

Work Capacity Test, Table 1 Work capacity test classification levels

Work category	Test	Distance [mi (km)]	Pack [lbs (kg)]	Time [minutes]
Arduous	Pack	3 (4.8)	45 (20.4)	45
Moderate	Field	2 (3.2)	25 (9.1)	30
Light	Walk	1 (1.6)	None	16

These tests are designed not to be a maximal effort test, due to the nature of work shifts for wildland firefighters. These test for sustainable fitness levels, which have a high correlation to long-duration tasks.

Cross-References

- ▶ [Wildland Firefighter Physiological Job Demands](#)
- ▶ [Wildland Firefighting Personnel](#)

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Work Demands

- ▶ [Wildland Firefighter Physiological Job Demands](#)

WUI Risk Assessment at the Landscape Level

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Synonyms

[Risk analysis](#); [Risk mapping](#); [Risk modelling](#)

Definition

Wildland-urban interface (WUI) risk assessment is about how wildfires and human communities interact at the landscape level. By spatially mapping factors that influence the likelihood and intensity of wildfires burning into communities, more effective mitigation and response strategies may be implemented.

Introduction

Many parts of the globe are experiencing some level of increased wildland fire activity (often referred to as bushfire in the southern hemisphere, as wildfire in North America and forest fires in Europe) (Gill et al. 2013; Moritz et al. 2014).

Along with this increase in activity, the intensity of wildfires, and most importantly associated negative impacts to humans, developed assets and highly valued natural resources appear to be increasing (Moritz et al. 2014). Wildfire is both an important natural regeneration process and tool for human manipulation of the environment. However, several factors have coalesced to drive increasingly large destructive wildfires that kill citizens and fire responders and result in the destruction of tens of thousands of homes annually and loss of important natural resource values.

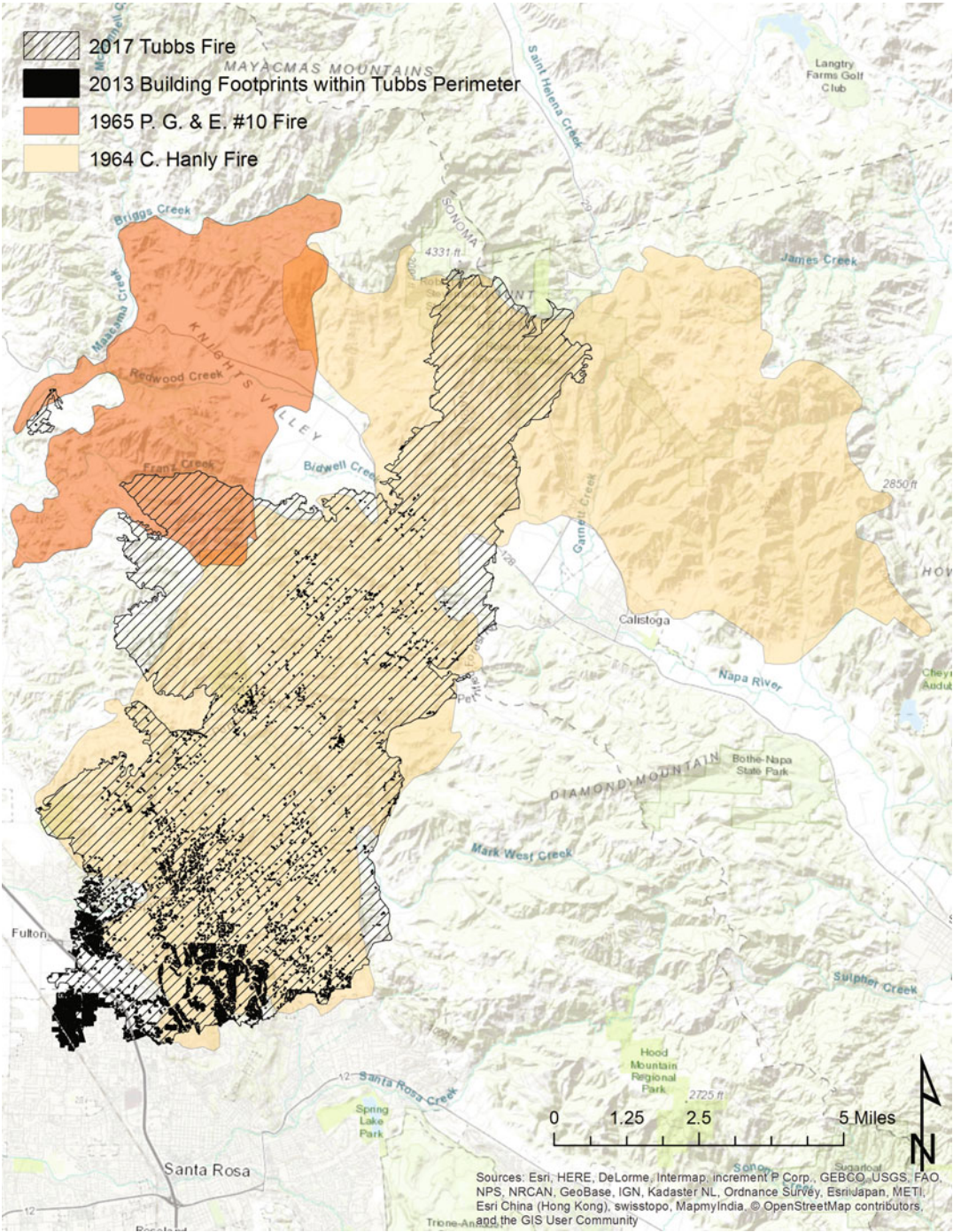
Highly destructive wildfires are not unique to any one continent (for more information the reader may see the contribution on Historical WUI Fires). For example, in October 2017 a series of fires fanned by winds with gusts exceeding 100 km per hour burned in central California. These fires, collectively termed the North Bay, burned nearly 100,000 ha resulting in 44 deaths, almost 9000 structures destroyed, and projected economic losses in excess of \$85 billion (US) (Nauslar et al. 2018). A dramatic incident in modern history was the Black Saturday fires on 7 February 2009 in Victoria, Australia, where 173 people lost their lives and 2200 buildings were destroyed (Teague et al. 2010). On June 17, 2017, wildfires in Portugal caused 65 deaths and more than 200 injuries representing the most significant wildfire disaster in the history of Portugal and among the worst ever in Europe (Viegas et al. 2017).

