HOUSING LOSS TO WILDFIRES IN THE WILDLAND URBAN INTERFACE IN THE US

(CONTRIBUTING FACTORS TO HOUSING LOSSES IN THE WUI)

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OVERVIEW

Wildfires in the United States now burn 75,600 acres annually on average (NICC, 2002 - 2011). These fires affect not only forest communities, but the human communities with which they are intermingled. The costs related to fire, i.e., fire prevention and firefighting, are approximately three billion dollars annually (Service, 2011), and home loss is still an inevitable result. In this dissertation, I ask four major questions related to wildfires and homes: 1) what are the key variables among vegetation measures, terrain and spatial arrangement of houses and their location that explain why houses burn in wildfires? 2) does the role of vegetation, terrain, location and the spatial arrangement of homes regarding the probability that individual homes will burn in a wildfire differ among ecoregion across the conterminous United States? 3) what is the spatial distribution of the vulnerability of homes to burning when wildfires occur, across the United States? and, 4) what are the rebuilding patterns after wildfires?

People want to live “closer to nature”. With increasing and broad access to better communication and transportation technology, what was once wild and isolated is now easily accessible (Theobald, 2005). In particular, forestlands are very attractive as residential building sites because they provide positive externalities like scenic views, wildlife and bird watching opportunities, shade, screening from neighbors and easy access to forest-based recreation opportunities (Tyrvainen and Hannu, 1998). Consequently, in many parts of the US there is increasing pressure from residential housing development on both public and private forested lands (Radeloff et al. 2010, Hammer et al. 2009). These areas, where houses meet or intermingle with undeveloped wildland vegetation, are called the wildland-urban interface (WUI) (Radeloff et al. 2005).

The WUI is a pivotal area for a number of human-environment conflicts, including the destruction of homes by wildfires (Radeloff et al. 2005, Gonzalez-Abraham et al. 2007). Fire policies have explicitly considered the WUI since at least 1960 (USDI and USDA 1995), as firefighting resources in the WUI are typically focused on defending homes rather than containing fires (Hammer et al. 2007). Six of the 10 fires with the largest losses of lives and homes of the 20th century occurred in the WUI, and all of them occurred within the last 20 years (NFPA 2007). Such fires have huge economic consequences and high public costs, as federal resources for suppression and wildland fuel treatments are allocated preferentially in WUI areas (Mell et al. 2010). The annual costs are enormous, and growing, increasing from US$1.3 billion annually from 1996 to 2000, to US$3.1 billion annually from 2001 to 2005 (GAO 2007). The increase in fire related costs raises the question how to curtail these costs and minimize fire risk.

There is a relationship between human settlement patterns and vulnerability to natural disasters. Land use changes and housing growth not only create stresses on natural ecosystems, they also increase society's vulnerability to natural hazard (Liu et al., 2007). Human communities are both a source of, and a victim of, natural hazards (Alig et al., 2008), particularly when it comes to wildfires. Exurban development caused increased vulnerability to wildfire in two ways. First, isolated communities, and especially unincorporated areas, have fewer infrastructures (e.g., roads and water supply systems) and fewer resources for providing protection services (e.g., police and fire protection). Second, wildland fire is a very real threat to homes in the WUI, the same area where housing growth has been most dramatic (Alig et al., 2008). However, people are also contributing to the increase in the probability of fire occurrence because they are themselves a source of ignitions, making this a vicious cycle.

Loss of homes to wildfire in the WUI is partly caused by housing, as people are often a source of ignitions (Bar Massada et al., 2011), and a non-linear function of housing density (Syphard, 2012). Other factors contributing to the likelihood that individual homes will be lost to wildfire include the surrounding vegetation, terrain, location and spatial arrangement of houses (Syphard, 2012). The construction of houses and subdivisions in highly flammable landscapes is another aspect of wildfire house loss, as is the specific house location within the landscape (Syphard et al., 2012). Houses located at higher elevations, or steeper slopes, or with difficult road access, are more susceptible to fire conditions that can ignite a house. While many efforts have focused on reducing vegetation and fuel load in the WUI, it is not clear how much the surrounding vegetation is in fact contributing to house losses to wildfires, nor where in the United States vegetation may play a more determinant role than terrain or the spatial arrangement of homes. Furthermore, the question that remains is how all of these factors interact, and whether there are regional differences in these relationships.

Another aspect of wildfires in the WUI is disaster recovery, with home building as a main issue. For political reasons, local governments are usually quick in announcing financial or other types of aid for those who have lost their homes in natural disasters (Nakazato and Murao, 2007). Because homes are one of the fundamental investments of families, rebuilding them is of paramount importance to the families who live there. Wildfires, however, affect communities in a semi-random way. One house may burn while the house next to it is unaffected. This apparent randomness in fire effects makes rebuilding a case by case situation, in which homeowners find themselves dealing with their insurance companies and local authorities individually. Rebuilding, however, provides an interesting insight on how people react and adapt to wildfire, because they are aware of the fire, but they still make the choice to rebuild. Rebuilding is an often forgotten part of the recovery process, and little is known about rebuilding patterns and rates across the United States.

My objectives for this dissertation are to identify and quantify the factors related to vegetation, terrain and spatial arrangement that contribute to house loss from wildfires, and examine nationwide spatial patterns of vulnerability and rebuilding. In my ***first chapter***, I will identify the factors and create a list of measurable variables that determine why a house burns once a fire reaches it. I will do this through an in-depth analysis of three fires: two in California and one in Colorado. I will measure vegetation metrics based on satellite images and determine which metrics are most significant in explaining the probability of a house burn. In my ***second chapter***, I will build on the results from chapter 1, analyzing all fires that occurred between the years of 2000 and 2009 in the conterminous United

States and determining which factors identified in Chapter 1 are most important to the loss of individual homes from wildfire for each region. In ***chapter three*** I will create a predictive model for each ecoregion to produce vulnerability maps for house loss due to wildfire for the conterminous United States using the knowledge acquired in the preceding chapter. Finally, in ***chapter four*** I will characterize rebuilding patterns after wildfires that occurred between 2000 and 2005.

Chapter 1

Which vegetation, terrain and spatial arrangement factors contribute to housing loss to wildfires? Case studies in California and Colorado.

INTRODUCTION

Wildfires are integral parts of many terrestrial ecosystems, but the frequency, extent, and severity of such wildfires has increased, contributing to growing social, economic, and ecological losses (Syphard et al., 2008). In recent decades, the United States experienced significant housing growth and development within or adjacent to wildland vegetation (Radeloff et al., 2009), and despite increasing expenditures on wildland fire suppression, the average acreage burned nationally has not decreased (NOAA, 2012), and has even increased in the western United States in the last half of the twentieth century (Littell et al., 2009). Wildfire is thus a major concern to Wildland Urban Interface (WUI) communities, where houses adjoin or intermingle with wildland vegetation (Radeloff et al. 2005). In these areas, residential losses associated with wildland fire have been increasing globally (Cohen, 2000; Boschetti et al., 2008; Blanchi et al., 2010).

The problem of housing growth in the WUI is a serious concern and several political measures (e.g., The National Fire Plan and the Healthy Forest Restoration Act) have been taken to provide incentives for fire risk mitigation in the WUI (Radeloff et al., 2005; Stewart et al., 2007, 2009; Hammer, et al., 2009). All over the United States, protection of structures has become the primary activity of wildland fire agencies due to the scattered patterns of suburban and exurban land development that has placed a large number of homes at risk (Pincetl et al., 2008). At the same time, in 2000 the US National Fire Plan (NFP) established a long-term plan promoting fuel reduction with the purpose of reducing the risks of catastrophic wildland fire to communities (http://www.forestsandrangelands.gov/), thus focusing fuel management funds to the WUI (Husari et al., 2006), because vegetation, live or dead, serves as fuel for fires (USDA, 2004). Fuel treatments are intended to remove biomass in order to reduce fire intensity and risk at a broader scale (Agee and Skinner, 2005), and have been the main approach for preventing or minimizing wildfire risk in the WUI (Schoennagel et al., 2009). Fuel management can alter the fire regime (Busenberg, 2004) and lead to undesirable ecological consequences; therefore new alternative management concepts have risen, such as the Home Ignition Zone (HIZ) and the maintenance of defensible space around homes (Cohen, 2000). The HIZ concept is based on experimental findings that structure ignition is unlikely unless flames and firebrand ignitions occur within 40 meters of the structure (Cohen, 2000). Furthermore, the likelihood of structure ignition is affected by its building materials and the characteristics of fuels in its immediate surroundings (Cohen, 2000). This suggests that fire risk can be reduced by homeowner actions such as removal of fuels from the surrounding of the structure, and usage of non-flammable construction materials (Winter et al., 2009).

Fuel treatments are designed to reduce fire intensity and risk, to improve firefighter access, and in some cases, to restore historical fire regimes that naturally thinned stands and reduced the buildup of surface fuels making forests less susceptible to crown fires (Schwilk et al., 2009). Historically, in the US, Native Americans harvested timber for shelter, and used fire to clear areas for hunting, gathering and protecting their communities (USDA, 1995), but land use changed and with it the vegetation composition, creating higher forest density, higher proportion of saplings and sub-canopy trees that favor more shade-tolerant and fire intolerant species, fewer and smaller canopy gaps, and elevated surface fuel loads (Leopold et al., 1963; Kilgore, 1973; Parker, 1984; Covington and Moore, 1994; Skinner, 1995; Cowell, 1998; Taylor, 2000; Hessburg and Agee, 2003; Frost, 2006; Schwilk et al., 2009). However, not all forest types behave in the same way and regardless of their density some will always burn because fire is an integral part of the ecosystem. Therefore, to understand the effects of wildfire on WUI settlements it is important to account for the characteristics of the forests in and around them.

