problem Statement

The Wildland Urban Interface (WUI) is the area where urban structures meet with undeveloped wildland vegetation (Hammer et al., 2007; Radeloff et al., 2005). The rate of urban development in the WUI is increasing (Cleve et al., 2008; Gude et al., 2008), as is the rate of structure loss due to wildfires (Syphard et al., 2014). Conventional wisdom that these escalating losses are the result in part of development location in wildfire prone areas. However, various mitigation strategies such as defensible space and improved construction standards have recently been mandated for new developments in California so as to reduce the risk of these losses. Subsequently, older high-risk communities may actually become buffered from wildfires as the WUI expands and subsequently lessens their exposure to flames and embers. Thus, expanding WUI may either increase or decrease risk of residential loss dependent upon the extent of altered fire exposure and the application of mandated mitigation strategies.

To help elucidate this seeming dichotomy, we are utilizing various GIS strategies to spatially analyze changes to development, mitigation levels and subsequent risk of structural ignitions through time in three expanding, but demographically dissimilar, residential communities in southern California.

1.2 Statement of Overall Goal

In order to reduce the social, economic and environmental costs of wildfire in the wildland urban interface, it is necessary to understand how fire risk the wildland urban interface is changing over time. This risk level is impacted by both the level of fire hazard, and the level of mitigation undertaken by the homeowner. The overall goal of this study is to use GIS and Remote Sensing methods to observe changing fire risk over time in the Wildland Urban Interface.

1.3 Sub-goals to be investigated

- Conduct a statistical analysis of historical data to assess impact of Home Ignition Zone characteristics on structure loss.
- Develop a GIS model to assess changes in probability of structure loss over time.
- Analyze risk through time in 3 communities that vary in demographics, socioeconomic status, and local culture.

1.4 Importance of project

This research will be beneficial to the wildland fire community as it will present a method for remotely assessing fire risk to structures in the WUI. It is my hope that my research will allow fire agencies and land managers to easily analyze the fire risk in any WUI community.

1.5 General Approach

This study will assess the changing fire risk over time in the WUI communities of Rancho Santa Fe, Ramona and Julian in San Diego County California. This was achieved by detecting home ignition zone characteristics using GIS and remote sensing.

This study utilized available NAIP and NASA AVARIS aerial imagery for the area. Although limited to the features visible from the air, the method allows for an assessment of the entire Home Ignition Zone, whereas road surveys are limited to a driveway view. The data was then verified using a random sampling of homes on foot and via google street map to verify remotely sensed results. The risk model was created using a combination of theory and statistical analysis of historical data.

2.0 Review of Literature

2.1 The Wildland Urban Interface

Since 1990 seven fires over 50,000 acres in size have burned in California (Cal Fire FRAP, 2013). Throughout the US and across the Globe, the number of large and damaging wildfire incidents is rising (Calkin et al., 2014; Paton and Tedim, 2012), and given predicted climate change, the severity and frequency of these wildfire events is expected to increase (Dale et al., 2001; Hessl, 2011; Nicholls and Lucas, 2007). There is also an increase in the scale and consequences of potential losses as urban development encroaches further onto natural wildland vegetation prone to fire behavior (Cleve et al., 2008; Paton and Tedim, 2012). This area of development where the urban structures meet the natural vegetation is called the "Wildland Urban Interface" (WUI) (Radeloff et al., 2005), The classic WUI is described as an area where an urban development encroaches natural areas, creating an almost distinct line between them (Davis, 1990; Hughes, 1987; Marek and Gering, 2002; Theobald and Romme, 2007). There is also intermix WUI, where structures intermingle with wildland vegetation (Bar Massada et al., 2009; Cohen and Butler, 1996; Hammer et al., 2007) and occlusion WUI, where a pocket of wildland is surrounded by development. These pockets are often left undeveloped as cities grow (Macie and Hermansen, 2002).

The appeal of development within the WUI lies in the privacy, scenery and exclusivity of a home close to or intermixed with nature (Paton and Tedim, 2012). However this appeal has led to the rapid expansion of the WUI into forest lands (Alig et al., 2000; Theobald and Romme, 2007). According to Alig et al. (2010), the area of urban and developed land uses in the United States has increased by more than 1 million acres annually since 1982. This development had come at a cost to forested lands (Gude et al., 2008) and will continue to do so. It is projected that 49.7 million acres of forests will be converted to urban land uses by the year 2062 (Alig et al., 2010).

2.2 The WUI of San Diego County, California

Changing fire risk in the WUI is a factor of many factors including changing climate change, population dynamics and land use change (Gordon et al., 2010; Liu et al., 2010; Paton and Tedim, 2012; Syphard et al., 2014). Policies have been put in place to mitigate the fire risk in the WUI, however across varying demographics and ecosystems; there are many challenges facing planners and policy makers. In San Diego County, three major wildfires over 90,000 acres have occurred since 2003. With a population of over 3 million people (ESRI, 2015), policy makers face challenges to implement mitigation across WUI communities. This is because the most important fire risk mitigation is implemented on private land by the homeowner.

2.2.1 The Fire Regimes of San Diego County

The wildland fire problem in Southern California is extreme; the highest US structure losses in wildfire have occurred in this region (Keeley et al., 2009). The problem is caused by an exacerbated natural fire hazard in the current drought across California and the expanding WUI putting an increasing number of homes at risk (Safford, 2007).

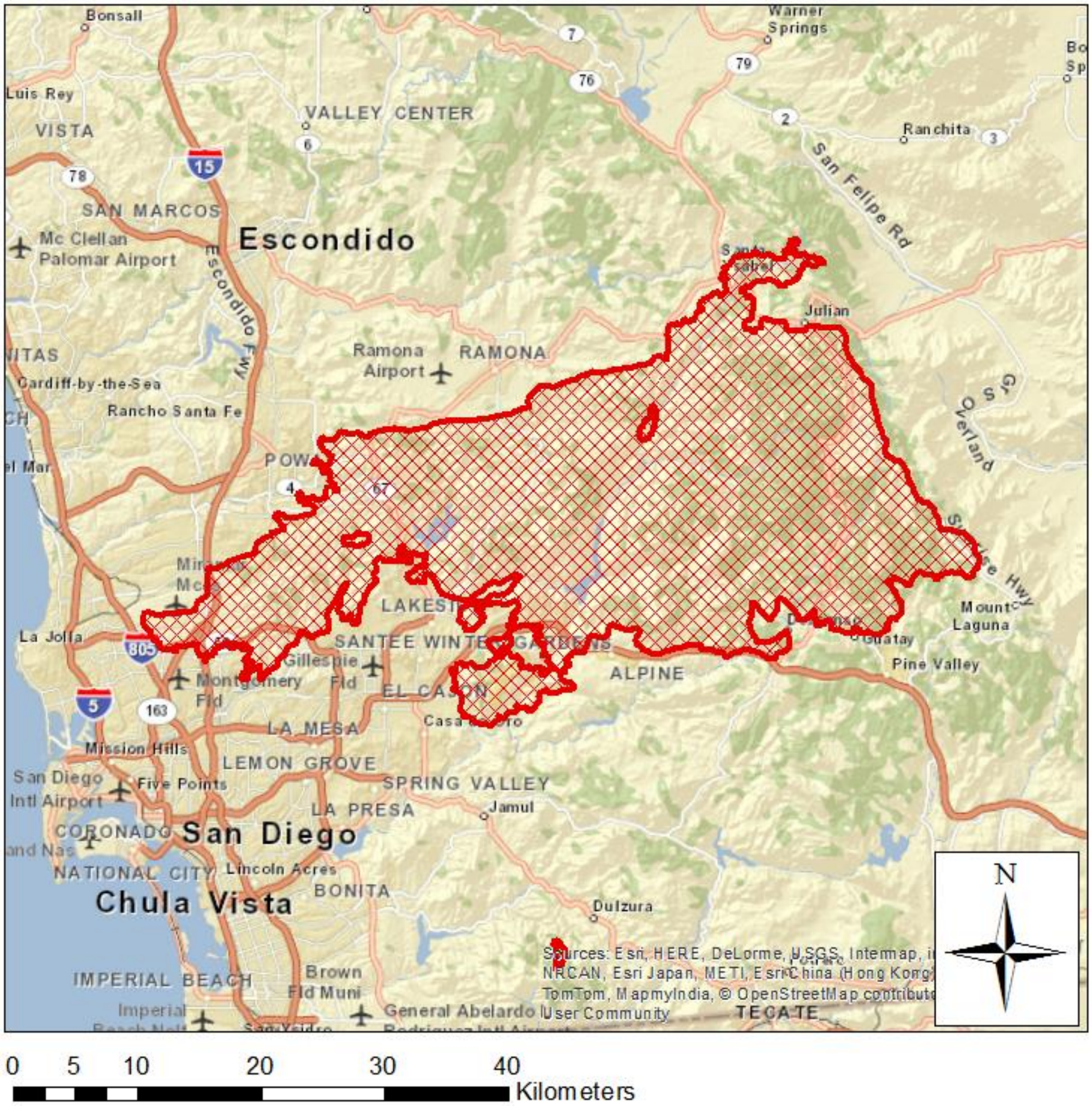
Before the settlement of the Euro-American population in Southern California, the fire regime in the region had a 10 to 30 year return interval in the conifer forests (Keeley, 2006; Safford, 2007) and every 60 to 100 years in the chaparral ecosystems (Keeley and Fotheringham, 2001). In montane forests, fire frequencies have significantly altered as a result of population growth in the lowlands and over-suppression of wildfire in the montane forests, 50% of which have not burned since the start of the 20th Century (Safford, 2007). In the forest ecosystems in San Diego County, a history of over suppression has led to high fuel loads with increases fire hazard in the area (Keeley et al., 2004; Keeley et al., 2009; Safford, 2007). Over suppression of wildfires is caused by a public perception that large wildfires are abnormal and destructive, however large wildfires have ecological benefits to forest ecosystems (Wuerthner, 2006), it is the presence of humans and our settlements in the forest that make wildfires destructive.

In contrast, the presence of modern settlements in the chaparral lands have increased the frequency of chaparral wildfires (Stephenson and Calcarone, 1999). Over time this has caused a type change from chaparral to weedy grassland (Safford, 2007). Large high intensity wildfires are inevitable in the chaparral ecosystem (Keeley et al., 2004), in California the majority of large and destructive fires are chaparral fires (Keeley et al., 2004; Wuerthner, 2006). An example of the intensity of chaparral wildfires is the Southern California firestorm of 2003, which included the Cedar fire in San Diego County.

With the expansion of the WUI, we have introduced a new and more dangerous fuel into this already volatile ecosystem. Structures can be highly flammable, and produce large embers. In a wildfire event, a burning home can spread wildfire throughout an urban community. However, if the proper defensible space and structural mitigation strategies are implemented, a structure can survive a wildfire. After all, in order for a structure to be ignited the structure must meet the fuel and heat requirements sufficient for ignition and continued combustion" (Cohen, 1999).

2.2.2 Fire History in San Diego County

The largest fire recorded California history took place in San Diego County; the 2003 San Diego Cedar fire (273,246 Acres)(Figure 2.1), which killed 15 people and destroyed 4847 structures (Cal Fire FRAP, 2013).



Sources: Esri, HERE, DeLorme, USGS, Intermap, i
NRCAN, Esri Japan, METI, Esri China (Hong Kong)
TomTom, MapmyIndia, © OpenStreetMap contribut
User Community

Figure 2.1. The Cedar Fire 2003 perimeter (Cal Fire FRAP, 2015a)

Only four years later, arching power lines moved by Santa Ana winds started a wildfire in the Witch Creek area east of Ramona, San Diego (Figure 2.2) (San Diego Fire rescue, 2015). What began as a small fire became the 197,990 acre Witch Creek fire that killed two people and destroyed 1650 homes (Cal Fire FRAP, 2013)

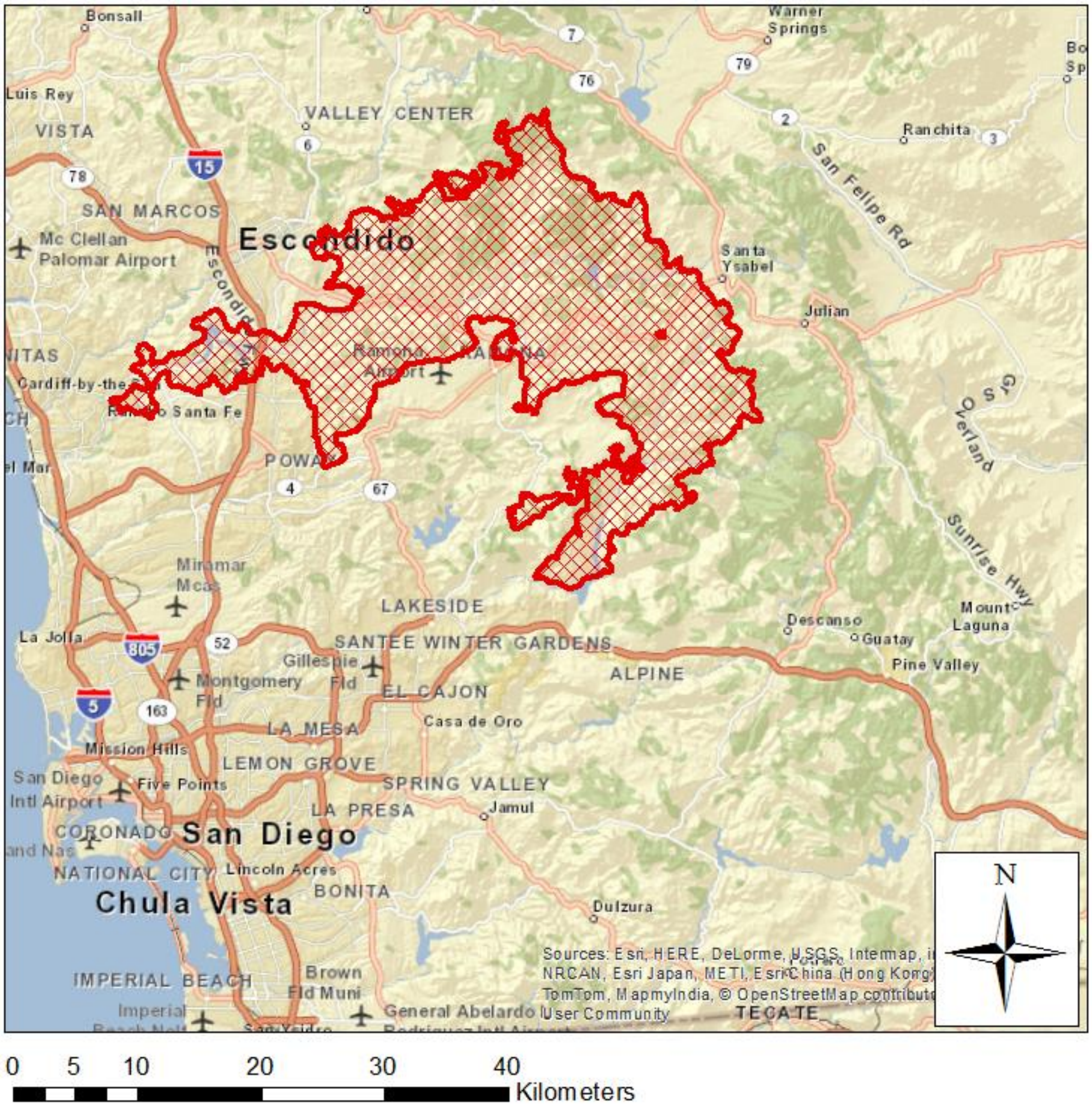


Figure 2.2. The Witch Creek Fire 2003 perimeter (Cal Fire FRAP, 2015a)

2.3 Reducing fire risk in the WUI

When discussing fire risk in the WUI, it is critical to understand the difference between “Fire Risk” and “Fire Hazard”. Fire Hazard is the physical conditions (fuel loading) and the resulting fire behavior that can lead to damage (Hardy, 2005; Sapsis, 2007). Fire risk is the expected damage to occur given the presence of a wildfire; the likelihood of loss in a wildfire event (Bachmann and Allgöwer, 2001). Conceptually, Fire Risk, for a given structure, can be defined using the equation: *Fire Risk = Hazard – Mitigation (Sapsis, 2007).*

Given this definition, the fire risk of an urban structure can be reduced with mitigation strategies. Even homes in very high fire hazard regions, such as the chaparral slopes of San Diego County, have the potential to survive a wildfire event given the correct mitigation of the structure and its surrounding landscaping (Calkin et al., 2014; Cohen, 2000).

There are three kinds of exposure that a structure can face in a wildfire; wind borne embers, radiant heat and direct flame contact (Figure 2.3) (Blonski et al., 2010). Wind borne embers can travel multiple kilometers in a wildfire event. Flammable materials such as patio furniture, wood chips and pine needles can act as a receptive fuel bed for embers. If structures are within 500 feet of a wildfire, the wildfire can provide sufficient radiant heat to ignite the home from a distance. Direct flame contact ignition happens when a wildfire comes into direct contact with a structure. The most common source of structure ignition in the WUI are windborne embers. However, the modification of vegetation around the home can greatly reduce the risk of all three hazards of structure ignition.

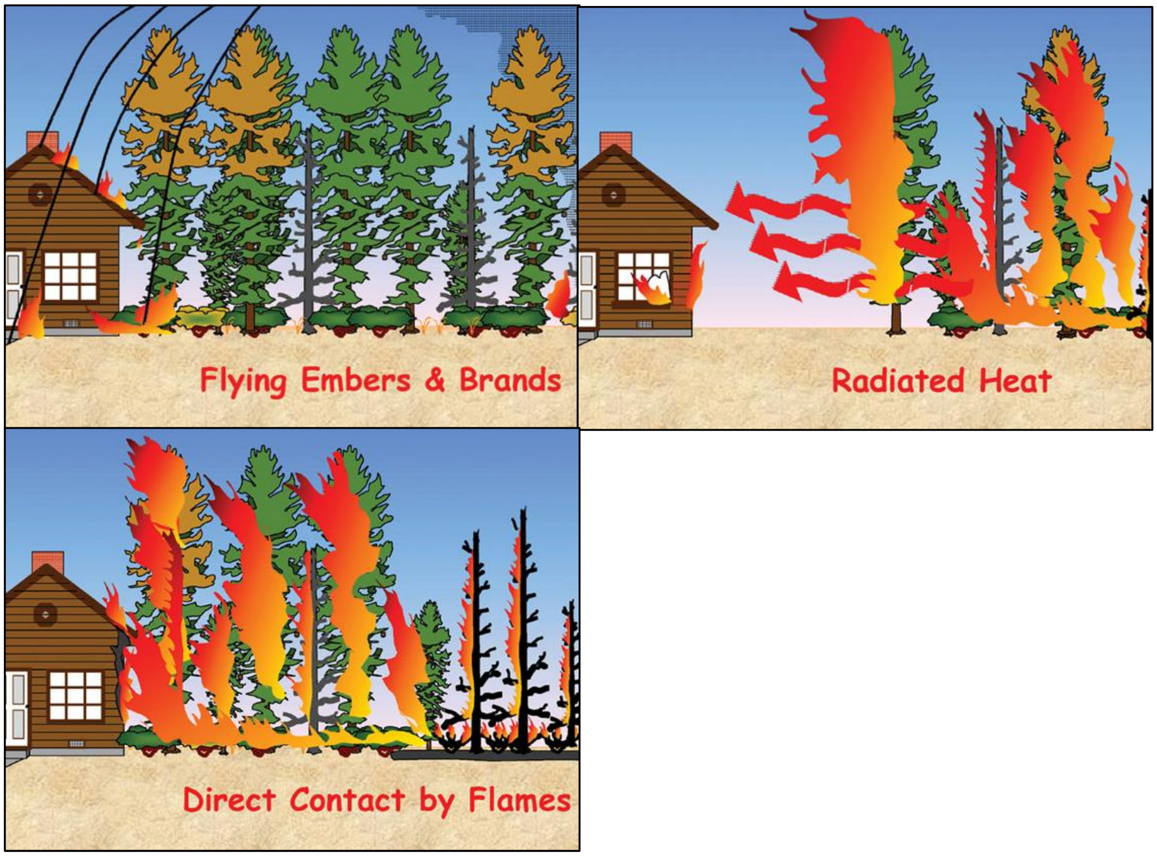


Figure 2.3. Hazards of structure ignition in a wildfire adapted from Firewise (2015)

In order to make a home resilient to wildfire, an architect or homeowner should take into account all three of ignition hazards in the selection of building materials, garden landscaping and vulnerability assessments on existing homes (Quarles et al., 2010).