Common features of all of these events include high winds, low relative humidity, prolonged drought, seasonally high temperatures, and high fuel loadings (Bradstock and Gill 2001; Calkin et al. 2014; Blanchi et al. 2010), and, in general, these factors have increased over recent decades (see, e.g., Hessburg et al. 2005; Miller et al. 2009; Blanchi et al. 2010; Calkin et al. 2015; Jolly et al. 2015). However, it is important to recognize that the physical events themselves are typically not without historical precedent. Not to diminish the reality of increasingly severe climate-induced fire weather and increasing fuel loads, but what has fundamentally changed in those areas where highest loss has occurred is the increasing

presence of people living in high-hazard areas (Moritz et al. 2014). For example, approximately 50 years prior to the 2017 California fires, the California Hanly Fire in 1964 and Pacific Gas and Electric #10 Fire in 1965 (CalFire 2019) burned a majority of the area burned in the 2017 Tubbs fire, the most destructive of the 2017 California fires (see Fig. 1). Between the 1960 and 2010 Census, the city of Santa Rosa, California's population increased over fivefold from 31,027 to 167,815, thus while the Hanly and PG&E # 10 fires resulted in only 84 homes destroyed and no fatalities, the Tubbs fire destroyed over 5600 homes and killed 22 residents. Similarly, the combination of drought and extreme fire weather that drove the 2009 Black Saturday fires co-occurs in Australia resulting in many memorable disasters (Ash Wednesday 1983, Black Friday 1939, Red Tuesday 1898, Black Thursday 1851), though none has ever caused so much loss of life as the 2009 Black Saturday events (Teague et al. 2010).

When wildfires burn into developed areas, loss of life is not restricted to those trapped in burning homes (Whittaker et al. 2013). In fact, many of the fatalities, particularly in Mediterranean Europe where most homes are built of non-burnable material, occur as people are trapped in vehicles trying to flee a wildfire. For example, during the Pedrógão Grande and Góis fires in Portugal, a majority of the victims died when they tried to escape by car on the roads (Viegas et al. 2017). Additionally, loss of life of fire responders is not uncommon, particularly in the USA. Between 2000 and 2016, 299 US wildland firefighters have been killed while working, averaging 18 fatalities per year from a range of factors such as aviation accidents, driving, heart attacks, burnovers, and being hit by falling trees (NIFC 2018).

The area where wildfire and people interact is often referred to as the wildland-urban interface (WUI). In this contribution, we focus on WUI fires, on wildfires that directly interact with human communities. We discuss common characteristics of these WUI fires with a specific focus on the landscape perspective. Large wildfires impact both the ecological condition



WUI Risk Assessment at the Landscape Level, Fig. 1 Map of the 2017 Tubbs fire relative to previous fires and building footprints within the Tubbs fire footprint.

(Figure courtesy of Karen Short (US Forest Service, Rocky Mountain Research Station))

of the lands and the social system of adjacent human communities, and these effects may be direct (e.g., home destruction) or indirect (e.g., post-fire erosion impacts to municipal water supplies, smoke-related health impacts). Successful and cost-effective mitigation strategies to reduce wildfire loss require consideration of the current ecological condition relative to the historic condition, expected future climate and its impacts on weather, as well as the social capacity, expectations, and economic conditions of impacted communities (Moritz et al. 2014). The approach of recognizing that both the fire ecology of the land and the community characteristics must be considered is often referred to as a social-ecological systems (SES) approach described later.