The factors that control fire intensity and duration are topography, weather, and fuels (Pyne et al., 1996). Topography and weather influence the spatial variability of fuels, as well as the biophysical conditions that may affect fire intensity and duration (Dillon et al., 2011a). Topography, in particular, influences vegetation distribution and productivity (Barbour et al., 1999) because it affects energy and water balances that control vegetation development and therefore, the accumulation of biomass that fuels fire when sufficiently dry (Dillon et al., 2011a). The type of fuel and the spatial pattern and distribution of vegetation determine the likelihood of fire ignition, its spread rate, fire intensity, and ultimately, the type of vegetation that will regenerate after the fire (Marlon et al., 2012). However, under extreme weather conditions (e.g., Santa Anna winds in southern California), fires are impossible to suppress until there is either no more fuel or weather conditions change. Under these circumstances, fire risk to houses and people is highest, but the role of the surrounding vegetation relative to other factors in affecting the probability of home ignition is unclear.

The root of the problem, however, may be that past land-use decision-making has allowed homes to be constructed in highly flammable areas (Pincetl et al., 2008). Despite the fact that it is not possible, nor feasible, to alter current housing patterns, it may be possible to reduce future fire risk by preventing future construction in high-risk areas. This requires the identification of the most hazardous locations across the landscape (Syphard et al., 2012). Identification of high fire risk areas is therefore important to aid decision making and urban planning and regulation, which can be powerful tools to reduce future fire risk (Schwab and Meck, 2005). The likelihood of property loss to wildfire is influenced by the spatial arrangement of houses, and it is higher for smaller, isolated housing clusters with intermediate housing density and fewer roads (Syphard et al., 2012). The location of houses in relation to other houses and its location on the landscape are also important factors in the likelihood of house loss (Syphard et al., 2012). These results are an interesting starting point for further analysis of the role of spatial arrangement, and therefore, of urban planning in fire risk reduction. Land-use planning and regulation need to be based on solid knowledge about the factors that contribute most to wildfire, and consequently where homes should be located and arranged to reduce fire risk (Syphard et al., 2012).

My main hypothesis is in addition to vegetation, spatial arrangement of houses and topography play a significant role in explaining housing loss to wildfire, and therefore land use planning can be used to reduce fire risk. My general goal is to identify the factors that determine why some houses burn and other do not when a wildfire reaches a community. My specific objectives are to:

- Understand the effects of the surrounding vegetation, topography, and spatial pattern of houses on the probability of structure ignition in a wildfire;
- Compare and rank different metrics of spatial pattern of vegetation as explanatory variables of structure ignition.

METHODS

Study area

I will analyze the three fires that occurred in Santa Monica Mountains National Recreation Area in Ventura and Los Angeles counties, CA in 2003 and 2007; and the Four Mile fire in Boulder, CO that occurred in 2010. If possible, and if there is enough imagery available, I will also analyze the two major fire events in Colorado from the summer of 2012: Waldo fire and/or the Colorado Springs fire, which together destroyed nearly 600 houses.

California is a Mediterranean-climate region where major metropolitan areas are juxtaposed with highly flammable ecosystems (Syphard et al., 2009). The WUI problem is particularly critical in southern California, where the highest losses of property and life from wildfires in the US occur, with ca. 500 homes lost every year (Calfire 2000). Santa Monica is a particularly fire prone area, under a Mediterranean climate, but also under the influence of the Ocean and strong winds. The three fires to be analyzed in this study burned close to 300 houses (Fig. 1).

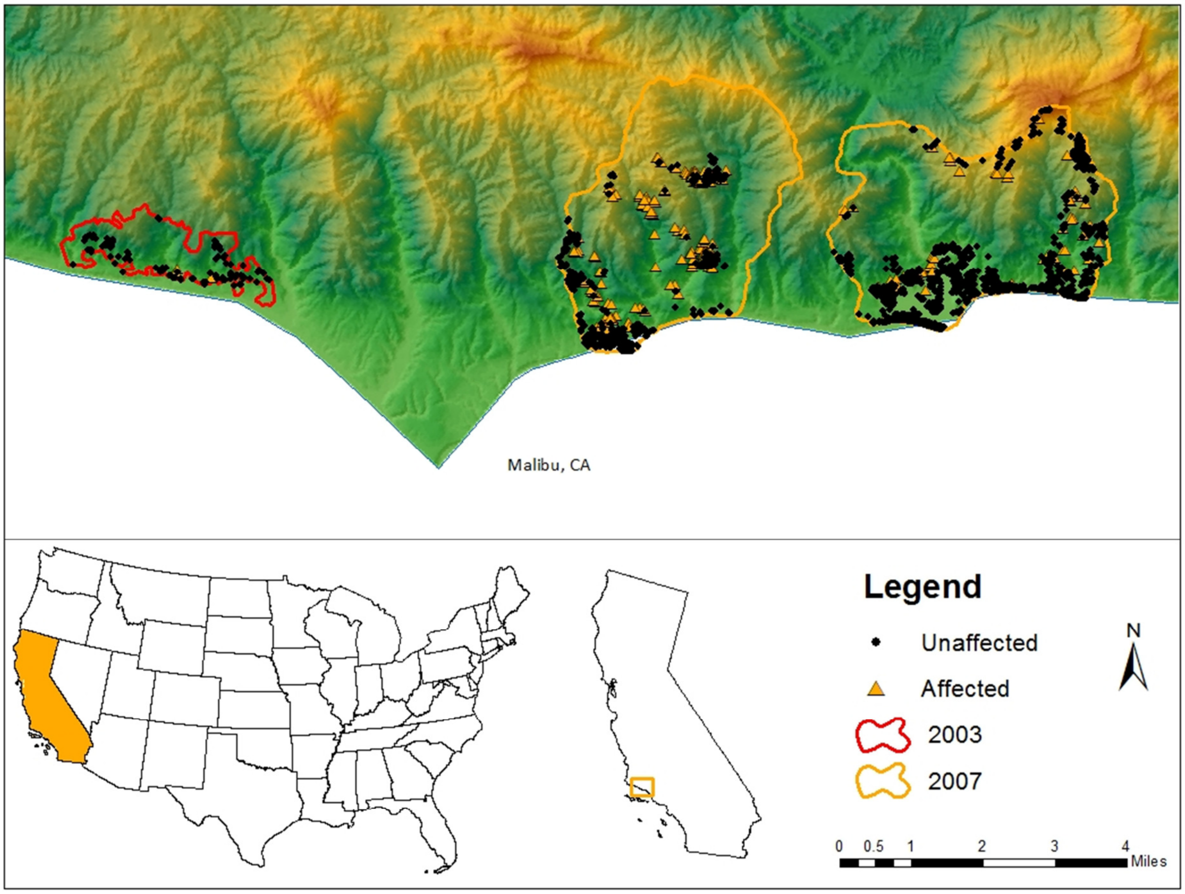

Fig. 1 – Fire perimeters in Santa Monica, California.

Similarly, since 2006, Colorado has been facing a significant amount of house losses to wildfires, with approximately 557 structures lost between 2006 and 2011 (http://dfs.state.co.us/NFIRS.htm). Fire regimes in Colorado are influenced by broad-scale climate patterns of the Pacific Ocean, both El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), that in certain years cause severe drought conditions providing conditions for large fires to occur regardless of the number of ignitions or fuel quantities (Sibold and Veblen, 2006). Boulder, CO, is where the Rocky Mountains meet the Great Plains. The climate is dry and the topography is a major driver of the landscape where those communities lie. The Four Mile fire in 2010 destroyed a record-high of 135 houses (Fig. 2), which was later surpassed by the Waldo fire which destroyed 248 houses and the Colorado Springs fire that destroyed 346 houses, both in 2012. These two fires together destroyed more structures than the total of the period between 2006 and 2010, with a total of 594 structures, all of which were in the WUI. I will use these last two fires in my analysis if the imagery on Google Earth is available.