2.3.1 Structural Materials

A structure can be fortified to be resilient against wildfire by using non-combustible building materials and ensuring resistance to ember penetration and radiant heat (Cohen, 2004; Cohen and Butler, 1996; Quarles et al., 2010). Ember entry to the structure should be of particular concern. Embers can enter a home through vents, roofing materials and non-tempered windows broken by heat. Two out of every three homes in the Witch Creek fire were ignited by embers (Maranghides and Mell, 2011).

The most critical part of the home for fire resilience is the roof (Cal Fire, 2014). Though aesthetically appealing to many homeowners, wood shingle roofs are the most dangerous choice for roofing in the WUI. Wood shingle roofs, are easily ignited with embers, they decompose over time and have may ‘nooks and crannies’ for embers to settle and ignite the home. The best roofing choice for homeowners in the WUI would be composition material, metal or tile. It is also important to block the gaps in the roof to prevent embers from penetrating the structure.

The California Building Code (Ch. 7) requires stops to prevent ember intrusion and coverings on roof gutters to avoid the buildup of leaf litter and debris which could ignite in a wildfire (Cal Fire, 2007a). Exterior walls should be made of non-combustible materials, and all exterior vents should be fire safe to avoid ember intrusion. Hazardous siding materials in the WUI include wood boards, panels and shingles. Fire resistant choices include stucco, fiber cement, wall siding or treated wood.

In addition to protecting the home from ember intrusion, it is important to consider direct flame contact and radiative heat. Radiative heat from a wildfire can cause windows to shatter before the fire reaches the home. A broken window will then allow burning embers to enter and ignite the inside of the home. Single-paned and large windows are particularly vulnerable to heat (Cal Fire, 2014). The best choice for a home in the WUI is dual-paned/double glazed windows preferably with one pane of tempered glass to reduce the chance of breakage in a fire. The homeowner could also limit the size and number of windows that face large areas of vegetation. Both the fire code and the building code provide standards for attic ventilation, exterior walls, doors, eaves and decks.

2.3.2 Defensible Space

In addition to material choice, structures can be fortified by the creation of 'defensible space' – i.e. a defendable space within 100ft of the home (or to the extent of the parcel) (Figure 2.4). This is achieved through the clearing of vegetation to eliminate horizontal and vertical wicks for the fire, as well as fuel. There are several state regulations that address defensible space; Public Resources Codes (PRC) 4290 and 4291 and Title 14 of the Natural resources code (CA Public resources code, 2014).

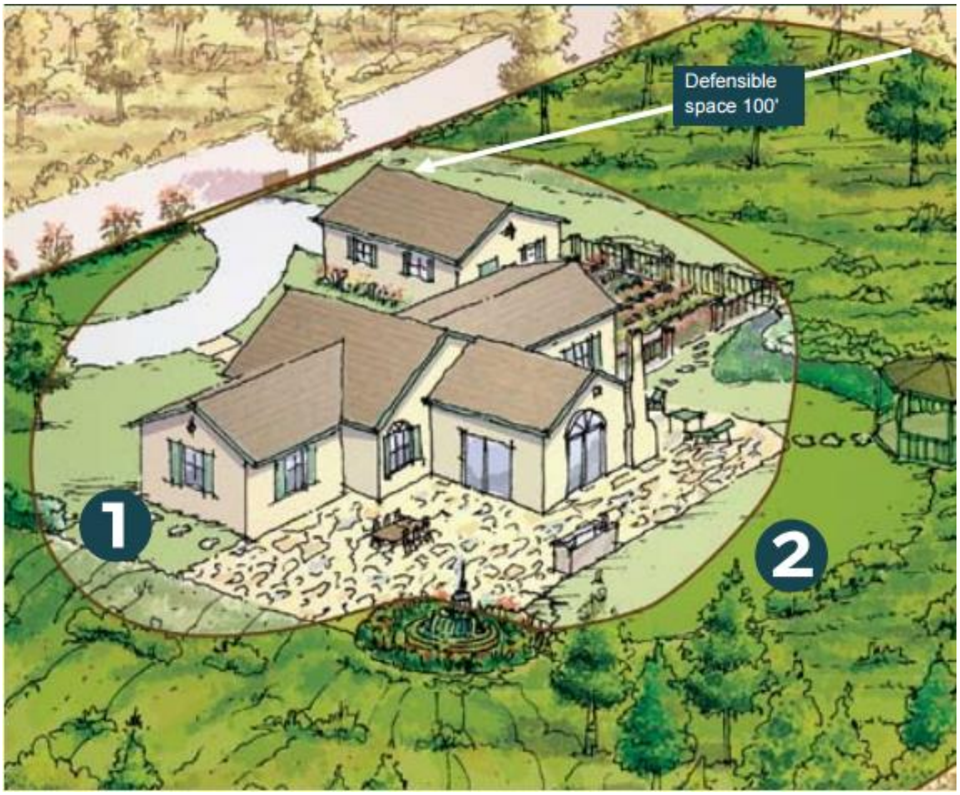


Figure 2.4. Defensible Space- (1) Lean Clean and Green Zone- An area of 30 feet (9m) surrounding your home. (2) Reduced Fuel Zone- The fuel reduction zone in the remaining 70 feet (9-30m)(or to the property line) (Cal Fire, 2007b).

‘Defensible space’ is a term used to describe the area around the home out to 100 feet (or to the edge of the parcel) where the vegetation has been modified to avoid ignitions during a wildfire event. California Law- PRC 4291, requires property owners within the SRA to create 100 feet of defensible space around homes and structures on their property (Cal Fire, 2007b). Title 14 (CCR 1299) requires a 30’ clearance 30-100’ reduced fuel zone (CCR, 2014). Good defensible space is not simply a complete clearing of vegetation, rather removing all ‘pathways’ for the wildfire to reach the home are eliminated. The key to effective defensible space is to break the vertical and horizontal continuity of vegetation to stop a wildfire from travelling to the structure. Fences are also important as they can provide a wick to the home. PRC 4291 states “Fuels shall be maintained in a condition so that a wildfire burning under average weather conditions would be unlikely to ignite the structure” (CA Public resources code, 2014). The law does not specifically prohibit certain species of vegetation, however homeowners and community planners should strive to avoid certain flammable species such as Queen Palm, Italian Cypress and many brush species such as Juniper and Manzanita.

2.4 WUI Policy in California

Policy to reduce fire risk in the WUI often comes as a response to catastrophic wildfire (Turner, 2013). Table 2.1 illustrates the major California wildfire policy that has been implemented as a result of major wildfires over the last 54 years.

Table 2.1. Policy Responses to catastrophic wildfires in California in the last 54 years data collected from Cal Fire (2009).

YEAR	Event	Losses		Policy response
1961	**Bel Air Fire**		505 Structures	Awareness of wood shake roofing
1980	**Panorama Fire**	4 Deaths	344 Structures	Cal Fire established vegetation management program
1989	**49er Fire**		312 Structures	California enacted Fire Safe regulations PRC 4290
1991	**Oakland Hills Firestorm**	25 Deaths	2900 Structures	'Bates Bill'- State identified Very High Fire Hazard Severity Zones in Local Response Areas (LRA)
1993	**Laguna Beach Fire**		441 structures	California Building Code requiring ignition resistant roofing
2003	**Southern California Firestorm**	15 Deaths	4847 Structures	WUI building codes adopted. PRC 4291 (2005) established 30m (100 feet) of defensible space

There are policies set in place that regulate structural materials, design and infrastructure in the wildland urban interface. In 1981 and 1982 Senate Bill (SB) 81 and 1916 were passed requiring CALFIRE to identify the fire hazards in California SRA (State Responsibility Area), and rank them (Medium High and Very High). This original mapping did not include LRA (Local Responsibility Areas). (CAL FIRE FRAP, 2012; CAL FIRE FRAP, 2015b). The Bates Bill (337) was later passed in 1992 as a direct response to the Oakland Hills fire of 1991 where around 2900 homes were lost, 150 people were injured and 25 people were killed (Adams et al., 1998; Ewell, 1995). New legislation like the Bates Bill is often passed as a result of a catastrophe causing shift towards safety and preparedness in residential communities to avoid future losses (Birkland, 2006). The Bates Bill requires CALFIRE to work with local governments to identify high and very high FHSZ's in LRA in California (CAL FIRE FRAP, 2015b; Long et al., 2004). Chapter 7A of the California Building code and Ch. 47 of the California fire code outline materials and construction methods for homes with exterior exposure to wildfire (Cal Fire, 2007a). Both codes apply to all new homes (or remodel permits) after 1/1/2008 in all FHSZ (Fire Hazard Severity Zones) of SRA (State Responsibility Areas), and homes within the Very High FHSZ (VHFHSZ) of LRA (Local Responsibility areas). It is not mandatory that local (city) governments adopt the FHSZ's suggested by the county. There are several reasons a city may not adopt the zoning; insurance may be higher as a result of a VHFHSZ designation, and costs of construction may be higher due to the requirements in the California Building code for VHFHSZ's. However, if the suggested VHFHSZ areas are not adopted in LRA areas, the WUI building and fire codes do not apply. It is therefore difficult to implement the mitigations in LRA WUI, causing a greater risk to communities.

2.4.1 Obstacles to Implementation of Policy

The objective of California fire laws and mitigation policies is to guide developers and homeowners in how to reduce the risk of losing properties in a wildfire event. However, policy is only as powerful as its implementation. As the most critical of mitigation policy is in the hands of the homeowner (defensible space and structure maintenance), there are limitations to the power of policy within the WUI.

The problem with policy implementation in the wildland urban interface are limitations on incentives inspections and enforcement (Turner 2013). With other laws, many agencies use the carrot and stick approach; offer the developer or resident an incentive and if they don’t comply “beat them with the stick” i.e. the enforcement of the laws. Sticks are often in the form of fines or penalties.

In the realm of wildfire management, the benefits “carrots” are not immediately visible; they come in the future when the mitigations result in a family keeping their home after a wildfire, or a community recovering quickly after a large fire event. It is therefore difficult to convince residents to comply with mitigations that are usually expensive and have no immediate benefits. Homeowners may face other barriers to implementation; for example, the replacement of a wood shake shingle roof into a Spanish tile roof is an expensive undertaking, requiring both a replacement of the roof and adjustments to the strength of the structure. Elderly homeowners may also face challenges in their ability to physically perform home maintenance such as clearing of leaf litter from the roof, creation of defensible space and structural repairs.

There is also the issue of ‘perceived low hazard’. If there has not been a major fire in the area for some years, or the house survived the last major fire, it is possible that the homeowner will feel artificially safe with their current level of mitigation and struggle to see the benefits over the costs of the policies (Gordon et al., 2010; Martin et al., 2009; Martin et al., 2010).

As previously mentioned, the critical mitigations required to keep a community safe are done within the private land of the homeowner. Inspections are not always possible as all CA laws must comply with the US constitution. The IV amendment prohibits unreasonable searches and seizures, and therefore many agencies are limited to what they can see from the road (Cornell, 2015). Also, agencies cannot easily enter the property to remove dangerous material without due cause and reason. “The stick” i.e. the enforcement is another issue as many fire departments have limited funding for inspections (when possible) to know who is not complying with the policies. Some funds exist for mitigation, such as the SRA fee ($150 per habitable structure) (CCR, 2014). However this money is for fire prevention activities only, cannot be used for suppression or to benefit one individual (i.e. on private property).

2.5 Using GIS to map Fire Risk the WUI

Spatial Analysis of the WUI is critical for wildfire risk management. As the WUI develops outward into the wildland vegetation, it must be monitored and mapped in order for planners to make effective policy decisions to mitigate risk (Stewart et al., 2007; USDA, 2007). Many methods of wildfire risk assessment in WUI involve the use of maps or spatial data (Bar Massada et al., 2009; Prestemon et al., 2002).

The development of Geographical Information Systems (GIS) has made it possible to define the Wildland Urban Interface remotely, using data and information from many sources. The use of GIS in risk analysis is effective because fire risk is a spatial and temporal process (Chuvieco et al., 2010; Keane et al., 2001). GIS is ideal to manage spatial information, provide adequate spatial processing and visualization of results. A GIS-based model is an especially good approach for areas where a large part of the forested land is being encroached upon by WUI development (Greenberg and Bradley, 1997; Stewart et al., 2007). Many studies of fire risk in WUI have used GIS (Chen et al., 2003; Jaiswal et al., 2002; Kamp and Sampson, 2002).

2.5.1 Methods of analysis

The two main approaches to risk analysis in WUI using GIS were spatial data analysis and remote sensing classification (Chuvieco et al., 2012). Spatial data analysis involves the layering of spatial datasets as vectors points and polygons that represent ground features in a GIS software program (such as ESRI® ArcMap™ 10.2) to observe and measure spatial patterns and distributions. Geospatial data for risk assessment could include housing density, fire behavior outputs (Mercer and Prestemon, 2005) and vegetation maps (Bar Massada et al., 2009). Remote sensing can support GIS analysis by locating specific spectral reflectance signatures in aerial or satellite imagery that respond to a material on the ground such as vegetation or roof type (Campbell, 2002; Curran, 1985).

The first step of a WUI risk analysis using GIS is to define the spatial extent of the community in question. The definition outcome will differ depending on the data available at the time (Stewart et al., 2007). One method of defining the spatial extent of WUI is to combine census data with aerial imagery (Marek and Gering, 2002; Radeloff, 2004; Radeloff et al., 2005). Housing growth is the most volatile factor influencing the WUI (Hammer et al., 2007; Rykiel Jr, 1996). In order to spatially analyze fire risk, an effective WUI map must therefore be sensitive to temporal housing change (Bar Massada et al., 2009; Platt et al., 2011; Syphard et al., 2012) The housing characteristic allows a WUI model to detect change over time (Stewart et al., 2007), which enhances its usefulness for resource management (Rykiel Jr, 1996).

GIS maps can be used to observe the spatial distribution of fire risk in WUI communities (Bar Massada et al., 2009; City of Morro Bay, 2006; Cohen and Butler, 1996). As fire spread in the WUI is complex, involving the interaction of topography, weather, vegetation and structures (Cal Fire, 2007a), a WUI map must contain the appropriate urban and natural landscape data to express this complexity accurately.

Several studies have included output layers from fire behavior modelling software such as; BEHAVE, FARSITE, and FLAMMAP in their GIS risk analysis (Bar Massada et al., 2009; Mercer and Prestemon, 2005; Prestemon et al., 2002). This method allows the inclusion of fire potential and fire exposure data in the model to characterize risk levels (Schmidt et al., 2002) Bar Massada et al. (2009) combined raster land cover data, housing data and burn probability maps obtained from fire behavior prediction software to detect fire risk in the WUI.

The burn probability data is useful in identifying areas of the landscape where structures will have a high level of exposure to wildfire (Mercer and Prestemon, 2005). In order to assess fire risk, this data needs to be combined with data describing the vulnerability of the assets within the WUI (Chuvieco et al., 2012). A key term in WUI risk assessment is “The home ignition zone (HIZ)” (Cal Fire, 2007b; Menakis et al., 2003). The HIZ includes the structure and its surroundings out to 100 feet or 30 meters (Christman et al., 2014; Firewise, 2015). The characteristics of this zone determine home ignition potential during extreme wildfires (Calkin et al., 2014; Menakis et al., 2003). Therefore in order to accurately assess risk in the WUI interface, it is necessary to identify the HIZ characteristics for each structure. This can be done using a combination of spatial data analysis and remote sensing. Variables such as defensible space, roof type, vegetation type, and vegetation proximity to structures can be assessed using multispectral and hyperspectral analysis (Chuvieco et al., 2010; Herold et al., 2004; Roberts and Herold, 2004).

2.5.2 Remote sensing analysis of urban features

Remote sensing methodologies allow the user to classify images and extract features to determine where development exists (Ridd, 1995; Xu, 2007). Remote sensing can also be used to assess vegetative characteristics related to human presence (Greenberg and Bradley, 1997; Lein, 2006). Due to the spatial and spectral heterogeneity of land cover imagery, mapping the urban environment requires specific spectral reflectance data (Herold et al., 2004). This c

Xu (2007) examined three remote sensing methods for detecting urban land uses; principle components analysis (PCA), logic calculation and supervised classification (Figure 2.3). PCA is a statistical technique resulting in a linear transformation of a set of variables into a smaller set of uncorrelated variables with the goal of reducing the dimensionality of the data (Dunteman, 1989). The result of a PCA is the target pixel being either dark or bright according to the magnitude and sign of the eigenvectors (Xu, 2007). Features are then extracted to form a binary image where the built up land class assigned a value of 1 and all other land assigned a value of 0 (Xu, 2007). For the second method, an if-then-else logic calculation was used to sort the image pixels into a binary image. The third method: supervised classification, created a binary image using a maximum likelihood algorithm. The resulting binary image was then intersected with a vector polygon of the city limits. All three methods successfully extracted urban landscapes; the if-then-else logic calculation was the fastest and easiest method with the highest accuracy. However a vegetation element would further increase accuracy of the model (Xu, 2007). An if-then-else method could be used to map the expansion of WUI development over time and measure defensible space by detecting the distribution of permeable and non-permeable surfaces within WUI.

A critical factor of home survival in the WUI is roof type (Haines et al., 2008; Quarles et al., 2010). Flammable roofing materials can provide a receptive fuel bed for wind borne embers (Cohen, 2000), as well as being a source of embers once ignited (Calkin et al., 2014; Herold et al., 2004; Paveglio et al., 2014). Detecting roofing materials using aerial or satellite imagery is challenging. Several studies have attempted to detect roof types through the remote sensing of multiple types of hyperspectral imagery including, LIDAR (Hofmann et al., 2003), VHR optical data (Bar-Massada et al., 2014), and NASA Airborne Visual Infrared Imaging Spectrometer (AVARIS) hyperspectral imagery (Herold et al., 2004).

