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The importance of building construction materials relative to other factors affecting structure survival during wildfire

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ABSTRACT

Structure loss to wildfire is a serious problem in wildland-urban interface areas across the world. Laboratory experiments suggest that fire-resistant building construction and design could be important for reducing structure destruction, but these need to be evaluated under real wildfire conditions, especially relative to other factors. Using empirical data from destroyed and surviving structures from large wildfires in southern California, we evaluated the relative importance of building construction and structure age compared to other local and landscape-scale variables associated with structure survival. The local-scale analysis showed that window preparation was especially important but, in general, creating defensible space adjacent to the home was as important as building construction. At the landscape scale, structure density and structure age were the two most important factors affecting structure survival, but there was a significant interaction between them. That is, young structure age was most important in higher-density areas where structure survival overall was more likely. On the other hand, newer-construction structures were less likely to survive wildfires at lower density. Here, appropriate defensible space near the structure and accessibility to major roads were important factors. In conclusion, community safety is a multivariate problem that will require a comprehensive solution involving land use planning, fire-safe construction, and property maintenance.

1. Introduction

With recent increases in wildfire frequency and extent [37], structure loss to wildfires has become a growing problem in fire-prone ecosystems worldwide (e.g., [3,51,47]). In addition to structure loss, increasing wildfire activityconnotes a much wider range of economic, social, and ecological issues, such as loss of human lives, exorbitant firefighting expenses, and impacts to biodiversity. Unfortunately, future projections suggest that these losses are likely to continue, or even worsen, due to the potential for increased fire activity resulting from climate change [26], coupled with ongoing housing development within and adjacent to wildland areas i.e., the Wildland Urban Interface (WUI) [42].

Given the serious nature of this ongoing problem, a growing body of research has focused on understanding the factors that influence community vulnerability to fire, and in turn, identifying those land management practices that may provide the best protection against structure loss [17]. Historically, fuels-based hazard assessments and the use of fuels management for protecting communities have been the central focus of study [16,44], but recent research has contributed to a growing recognition that community safety is a function of a large suite of variables, which when considered together, may lead to the most effective management [18,35,9]. For example, studies now show how land use decision-making [47,48,7], defensible space and homeowner preparation [11,49,8], and ignition prevention strategies [10,39,46], can complement traditional management actions of fire suppression and fuels management.

Another factor that is broadly recognized as critical for preventing structure loss to fire is the design and materials used in the building's construction. That is, the physical attributes of a structure confer ignitability either through flames and heat [12] or via embers produced during wind events, which can blow 1–2 km ahead of a fire front [41]. In fact, it is these embers that are most responsible for homes igniting during wildfires [25,29,41,43].

In many regions, building construction standards are now being incorporated into policies regulating new housing development (e.g., http://www.fire.ca.gov/fire_prevention/downloads/2007CaliforniaBuildingCode.pdf, http://www.nash.asn.au/nash/publications/nash-standards accessed 11/4/16,). Many of these standards are based on test results from laboratory experiments in

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which different wall, window, roofing, or deck materials are exposed to heat fluxes from flaming fronts [4,33]. Tests are also being developed to evaluate the potential for firebrand ignitions of different materials, design, and construction choices under simulated wind conditions (e.g., [27,28]).

While the data resulting from these lab tests are critical for understanding fire resilience of different materials, there nevertheless has been little empirical research examining the role of structural attributes in home survival during actual wildland fires, where a wide range of other conditions are present. Thus, systematic study using empirical pre- and post-fire data has been identified as critical research needed for better understanding structure loss at the WUI, particularly in terms of the relative effectiveness of building design materials, relative to other factors such as defensible space and housing density [33]. Different components of building structure and design may also vary in their importance for structure survival.

In previous work, we developed an extensive geographical database of homes destroyed and unburned during wildfires and analyzed the data relative to a range of local and landscape factors explaining structure loss to wildfire (e.g., [47,48,1]). Despite the comprehensive nature of the dataset, it lacked information on the physical attributes or age of structures. Thus, for this study, we acquired site-specific data on building construction materials for a subset of homes in this dataset that were either destroyed or survived exposure to wildfires. We also attained year of construction, an indirect measure accounting for all building construction material and design, for a larger proportion of the dataset of burned and unburned homes [49]. This information allowed us to evaluate the role of building construction in structure survival during wildfires, particularly relative to other important local and landscape factors.