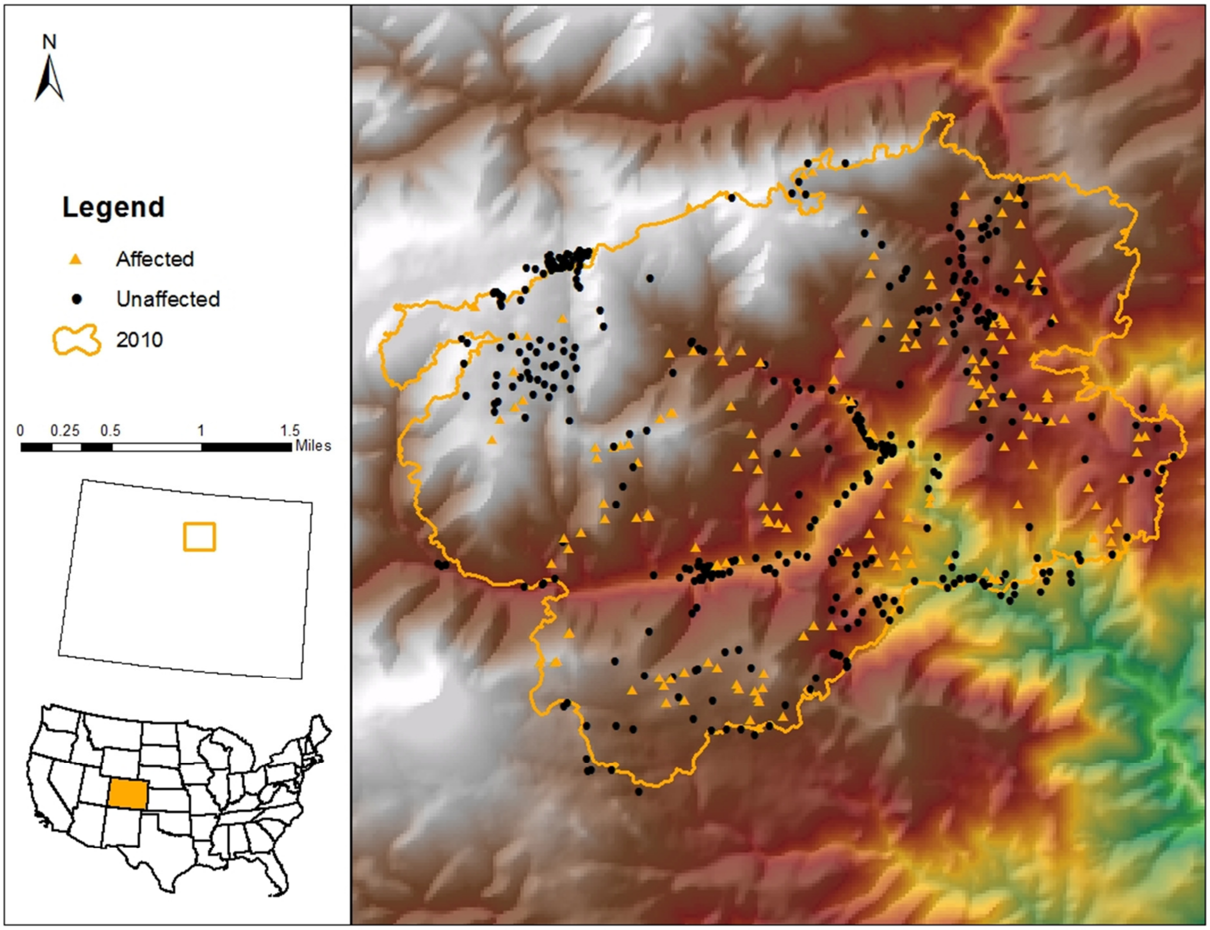

Fig. 2 – Four Mile Fire perimeter and affected houses in Boulder, Colorado.

Housing data

I will use Google Earth's imagery to collect spatially explicit data on housing loss due to wildfires in the two study areas (for an example, see Fig. 3). For the Santa Monica area, the data will be digitized from the most recent imagery available in Google Earth, together with government reports on housing loss, and visual interpretation of aerial imagery before and after wildfires. In Santa Monica Mountains, the total number of structures within the three fire perimeters was 1889, of which approximately 300 were affected (structures that burned to the ground and that are visible from satellite images) by three wildfires, one in 2003 and two in 2007. All the houses inside the Four Mile fire in Boulder were digitized by Boulder County and are available online. Both Residential and accessory buildings were affected by the fire, of which 169 residential houses, and 157 accessory buildings, were destroyed by the fire. However, I will also collect the data myself, using Google Earth imagery and compare my results to the data obtained by the county. This will provide a measure of the error associated with data collection using Google Earth.

Fig. 3 – Example of Google Earth imagery before and after the Four Mile Fire in Colorado in 2010.

Vegetation Data

I will reclassify the National Land Cover Dataset (NLCD2006 - Fry et al. 2011) into flammability classes to be defined. Once reclassified, I will use sub-sets of the map using a radius of 2.5 km from each house. The 2.5 km distance is based on the distance that an ember or fire brand can fly during a fire event (Cohen 2000). Each resulting sub-set will be analyzed using FRAGSTATS 3.3 (McGarigal, Marks 1995) in order to produce class and landscape metrics. Using Landscape metrics provides a measure of how the landscape surrounding a house is connected, which is important from the fire spread point of view. In addition, knowing the fuel type provides information on how intense and how fast a fire can be. Given that my time frame is between 2003 and 2010, I will use as a proxy of the vegetation around the houses, the vegetation type and fuel models data from LANDFIRE version 1.0.5 (http://www.landfire.gov) because it represents vegetation conditions around the year 2001, i.e., before all the fires occurred.

I will also test the visual measurement and identification of the vegetation around the houses previous to the fire occurrence using Google Earth. I will measure the distance between the house and the nearest vegetation patch, which can be shrubs, trees or grasslands and quantify them in terms of number and/or area if it is not possible to count them individually. To do so, it will be necessary to digitize these vegetation patches so that later I can measure both the area of the patch and its distance to the house, but also the percentage of vegetation cover within 40 m from the house. The 40 m value is based on Home Ignition Zone experiments that concluded that a house is not likely to ignite if the heat source is farther than 40 m away (Cohen, 2000).

Topographic/biophysical data

I will also account for biophysical variables, including elevation, slope, aspect, topographic position, and southwestness (Syphard et al., 2007). Biophysical variables can be determinant of fire behavior because micro weather conditions are influenced by elevation and aspect (moisture gradients), while fire spread can be influenced by topographic features like narrow valleys or steep slopes. Topography also affects vegetation distribution and productivity (Barbour et al., 1999) because it affects energy and water balances (Dillon et al., 2011b), and therefore precipitation, runoff, temperature, wind and solar radiation (Daly et al., 1994). For these reasons, topography might help explaining why a certain house burned and another did not, and I will use them as co-variables in the models.

Slope, aspect, elevation and southwestness are part of the LANDFIRE dataset. LANDFIRE has a 30 m resolution and covers the whole United States. Topographic position is calculated based on a Digital Elevation Model (DEM) using an algorithm that utilizes the flatness and lowness. Flatness is measured by the inverse of slope, and lowness is measured by ranking elevation (Gallant and Dowling, 2003).

Spatial arrangement data

Information related to the spatial arrangement of houses will be created using a Geographic Information System. In order to quantify and discriminate the spatial pattern of houses, I will analyze spatial relationships among individual houses and the arrangement of houses within housing clusters. Clusters are defined by groups of houses with a maximum distance of 100 m from any other house. For each cluster I will calculate the area, total number of houses, and density of houses. I will also calculate the distance from each individual house to the edge of the cluster (the assumption is that houses in the interior of the cluster are less susceptible to wildfire than the one at the edge, - Syphard et al. 2012), and the distance to the nearest neighbor.

Other variables of interest and that will be calculated are: road density, total road length within a cluster, and distance to the nearest vegetation patch (Table 1).

Table 1 – Potential explanatory variables to be used in the statistical model

Category	Variable	Source
Vegetation / Fuel	% cover of trees and shrubs within 40 m	Create a 40 m buffer around each house and do a zonal statistic using the Landfire EVC(existing vegetation cover - percent of canopy cover be tree, shrub, or herbaceous) variable.
	Veg type	Landfire EVT (existing vegetation type)
	Distance to the nearest tree or shrub	Visual assessment on google Earth or using landcover data, or the evt landfire data, on ArcMap and calculate distances using the Near tool.
	Vegetation growth Average and peak (the atlas.gov website has this but only till 2005 and I really don't know what kind of information this is)	Atlas.gov
Spatial arragement	Structure density	Calculated on a GIS environment
	Buildings within 40 m radius	Calculated on a GIS environment
	Neighborhood size	Calculated on a GIS environment
	Structure dispersion	Calculated on a GIS environment
	Close to edge of neighborhood	Calculated on a GIS environment
	Distance to nearest Structure	Calculated on a GIS environment
	Distance to nearest neighborhood	Calculated on a GIS environment
Fire history	Time since fire	Calculated on a GIS environment
	Forest burnt within 5 years	Use the MTBS data set that starts in 1984 and build a fire history field in arcmap
Biophysical	Elevation	Landfire DEM
	Slope	Landfire SLP
	Topographic position (Gibbons, 2012)	Use FLAG model in arcmap
	Aspect	Landfire ASP
	Southwestness (cosin aspect southwestness, Syphard et al, 2007)	Create a new field and calculate the sin(ASP) in arcmap
	Forest Fire Danger Index FFDI 2*exp(0.45+0.987ln(DF) 0.0345RH+0.338T+0.0234V), DF = drought factor; RH = relative humidity (%); T air temp (C); V = wind speed (km/h)	PRIMS - Using the values for the weather conditions on the day of the fire
People	Length of roads	Tiger
	Census data, 1980, 1990, 2000, 2010?	
	Income and employment	atlas.gov
	Amount of private land (Gibbons, 2012)	

Statistical analysis

I will use a set of statistical procedures in order to select which variables to use in the model. The first step will be to conduct an exploratory analysis of the data by plotting the data and creating summaries using the statistical software R (R Development Core Team. 2012). My response variable is binary (affected or unaffected by fire) and I want to test hypothesis about my binary response variable and categorical and/or continuous explanatory variables. Therefore, the best suited model is a logistic regression. The logistic regression model predicts the probability of a house being affected, given the collection of explanatory variables. Since probability is not likely to be a linear function of the explanatory variables (probabilities must be between zero and one), a logistic regression instead uses the *logit* of the probability, which is the logarithm of the odds of being affected, and models this as a linear function of the explanatory variables (Hosmer and Lemeshow, 2000).

I will fit single-variable logistic models of affected/unaffected versus each of my predictor variables, resulting in as many single logistic regression models as variables. The next step will be to determine correlations among variables and look for collinearity. I will use a threshold of 0.8 for correlation values ($|r|>0.8$). For variable pairs that have correlation values higher than 0.8, the variable with lower model fit (obtained in the single-variable models) will be omitted from the analysis.