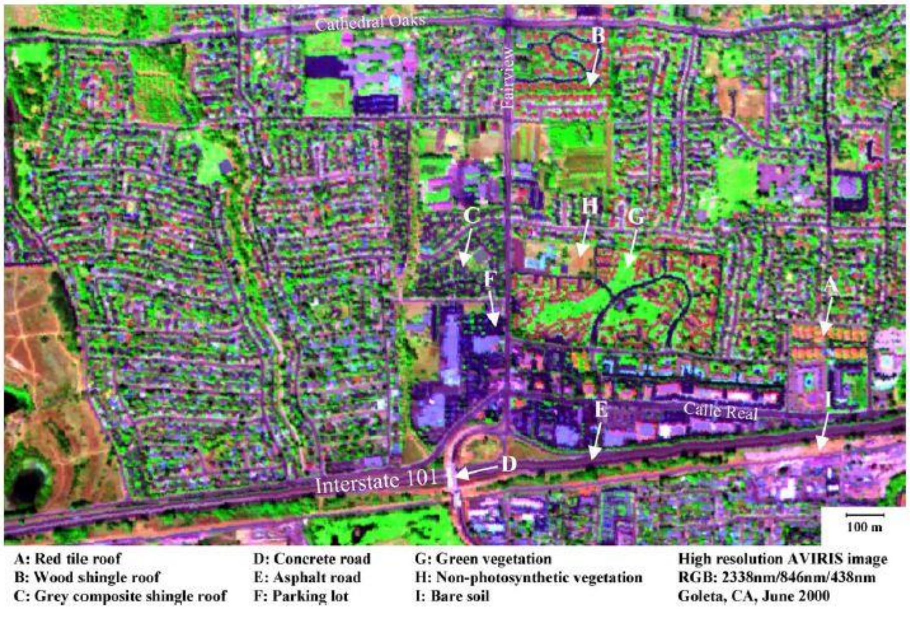


Figure 2.5. Results of remote sensing analysis to detect roof type using feature extraction of NASA Airborne Visual Infrared Imaging Spectrometer - extracted from (Herold et al., 2004)

Herold et al. (2004) collected spectral signatures of 108 urban surface materials in Goleta, California using an Analytical Spectral devices (ASD) Full- Range Spectrometer. The resulting spectral reflectance values where then applied to a Mixed Tuned Matched Filtering (ENVI, 2010)remote sensing analysis of NASA AVARIS imagery (NASA, 2014) to detect urban materials across Goleta (Figure 2.5)(Roberts and Herold, 2004). This included locations of wood shake shingle roofing (Figure 2.6).

a) Wood shingle roof

b) Reference Data

Figure 2.6. Results of matched filter analysis for wood shingle roofs (a) compared to reference data (b) for wood shingle roofs. Adapted from (Roberts and Herold, 2004).

Figure 2.5 illustrates the potential for detection of hazardous urban materials using remote sensing of hyperspectral imagery such as AVARIS. Many studies have created WUI maps for wildfire risk analysis where it has been assumed that all structures are equally flammable and HIZ characteristics were not considered (Bar Massada et al., 2009; Menakis et al., 2003; Prestemon et al., 2002). The inclusion of HIZ characteristics in a remote sensing analysis would allow for an accurate risk analysis (Calkin et al., 2014; Menakis et al., 2003).

2.6 Summary

Knowledge of a structures' location and arrangement relative to other structures or flammable materials is critical in preventing wildfire-related losses in the WUI (Cohen, 2000; Murnane, 2006; Price and Bradstock, 2013). Recent studies have shown that there is a multitude of ways to categorize fire risk in WUI.

In order to have an effective risk model that takes into account the ecological and structural dimensions of a WUI community, it is necessary to combine the GIS and remote sensing methodologies outlined in this literature review. Much of the research discussed a need for the development of a WUI risk assessment considering the characteristics of the HIZ (defensible space, building materials and roof type) (Calkin et al., 2014; Menakis et al., 2003) in addition to the more traditional model parameters of housing density, wildland vegetation characteristics and fire hazard.

3.0 Modelling Urban Expansion in the WUI using GIS

3.1 Introduction

To aid policy development that reduces fire losses in the wildland-urban interface, this study aims to evaluate changes to risk through time in dissimilar communities that are expanding into fire-prone areas of southern California, USA. Mapping and defining the WUI is critical for wildfire risk management because as the WUI expands, it must be monitored in order for planners to make effective policy decisions to mitigate risk (Stewart et al., 2007).

Conventional wisdom states that escalating losses are caused, in part, by an expansion of residential development into fire-prone areas. However, various mitigation strategies such as defensible space and improved construction standards have recently been mandated for new developments in California so as to reduce the risk of these losses (CA Public resources code, 2014; Cal Fire, 2007a). Subsequently, older high-risk communities may actually become buffered from wildfires as the WUI expands and lessens their exposure to flames and embers. Thus, expanding WUI may either increase or decrease risk of residential loss dependent upon the extent of altered fire exposure and the application of mandated mitigation strategies.

To help elucidate this seeming dichotomy, I utilized various GIS strategies to spatially analyze changes to development and subsequent risk of structural ignitions through time in three expanding, but demographically dissimilar, residential communities in southern California. A GIS method allows for a remote assessment of urban expansion over time using historical data (Greenberg and Bradley, 1997).

In this chapter I quantified temporal changes in the area exposed to fire hazards in each of the communities over a 26-year period. The amount of area exposed to wildfire increased in each of the communities. The degree and location of newly exposed development, however, differed between communities, which may influence fire risk in the final risk model which this analysis will be incorporated into.

3.2 Methods

3.2.1 Study Sites

Three residential communities in San Diego County, California, USA were assessed including Rancho Santa Fe, Ramona, and Julian. These three communities all have conditions conducive to high fire hazard, including a Mediterranean climate with extended drought, regular occurrence of high velocity foehn winds (commonly referred to as Santa Ana winds), steep terrain, and flammable vegetation. These conditions have led to several high-intensity, high-loss wildfires in the area in the past 10 years including the Witch Creek and Cedar Fires. The three specific communities represent a range of rates of development, demographics, housing density and geographic area deemed WUI.

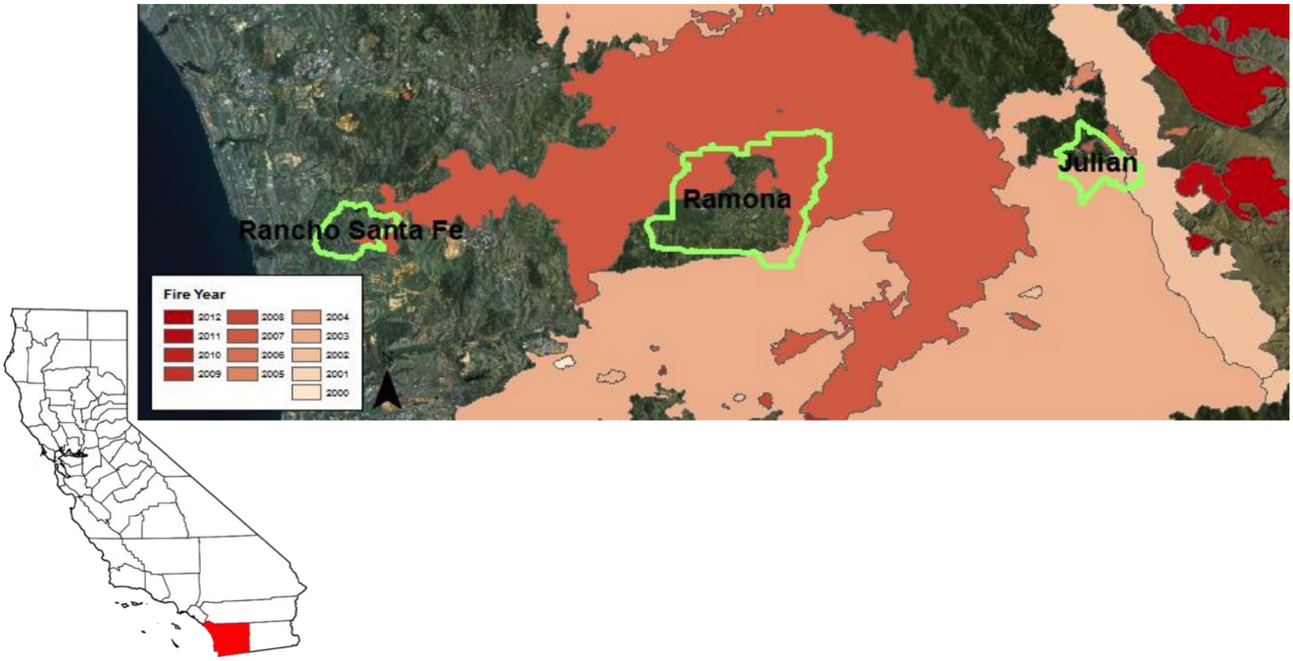


Figure 3.1. Location of study sites and map of 12-year fire history around study sites (Top Left)

3.2.2 Data Collection

In order to determine land use changes from non-urban to urban through time, we utilized publicly available land use data from the San Diego Regional Data Warehouse (SanGIS 2014). Land use data were available for pre-1986, 1990, 1995, 2000, 2004, 2008 and 2012. The data contained many classes of land use; for the purpose of this study, each year of land use data was classified as either urban or non-urban. Agricultural and landscaping uses (e.g., vineyards and parks) were considered non-urban.

All land uses involving clearing of vegetation and/or paving (e.g., telecommunication right-of-way) were considered urban. The years of land use were then layered chronologically to show development over time (Figure 2). To quantify the changes in land use over time, the area of the polygons were clipped to a defined study area. In order to be inclusive of all structures within the WUI, a 3.2 km buffer was created around each of the US census-designated place (CDP) boundaries of the study sites, the size of which was chosen because embers regularly travel 1.6 km (i.e., half the buffer size) or more during extreme weather conditions. Also, we included any structures that resided within the 3.2 km buffer from the CDP boundary. Given the nature of urban expansion, it is intuitive to include structures on the outskirts of current boundaries, as the developments of the future are likely to be located here. The land-use data was then clipped to each buffer zone, and the area for each polygon was calculated using GIS. Evaluation included percentage change in urban land use.

3.3 Results

Figure 3.2 shows the results of the land use mapping over time. Rancho Santa Fe has clustered recent development in the eastern portion of the community, which was expected because other existing communities on the western portion limit development there. As can be seen in Figure 3.1, wildfire events have historically approached Rancho Santa Fe from the east, which is due to the general direction of Santa Ana winds. The newer developments (purple and pink polygons) therefore have the potential to act as a buffer for the town if developed with more fire-resistant construction and landscaping is maintained.

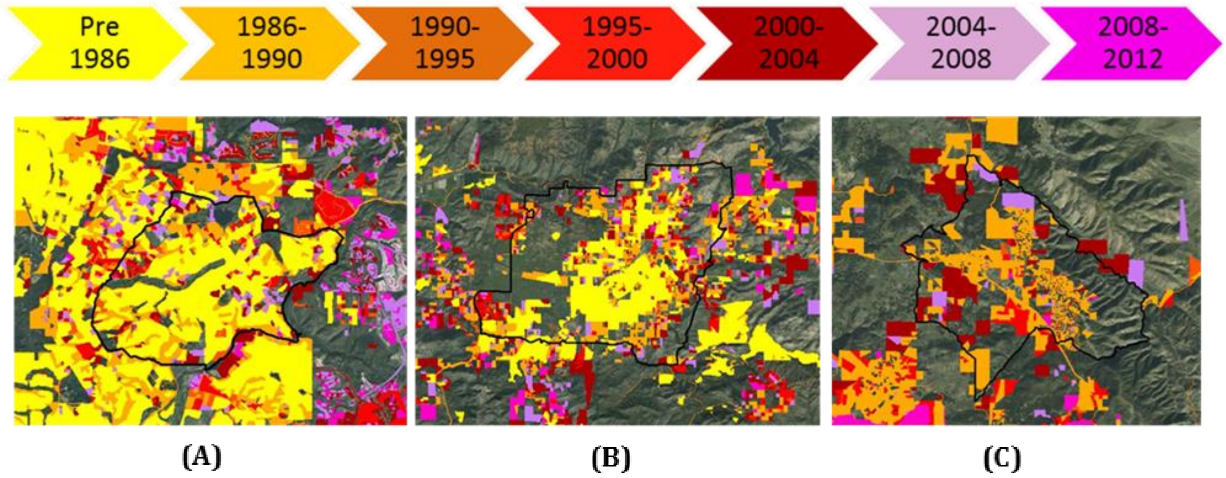


Figure 3.2. Change in designated land use from “non-urban” to “urban” over time in Rancho Santa Fe (A), Ramona (B), and Julian (C). Data per SanGIS (2014)

Much of the new development in Ramona has taken place on the outskirts of the town to the northeast and southwest, which might be result of the topography of the area limiting new development to those areas. The 2007 Witch Creek burned through the northeast portion of Ramona.

Land use data was not available for Julian pre-1986. The community has experienced little development in the past 8 years. Although the polygons depicting new development in Julian may appear large compared to Rancho Santa Fe and Ramona (Figure 2), many of these polygons only contain 1-3 structures within them. Julian differs from the former two communities that form a classic interface between the built and natural environments. Instead, Julian represents a classic intermix WUI community, where many structures are isolated from each other and have larger areas of vegetative fuels between them. This is especially the case near the borders of the community. This differs greatly from Rancho Santa Fe, where there is a higher density of structures in both the new and old developments.

Figures 3.3-3.5 illustrate the change in urban land use over time in each of the communities. Each community demonstrated an upward trend over the 26-year period in the percentage of total lands deemed urban development. Results indicate that the majority of urban development in all three of the study sites is taking place as a result of expanding WUI (vs. residential infill into the existing communities). Rancho Santa Fe had the greatest rates of development of the three study sites.

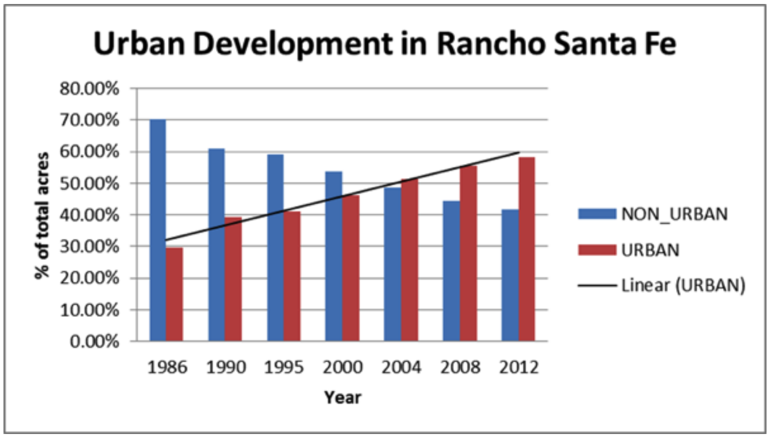


Figure 3.3. Proportional changes over time of urban and non-urban land uses in Rancho Santa Fe (including 3.2 km buffer outside of CDP boundaries) (SanGIS, 2014)

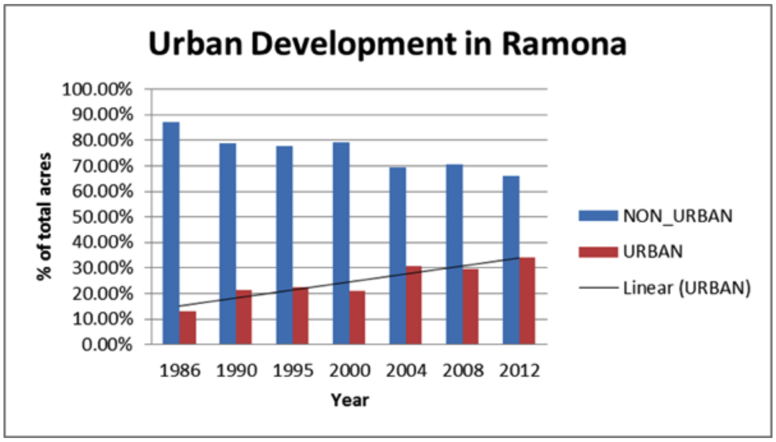


Figure 3.4. Proportional changes over time of urban and non-urban land uses in Ramona (including 3.2 km buffer outside of CDP boundaries) (SanGIS, 2014).

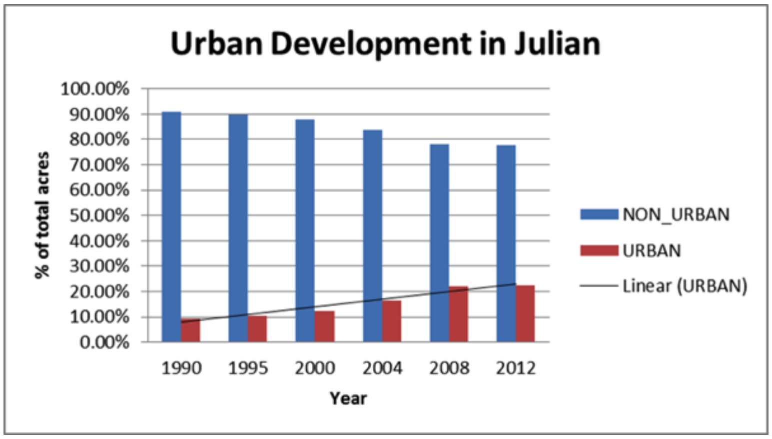
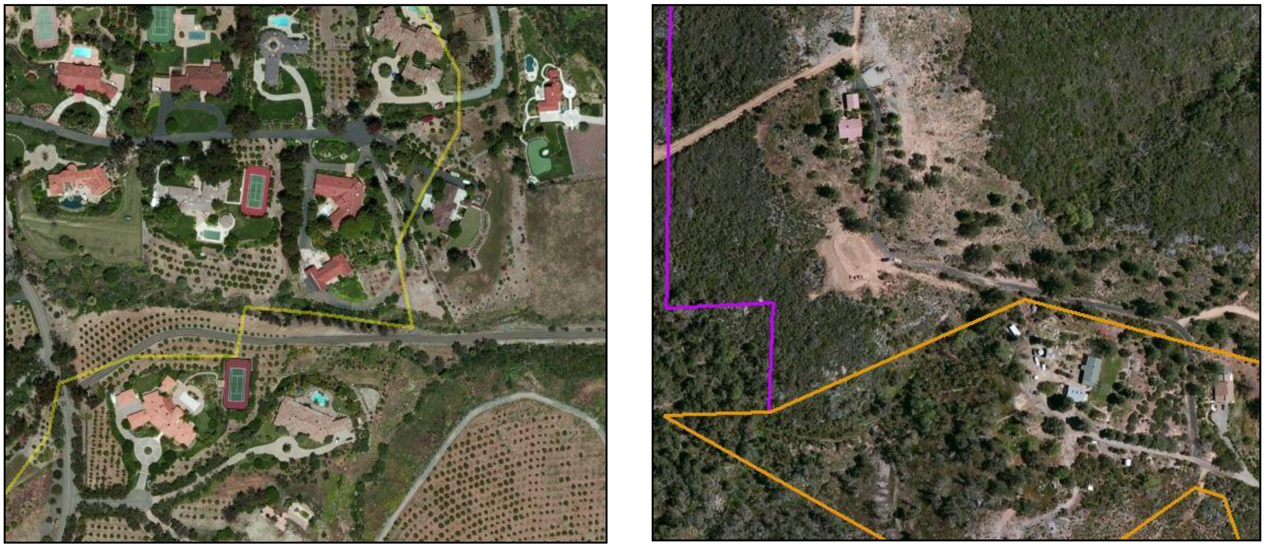


Figure 3.5. Proportional changes over time of urban and non-urban land uses in Julian (including 3.2 km buffer outside of CDP boundaries) (SanGIS, 2014).

3.4 Discussion

The results confirm that all three communities experienced expansion of the WUI over the past 26 years. Despite major wildfires in San Diego County in 2003 and 2007, which destroyed thousands of buildings, structures continue to be built in fire-prone areas, both to replace existing homes destroyed during wildfires and because of increasing populations in these communities. As previously noted, however, this new development could either exacerbate an already tenuous situation or could provide a means to reduce fire risk to older building interior to the new development, dependent on the nature and degree of fire mitigations that are employed.

Figure 4 illustrates how newer communities could potentially buffer the older communities if appropriate mitigation measures are employed in the new developments. In Rancho Santa (Figure 3.6a), the parcels east of the yellow line were developed 2004-2010 and could potentially provide a buffer to the structures built 1986, which are west of the yellow line. Likewise, in Julian (Figure 3.6b), the purple polygon contains a parcel developed in the 2004-2008 time frame (represented by the purple line) could buffer the structure built pre-1990 (the parcel of which is represented by the orange line).



(A) **(B)**

Figure 3.6. Examples of how new developments (with stricter construction and landscaping standards) could buffer older developments in Rancho Santa Fe (A) and in Julian (B).