Using two different datasets, one a subset of the other, we conducted analyses at both local and landscape scales. Using the dataset for which we obtained specific construction material information, we evaluated the role of local-scale factors associated with homeowners' properties to answer:

1) Which feature in building construction is most important for structure survival?
2) How does the importance of building materials compare to defensible space variables?

In addition, we used a larger, more geographically expansive database with structure age information, to answer the question:

1) How important is structural design (as determined by age) when compared to a full suite of local and landscape factors known to affect structure loss?

2. Methods

2.1. Study area

The study area encompassed a portion of San Diego County, CA, USA extending from the coast through the foothills and mountains (Fig. 1). During the last decade, thousands of structures were destroyed in a number of large fire events, and this region is where some of the highest housing losses to fires occurs in the world [22,23]. The area has a Mediterranean climate, with cool wet winters and hot dry summers, and at the end of a long summer drought, fuel moisture is very low in the fire-prone native shrublands. Periodic large, high-intensity crown fires are part of the natural fire regime, and these large fires are typically driven by an offshore flow of hot, dry Santa Ana winds that occur annually at the end of the summer drought. These are the fire events associated with the most loss in housing and lives [21].

Community vulnerability is due not only to the severe fire-weather conditions, but also to the extent and pattern of housing development, as there has been a trend of enormous expansion of low to medium-density housing into wildland areas [20]. These exurban housing developments are also located within complex terrain and may be more difficult to access by fire suppression crews; thus, low housing density has shown to be a major factor contributing to structure destruction in the region [47]. Given the vast extent of WUI in the region, many fire-safe councils and local organizations are strongly encouraging homeowners to appropriately prepare their homes and properties for better resilience to fire when it occurs (http://www.firesafesdcounty.org/home.aspx#, accessed 2/28/16).

The County of San Diego has been enforcing fire codes for building construction in the WUI since 1997, when it adopted a requirement for class "A" residential roof covering on new construction; which means that the roofing material must pass a relatively stringent series of fire tests (http://www.buildings.com/article-details/articleid/15175/title/the-abcs-of-roof-fire-ratings/viewall/true.aspx, accessed 2/27/16). Adopted in 2001 and made a requirement in 2002, the first comprehensive WUI code in the county required, in addition to the above, dual glazed/tempered windows, residential fire sprinklers, rated exterior construction, fire resistant decks and patios, no eave vents, no paper-backed insulation in attics, and 30 m (100 ft) vegetation modification around structures (Clay Westling, personal communication, 3/3/15). The WUI fire code has undergone minor revisions in 2004 and 2008 in response to the large fire events of 2003 and 2007. These regulations for fire-safe building construction are enforced through the issuance of building construction permits and approval of new subdivisions, and thus they do not apply to older homes.

2.2. Data assembly

The building construction data were collected during several damage assessments conducted by the County of San Diego Department of Planning and Land Use (DPLU) after the large fire events that occurred in October of 2003 and 2007. Although we did not have the information to account for the exact fire behavior at the time of structure exposure, the fire weather and environmental conditions were remarkably similar in both years. Both fire events occurred after extraordinarily long antecedent drought during severe Santa Ana wind conditions [22,23]. To perform these assessments, DPLU staff with a range of expertise in fire science, architecture, and engineering conducted site inspections and interviews to evaluate the degree of structure damage or destruction and to record characteristics of the properties.

Although documentation of destroyed structures in the 2003 Cedar Fire accounted for the majority of the data collection, DPLU teams also collected some information on structures that were unburned or had only experienced minor damage. The number of homes inspected equaled approximately one-third of the homes destroyed in that fire. After the fires of 2007, a more concentrated effort was focused on collecting information on homes that survived fires in addition to those that were destroyed. For these assessments, the DPLU evaluated a random sample of homes that survived within areas where many other homes had been destroyed, allowing for comparison among properties with similar exposure and fire behavior, but different outcomes. Although we included all of these data in our analysis, we simplified the classification of outcome so we could conduct a comparative analysis with a binary outcome of survived or destroyed. Thus, we specified structures with minimal damage to belong with the unburned homes, and labeled them "survived." We grouped those with moderate damage with the "destroyed" structures. Although minimal and moderate damage to homes was not quantitatively determined, the number of structures in these two categories only comprised eight percent of the dataset.

From the DPLU data available in the 2003 and 2007 assessments, we focused on four structural characteristics that are considered