Once the final list of variables is set, the explanatory power of the remaining variables will be evaluated using best-subsets regression (Miller, 1990). Best-subsets regression exhaustively computes all possible combinations of predictor variables and the "best models" will be selected based on specific selection criteria such as Akaike's Information Criterion (AIC). Best-subsets regression provides a good idea of variable importance, especially when there is a large pool of explanatory variables. Best-subsets creates a rank of the individual variables according to the number of times the variable appears in the top 25 models. However, depending on the analysis parameters that are used (number of top models, and number of variables per model), the outcomes can differ. I will use the 12 variables that occur more frequently on the top 25 models given by the best-subset analysis.

OUTLINE OF THE RESULTS

- Development of a methodology for data collection regarding housing loss;

- Development of several ways to measure vegetation around individual houses, and evaluation of which method is more expedient for larger datasets without losing its biological meaning;
- Development of different variables that represent spatial arrangement, and development of houses and respective measurement methodology;
- Generation of a set of variables that are representative of vegetation, spatial arrangement and topography that are straightforward to measure and/or are easy to obtain, that can be used to predict the risk of home destruction by a wildfire.

Conclusions and importance

Wildfires will continue to occur in vegetated areas while urban development will keep sprawling into these same areas. Housing loss in the WUI is a reality, and it is important to understand not only which factors contribute to it, but also which of those factors can be managed in order to reduce the vulnerability of houses in WUI areas.

Using two different regions in the US and fires from different years will allow me to understand the common factors that contribute to house loss to wildfires. By providing a better understanding of what factors are contributing to house loss, I will deliver a set of variables that can be used in future assessments in different regions, and offer opportunities for improved management in the WUI. From the management point of view, understanding that certain vegetation types are more prone to conduct fire to houses or that certain spatial arrangements of development are more susceptible to house loss is of major importance for future development policy and planning.

Once the methodology for data collection is set, it will be easy to reproduce the analysis in other places of the world, since the main data is free and widely available (Google Earth). The use of open source imagery coupled with a historical database is a new approach to data collection on large areas affected by wildfires.

Chapter 2

Contributing factors to house loss due to wildfires in different ecoregions in the conterminous United States

INTRODUCTION

Wildfire has become a growing concern to Wildland Urban Interface (Fig. 4) communities (WUI - the area where houses meet or intermingle with undeveloped wildland vegetation - Radeloff et al., 2005), where millions of dollars in homes and other structures are at risk from wildfire. Approximately three billion dollars are spent every year in fire prevention (i.e. fuel management), and suppression (Colburn, 2008; Service, 2011), making wildfire in the WUI a National problem. National Fire policy in the United States has its origins after several years of severe fires between 1910 and 1935 (e.g. the Great Fire in 1910 in Idaho, Montana, and Washington, or the Porcupine Fire, in 1911 Ontario - Egan, 2009). Due to the catastrophic consequences of those fires, fire suppression and the "10 AM Policy", which mandated that all fires had to be contain by 10 am of the following day, ruled until 1964 when the Wilderness Act, Tall Timbers Research Conferences, and Southern Forest Fire Lab research demonstrated the positive benefits of natural and prescribed fires. In 1968 the National Park Service changed its policy to recognize the natural role of fire. These policies have since evolved to today's policy: a pluralistic approach where the benefits of fire are recognized, but where the inherent risks and liabilities are addressed as well (Calkin et al., 2011). Within this pluralistic framework, there is the recognition that policies need to be flexible to different environment and ecosystems. It is with this understanding that different regions have different regimes and characteristics that I intend to obtain a better understanding of what factors contribute to house loss due to wildfires in the WUI for each of the 48 contiguous states.

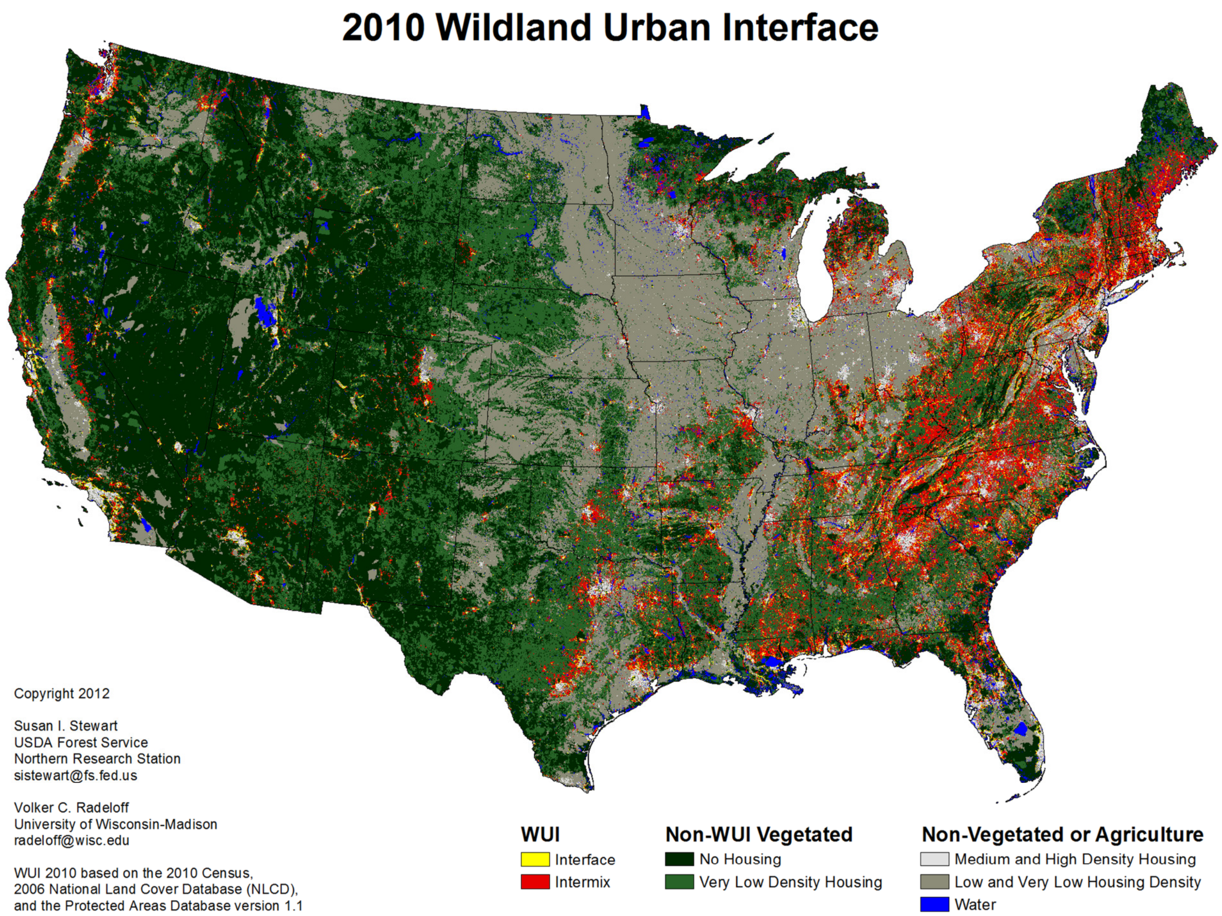

Fig. 4 – 2010 WUI map

In recent decades, the United States experienced significant housing growth into wildland areas (Radeloff et al., 2005; Theobald and Romme, 2007). Despite increasing expenditures on wildland fire suppression, the average acreage burned nationally has not decreased (Westerling et al., 2006; USDA, 2011a), which has lead to an increased concern of the risk to houses and communities in the WUI (Noss et al., 2012). As a political response, in 2000 the US National Fire Plan (NFP) established “a long-term hazardous fuels reduction program to reduce the risks of catastrophic wildland fire to communities” (http://www.forestsandrangelands.gov/), thus focusing fuel management funds on the WUI (Husari et al., 2006). Consequently, throughout the United States protection of structures has become the primary activity of wildland fire agencies due to the scattered patterns of suburban and exurban land development that place an exceptionally large number of homes at risk (Pincetl et al., 2008).

Landscapes have different characteristics that are related to geology, topography, and weather, which result in different vegetation covers with different fire types and regimes. Therefore, both government and private land managers use ecological land classification (Bailey's Ecoregions, Fig. 5) to "estimate ecosystem productivity, to determine probable responses to land management practices, and to address environmental issues over large areas, such as air pollution, forest disease, or threats to biodiversity" (http://nationalatlas.gov/mld/ecoregp.html).