Fire managers have multiple mitigation strategies to reduce the risk of fire loss in the WUI at their disposal. One mitigation activity is management of vegetative fuels. There is considerable evidence that fire intensity (and subsequent loss) is reduced when a fire advances through vegetation that has recently been treated by prescribed fire or by mechanical means (Agee and Skinner, 2005; Finney, 2005; Martinson et al., 2002). Thus, there has been an escalating call by both land management agencies and the public to significantly modify the amount and arrangement of vegetation in wildlands near the communities so as to mitigate the potential negative impacts of high-severity fires (Dombeck et al., 2004; Ostergren et al., 2006) Indeed, the 2001 National Fire Plan, the 2003 Healthy Forest Restoration Act, and the 2014 National Cohesive Wildland Fire Management Strategy all prioritized fuel treatments into national fire policy in the US.

That said, many argue that treating vegetation outside the area immediately surrounding a structure (commonly referred to in the US as the "Home Ignition Zone") is largely futile because of its minimal impact on the factors that impact structural ignition (Cohen, 2000). Creation of a defensible space immediately surrounding a building would reduce structural ignitions via direct flame impingement or radiant heat transfer (Cohen and Butler, 1996). To that end, the California Public Resources Code Section 4291 has required 9.15 m of defensible space around structures since 1991, which was increased to 30.48 m in 2006.

Even if current regulations are enforced, it must be noted that defensible space would not impact structural ignition from lofted embers, which is a more critical factor in residential losses than flame impingement or radiant heat (Cohen, 2000). To mitigate potential residential losses, in 2008 California enacted building standards for new construction in areas in which the state has primary fire protection responsibility. California Code of Regulations Title 24, Part 2, Section 701.A now requires standards for some portions of dwellings that are most prone to ignition, including roofs, siding, attic ventilation, windows, decks, and others. While the new standards will likely reduce fire losses in future development, they cannot impact vulnerability of existing structures.

Additionally, there has been a greater call to limit new construction into areas in which topography, such as steep slopes, naturally facilitates active fire spread (Syphard et al., 2008). Indeed, some areas in California now require a minimum setback of structures away from slopes so as to limit their exposure to convective heat transfer from burning vegetation. Of interest, some high-value communities (e.g., Rancho Santa Fe in this study) have taken novel approaches to meet setback regulations such as constructing enormous retaining walls (costing in excess of $400,000 USD) on the sides of slopes in order to artificially meet the setback standards there (Mike Scott, Rancho Santa Fe Fire District, personal communication).

Unfortunately, WUI residents seem to frequently resist the very regulations that were developed to protect them and their property. For example, residents of one fire-prone area in California did not adhere to defensible space standards because of privacy concerns and a desire to be immersed in “natural” conditions (Delfino and Dicus, 2007). Further, fire agencies commonly do not enforce the state-mandated defensible space regulations due to reasons such as lack of budget and personnel or unwillingness to play a perceived adversarial role with the public that they serve. Thus, adherence to sound mitigation standards varies by place and depends in part on the fiscal ability of residents to implement these strategies and the willingness of fire agencies to enforce existing regulations.

3.5 Management Implications

The expansion of the WUI is predicted to continue in California and in many fire prone areas around the globe (Hawbaker;, 2007; Price and Bradstock, 2014). It is critical for policy makers to understand the local dynamics in terms of growth and urban encroachment of wildland vegetation (Bradley, 1984; Davis, 1990). As our urban areas become blurred with the natural ecosystem, more precautions need to be taken to make structures and communities resilient to natural hazards including wildfire. Developments on the outskirts of the WUI which are not resilient to wildfire could pose a threat to the entire community. The implementation of strict construction standards and defensible space policies could prevent major losses to urban areas in wildfires. Communities that meet these standards have the potential to act as a fire buffer for a WUI community, greatly reducing the possibility of major structure losses like those seen in the Cedar and Witch Creek fires.

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4.0 Changes to Defensible Space through Time in Three Contrasting WUI Communities in Southern California, USA

4.1 Introduction

Despite advances in knowledge and technology, community losses to catastrophic wildfires have escalated globally over recent decades (Gill and Stephens, 2009; Syphard et al., 2014). Nowhere is this phenomenon more acute than in southern California, where urban development has burgeoned into high-intensity, stand-replacement fire regimes. Since 2003, five of the State's ten most destructive wildfires have occurred there, burning in excess of 8,000 buildings (Cal Fire 2014).

In the United States, changing policy at the national, state, and local scales have subsequently reflected the need to make homes and communities that are more fire-resilient (Birkland, 2006; Winter et al., 2009). To mitigate fire risk in California, policy makers have developed multiple legal standards for both home construction and for landscaping on properties in which the State has primary fire protection responsibilities. In addition, local authorities sometimes require even higher standards for properties under their jurisdiction. For example, Chapter 7A of the California Building Code mandates standards for materials and construction methods of exterior building features that are exposed to wildfires, including roofing, attic ventilation, siding, decking and others. Local fire authorities then may require even more stringent standards that exceed those of the State.

Germane to this study, defensible space is a strategy widely accepted to lower the risk of structure loss in wildfires (Cohen, 2000; Syphard et al., 2014). Subsequently, California Public Resources Code 4291 requires residents to maintain 30 m of defensible space (i.e., vegetation managed to reduce fire risk) around structures (CA Public resources code, 2014). This criterion was increased from a previous 9 m standard following the 2003 southern California Firestorm, which consumed over 4,000 buildings.

Even if defensible space regulations are in place, however, a major challenge facing fire agencies is how to influence residents to move from knowledge to action (Reams et al., 2005; Renner et al., 2006). Unfortunately, residents commonly do not voluntarily create or maintain defensible space, even in areas of high fire risk, due to diverse reasons such as low perceived risk, lack of previous wildfire experience, desires for privacy afforded by vegetative screening, inability to pay for landscaping, lack of faith in the local fire department, and others. (Bradshaw, 1987; Renner et al., 2006). While agencies have the regulatory authority to enforce existing defensible space standards via fines and other measures, many jurisdictions do not regularly enforce existing regulations due to low prioritization or funding constraints. Unlike building regulations, which are enforced once during planning and construction stages of development (Cal Fire, 2007a; San Diego County, 2013), defensible space regulations needs be enforced annually due to normal vegetative growth and to new planting of ornamental landscaping.

There has been minimal research into the degree to which residents implement defensible space regulations. Surveying defensible space via traditional “on site” methods allow for a street view of the home that may be limited by driveway length, vegetation or other access issues. Numerous WUI studies have used Geographic Information Systems (GIS) and remote sensing to measure changes in fire risk though time (Greenberg and

Bradley, 1997; Jain et al., 1996; Nourbakhsh et al., 2006; Syphard et al., 2014). We modified these techniques to assess the defensible space through time in three nearby WUI communities that varied in demographics, culture, and socioeconomic status.

4.2 Methods

4.2.1 Study Sites

We assessed three residential communities in San Diego County, California, USA, including Rancho Santa Fe, Ramona, and Julian, which share common latitude of 33 degrees north and span a longitudinal distance of 56 km (Figure 1).

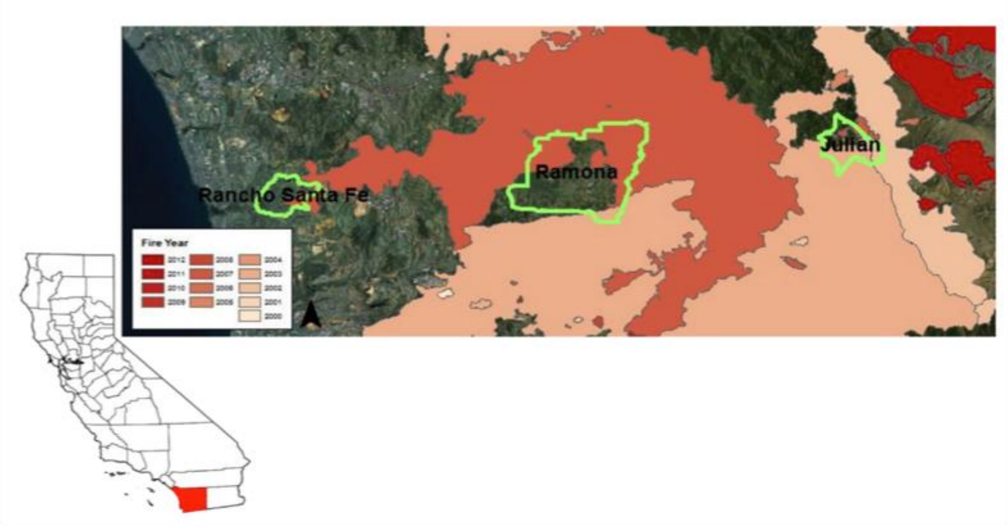

Figure 4.1. Location of the three study sites, including 12-year fire history in the local area.

All three communities have a recent history of large, destructive wildfires, conditions conducive to high fire hazard, and densely developed areas within or in close proximity to highly flammable wildland vegetation (Dicus et al., 2014). However, the three communities differ in demographics, socioeconomic status, local culture, rates of urban development, housing density, and others (Table 1), all of which aid in determining if local level of defensible space compliance might be influenced by social factors.

Table 4.1. Population size, annual average income, and average house value for three nearby, but diverse communities in San Diego County, California, USA. Data from (SanGIS, 2014)

Study Site	Population	Average Income (USD)	Average House Value (USD)
Rancho Santa Fe	3117	$180,612	$1,139,911
Ramona	20,292	$60,033	$485,597
Julian	1,502	$65,781	$510,138

4.2.2 Analysis

Defensible space was assessed through time around 11,727 structures in the three communities. We digitized every structure in each of the three communities, using the city boundary shape file as a sample zone. The structures were digitized in ArcMap 10.2 using the 2009 NAIP imagery at a scale of 1:500. To accurately represent the location of structures and vegetation across years, the structures were horizontally shifted to match the NAIP imagery for the years 2005, 2010 and 2012. In addition, known locations of burned structures, rebuilt structures and other changes were accounted for. Surrounding each structure, we created four zones of increasing distance away from the building using multi-ring buffers (Figure 2). These distances were:

- Zone-A: the roof of the structure
- Zone-B: 0 m – 1.5 m from structure
- Zone-C: 1.5 m – 9 m from structure
- Zone-D: 9 m – 30 m from structure

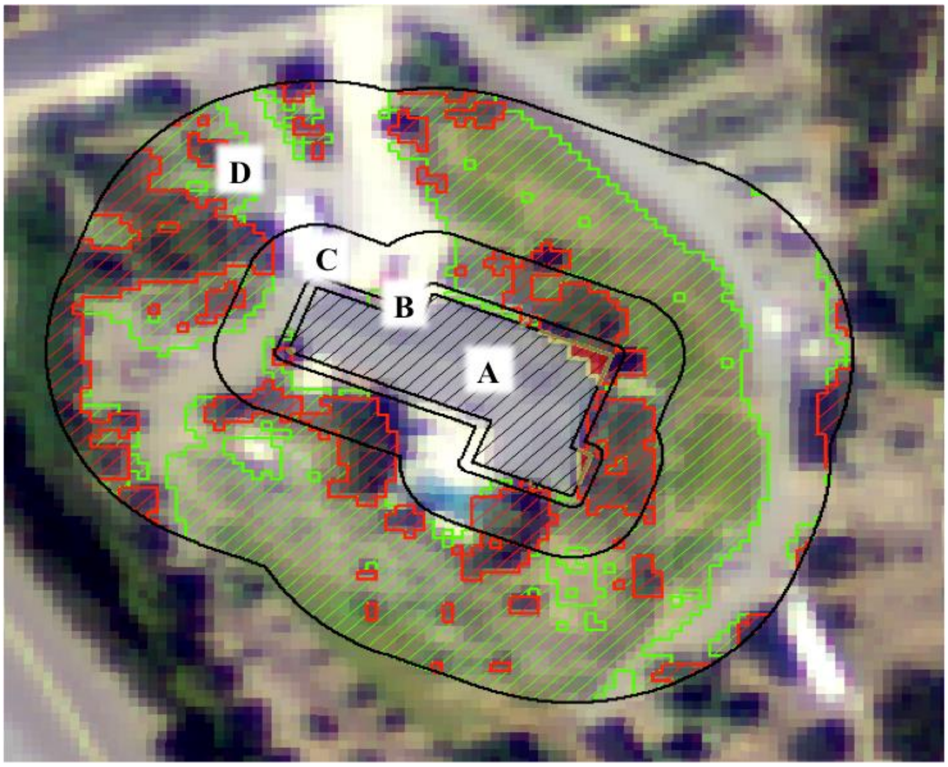

Figure 4.2. Example of Interactive Supervised Image Classification of grass and tree/shrub coverage in each of the buffered Zones surrounding a given structure. Zones include (A) the structure itself, (B) 0 m – 1.5 m from structure, (C) 1.5 m – 9 m from structure, and (D) 9 m – 30 m from structure.

We developed these zones based on current California Public Resources Code (PRC) Section 4291, which divides defensible space into two zones that vary in the degree of allowable vegetation density. Per PRC 4291, all flammable vegetation should be removed up to 9 m from the structure with exceptions provided for single, well maintained plants that would not contribute to fire spread; in the "Reduced Fuel Zone" (9 m – 30 m), more vegetation is allowed, but certain requirements remain, dependent on the site-specific conditions of the property. We created Zone-B (0 m – 1.5 m) based on recommendations to reduce the potential for wind-blown embers igniting materials immediately next to the structure (IHBS, 2014).

To assess vegetation coverage around the structures, we utilized four-band multispectral aerial imagery from the National Agriculture Imagery Program (NAIP) at a m Ground Sample Distance (GSD) resolution. We used an Interactive Supervised Classification within ESRI ArcMap 10.2 (ESRI, 2014) to extract information classes from the NAIP imagery for the years 2005, 2009, 2010, and 2012. A supervised classification uses spectral signatures obtained from training samples to classify an image into groups, which were then used in a spatial analysis to measure the distribution of the classes. Using raster output of the Interactive Supervised Classification, grass and tree/large shrub polygons were created and then intersected with the zoned buffer polygons around each structure (Figure 4.2). In Zone-A (the roof), we calculated the percentage of the roof covered with overhanging vegetation by intersecting the tree/shrub polygons with the structure boundary. In each successive zone away from the structure, the percentage of trees/shrubs and of grasses covering the zone was also calculated. The result was a grass and a tree/shrub polygon for each buffer for each of the 11,727 structures (Figure 4.2). The area for each of these polygons was then summarized to calculate the percentage cover for tree/shrub and for grass for each of the Zones around each structure. We then summarized the resulting outputs by Zone, structure and community.

In order to verify our findings, we used an error matrix to find the producer and user accuracy of the remote sensing results. We created the error matrix using the Congalton (1991) method for assessing remotely sensed data. We created 100 random points using the Arc Map random points tool (ESRI, 2014) and recorded the expected value given the imagery (Urban, Grass or Tree/Shrub) and the resulting value in our output (Urban, Grass or Tree/Shrub). We used this data to calculate producer accuracy and user accuracy. Producer accuracy is the probability that the method will correctly identify the feature, and user accuracy indicates the likelihood that the resulting polygon depicts the correct feature on the ground. We found that the analysis had a 92.3% probability of detecting tree pixels correctly and a 70.3% probability of detecting grasses correctly (Table 2).

Table 4.2. Error matrix for remote sensing results of NAIP imagery and Supervised Image Classification

Producer		**User**	
Tree	92.3%	Tree	92.3%
Grass	70.3%	Grass	83.9%
Urban	83.3%	Urban	66.7%

The 92.3% probability of correctly detecting tree pixels is considered to be very high and leads us to have a great degree of confidence in our results. The lower grass classification was likely affected by the weather conditions when the imagery was taken. Grasses that appear brown in the imagery because of high temperatures and low fuel moisture will incorrectly classify into the urban group; similarly, bare soil may incorrectly classify as grass, both of which would lead to error in correctly classifying grass and urban coverage.

4.3 Results

We found that defensible space (i.e., vegetation coverage) varied, dependent on community, distance from structure, and year. For all communities, tree/shrub coverage generally increased farther from a given home (Figure 4.3), which is consistent with state regulations regarding defensible space that calls for clearing all flammable vegetation in the 9 m immediately surrounding a house and “Reduced Fuel Zone” of managed vegetation from 9 m – 30 m from the structure. The average tree/shrub coverage in

Zone-A (overhanging the roof) across all years and all communities was 8%, while tree/shrub coverage in Zone-B (0 m – 1.5 m), Zone-C (1.5 m – 9 m), and Zone-D was 17%, 23%, and 26%, respectively. Julian had the largest tree/shrub coverage in Zone-A in all years except 2012 (Rancho Santa Fe was 0.5% greater).

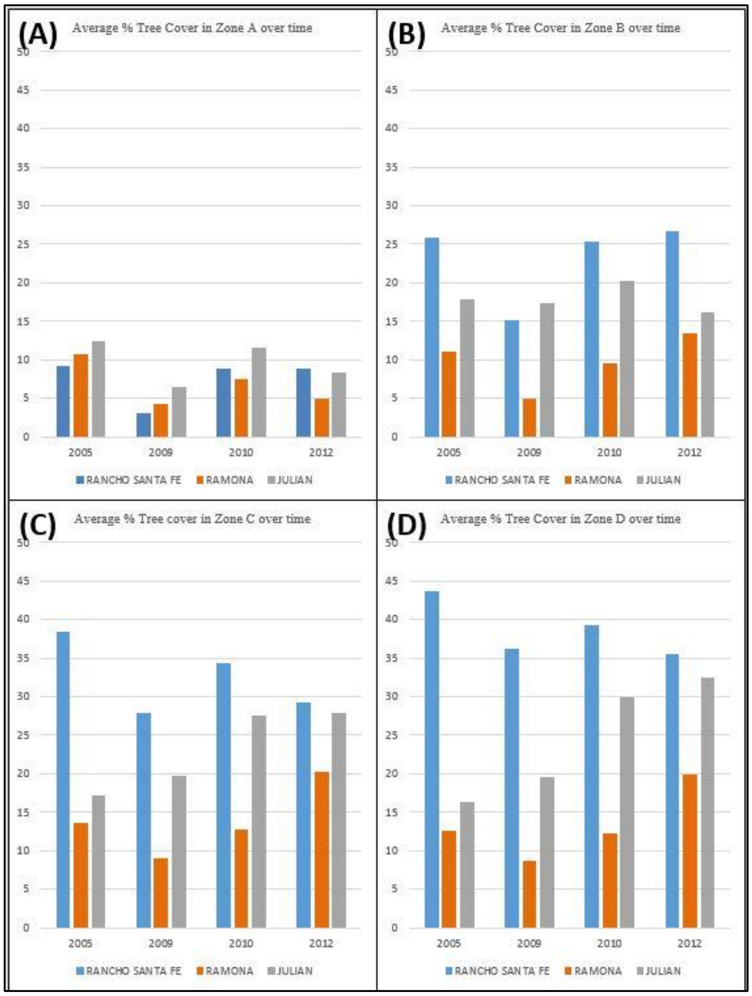

Figure 4.3. Average percent tree/shrub cover (A) overhanging the roof, (B) 0 m – 1.5 m from structure, (C) 1.5 m – 9 m from structure, and (D) 9 m – 30 m for four distinct years in the three study sites.

Rancho Santa Fe had the highest coverage in Zones B, C, and D for every year except for Zone-B in 2009. Ramona had the lowest tree/shrub coverage in Zones B, C, and D in all years. Over the 7-year data range (2005 – 2012), Rancho Santa Fe, however, experienced an average decrease in tree/shrub coverage in all Zones other than Zone-B; both Ramona and Julian experienced a decrease tree/shrub coverage in Zone-A, but an average increase in in all other Zones (Table 4.3).

Table 4.3. Seven-year average of changes in tree/shrub cover in each of the four zones of increasing distance from a given structure. Communities where tree cover has increased are in red.

	RANCHO SANTA FE	RAMONA	JULIAN
Zone A	-0.21	-5.73	-3.95
Zone B	0.71	2.43	-1.62
Zone C	-9.16	6.69	10.61
Zone D	-8.17	7.35	16.17
7 Year Average	- 4.21	+ 2.69	+ 5.30

Figure 4 illustrates grass cover through time in Zone-B (0 m – 1.5 m from a structure). We only report grass coverage for this Zone because it is highly unlikely that grasses farther away would cause home ignition via direct flame impingement or by radiant heat. Over the 7-year span of the imagery, all 3 study sites have increased average grass coverage by 5% or more in the 1.5 m Zone immediately surrounding a structure. Julian experienced the largest overall increase of grass cover (14.12%).

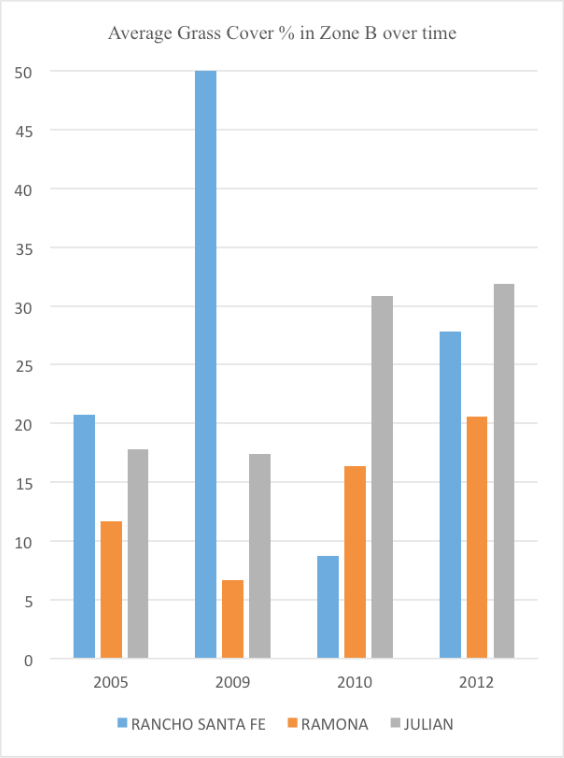

Figure 4.4. Average percent grass cover 0 m – 1.5 m from structure for four distinct years in the three study sites.

4.4 Discussion

Syphard et al. (2014) found that the effective tree coverage on a property to reduce the risk of structure loss was ~60%, with no significant advantage of lowering beyond that level. We found tree cover in all Zones remained below 60% cover for the entire 7-year period. However, in Rancho Santa Fe, Zones C and D reached 40-45% tree cover in 2005 and then reduced over time. In Julian, there have been reductions made in the tree cover in zones A and B, but not in zones C and D. Over 80% of homes in Julian are located on parcels where Zones C and D of the structure overlap onto a neighboring parcel. Because California law requires defensible space 30 m from the structure or to the property boundary, a resident can remain compliant even if their neighbor's vegetation poses a significant threat to structure survivability. (Cal Fire, 2007b). Ramona had the overall lowest tree cover coverage in all Zones, which is unsurprising considering the majority of parcels are in urban or grass fuel types. However, over time the tree cover in Ramona had increased in zones B C and D. Julian had the highest overall 7-year average increase, which was somewhat expected because Julian generally resides in a forested area.

The 2009 spike in grass in Rancho Santa Fe is likely the result remote sensing error. High temperatures when the imagery was collected caused dry, brown grasses, which were sometimes classified alongside brown paving and soil, thereby leading to a potential overestimation of grasses for this year.

The importance of managing vegetation around a structure is clear (Foote et al., 1991; IHBS, 2014; Syphard et al., 2014). However, many defensible space ordinances do not clearly state the importance of the immediate area around the home. For example, even mowed grass or mulch could ignite a house if directly against the siding of a home. Further, trees that overhang a structure will deposit leaf litter on the roof or in rain gutters, thereby providing readily receptive fuelbed for ignition via lofted embers. In all three communities, vegetation overhanging the structure decreased from 2005 to 2012, with the greatest reductions found in Ramona and Julian. Rancho Santa Fe has overall the highest improvement in defensible space across zones C and D, but the least improvement in zones A and B, which could be partially explained by the community's high demand for privacy and aesthetic vegetation.

The results illustrate differences between communities in defensible space, which may be related to differences in how residents have responded to policy changes and fire occurrences in the three communities. In 2007, both Rancho Santa Fe and Ramona suffered major losses in the Witch Creek Fire, which occurred only four years after the 2003 Cedar Fire, the largest fire in California history (Cal Fire FRAP, 2013). Homeowner responses are often related to risk perception (Martin et al., 2009). While many residents who have not experienced catastrophic wildfire can underestimate their risk level, some residents with firsthand experience still take minimal action to reduce risk. Figure 5 illustrates residential actions following wildfire. In 2003, Residence-1 had poor defensible space (Figure 4.5A), but reduced vegetative cover on part of the property following the destruction of Residence-2 during the 2003 Cedar Fire (Figure 4.5B). By 2006, Residence-2 had rebuilt and Residence-1 had allowed the previously reduced vegetative cover to grow back (Figure 4.5C), which likely led in part to destruction of the home during the 2007 Witch Creek Fire (Figure 4.5D).

In order to effectively manage wildfire risk, it is necessary to understand public perception of wildfire hazard and risk (Brunson and Shindler, 2004) . Public responses to policy are a critical piece of information to policy developers, as a law is only as powerful as its implementation (Bates et al., 2009). Homeowners are less likely to comply with mitigation policy if they estimate the hazard to be low (McCaffrey, 2004). However, Figure 4.5 readily illustrates that nearby losses to wildfire do not always result in actions to mitigate future loss.

Figure 4.5. Resident response to defensible space following neighboring structure loss. Imagery taken via Google Earth in (A) March 2003, (B) June 2004, (C) January 2006, and (D) February 2008. Numbers represent specific properties.

Hazard awareness alone is not sufficient to ensure residential mitigation measures on private property (Pearce, 2003). McCaffrey (2004) showed that previous experience with large wildfires have an inconsistent effect on homeowner perception of risk and willingness to mitigate (McCaffrey, 2004). Our results appear to be consistent with this theory as, despite a cumulative loss of over 3,600 homes in the 2007 Witch Creek Fire, tree cover in all zones increased from 2009 to 2012 in Rancho Santa Fe and Ramona. We found a significant drop in tree cover in Zone D (9-30m) from 2005 to 2009 in Rancho Santa Fe and Ramona. Rather than a response to the 2007 Witch Fire, this could be a response to a more rigid defensible space regulations that became effective in 2005 (CA Public resources code, 2014).

When examining the results, it is also important to consider the spatial and demographic differences between the three communities. Rancho Santa Fe is a high-income community with mostly large high value homes and large parcels. The residents in Rancho Santa Fe have a large amount of disposable income to put towards home maintenance and general landscaping. The apparent poor defensible space there seems to largely result from ornamental landscaping rather than overgrown natural vegetation, which is the more common case in Julian. Ornamental vegetation in some cases can be more hazardous than native vegetation; certain species of palm trees, Italian cypress and other ornamental plants popular in high income areas are extremely flammable (Franklin, 1996). Local Ordinances in Rancho Santa Fe have strict requirements for building materials and design, and although it is more important for flammable structures to maintain excellent defensible space, even a fire resistant home can be lost in a wildfire if embers enter the structure. It is therefore important even for fire resistant homes such as those in Rancho Santa Fe to maintain adequate defensible space.

We acknowledge limitations to our analysis. First, the GIS approach here examines the percent coverage of vegetation in each of the zones by looking down upon a given property, but cannot account for vertical continuity of fuels on that property, which may greatly influence the potential to ignite and threaten the structure. For example, a home could possibly have had a high percentage of tree cover in Zone-C (1.5 m – 9 m from the structure), but a very high distance from the ground to the tree canopy, which would greatly inhibit transition from a low-intensity surface fire to a high-intensity crown fire. We considered approaches such as using Google Street View to remotely calculate vertical continuity of fuels, but were severely limited if the home was located away from the street, which was commonly the case in Rancho Santa Fe where parcels sizes are relatively large and homes are screened by vegetation. Further, our analysis did not allow us to distinguish between highly combustible conifers and less combustible broadleaves. Additionally, we did not consider housing density here, which could greatly influence structure-to-structure fire spread. Finally, our analysis does not consider features of the home such as attic ventilation, etc. that would promote or inhibit ignition via lofted embers, which can travel multiple kilometers and ignite structures even with complete vegetation removal (Cohen, 2000; Quarles et al., 2010). That said, we purposefully focused our analysis here exclusively on changes to vegetative cover through time, which was used as our measure of defensible space. Future work will incorporate these findings, roof type, and other property features into a model that calculates actual risk to these same structures through time.

4.5 Management Implications

Defensible space is a critical component of a holistic approach to minimize costs and losses from WUI fires. We found that defensible space (i.e., vegetation coverage) varied, dependent on community, distance from structure, and year, which may be influenced by recent wildfire occurrence and by changes to defensible space policy. Identifying areas of the WUI that are most likely to incur damage during a wildfire event is key to successful fire prevention and preparedness efforts (Haight et al., 2004). As urban development expands into the WUI, the potential costs of societal losses increase (Murnane, 2006). Being able to locate areas within communities with elevated risk can help to direct future policy and also adapt to responses of residential compliance (or lack thereof) of existing regulations.

5.0 Fire risk over time in three varying WUI communities in southern California

5.1 Introduction

Identifying the areas of the Wildland Urban Interface (WUI) that are most likely to suffer damage during a wildfire event is key to successful fire prevention and preparedness efforts (Haight et al., 2004). As urban developments move out into the WUI, the potential costs and losses increase (Murnane, 2006). Therefore, wildland fire risk assessment is becoming an increasingly important component of land management activities (Martin et al., 2010). Fire risk can be defined as the likelihood of loss during a wildfire (Bachmann and Allgöwer, 2001; Hardy, 2005; Sampson et al., 2000). As projections indicate that the WUI will continue to expand, the assessment of how fire risk is changing over time is important for WUI planning and fire risk reduction (Alig et al., 2010; Theobald and Romme, 2007). Ideally, a fire risk assessment should include a quantification of structural and home ignition zone attributes. Of these attributes, roofing material and the defensible space surrounding the structure are commonly accepted as the two primary determinants of a home’s survival in a wildfire (Cohen, 2000; Haines et al., 2008; Syphard et al., 2014).

Over time in California, local and State authorities have responded to catastrophic wildfire by creating new legislation for fire risk reduction. People became aware of the hazard of wood shake shingle roofing in the WUI after the Bel Air Fire of 1961 but it wasn’t until 1993 that the California Building code required ignition resistant roofing in the WUI. Other significant policy responses to wildfire in California include the 1992 Bates Bill (Ewell, 1995; Sapsis, 2007), Public Resources codes 4290 and 4291 (CA Public resources code, 2014) and the 2008 WUI building codes (Cal Fire, 2007a; Turner, 2013). In the WUI, fire policy is only as effective as its implementation, and it is therefore critical to assess the efficacy of policy by measuring homeowner and community compliance. Many local authorities achieve this through on-site home inspections.

On site surveys conducted by local fire agencies may be limited by staff availability and funding. Without access to the property, surveying via traditional “on site” methods are limited to a street view of the home which may be obstructed by driveway length or vegetation. Alternatively, a GIS and remote sensing approach to home surveying allows for a full assessment of the parcel over time (Greenberg and Bradley, 1997; Jain et al., 1996; Nourbakhsh et al., 2006), including Home Ignition Zone (HIZ) characteristics which can indicate structure vulnerability.

The overall objective of this study was to measure risk over time in the WUI. In order to accurately portray the risk of the three communities; I included home ignition zone variables including defensible space and structural materials. This study also measured housing density as a factor of defensible space. Knowledge of a structure’s location and arrangement relative to other structures or flammable materials is critical in effective risk analysis (Cohen, 2000; Murnane, 2006).

In order to create a risk model that can be applied across the State, I assessed three demographically disparate communities in San Diego County, California. This sample is representative of multiple demographic groups in the WUI. It is important to consider this because elements of risk can vary across communities. There is no ‘one fits all’ strategy for mitigation of fire risk in the WUI. Strategies that depend on homeowner cooperation can have varying success rates across a community. Sociopolitical factors such as disposable income and perception of risk can influence homeowner implementation and policy support (Dicus and Scott, 2006; Gordon et al., 2010; Martin et al., 2010). It is therefore critical to consider sociopolitical factors when interpreting the results of a risk analysis.

The objectives of this study where to conduct an analysis of historical data to assess impact of characteristics on structure loss, develop a risk model to assess changes in probability of structure loss over time and analyze risk through time in 3 communities that vary in demographics, socioeconomic status, and local culture.

5.2 Methods

5.2.1 Study Sites

Three residential communities in San Diego County, California, USA were assessed, including Rancho Santa Fe, Ramona, and Julian (Figure 5.1). In order to be representative of a range of communities, the criteria for site selection included: recent experience of catastrophic wildfire and varying community. These three communities all have conditions conducive to high fire hazard, including a Mediterranean climate with extended drought, regular occurrence of high velocity foëhn winds (commonly referred to locally as Santa Ana winds), steep terrain, and flammable vegetation. These conditions have led to several high-intensity, high-loss wildfires in the area in the past 10 years, including the 2007 Witch Creek Fire and the 2003 Cedar Fire.

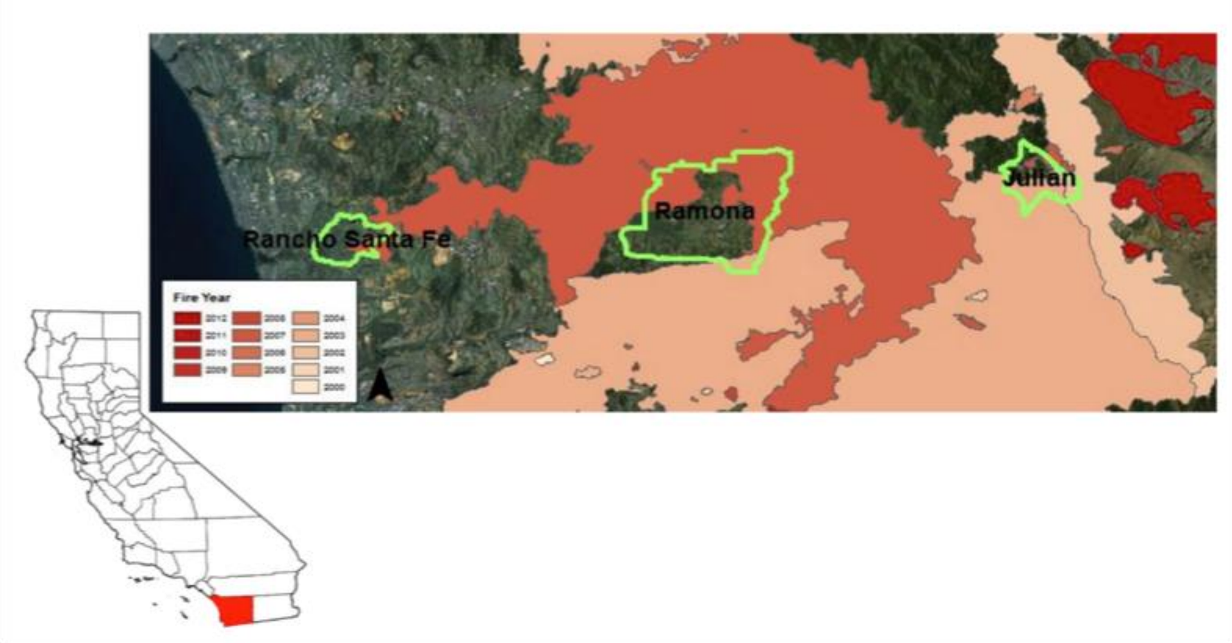

Figure 5.1. Location of the three study sites, including 12-year fire history in the local area.

A 100% sample of structures was taken from each of the three study sites for analysis. The study included 11,727 structures in total.

5.2.2 Fire Risk Model

In order to adequately assess risk, I employed a WUI risk assessment protocol that considered aspects of both individual structural ignition as well as surrounding community variables such as housing density and proximity to wildland fuels. I used a basic definition of fire risk as my basis for the model.

(1) *Risk = Hazard – Home Ignition Zone Mitigations*

I used California Fire Hazard Severity zones (FHSZ) to represent hazard levels in the risk model. These zones (moderate, high and very high) incorporate multiple factors including but not limited to, slope, vegetation type, ember production potential and fire probability (Sapsis, 2007). Home Ignition Zone (HIZ) Mitigations were measured using a multitude of GIS and remote sensing methodologies. All measured components were tested using a logistic regression for significance in home loss. Only variables found to be significant ($\alpha=0.05$) were used towards a HIZ mitigation score.

(2) Hazard:

Cal Fire FHSZ

- ***Very High (3)***
- ***High (2)***
- ***Moderate (1)***

(3) Home Ignition Zone Mitigation Score:

Very Poor (1)

Poor (2)

Moderate (3)

The home ignition zone data contains both structural and landscape measurements. The two primary determinants of a home's survival in a wildfire are the roofing material and the defensible space surrounding it (Haines et al., 2008). In the defensible space analysis (Chapter 4), I included the structure as the first zone of defensible space (Zone A). Structural factors are critical in measuring structural vulnerability as defensible space may not impact structural ignition from lofted embers, which is a common cause of residential losses in wildfires., more so than flame impingement or radiant heat (Cohen, 2000; Nourbakhsh et al., 2006). I collected data on all available HIZ variables for the 11,727 structures in Rancho Santa Fe, Ramona and Julian.

Structural Variables

- Locations of known Wood shake shingle roofing
- Period of urban development (Chapter 3)
- House size m^2

Non Structural Variables

- Defensible Space (Chapter 4)
- Housing Density (Presence in defensible space zones)
- Distance from Wildland vegetation

5.2.3 Locations of known Wood Shake Shingle Roofing

I used hyperspectral aerial imagery and a methodology based on research conducted by Herold et al. (2003) to determine the location of wood shake roofs in the 3 communities. Hyperspectral imagery coverage was not available for all three of the study sites. The available imagery covered the majority of Rancho Santa Fe, a small portion of northern Ramona and a small portion of northwestern Julian. I used the Mixture Tuned Matched Filtering (MTMF) tool in Exelis Visual Information Solutions (ENVI, 2010) software to detect wood shake shingle roof types in Rancho Santa Fe. Mixture Tuned Matched filtering is a preferred method to Matched filtering as by including an infeasibility image it reduces the number of false positives. I defined a Region of Interest (ROI) over two homes in Rancho Santa Fe known to have wood shake shingle roofing in order to match the spectral signature for wood shake shingles (Figure 5.2) and locate possible matching pixels in the image.

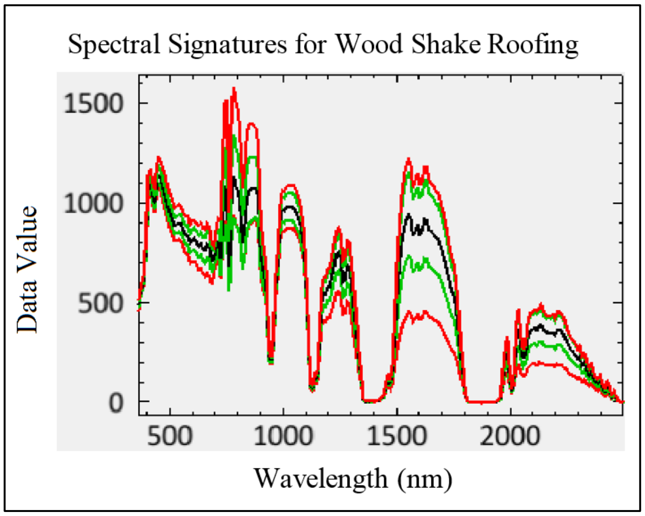

Figure 5.2. Plotted Spectral Signatures for Wood shake shingle Region of Interest (ROI). Min Max and Mean for range of values (ENVI output) (ENVI, 2010).