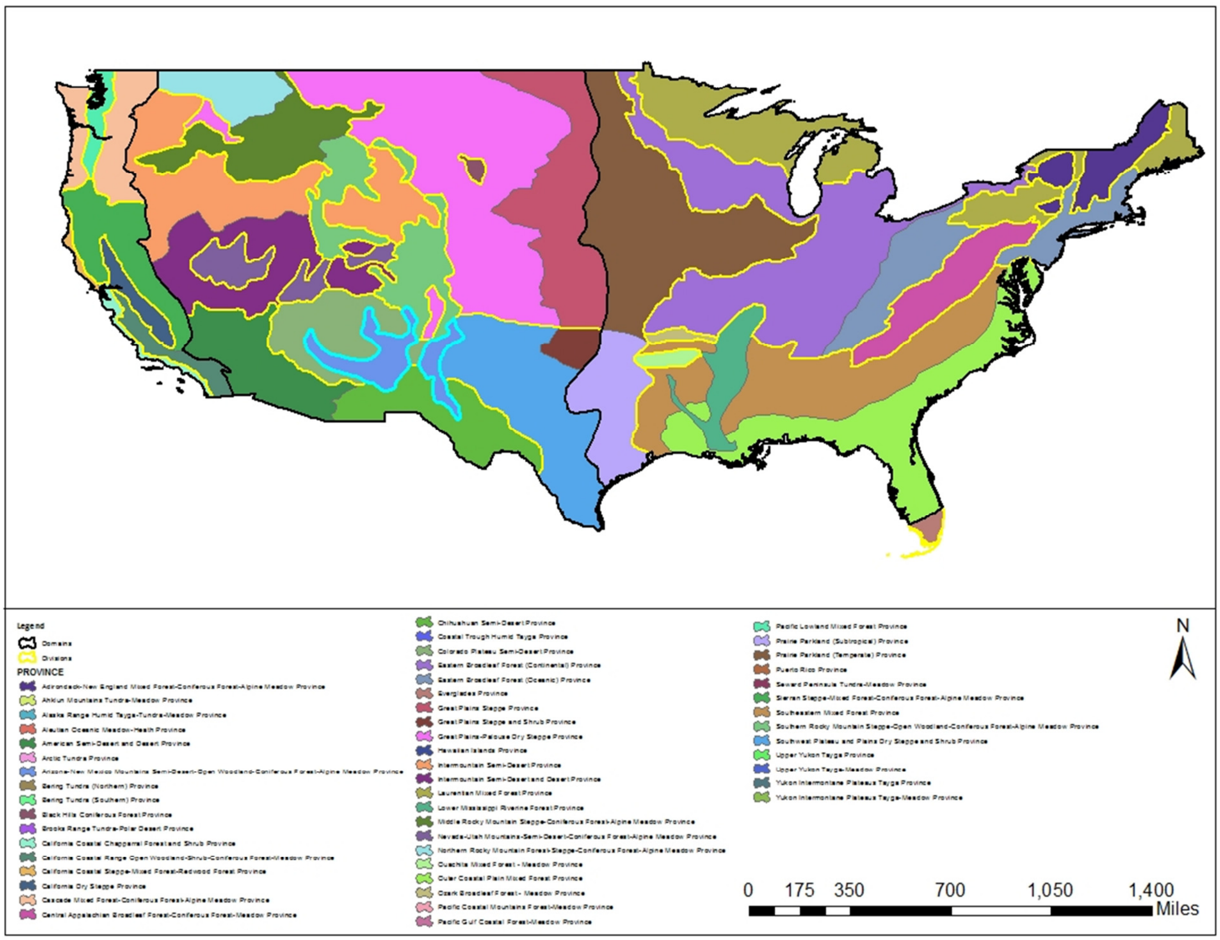

Fig. 5 – Province level for Bailey's Ecoregions classification

Simultaneously, there are different housing and development patterns, zoning regulations, and percentages of public versus private land. All of these factors contribute to the wildfire problem in the WUI. There are studies related to housing patterns in California (Syphard et al., 2012) and in Australia (Gibbons et al., 2012). My first chapter will also extend this approach to Colorado. However, there has been no study that combines vegetation, terrain, and housing patterns together across the Nation. Based on the set of variables generated from the previous chapter, I expect to find different variables important for housing loss in different ecoregions. For example, southwestness and vegetation type might be highly important to explain house loss in one region, but housing density and slope might be more important in another. In certain regions urban planning may have more influence on the outcome of fire event as this has a direct impact on decisions where to conduct fuel treatments or where to emphasize homeowner awareness to the Home Ignition Zone.

Wildfire events are related to climate, topography and vegetation (fuel). Among these factors, only fuel can be changed by management through fuel treatments (Husari et al., 2006). Therefore, fuel manipulation is seen as the most common and effective way to influence future wildland fires (Husari et al., 2006). However, fire frequency and intensity vary spatially with fire occurring more often in some areas than others. In addition, temporal scale can be important as many forest types historically burn infrequently but with high intensity (Agee, 1993), while others have long dry seasons and easily combusted forest floors, thus burning more frequently. It is therefore dangerous to make a general policy on fire for the entire nation (Schwilk et al., 2009) or to assume that fuel treatments alone are sufficient when empirical data are lacking on how effective fuel treatments are for protecting houses from wildfire and how other factors such as spatial arrangement, vegetation, and terrain are contributing to house loss to wildland fire. In addition, uncontroled, unplanned housing growth occurs with little regard as to whether a certain region is fire prone or not. For example, the northern hardwoods have a high moisture content and “high” productivity with fire interval return much higher than 35 years, while California has “dry” conditions with highly variable flammable vegetation that it is adapted to fire and where fire return intervals are less than 35 years. These two landscapes do not have the same drivers when it comes to fire, consequently they have different fire behavior. They also have different housing patterns, regulations and topography. There is a need to understand the differences among ecoregions, i.e., which factors are most important for each region when it comes to the probability of a house be lost to a wildfire.

I propose to use the results and acquired experience from my previous chapter and amplify the study to all fires that occurred within the 48 contiguous states between the years 2000 and 2010, where houses were both lost and survived to wildland fires, in order to help improve the understanding of what factors are contributing to house loss throughout the United States. My goal is to depict differences among ecoregions and provide a better understanding of what factors of vegetation, spatial arrangement, and other biophysical variables are influential to house loss to wildfire within each region.

METHODS

Wildfires are a difficult phenomenon to study because they are not replicable. As houses are usually clustered (i.e. they are not independent from one another), replication across landscape is difficult, if not impossible. In addition, adequate pre- and post-fire data are not always available or are easily extractable. To overcome the problem of replication across landscapes I will use fire perimeter information from the last decade (2000-2009), across the contiguous States.

Data

I will identify burned houses/structures across the United States using the Monitoring Trends in Burn Severity (MTBS - F. S. USDA 2011b) dataset, which consists of fire perimeters. The MTBS is my base reference of locations for potential structure loss. The analysis focuses in fires that occurred between the year 2000 and 2009 (possibly 2010 if it will become available on the MTBS website) within the 48 contiguous states (Fig. 6). I have intersected these fire perimeters with the US Census (U.S. Census Bureau, 2011) block level data containing 1990 and 2000 housing units counts to obtain an estimate of the house density within each fire perimeter in order to exclude fires with no houses. Preliminary analysis showed that there are approximately 4,900 fire perimeters for all the 48 contiguous States between the years of 2000 and 2009. At this point, between 2001 and 2006 there are 767 fire perimeters with houses affected by fire, out of a total of 2,456 fire perimeters.

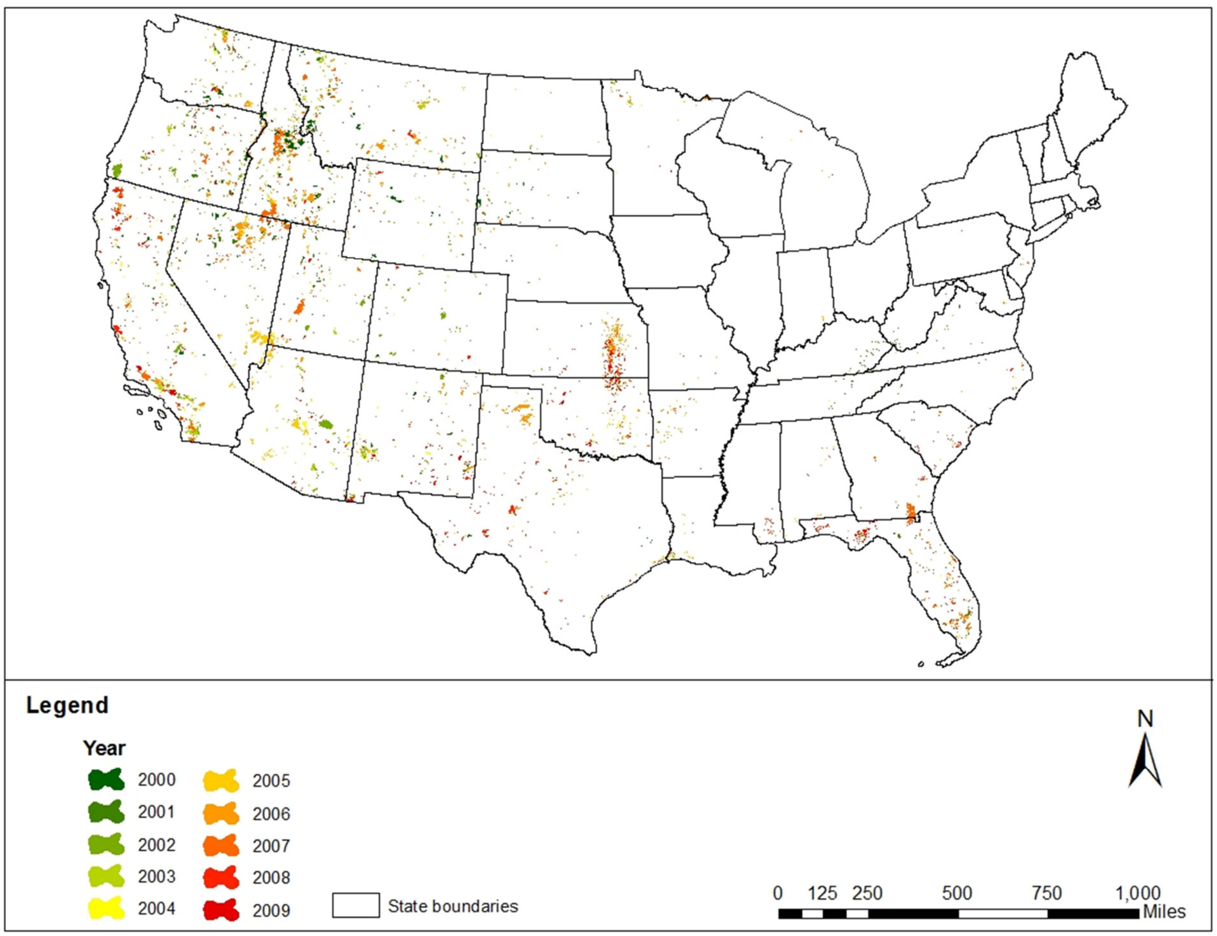

Fig. 6 – Fire perimeters between 2000 and 2009 (Source: MTBS)

I will use Bailey's Ecoregions (http://www.fs.fed.us/land/ecosysmgmt/index.html) as my units of analysis and create a logistic regression for each Ecoregion. Ecoregions are defined by common climatic and vegetation characteristics (Bailey, 2004) with daily and seasonal fluxes of energy and moisture as the most important climatic factor in defining the climatic regime. Bailey's Ecoregions classification has 4 Domains, 19 Divisions, and 35 Provinces in the conterminous United States alone, which show a variety of vegetation, climate and consequently, fire regimes. Once I have finished my data collection, I will use all the 34 provinces if there are a minimum of 10 fires within each province. If the minimum of 10 fires cannot be met, then I will proceed for the next level, the 19 Divisions.

Digitizing

I will digitize every structure within the fire perimeter. I will include all structures that can be digitized on screen, and this represents homes, outbuildings, guest houses, barns, etc., with the assumption that factors explaining impacts to homes are similar to those explaining impacts to other structures. Given the on screen digitizing process, an affected structure means that it burnt to the ground and therefore no longer visible in a satellite image.

The sampled fire perimeters will be imported into Google Earth where I will collect my data. Google Earth has high-resolution satellite imagery beginning in 1991. The quantity and frequency of historical images available varies from place to place. I will visually inspect each fire perimeter to identify houses/structures existing before and after the fire date to determine which structures were affected by the fire. Given that I will be doing a visual assessment from images that can only capture the roof of houses, my definition of "affected house" means that the house was burnt to the ground and the debris are clearly visible in the image. If a house lost a wall or had just smoke damage, but is still standing, it will not be considered affected because this kind of damage is not visible in the images.

The information on Google Earth will be collected as a point feature (shapefile) that will then be analyzed within a Geographic Information System (ArcGIS) and in statistical software package (R).

Statistical analysis

The set of variables used will be determined by the results from the previous chapter. However, given that I am including new and different regions with different characteristics, I will consider the final set of variables from the previous chapter. My expectation is that different variables will have different weight and explanatory power depending on where the fire occurred.

I expect to find differences among ecoregions, so I will specify a separate logistic regression model for each ecoregion. The idea is that among ecoregions the relative significance of the explanatory variables will be different, and the result will be a different group of explanatory variables for each ecoregion. Unlike a simple linear regression, the logistic regression does not have an R^2 to measure the variance explained by the model. Instead, I will use an chi-square test to indicate how well the logistic regression model fits the data, i.e., it is a measure of goodness of fit (Gelman and Hill, 2007). The chi-square measures the deviance between the observed values from the expected values and ideally this value should be as small as possible. As we add more variables to the equation the deviance should get smaller, indicating an improvement in fit (Peng et al., 2002).

Outline of the results

- I will create a data set of structures lost to wildfire across the conterminous States;
- I will create a table containing each of the measured variables and its respective explanatory power for each ecoregion;
- I will provide a model for each ecoregion that will provide the probability of a house burn given that a fire occurs;
- I will create a map with the relative importance of vegetation vs. spatial arrangement for each ecoregion.

Conclusions and Importance

Wildfires in the WUI will not stop, and the WUI will not stop growing. The obvious conflict between fire and people will continue to exist and needs to be addressed as such. However, having a better understanding of what role each of the factors play in this equation is of high importance for future planning and for community adaptation to fire events. On the other hand, the United States is a large country with many different regions and regimes that make management a localized decision. Fire frequency and intensity are matters of scale, with fire occurring more often in some areas than others. For this reason, having a national integrative and comprehensive analysis is of major significance to better understand the magnitude as well as the specifics of this problem.

The results from my work can help improve the efficiency of the prioritization and consequent allocation of resources. For example, the proposed fuel reduction funding for 2012 was $157 million, which was the lowest level since 2000 (Gorte, 2011). Having reduced funds makes it more important to know what factors are important and where, in order to help distribute the money in a more efficient way.

Chapter 3

Fire Vulnerability Map

INTRODUCTION

Large contiguous forested areas in the United States have been influenced by human activities to a large extent. Human development in the form of housing growth contributed to the fragmentation of vegetated areas that are now surrounded by or intermixed with urban development (Lampin-Maillet et al., 2010). The areas where houses intermix or intermingle with natural vegetation (Radeloff et al., 2005) are called the Wildland Urban Interface (WUI), and represent an area of human-environment conflict with particular emphasis on wildfires (Radeloff et al., 2005).

Wildfires have always captured media attention and coverage, in particular when houses and property are lost causing losses of millions of dollars (Stewart et al., 2009). Housing growth in areas that naturally have a high fire risk is a major management, public and political problem (Boxall 2008; Hammer, Stewart & V C Radeloff 2009). In the political arena, incentives for wildland fire risk mitigation are not a novelty in the WUI. Under the fuel management and decision making context, maps are a pragmatic and powerful visual policy tool (Stewart et al., 2009). Mapping the WUI per se it is not a challenge anymore, since some authors have developed mapping techniques (Radeloff et al., 2005; Wilmer and Aplet, 2005; Theobald and Romme, 2007). These maps do provide a good estimates of fire vulnerability at a national scale, which are needed to improve the efficiency of prevention actions (Lampin-Maillet et al., 2010). My goal is therefore to produce a vulnerability map for the conterminous United States showing the likelihood of a house burn given that a wildfire occurs. I do not intend to map the probability that a fire will occur, but rather the vulnerability of a house burn if a fire occurs in that place.

Housing growth is predicted to increase and, consequently, the WUI will increase as well (Nowak and Walton, 2005; Theobald and Romme, 2007; Bar Massada et al., 2009). Simultaneously, housing development alters fire size and distribution around the WUI due to a potential increase in ignitions, although most fires are quickly extinguished and fire sizes remain small (Spyratos et al., 2007). However, every ignition has the potential to become a large fire (Bar Massada et al., 2009), and when it does, the potential loss is high. For these reasons it is important to assess the vulnerability of house loss to wildfire.

Most fire risk and probability assessments focus on biophysical and climate variables (e.g. Bradstock et al. 1998; J.S. Fried et al. 1999; Diaz-Avalos et al. 2001; Rollins et al. 2002; Preisler et al. 2004) consider fire only as a physical phenomenon function of weather, fuels, and topography (Countryman, 1972). Other models are used to predict fire behavior within different fuel types and weather condition inputs (Burgan and Rothermel, 1984; Forestry Canada, 1992); or identify where a fire is more likely to occur by predicting the probability of lightning ignitions (Larjavaara et al., 2005; Wotton and Martell, 2005). All the examples given have a biophysical approach, which is important to understand fire behavior and fire patterns. However, it is equally relevant to understand how houses are affected by fire and how vulnerable they can be in case of fire occurrence, particularly in places where fire regimes have been altered (Pyne, 2001; DellaSala et al., 2004; Haight et al., 2004). Human variables have been considered in some models of fire risk, the majority of which are based on fire ignition points (e.g. Pew & Larsen 2001; Badia-Perpinya & Pallares-Barbera 2006; Dickson et al. 2006; Yang et al. 2007), or fire occurrence data (any location that burned regardless of point of origin) (e.g. Y.-H. Chou 1992; Y. H. Chou et al. 1993), but no model has actually used a combination of vegetation, terrain, and burned houses data to predict fire vulnerability of houses given that a fire occurs. Syphard et al. (2008), used a combination of biophysical and human explanatory variables to produce spatially explicit statistical models and maps predicting patterns of fire ignitions and fire frequency in a human-dominated southern California landscape and proved that fire ignition patterns were strongly influenced by variables related to human activities (roads, trails, and housing development), as well as fire history. Later, the same author showed that spatial arrangement also plays a role in housing loss due to wildfires (Syphard et al., 2012), at least for California conditions. The results from the previous chapters will allow me to now use the most important variables for each region in a predictive model and build a national vulnerability map.

Models are useful tools in several fields of science and they can be either explanatory or predictive. Explanatory models test hypotheses that specify how and why certain empirical phenomena occur, while predictive models are aimed at predicting the future or new observations with high accuracy (Shmueli, 2010). In other words, the primary goal of explanatory models is to depict relationships between an observed pattern and its causal factors, while in prediction the relationships are not as important as the accuracy of the prediction given a set of predictors (Elith and Leathwick, 2009). When using explanatory models, the statistical techniques (e.g. linear regression) are somewhat intuitive and easier to understand the relationship between the response phenomenon and the explanatory variable. The assumptions that are required are also stronger (e.g. normality, and independence of data). When prediction is the main objective, other techniques, such as machine learning, neural networks, maximum entropy, generalized linear models (GLM), or support vector regression, can produce very good predictions and are less demanding when it comes to data requirements (e.g. no requirement of normality - Culbert, 2012). Explanatory models are used nearly exclusively for testing causal hypotheses (Shmueli, 2010), and seek to provide insight into ecological processes that produce patters (Guisan et al., 2002). In sum, a predictive model is any method that produces predictions, regardless of its underlying approach: Bayesian or frequentist, parametric or nonparametric, data mining algorithm or statistical model (Shmueli, 2010).