5.2.4 Period of Urban development

Given the fire policy changes over time in the California, the year in which a structure was constructed will have a significant impact on the materials used for construction. Using parcel data from San GIS (SanGIS, 2014), I mapped urban development over time in each of the three study sites (Chapter 3) using a simple intersect in GIS (ESRI, 2014). I was able to match homes to an estimated period of urban development historical land use data using a spatial join in GIS.

Table 5.1. Periods of Urban Development used in risk model (SanGIS, 2014)

Period of Urban development	*Score*
Pre 1986	1
1987 - 1990	2
1991 - 1995	3
1996- 2000	4
2001-2004	5
2004-2008	6
2009-2012	7

5.2.5 Defensible Space

Defensible space was assessed through time around 11,727 structures in the three communities (Chapter 4). Each of the structures was digitized manually using aerial imagery and multi-zone buffers. To assess vegetation coverage around the structures, we utilized four-band multispectral aerial imagery from the National Agriculture Imagery Program (NAIP) at a 1 m Ground Sample Distance (GSD) resolution. We used an Interactive Supervised Classification within ESRI ArcMap 10.2 (ESRI, 2014) to extract information classes from the NAIP imagery for the years 2005, 2009, 2010, and 2012. A supervised classification uses spectral signatures obtained from training samples to classify an image into groups, which were then used in a spatial analysis to measure the distribution of the classes.

5.2.6 Housing Density

During a wildfire, a burning home is a volatile fuel in the WUI. High density communities can facilitate rapid fire spread and urban conflagrations via structure to structure fire spread. I used the defensible space methodology outlines in Chapter 4 to characterize structure density in my three study sites (Table 5.2).

Table 5.2. Density Rating System using buffer model.

Structure Present in Zone	*Density Rating*
B 0-1.5m	4
C 1.5-9m	3
D 9-30m	2
No Structure in Zones	1

5.2.7 Distance from Wildland vegetation

Using San GIS vegetation data (SanGIS, 2014) I created multiline buffers around all wild land vegetation. I then performed a spatial join (ESRI, 2014) to sort the homes into distance groups (Table 5.3). At this point in the analysis, I did not have a significant distance from wildland vegetation to test, so therefore, I created multiple buffers in increments of .5km to later be tested for significance.

Table 5.3. Distance from Wildland Vegetation Rating System using buffer model.

Distance From Wildland Vegetation	*Distance Score*
Within wildland Vegetation	0
.5km	1
1km	2
1.5km	3
2km	4
2.5km	5
3km	6

5.2.8 Binary Logistic Regression

In order to fit the HIZ Model mitigation model, I performed a binary logistic regression using SPSS (IBM, 2013) to test which of the community and structure characteristics influenced the probability of structure loss in a wildfire event. I used known locations of homes destroyed in the 2007 Witch Creek Fire and the historical data collected for the 2005 homes to test for possible significant variables in predicing home loss. I sampled 3669 homes in total, which included all homes that were inside the fire perimeterand all homes within a 0.5km buffer beyond the perimeter. This buffer was included so as to include surviving homes with a close proximity to the fire.. A Binary logistic model is necessary for this analysis as the Y variable (Burned/ Unburned) is dichotomous.

The overall binary logistic model was

$$(2)\ \ln\left(\frac{\rho}{1-\rho}\right) = \beta_0 + \beta X_1 + \beta X_2 + \beta X_3 + \beta X_4 + \beta X_5 + \beta X_6 + \beta X_7 + \beta X_8 + \beta X_9 + \beta X_{10} + \beta X_{11} + \varepsilon_i$$

where

Y= Home burned in the witch Witch Creek fire (0,1)

X1- Within the Fire perimeter (0,1)

X2- Period of urban development (1-5) (Values 6 & 7 were out of range of 2005 data)

X3- House Size (m^2)

X4-Percent Tree coverage Zone A (%)

X5-Percent Tree coverage Zone B (%)

X6-Percent Tree coverage Zone C (%)

X7-Percent Tree coverage Zone D (%)

X8-Percent Grass coverage Zone B (%)

X9-Percent Grass coverage Zone C (%)

X10-Percent Grass coverage Zone D (%)

X12- Distance to Wildland vegetation (0-2)

I used the results of this regression (Table 5.3) to inform the mitigation score for each structure (Figure 5.3). With the exception of housing density, I included only variables that were found to be significant in home loss. The logistic model found that, Period of urban development, Tree cover in zone B, Grass cover in zone B and Distance to wildland vegetation were significant in predicting home loss in a wildfire (Table 5.4). Density was not included in the regression as after an exploration of the variable in the regression, I found that the majority of high-density homes were outside of my sample and therefore the model did not have a sample representative of density range. I chose to include density in the mitigation model as a factor of home ignition based on previous studies on the effect of housing density and house to house ignition in wildfires (Price and Bradstock, 2013).

Table 5.4. Binary Logistic Regression results for Home Ignition Zone Mitigation Model n = 3669

Variable	***Significance***	***Interpretation***
Period of Urban development	<.000	The odds of home loss decrease over time across the periods of urban development. Older homes have a higher probability of loss.
Percentage of Trees in Zone B (0-1.5m)	<.000	Increases in percentage of tree in B increase odds of losing home
Percentage of Grass in Zone B (0-1.5m)	<.024	Increases in percentage of grass in B increase odds of losing home
Distance from wildland vegetation	<.005	Increases in distance from wildland vegetation decrease odds of losing home. Significant scores 0 and 1, no significance in score 2.

The order of the variables included in the model (Figure 5.3) was based on the Beta coefficients of the Binary Logistic Regression. The regression results showed that that percentage cover of trees in zone B had a higher coefficient (β=0.053) than the percentage cover of grass (β=.019). These numbers mean that for an additional 1% in cover the odds of the home being destroyed are increased by a factor of 0.053 for trees in B and 0.019 for grass in B. Therefore an increase in percent cover of trees in zone B has over 2 times the effect of a percent increase of grass cover on probability of structure loss in a wildfire. In order to deliniate between high risk levels of tree and grass cover and mitigation levels in the model, I used the mean tree cover in Zone B and mean grass cover in Zone B for homes that burned during the Witch Creek Fire (Table 5.5) as a bench mark for potentially hazardous levels of vegetation cover in Zone B. Homes which were burned in the 2007 Witch Creek Fire had a 2% higher mean tree cover in Zone B than homes which survived. Burned homes also had a 1% higher mean grass cover in Zone B than surviving homes, as there appeared to be a small margin between the averaage cover in surviving homes and burned homes; I used the mean % cover values (highlighted) as an indicator of hazardous defensible space (i.e., >18% tree cover is potentially hazardous).

Table 5.5. Mean Vegetation cover for surviving and destroyed homes in the 2007 witch fire (output from logistic regression model, Total n=3669) Highlighted values used as benchmarks for

Burned	Mean % Tree Cover in Zone B	Mean % Grass Cover in Zone B
No (n= 1846)	16%	10%
Yes (n= 1823)	18%	11%

As Pre 1990 urban development was used to represent wooden roofing and pre WUI building code construction type, the pre 1990 homes were given a mitigation score of 1 (poor). This is because homes with wooden roofing materials could be ignited by embers even with effective defensible space. A limitation of the mitigation score is the inability to identify accurate year of construction and individual structure materials. Given the nature of grouping homes by year of development, it is important to use the Fire risk model to identify communities of probable high and very high fire risk rather than individual structures.

The distance from wildland vegetation and defensible space variables were informed using the results of the logistic regression (Table 5.4). Housing density was included based on literature referencing the effect of structure to structure fire spread (Price and Bradstock, 2013).

The mitigation scores (Poor, Moderate and Good) were created based on the regression results. Poor mitigation was assigned to structures with >18% of tree cover in Zone B and structures with possible pre 1990 construction. Moderate mitigation was assigned to homes which had >11% grass cover in Zone B. The presence of a structure within Zone B (0-1.5m) resulted in a Poor mitigation score, and a structure within the 30m home ignition zone of a structure resulted in a moderate mitigation score. This was due to the significance of Zone B in the regression and to account for the mitigation level of the adjacent structure.

5.2.9 Home Ignition Zone Mitigation Model

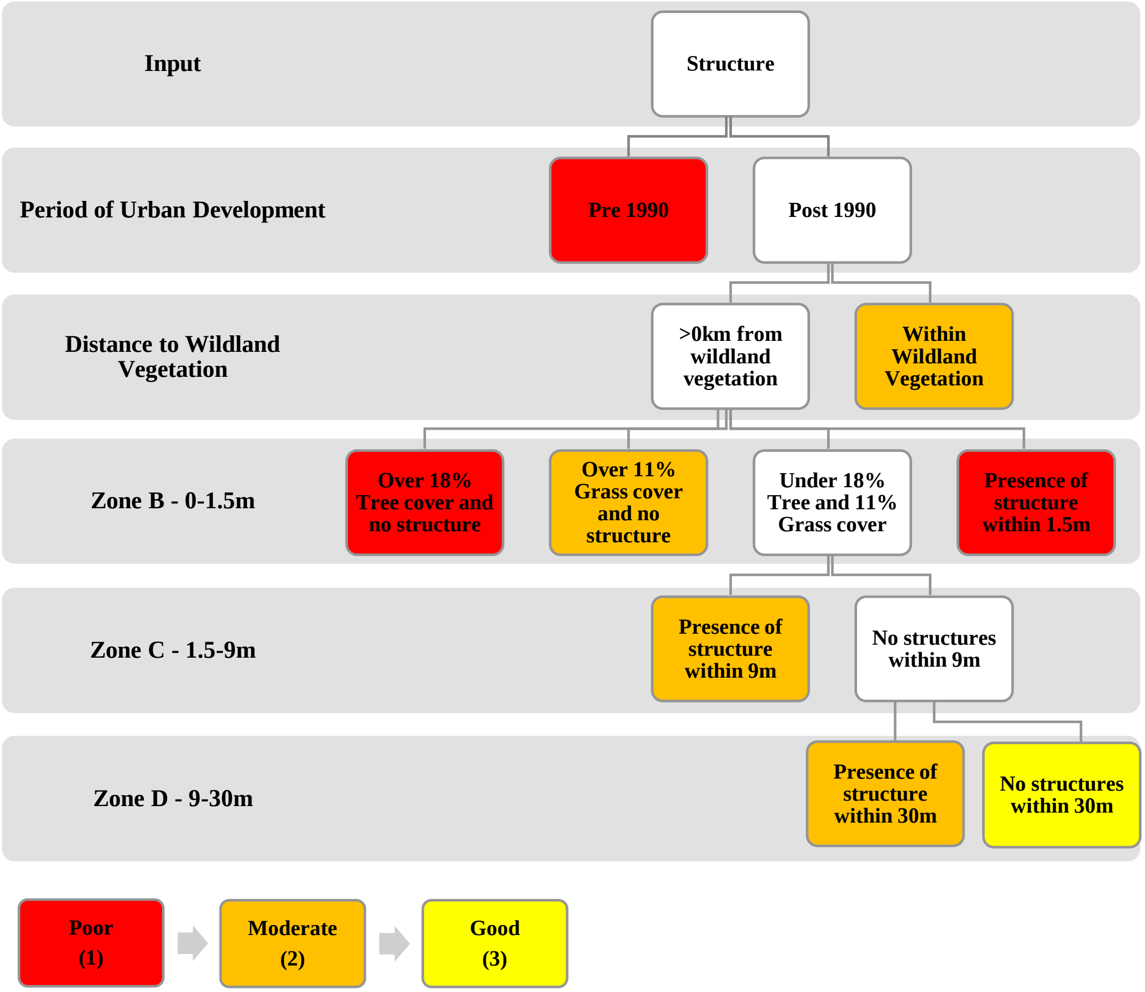

Figure 5.3. Home Ignition Zone Mitigation Model design based on results of Binary Logistic Regression and known effect of housing density on home loss (Price and Bradstock, 2013). Results will be used in final model to represent observed mitigation.

This risk model was used to assign each house with a structural risk score of Moderate, High or Very High. This score provided the level of mitigation to be included in the equation for fire risk:

Fire Risk = Hazard – Observed Mitigation (Table- 5.6)**.**

Table 5.6. Risk Scoring Methodology, groupings were based on the Cal Fire Fire Hazard Severity Zone Methodology (Sapsis, 2007).

Hazard	**Home Ignition Zone Mitigation Score**	**RISK = *(Hazard – HIZ Mitigation)***	**Fire risk Score**
Moderate (1)	3	-2	MFR
	2	-1	MFR
	1	0	HFR
High (2)	3	-1	MFR
	2	0	HFR
	1	1	VHFR
Very High (3)	3	0	HFR
	2	1	VHFR
	1	2	VHFR

Fire risk Scoring

MFR ≤ -1	***Moderate Fire Risk***
-1 < HFR <1	***High Fire Risk***
VHFR ≥ 1	***Very High Fire Risk***

In Ramona, some structures had an unknown fire hazard severity. Structures in areas where the FHSZ was unknown were allocated a Fire Risk score based on the Mitigation Score i.e. Poor mitigation (Very High Fire Risk), Moderate (High Fire Risk), Good (Moderate Fire Risk).

5.3 Results

5.3.1 Defensible Space

In regards to defensible space, the binary logistic regression indicated that the percentage of trees and of grass in zone B (0-1.5m) were significant factors ($\alpha = 0.05$) in predicting home loss in the Witch Creek Fire (Table 5.3). Homes that burned in the Witch Creek Fire had a slightly higher mean percent cover of Tree cover and Grass cover in zone B (Table 5.4). An increase in percent cover of trees in zone B was found to have over 2 times the effect of a percent increase of grass cover on probability of structure loss in a wildfire.

The mean percentage cover values for the burned homes (18% for Trees in Zone B and 11% for Grass in Zone B) were used in the Mitigation score (Figure 5.3) as high risk factors for defensible space (Figure 4.3). All detailed results of the defensible space analysis can be found in Chapter 4.

5.3.2 Estimated Roof Type

The Mixture Tuned Matched Filtering (MTMF) identified 85 Wood shake roofs in Rancho Santa Fe. Google imagery and street view (Google Inc, 2013) validated that 70 of these roofs were indeed wood shake (user accuracy 82%). I was unable to include roof type in the HIZ model directly because the AVARIS imagery available was collected by NASA in 2014. However, 89% of the homes identified to have wood shake roofs were constructed before 1990. There was not enough coverage of Ramona and Julian to identify any wood shake roofing; however, our onsite survey did locate multiple homes with wood shake shingle roofing in pre-1986 and pre 1990 areas of Julian. As there is a direct correlation between roof type and the age of the structure, I used ‘Year built’ as a substitute for roof type for the risk model.

5.3.3 Period of Urban Development

Rancho Santa Fe had the largest proportion of homes built pre-1990 with 86% (74% were built pre 1986) (Figure 5.4). 84% of the structures in Julian were pre 1990 (9% pre 1986). The majority of homes in both Ramona and Rancho Santa Fe were estimated to have been built pre 1986. Ramona has the largest proportion of post-1990 homes with 19% (Figure 5.4a).

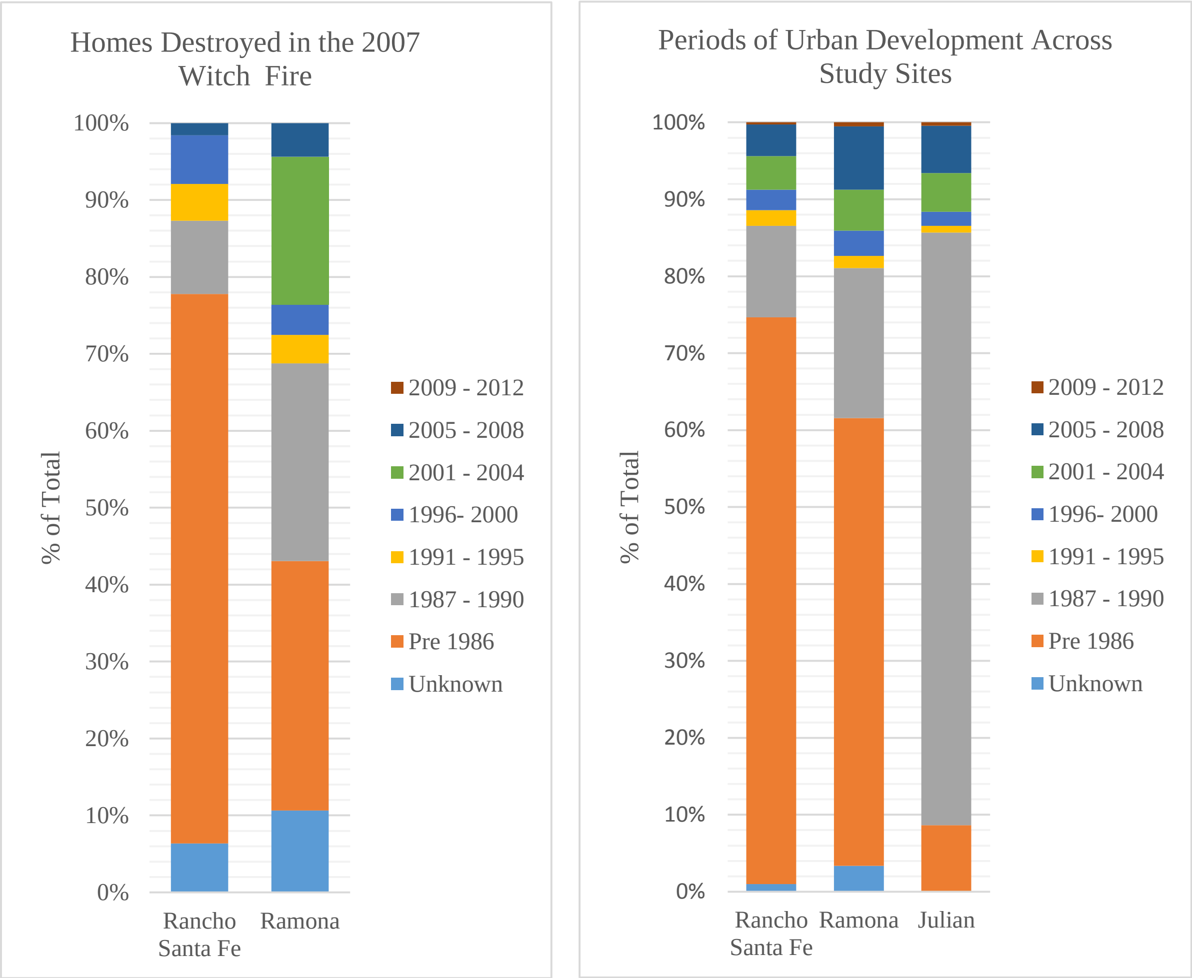

Figure 5.4. (a- Left) Estimated age of structures across study sites using San GIS land use data (SanGIS, 2014). (b- Right) Age of homes destroyed in the Witch Creek fire 2007 within study sites.

The majority of homes destroyed in the 2007 Witch Creek fire were identified as pre 1986 construction (Figure 5.4b), which support the decision to use ‘Period of Urban development’ as a pseudo roof type and a representation of structural materials in the risk model. In 1993, the California Building code was enacted which required ignition resistant roofing in the WUI; therefore the Pre 1986 and 1987-1991 groups are most likely to contain homes with non-resistant roofing and other ‘pre fire code’ materials.