In the previous chapters the intention was to find the factors that contribute to explain why houses burn. In this chapter the goal is to use that information and build predictive models that will provide maps of areas where the probability of loss to fire is higher due to higher vulnerability.

METHODS

To map the potential vulnerability of homes being lost to wildfires, I will integrate the results obtained in the previous chapters into a predictive model that will generate a probability of house burn given that a fire occurs. I distinguish between vulnerability and risk, where I define vulnerability as the ability of, or susceptible to, being wounded or hurt, and risk as the exposure to the chance of injury or loss, or the degree of probability of such loss. The maps I will create will be a measure of the ability to be "hurt" by a hazard, in this specific case, wildfire. It is important to make this distinction here because of the different implications these two definitions have on the type of data they demand. A risk map would require information on variables that are related to the process of fire itself, which include ignitions, fire behavior and how a fire spreads in the terrain. This is not what I want to do in this chapter. I want to assume that a wildfire will occur at some point in time and predict how vulnerable houses are to that particular hazard. The variables I will use will be determined on my previous chapters. My approach will be to use the concept of species distribution models (SDMs) to identify the probability of a burnt house to occur.

In my particular case, the idea is to treat housing as a species where each burnt house location is an occurrence (or presence), and each unburned house is considered absence. I can say my data is true presence-absence data, with a sample bias because data collection only happens within fire perimeters. Given that I have presence-absence data, I will use Generalized Linear Models (GLMs), which are a particular class of statistical methods have the ability to include nonlinear terms, and therefore, nonlinear relationships (McCarthy and Elith, 2002). This method is rigorous and robust in predicting the occurrence of species and explicit in its ecological rationality (Austin, 2002). GLMs are widely used, in particular logistic regression, because they are a generalization of the multiple regression model that uses a link function in order to allow response variables that do not have a normal distribution (Franklin, 2009). The result is an equation that predicts the abundance or occurrence of a species based on the site attributes (McCarthy and Elith, 2002). One of the advantages in this method is that the uncertainty in the predictions can be tested and assessed using confidence intervals (Guisan and Zimmermann, 2000). My data involves multiple predictors, which I expect to have non-linear relationships with my response binary variable. Therefore, the use of a GLM with a logistic regression is appropriate for my type of data.

Prediction models have error associated with deficiencies in the modeling data and with decisions that are made within the modeling process. These errors affect the output overall, but with different spatial distribution due to the spatial nature of the data itself. For this reason, visualizations of uncertainty should be part of the suite of maps relevant to the problem (Elith et al., 2002). Levels of uncertainty can be quantified with prediction intervals and mapped (Rocchini et al., 2011). I will create uncertainty maps and I will also assess the usefulness, or the predictive performance, of my models.

I will predict house vulnerability in all places in the conterminous United States that are within the range of variability of my explanatory variables. I believe that maps are important management tools and for that reason the resolution needs to be fine enough for management purposes. Ideally, very high resolution is desired because it provides detail. However, too high resolution may result in high computational effort, and therefore processing time. Another aspect to consider is the resolution of the explanatory variables. Landcover, for example has a resolution of 30 meters, as well as all the LANDFIRE data. At this point it is not possible to know which variables will be part of the final models, but I expect to produce predictive maps with spatial resolution between 30 m and 250 m.

OUTLINE OF THE RESULTS

- Production of predictive vulnerability maps for the conterminous United States;
- Production of uncertainty maps for the conterminous United States.

CONCLUSIONS AND IMPORTANCE

The creation of maps facilitates the decision process by providing managers, land planners and even to the public in general with information about burning vulnerability. Fire risk maps are used in the decision process in California, where they are available online to the public via the California Department of Forestry and Fire protection (http://www.fire.ca.gov). However, Syphard (2012), showed that these maps are not good predictors of where people and their houses are at risk, and therefore, they need to be improved. At a National scale, what is readily available is current fires and smoke maps, such as the NOAA Satellite and Information Service (http://www.osdpd.noaa.gov), the NASA active fire data (http://earthdata.nasa.gov), or the current fuels and fire behavior advisory map made by the National Interagency Coordination Center (http://www.predictiveservices.nifc.gov). These maps are useful for disaster management and short-term prevention in situations where the hazard is already ongoing and people surrounding the affected area can use the information to make decisions about whether or not to stay.

The few existing fire risk maps can only be useful if they properly identify areas where property loss is most likely to occur. In order to evaluate the effectiveness of such maps they must be analyzed against empirical data. My work and my data collection allow for such comparison, and allow the creation of a national map where home vulnerability is explicit, along with a map of uncertainty. This map will be of major significance for local government agencies that need to plan ahead of time and allocate resources before the hazard occurs. The results and outputs of this chapter have significant applicability to managers, government agencies that deal with fire prevention, and to the public in general. Having access to a map of vulnerability might inform the decision of where to buy a new home or a second home.

Chapter 4

Housing Development and rebuilding after wildfire

INTRODUCTION

Wildfires affect extensive areas, including the Wildland Urban Interface (WUI), causing social and economic damage that frequently reflects into high fire suppression and prevention costs (Lampin-Maillet et al., 2009). Every year more than 60,000 forest fires affect about 6,000,000 acres in the United States (Historical Wildland Fire Summaries – National Interagency Fire Center - http://www.nifc.gov). The lack of information on rebuilding is particularly unfortunate given that the number of communities exposed to and affected by wildfire, particularly in the Wildland urban interface, increases every year (NIFC, 2011a), with enormous economic consequences. The annual average fire loss (between 1999 and 2011) is 1354 residences, 1199 outbuildings and 45 commercial structures destroyed nationally by wildfires (NIFC, 2011b). However, 2011 had 5246 destroyed structures, including 3459 residences, which is above the annual average from the previous 11 years (NIFC, 2011b). The costs related to fire suppression due to the presence of houses have also increased, with an average annual budget of \$2,0000.00 (USDA, 2011c). These numbers do not include property and personal damage caused by wildfires. Despite the increase in costs, the number of houses lost to wildfires continues to increase (USDA, 2011c). However, despite the frequency and re-occurrence of wildfires, people are still moving into natural areas and building their houses right in the middle of the hazardous natural environment.

For wildfires where housing is lost, similar to other natural disasters, restoring homes is one of the most important aspects of community recovery (Zhang and Peacock, 2009). However, rebuilding in the same place might not be the best strategy in terms of preventing losses in future fires. There is a dichotomy between the desire for a quick recovery of the communities and how the decision of rebuilding in fire prone areas affects future fire events. Rebuilding means that people will still be in a fire prone area and that the probability of fire ignitions is higher (Bar Massada et al., 2011), and thus people are still vulnerable to future fire events.

The recovery after a wildfire presents the perfect opportunity to rethink the community situation and even adopt a firewise strategy. However, some locations will always be at higher risk whenever a fire comes, and if a house has been totally destroyed by a wildfire, this creates a window of opportunity to rethink where houses should be placed. My study will provide insight about peoples' decisions to rebuild and an indirect way of evaluating if people are rethinking after a wildfire event. Rebuilding patterns after wildfires have not been previously studied.

Despite concerns about fire risk after rebuilding, much of the recovery after wildfires and natural disasters focus on rebuilding housing. Housing not only provides shelter, but in most cases is the major investment of homeowners, as well as an important component of local social and economic fabric (Comerio, 1998; Campanella et al., 2004). Past research on natural disasters focused mainly on other hazards, such as floods, hurricanes, earthquakes, and tsunamis, all of which destroy more homes than wildfires, and their study areas are usually at relatively small scales (Morrow, 1999; Lyons et al., 2010; Daly and Brassard, 2011; Fillmore et al., 2011; Fujimi and Tatano, 2012). Studies related to natural hazards such as hurricanes and floods show that most homeowners rebuild their damaged property as fast as possible (Comerio, 1998). The main reasons presented are that a house/home is their biggest investment in addition to being the primary shelter (Zhang and Peacock, 2009). Either because that is what usually happens in other natural hazards such as hurricanes, floods, tsunamis, or because local government publically announces that they will do all they can to help people to go back to their homes as soon as possible. In tsunamis, hurricanes, or even floods, "solutions" that do not differentiate house types and lot sizes tend to fail to take account of individual family needs or cultural differences (Lyons et al., 2010). The most successful housing emerges and consolidates incrementally, in pace with the needs and budgets of people and the aspiration of the community, and when this is denied in the rush of rebuilding, it pushes people back into the insecurity from which they emerged (Turner, 1972). This is particular prevalent when affected populations are poor.

The common aspect among natural disaster recovery studies is the human component of community recovery and the importance of community participation in the rebuilding process. In general, people prefer to move into their own home as quickly as possible instead of public housing, shelters or even renting subsidies (Lyons et al., 2010; Daly and Brassard, 2011; Fillmore et al., 2011; Fujimi and Tatano, 2012). The majority of these examples involve high government participation during the recovery period. In wildfires, government participation is mainly focused on fire fighting and evacuation, while the recovery seems to be largely an individual effort with some sporadic support from local authorities (e.g. The Four Mille fire in Boulders, CO, had a two-year period after the fire where the county assigned one staff member to each household in order to facilitate the rebuilding process – Data from personal interviews). In the United States, individual households are expected to use their own private resources, including homeowner's insurance, to mitigate, prepare for, respond to, and recover from disaster (Morrow, 1999). Despite the example from the Four Mille fire, in Boulder CO, little is known about post-wildfire recovery and the most general attitude is to assume that people will rebuild their homes. In the WUI, whether a wildfire destroys entire communities or dispersed houses in the landscape, communication media provide wide coverage of wildfire but rarely follow up on the recovery process. In practice, little is known if in fact all the homes are rebuilt.