5.3.4 Housing Density

Rancho Santa Fe has the highest percentage of high-density structures over the 7 year study period (10%). It is important to note that I considered each structure individually regardless of parcel and ownership. Many homes in Rancho Santa Fe have guest houses close to the main house; thus despite large parcel sizes, many parcels have multiple structures. Ramona had the highest total number of structures designated as high density; (300 within 0-1.5m), but this only consisted of 3% of the total structures in Ramona due to its larger population. 80% of structures in Julian had other structures within 30m, compared to 75% both in Rancho Santa Fe and Ramona (Figure 5.5).

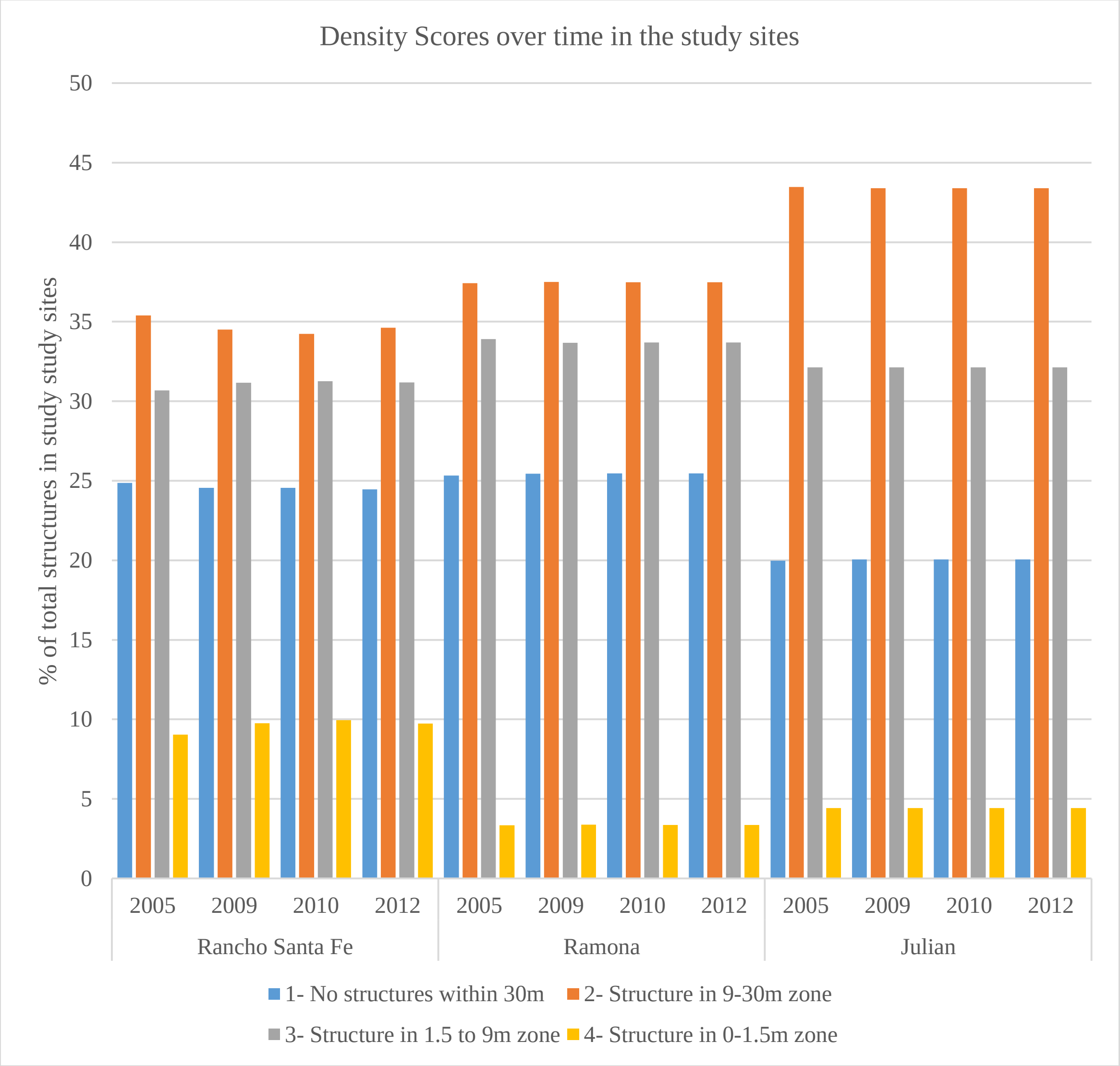

Figure 5.5. Density results over time in each of the three study sites.

5.3.5 Home Ignition Zone Mitigation

Ramona had the highest total number of structures with a poor mitigation score, and Rancho Santa Fe had the highest percentage of structures with a poor mitigation score (~95%). However, Rancho Santa Fe also had the greatest improvement over the 7-year study period with a 1.5% of homes there improving over the 7-year study period from poor mitigation to moderate. Julian had the second highest proportion of structures with poor mitigation (90%). Ramona had the highest proportion of homes with moderate and good mitigation (Figure 5.6).

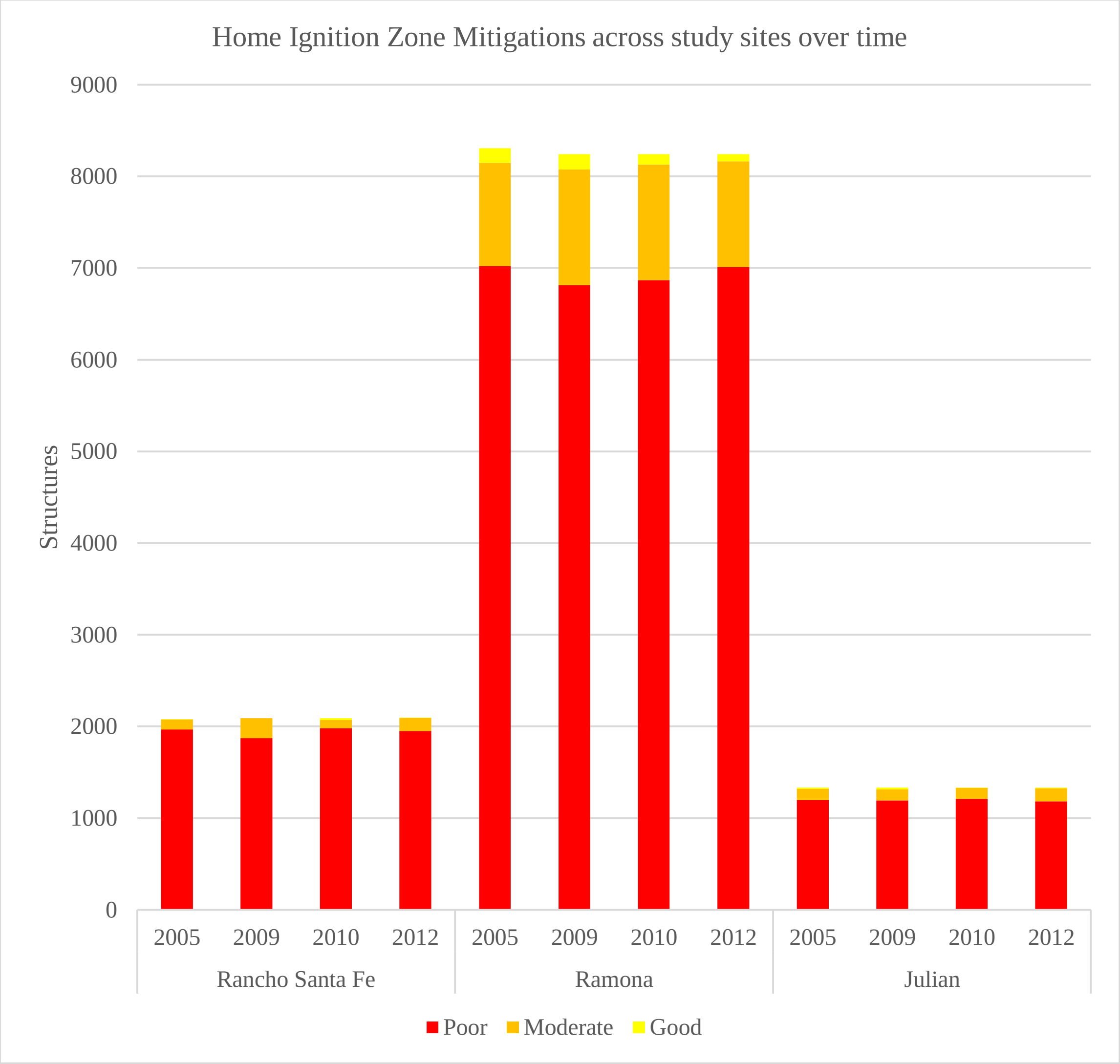

Figure 5.6. Home Ignition Zone (HIZ) Mitigation Ratings over time across study sites.

5.3.6 Fire Risk

Ramona has the greatest number of structures classified as high fire risk and Julian had the greatest proportion of very high fire risk structures (89%) (Figure 5.7). Rancho Santa Fe has the smallest proportion of structures categorized as very high fire risk (33%). Rancho Santa Fe also had the greatest overall reduction in risk levels over the 7 year study period, with a 0.5% decrease in the very high category, a 1.2% decrease in the high category and a 1.7% increase in homes with moderate risk. Ramona had a .5% increase in structures with very high fire risk over the 7 year study period.

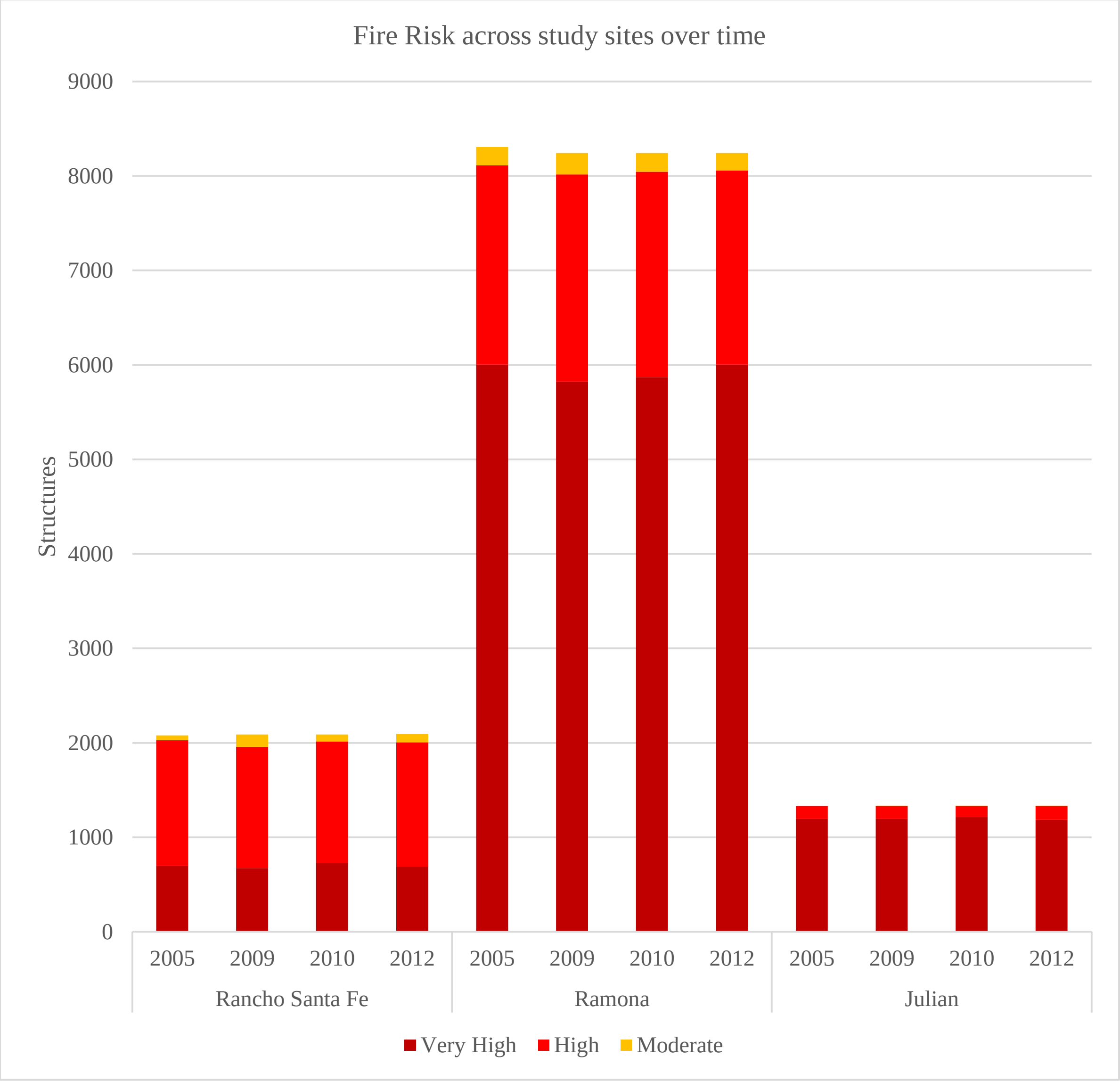

Figure 5.7. Fire Risk Ratings over time across study sites (*Fire Risk* = *Hazard* – *Mitigation*)

5.3.7 Demographic Distribution of Risk

The fire risk results were compared spatially with ESRI Business Analyst data (ESRI, 2015) for demographics and homeowner expenditures (Table 5.7a b and c). Demographic data was collected by Block Group (ESRI 2012 Census data).

Table 5.7(a). Demographics across fire risk groups in Rancho Santa Fe (2012 data)

Fire Risk	Population Density	Average Family size	Vacant Homes	Median Age	Average Household Income	Average disposable Income	Minority Population
Very High	477.08	2.95	62	52.00	$183,181.00	$133,138.00	135
High	467.50	2.91	64	53.00	$181,863.00	$132,521.00	135
Moderate	470.22	2.93	63	52.00	$182,285.00	$132,685.00	136
Community Average	471.60	2.93		52.33	$182,443.00	$132,781.33	135
Total			188				

Table 5.7(b). Demographics across fire risk groups in Ramona (2012 data)

Fire Risk	Population Density	Average Family size	Vacant Homes	Median Age	Average Household Income	Average disposable Income	Minority Population
Very High	1317.70	3.33	47	38	$82,573.00	$64,100.00	802
High	1237.30	3.28	49	41	$82,792.00	$64,070.00	686
Moderate	917.60	3.34	59	38	$86,212.00	$66,190.00	835
Community Average	1157.53	3.32		39	$83,859.00	$64,786.67	774
Total			155				

Table 5.7(c). Demographics across fire risk groups in Julian (2012 data)

Fire Risk	Population Density	Average Family size	Vacant Homes	Median Age	Average Household Income	Average disposable Income	Minority Population
Very High	112.03	2.81	134	52	$91,958.00	$71,332.00	139
High	111.78	2.81	138	52	$92,136.00	$71,410.00	182
Moderate	113.90	2.82	111	51	$91,050.00	$70,935.00	175
Community Average	112.57	2.81		52	$91,714.67	$71,225.67	165
Total			383				

In Rancho Santa Fe and Julian, the very high fire risk homes are located in higher income communities. In Ramona, the moderate risk homes were in higher-earning communities. Ramona had the lowest levels of household and disposable income and the largest average family size. I included the average number of vacant homes in this study to represent homes with no homeowner present to undertake mitigation strategies. Julian had the highest number of vacant homes in all three risk groups (383 total vacant homes) (Table 5.7c). Table’s 5.8a b and c illustrate the demographic differences between the HIZ Mitigation ratings.

Table 5.8(a). Demographics across Home ignition zone mitigation levels in Rancho Santa Fe (2012 data)

Mitigation	Family Size	Average Income	Disposable Income
Poor	2.93	$182,351.00	$133,217.00
Moderate	2.93	$181,803.00	$132,328.00
Good	3.10	$185,030.00	$132,760.00

Table 5.8(b). Demographics across Structural fire risk ratings (observed mitigation) in Ramona (2012 data)

Mitigation	Family Size	Average Income	Disposable Income
Poor	3.33	$82,230.00	$63,855.00
Moderate	3.25	$85,353.00	$65,700.00
Good	3.29	$86,681.00	$66,603.00

Table 5.8(c). Demographics across Structural fire risk ratings (observed mitigation) in Julian (2012 data)

Mitigation	Family Size	Average Income	Disposable Income
Poor	2.81	$91,489.00	$71,127.00
Moderate	2.80	$92,160.00	$71,421.00
Good	2.81	$91,959.00	$71,332.00

Tables 5.8 a b and c illustrate the possible demographic connections with observed homeowner mitigations for the study. In all 3 communities, poor mitigation corresponds

with lower average household income, disposable incomes, and a larger average family size.

5.4 Discussion

The most critical portion of the home ignition zone was found to be the initial zone (Zone B -0-1.5m) immediately adjacent to the structure. I found that the vegetation cover in this zone is statistically significant in predicting structure loss in a wildfire ($\rho<.000$). Tree cover in this zone was found to be twice as influential on the odds of losing a home in a wildfire when compared to grass cover. Homes that burned in the Witch Creek Fire (within the study sites of Rancho Santa Fe and Ramona) had an average of 18% tree cover in zone B and 11% grass cover in zone B. Zones C (1.5-9m) and D (9-30m) were not found to be significant in the regression. It is important to note that the limitations of a logistic regression on spatial data include the possible underestimation of the importance of zones, given that vegetation may lie on the boundaries of zones, or two zones may share a single tree. Therefore, while zone B (0-5m) is the most critical zone, all zones are important for home mitigation to reduce structural ignition from embers, radiant heat and direct flame contact.

The majority of homes lost in the 2007 Witch Creek fire where pre-1991 construction (based on ‘Period of Urban Development’). Older homes also had higher probability of being destroyed during a wildfire event. These results suggest that the California Building code instituted in 1993 (Cal Fire, 2007a) has been successful in reducing home loss by eliminating the new construction of wood shake shingle roofing in the WUI.

Housing density was included in the final risk model alongside defensible space to represent proximity to hazardous structural fuels. It should be noted that the hazard posed by high-density housing is dependent on structure type. Studies have shown that homes with other structures within 50m are more likely to be destroyed during a wildfire event (Price and Bradstock, 2013). The effect of the adjacent home would depend on the flammability of the adjacent structures. High-density flammable housing is high risk whereas high density fire resistant housing could form a fuel break. Therefore, clusters of pre-1990 homes with poor defensible space in high density areas are of particular concern.

The key objective of this study was to discover how risk is changing over time in the three communities and how risk across the communities differed. While relatively small, there were changes within the communities over the 7 year study period (Figure 5.7). Of the small changes observed from 2005 to 2012, Rancho Santa Fe had the most risk reduction whilst Ramona increased its number of Very High fire risk structures over time. These results support the view of Rancho Santa Fe as a community with high levels of fire safety awareness; Rancho Santa Fe has implemented many local ordinances which go beyond the CA building code to reduce fire risk (See 5.5.1 – Rancho Santa Fe).

The study found that the majority of Very High and High Fire Risk homes are located in the more affluent areas of the Rancho Santa Fe and Julian. This is a result of development on the outskirts of the WUI, within or directly adjacent to wildland vegetation. In Rancho Santa Fe, the average disposable income of the ‘Very High’ Fire risk homes was over $133,000. In Ramona, where the average disposable income of a ‘Very High’ Fire Risk home was ~$64,000 the very high risk structures are mostly in lower income communities.

Homes with Moderate Fire risk had an average disposable income of ~$132,000 in Rancho Santa Fe and $66,000 in Ramona. Julian had a disposable income range of ~$70,000 (Moderate Fire Risk) and ~$71,000 (Very High Fire Risk).

When comparing homeowner mitigation and compliance, the higher income structures had higher levels of compliance across all three study sites, however these homes often had a high risk rating due to a very high fire hazard. In Rancho Santa Fe, very high risk ratings were often the result of high fire hazard, whereas in Ramona very high risk ratings were due to poor mitigation. In Ramona, lower income communities had poorer mitigation scores than areas with higher income. In Julian, income and family size did not appear to be a strong indicator of mitigation compliance. It is critical to consider these demographic differences when analyzing the efficacy of fire risk reduction policy.