Although homeowners need to be in conformity with the local zoning regulations, the reality is that the planning process in the United States has little intervention from either the federal or state governments, resulting in a highly diverse and heterogeneous system at all levels of governance (Schmidt and Buehler, 2007). In general, zoning is normally exercised by counties or municipalities with a zonin-enabling law from the state (Nelson, 1980). Despite the existence of zoning laws, recognized private interest groups play a role in the decision-making process (Evers et al., 2000). In fact, a legal, institutional and ideological framework encourages individual fee-simple property ownership protected from government intrusion, which limits the ability of local planning efforts (Schmidt and Buehler, 2007). Due to the heterogeneity that exists in the land use planning in the United States, I will summarize the rebuilding patterns per county as well as by state.

In sum, little is known about rebuilding patterns after wildfires, particularly in the WUI and at a national level. I intend to fill the knowledge gap by identifying and mapping rebuilding patterns in the conterminous United States.

My main goal is to describe the rebuilding pattern post a wildfire event in the conterminous United States. My objectives are:

- Identify and quantify the rebuilding rate for each state.
- Identify and quantify new housing development within fire perimeters.

Methods

I will identify burned houses and houses rebuilt across the United States using the data collected in chapter 2, i.e., using the Monitoring Trends in Burn Severity (MTBS - F. S. USDA 2011b) fire perimeters dataset. The MTBS will be my base reference of locations for potential house loss. In order to determine the housing rebuilding patterns after wildfires I will consider fires that occurred between 2000 and 2005 to ensure enough time and available satellite images for rebuilding after the fire occurrence (Fig. 7). I will also summarize the number of housing units within each fire based on 1990 and 2000 US Census (U.S. Census Bureau, 2011) block level data in order to exclude fires with no houses. Preliminary analysis suggests that this will result in approximately 2,300 fire perimeters across the 48 contiguous states between 2000 and 2005.

Fig. 7 – Example of a rebuilt home after a fire in 2003 in Colorado.

Measuring patterns of rebuilding after wildfires burned houses

For all the wildfires, I will use the data digitized on chapter two, which includes: a) each house within the fire perimeter prior to the fire in order to be able to distinguish between rebuilt houses and new houses, b) each house burned by the fire, and c) each house built within five years after the fire; Based on the digitized data, I will calculate the percentage of houses that burned; the percentage of burned houses that were rebuilt in the same location, and the growth rate of new homes within the fire perimeter. These values will then be summarized by county and by state.

OUTLINE OF THE RESULTS

- I will produce a map of rebuilding pattern for all the conterminous United States;
- I will produce a map of housing development after wildfires for all the conterminous United States;
- I will create a summary table with the rebuilding rate and new development rate, for each State.

CONCLUSIONS AND IMPORTANCE

Housing development in wildland areas will continue. The housing market boomed in the 90s and early 2000s due to low interest rates and easy access to credit and then slowed down around 2006 (Weller, 2006). Despite the slowing of housing development, predictions show that housing will grow at a slower rate, but still increase (Bork, 2012). At the same time, given climatic changes, wildfires intensity and burned area in the United States will increase as well (Dale et al., 2001). Climate change means local, regional, and global changes in temperature and precipitation, which can influence the occurrence, timing, frequency, duration, extent, and intensity of forest disturbances (Baker, 1995; Turner, 1998). Climate change impacts are expressed in forests, in part through alterations in disturbance regimes (Franklin, 1992; Dale et al., 2000). Multiple climate change scenarios suggest an increase in fire intensity and a 25%-50% increase in burned area in the United States (Dale et al., 2001).

Given both climate change and housing growth, in particular in certain regions of the world, wildfire in the WUI will continue to be a concern for both homeowners and federal agencies that deal directly or indirectly with wildfire. WUI areas provide an extraordinary opportunity for urban land planners to intervene and build fire wise communities. In the meantime, an understanding of rebuilding rates and locations and whether certain regions or states show higher tendencies for new development post-fire, is of major importance for future planning. Resource allocation, such as fire prevention measures (fuel treatment, prescribed fires, and awareness campaigns to homeowners) can be more effective if we know where and how fast rebuilding is happening.

Wildfire in the WUI is a problem that affects the public in general because, although the responsibility to repair and rebuild is the homeowner's, fire prevention and protection is still a government responsibility. The ultimate goal will be to understand what is behind peoples' decision whether or not to rebuild, but knowing where rebuilding is happening is the first step of the process and this is where my contribution will lie.

SIGNIFICANCE, CONTRIBUTIONS SECTION

Current demographic processes and trends point to an increasing number of people who will migrate and redistribute into wildland areas and continue to impact and profoundly change landscapes and ecosystems across the United States (Hammer, Stewart, and Radeloff, 2009). Housing has become increasingly dispersed, particularly in rural areas where land is more affordable, which leads to low-density development in wildlands (Gude et al., 2008). In the Western states only 14% of the potential WUI has been developed, which means that there is a potential for substantially more housing development (Gude et al., 2008; McDaniel, 2009). Assuming that population and income increase and technological changes are happening all the time, the expectation is that WUI fires will continue to be a serious and costly issue in the US (Radeloff et al. 2010). Given the magnitude and significance of wildfires in the WUI, I believe this is a rich but unexplored, research area with potential for many interesting contributions in several domains, such as scientific, methodological, and management.

The WUI represents a system where humans are interacting with a natural system (forests, shrub lands, or grasslands), causing relationships that are complex and not well understood (Liu et al., 2007). Due to climate change and faster-than-ever environmental and social changes, ecosystems are now facing new anthropogenic stressors, such as pollution, habitat fragmentation, land-use change, invasive plants, animals and pathogens, and altered fire regimes (Millar et al., 2007). The increase in climate variability together with anthropogenic stressors creates novel environmental conditions that are completely new to ecosystems (Millar et al., 2007). Wildfire in the WUI is an example of a novel ecosystem and a coupled human and natural system (CHANS) with emergent properties (of both landscape and people). This particular human-natural system presents reciprocal effects on both human and natural sides of the system, as well as nonlinear relationships (Liu et al., 2007). My research will improve the current understanding of this particular system, as well as quantify and characterize these relationships. Therefore, my **scientific** contribution is a better understanding of how the coupled human-natural system of the WUI is affected by wildfires and how people are adapting to it. My research will provide a proxy for how people react and adapt to natural hazards, which are projected to increase in the future due to climate change (IPCC, 2001). Understanding patterns and rates of housing development, and peoples' behavior and adaptation to fire risk is important to untangle the complex management challenge facing planners, foresters, and managers in WUI communities.

From the **methodological** point of view, the development of new measuring techniques using free satellite imagery (Google Earth) is of major importance for quick data access and data collection. I will provide a list of the most significant variables related to house lost to wildfires, and respective measuring methodology and data access. Future research can thus focus on the important factors, since there will be a better understanding of which factors influence housing loss given a wildfire. I will create new variables that represent spatial arrangement of houses in the landscape, using GIS tools to quantify them. The development of new methodologies provides time efficiency for future studies since these methods are easily reproducible in new regions of the world.

The characterization of post-wildfire rebuilding patterns has not been done before at this scale due to difficulty in accessing data. My methodological approach overcomes this obstacle providing the opportunity to depict patterns and identify for the first time what is in fact happening after wildfires. The location and type of one's home is a directly observable and almost universal human behavior that affects biodiversity conservation directly and it is potentially the most pervasive and direct link between human attitudes and intention (Peterson et al., 2008). The understanding of the why people are rebuilding, or not, after wildfires can only be pursued after the pattern has been clearly identified and characterized. My project provides the first step for a deeper understanding of this phenomenon.

My major contribution, however, is related to **management** and policy making. By providing a relative importance of vegetation, terrain and spatial arrangement for different regions in the United States, my research will allow for better planning and resource allocation. It also allows homeowners to focus on the most relevant factors in their own regions. It provides a customized approach to land management and urban planning. Given the global economy, funding sources are decreasing and therefore it is necessary to have a more efficient way to allocate these funds. For example, if it turns out that vegetation in relation to terrain is not as significant in Mountain areas, then these regions should focus on the aspects that are more relevant and funding for fuel treatments should be channeled to those areas where vegetation does have a major contribution to house loss. These results have major consequences for policy and decision makers all across the United States. Understanding which factors are contributing to house loss from wildfires can help inform future policy and land use decisions, as well as being useful to potential future homeowners. In particular, vulnerability maps can provide a better understanding of where housing development is more vulnerable to wildfires, but also, where prevention measures can be done to minimize vulnerability. Maps are also great to help prioritize management actions and create a hierarchy of prevention measures according to the regions vulnerability "hotspots".

In sum, fire, people and housing create a complex system with considerable economic, social, and environmental considerations. The WUI has unique dynamics at both the environmental and social levels in each instance. To analyze WUI communities individually is helpful at a very local management scale. However, if we want to have a broad understanding of the phenomenon and the similarities and differences among communities, it is necessary to analyze at a broader scale and look at the phenomenon as a whole. My main goals are to better understand how different factors contribute to house loss as a result of wildfires and how to best apply that information into maps in an attempt to better inform potential property owners regarding the risk and viability of property ownership in the WUI.

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