5.4.1 Rancho Santa Fe

The majority of Very High fire risk homes in Rancho Santa Fe are in high income communities, which is logical given the nature of development in Rancho Santa Fe. Many of the larger homes are built directly within the wildland vegetation, which is a high fire hazard area. Rancho Santa Fe has distinct areas of High and Very High risk homes. The majority of 'Very High' fire risk homes are located on the edges of the community in close proximity to the wildland vegetation (Figure 5.8). Despite the significance put on structure age in the mitigation score, 64.5% of the pre-1990 structures were classified as High risk in Rancho Santa Fe and only 35.5% were classified as Very High risk. This is due to the location of the fire hazard severity zones throughout the community. This result outlines the importance of considering proximity to fire hazard when mapping fire risk.

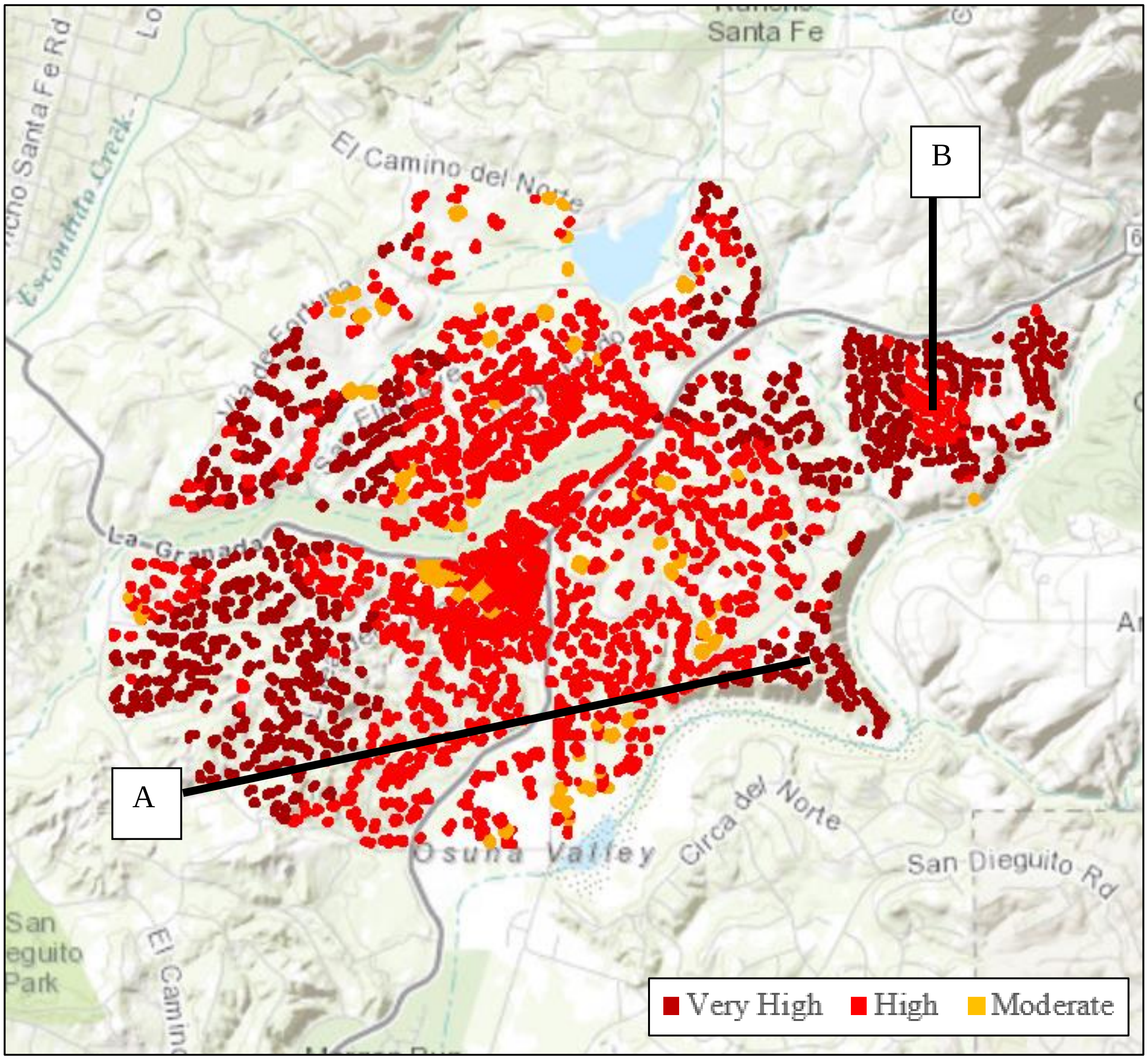

Figure 5.8. Distribution of Fire risk classifications in Rancho Santa Fe (2012 dataset)

Community (A) in Figure 5.8 is a cluster of homes with ‘Very High’ fire risk. This area was the site of much of the home loss in the 2007 Witch fire. If the fire resilience of these homes were improved, they could potentially act as a fire break for the Rancho Santa Fe community, thereby lowering the overall community fire risk. Community (B) in Figure 5.8 is a cluster of High Risk homes that are surrounded on all sides by Very High risk homes. The High rating is a result of the FHZS for that area. The homes were all found to have poor Mitigation levels. Given the proximity of multiple high-risk homes and the low level of mitigations in place, this community could be at risk of ember ignitions during a wildfire event.

Of the three study sites, Rancho Santa Fe had the lowest overall risk levels and the highest level of observed risk reduction over the 7 year study period. Rancho Santa Fe is known for high levels of fire safety awareness; Rancho Santa Fe has implemented many local ordinances which go beyond the CA building code to reduce fire risk. These ordinances include, but are not limited to, limitations on depth of woodchips, banned species of ornamental vegetation, and limits on decking and eave materials.

Despite the additional measures taken by the local fire department and homeowners association to reduce risk in Rancho Santa Fe, many homes were still found to have poor defensible space. Homes with poor mitigation scores had, on average, lower disposable incomes. Many of the home owners in Rancho Santa Fe are occupied by retired members of the community who have limited funds to implement structural and landscaping mitigations (Dicus and Scott, 2006).

Some of the higher income homes in Rancho Santa Fe were also found to have poor defensible space. Here, this could be a result of ornamental landscaping and vegetation within close proximity to the home for privacy and aesthetic value. Many flammable species of palm and Italian cypress were found during the on-site survey. Even in Rancho Santa Fe, where the homeowners are very involved in fire safety, it is difficult for the fire department to enforce the local ordinances across the community. It is also important to discuss that many of the higher income areas in Rancho Santa Fe have implemented the use of non-flammable plant species. This GIS methodology does not differentiate between tree and grass species, and therefore the results should be used to identify potential high risk areas for further analysis.

5.4.2 Ramona

Of the three study sites, Ramona has the lowest average income and the largest family of the three study sites, this could indicate possible financial constraints on residents, limiting ability to implement mitigation. Ramona also had the largest proportion of homes destroyed in the Witch fire 2007 out of the study sites (87% of regression sample).

Ramona had a large distribution of Very High risk homes across the community. In particular, the homes to the north and east of Ramona had Very High fire risk. Community (A) in figure 5.9 is the location of many of the structure losses in the 2007 Witch fire. This cluster of homes were found to have a Very High fire risk and poor HIZ Mitigation. This cluster of homes could potentially create a hazard for the adjacent Moderate fire risk homes (B). Community (C) is a cluster of homes with Moderate fire risk and Moderate HIZ Mitigation. This community could potentially provide a buffer for Ramona if a wildfire was approaching from the North West; reducing the fire risk of adjacent communities.

Unlike Rancho Santa Fe, the wealthier communities in Ramona contain the lowest Fire Risk ratings. The outer green belt of Ramona differs to Rancho Santa Fe in that it contains many older homes and lower income communities. High Risk ratings in low income areas of Ramona could be a result of financial barriers to implementation. These could include limited disposable income, lack of physical ability to undertake maintenance and a lack of education regarding hazard. Many structures in the center of Ramona had

Moderate fire risk. For the majority of these structures this was the result of a Moderate fire hazard (the lowest hazard rating).

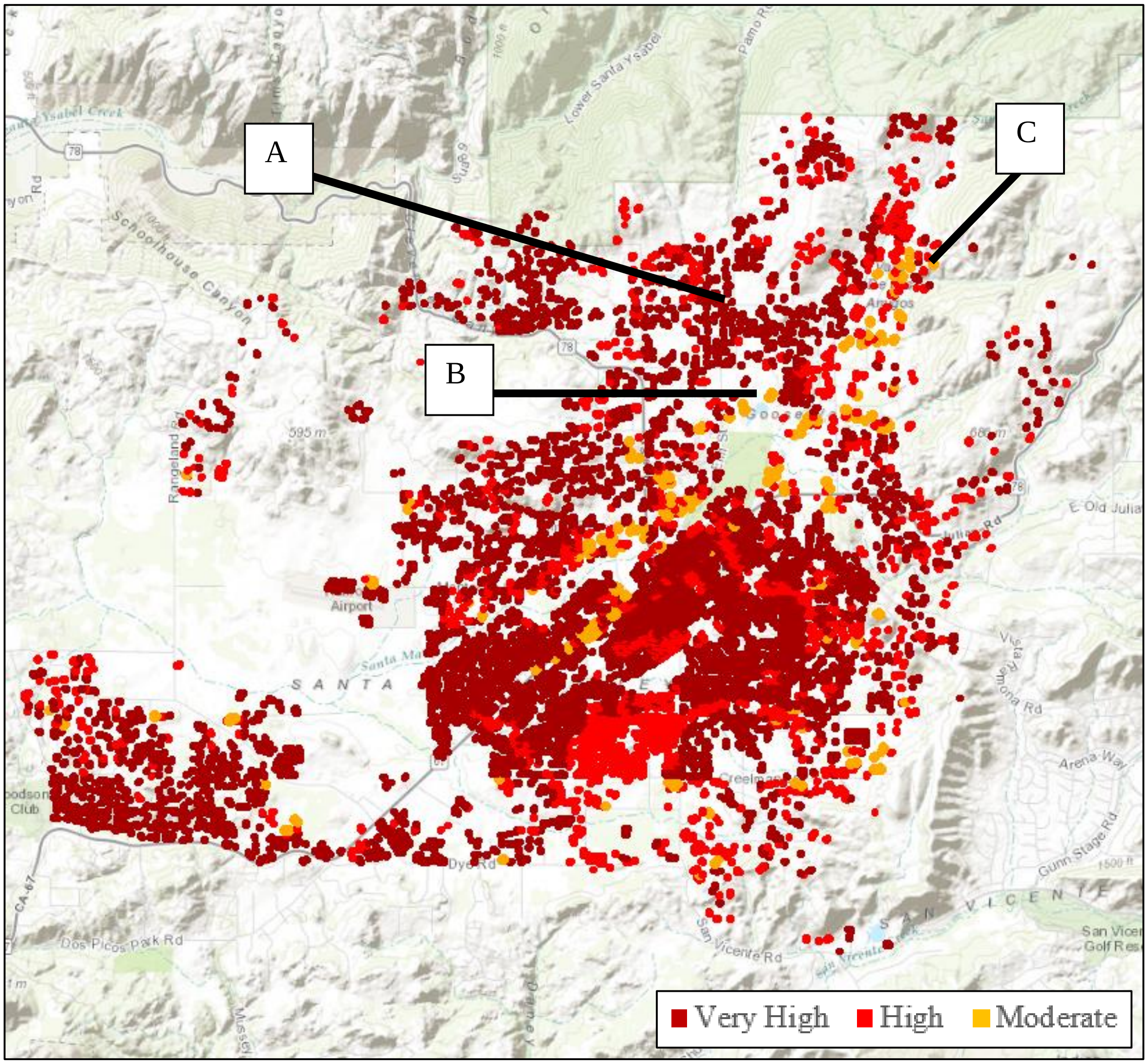

Figure 5.9. Distribution of Fire risk classifications in Ramona (2012 dataset)

5.4.3 Julian

Julian had the overall highest proportion of ‘Very High’ Fire Risk homes (~90%). Of the three study sites, Julian has had the least development from 1986 to 2012 (Chapter 1). Many of the homes in Julian are older (pre WUI building code) construction. Julian also had the highest proportion of vacant homes (383) indicating that many of the homes in Julian are vacation homes. Vacation homes could pose a high fire risk to the local community as there is no homeowner on site to undertake mitigations regularly. Although the hyperspectral imagery was not available for Julian, the on-site survey found many homes in Julian to have wood shake shingle roofing and wood siding.

The Fire Hazard in Julian is very high due to a large number of coniferous trees and steep slopes. The key areas for concern in Julian are the hillside communities where older structures have high fire risk and evacuation routes are long windy roads through a coniferous forest.

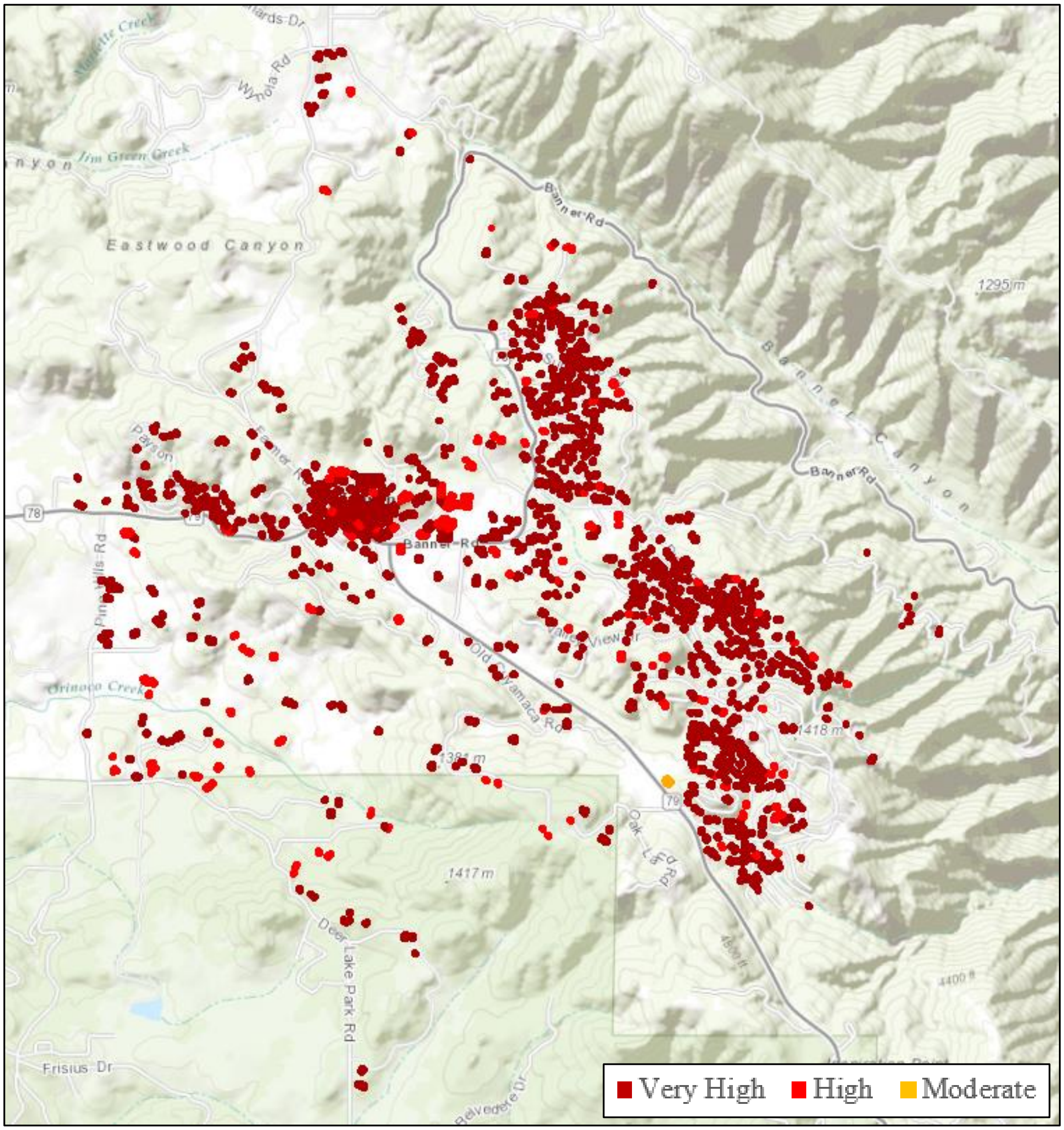

Figure 5.10. Distribution of Fire risk classifications in Julian (2012 dataset)

We acknowledge limitations to our analysis. First, the GIS approach to measure homeowner mitigation examines the percent coverage of vegetation in each of the zones by looking down upon a given property, but cannot account for vertical continuity of fuels on that property, which may greatly influence the potential to ignite and threaten the structure. For example, a home could possibly have had a high percentage of tree cover in Zone-C (1.5 m – 9 m from the structure), but a very high distance from the ground to the tree canopy, which would greatly inhibit transition from a low-intensity surface fire to a high-intensity crown fire. We considered approaches such as using Google Street View to remotely calculate vertical continuity of fuels, but were severely limited if the home was located away from the street, which was commonly the case in Rancho Santa Fe where parcels sizes are relatively large and homes are screened by vegetation. Greater availability of LIDAR remote sensing data may provide future opportunities to improve on measurement of vertical vegetation structure near structures. Further, our analysis did not allow us to distinguish between highly combustible conifers and less combustible broadleaves. Our analysis does not consider features of the home such as attic ventilation, etc. that would promote or inhibit ignition via lofted embers, which can travel multiple kilometers and ignite structures even with complete vegetation removal (Cohen, 2000; Quarles et al., 2010). That said, our methodology will allow land managers to identify areas of a community that are most likely to incur damage during a wildfire event.

5.5 Management Implications.

Homeowner implemented mitigation is a critical component of a holistic approach to minimize costs and losses from WUI fires. We found that levels of fire risk varied, dependent on community, year, and the average income of the homeowner. Mitigation of fire hazard was lower in low income communities. In these areas, financial assistance or incentive programs may improve homeowner compliance. Occurrences of poor mitigation in higher income communities appeared to be the result of ornamental landscaping.

Identifying areas of the WUI that are most likely to incur damage during a wildfire event is key to successful fire prevention and preparedness efforts (Haight et al., 2004). As urban development expands into the WUI, the potential costs of societal losses increase (Murnane, 2006). Being able to locate areas within communities with elevated risk can help to direct future policy and also adapt to responses of residential compliance (or lack thereof) of existing regulations.

6.0 Final Conclusions

As new communities are developed into fire-prone WUI areas, measures must be taken to prevent losses from wildfire. Strategic placement of new developments to buffer vulnerable communities could provide multiple benefits the community. It is significantly more cost-efficient to build a community in a fire resistant manner at the onset than it is to retrofit an existing community. To sustainably manage the WUI, stakeholders from diverse disciplines and worldviews must collaborate to reduce fire risk in a manner that is environmentally sound (Dicus and Scott 2006).

The methodology outlined in this study will allow land managers to identify areas of a community that are most likely to incur damage during a wildfire event. This information is key to successful fire prevention and preparedness efforts (Haight et al., 2004). As urban development expands into the WUI, the potential costs of societal losses increase (Murnane, 2006). Being able to locate areas within communities with elevated risk can help to direct future policy and also adapt to responses of residential compliance (or lack thereof) of existing regulations.

It is our hope that this research will provide land managers and policymakers with a means to facilitate that endeavor, creating a process that fosters meaningful dialogue between individuals and groups that sometimes have conflicting objectives. Indeed, while our research is regional in nature, it is intended that the process that we develop will be applicable on an international scale.

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