Assessing Wildfire Risk in the WUI at the Landscape Level

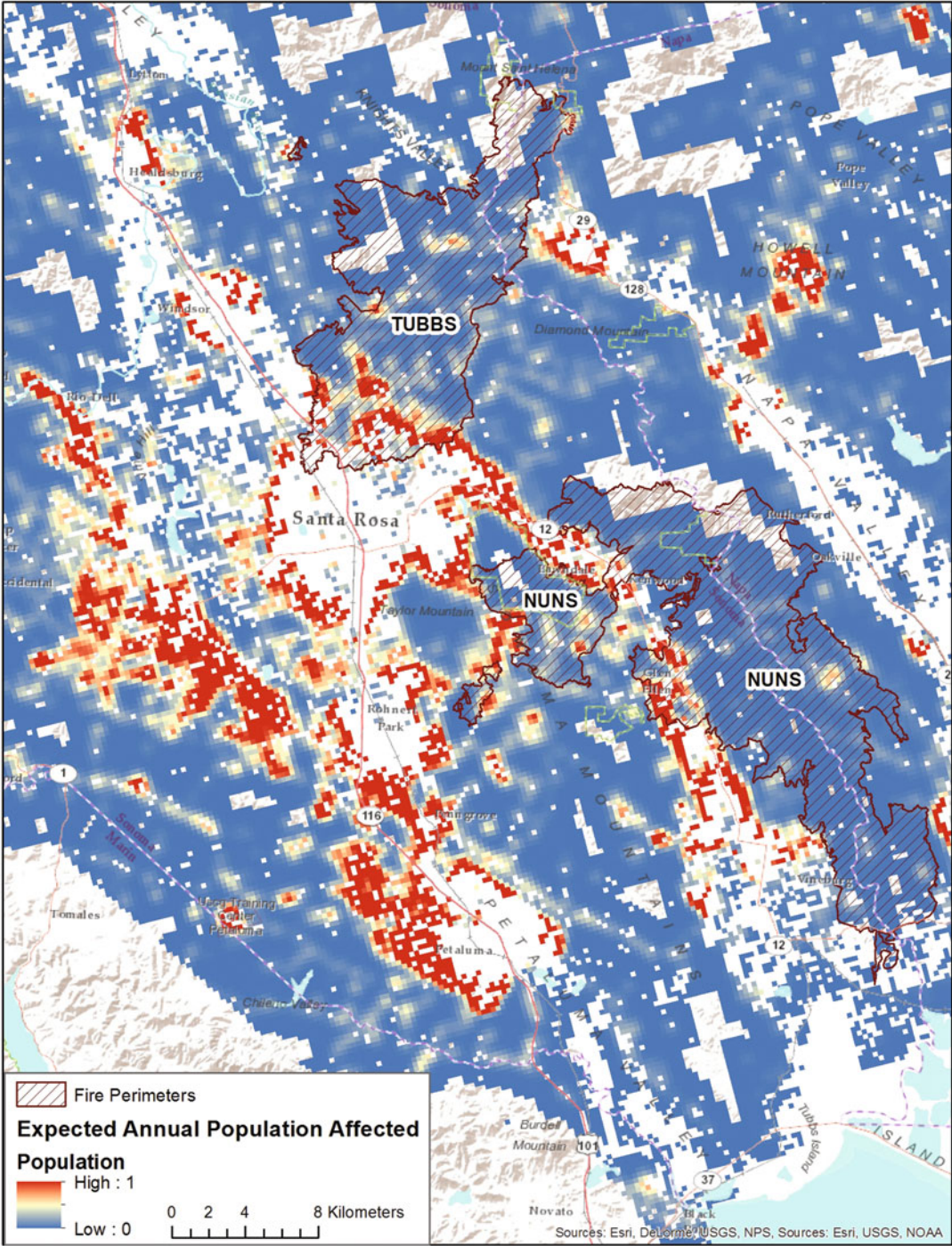
Wildfire risk assessment is a tool to identify and analyze the potential of wildfire to impact the WUI and a range of societal values that may be affected (both negatively and positively) by wildfire. Using the concept of risk as the probability times the consequence, we can break down the factors driving wildfire impacts into those that affect likelihood of a given fire and those that influence the potential consequence if a fire interacts with a highly valued resource or asset (Finney 2005). Different risk assessment models have been developed for use at different scales, ranging from the landscape to the single house level (Miller and Ager 2013). The objective of the assessments at each scale can vary greatly ranging from informing national programmatic investments, defining appropriate land use, and fire management strategies to zoning and building material requirement policies. The models include different variables such as vegetation (e.g., type, fuel load, structure, moisture content), output from fire behavior models (and fire simulation), topography, climate, fire regime, fire history, population growth, socioeconomics, human activities, land use, and land cover (see, e.g., Scott et al. 2013; Chuvieco et al. 2010).

Many efforts to define and map the WUI in the USA, Spain, and France, for example, have focused on identifying those areas where

natural vegetation and human development co-occurred (see, e.g., Caballero et al. 2007; Stewart et al. 2007; Chuvieco et al. 2010; Lampin-Maillet et al. 2010). Although these methods typically do not incorporate emerging research that explores the likelihood of vegetation and structures actually burning, they are still important tools for understanding development patterns and potential ecological stressors including wildfire (Radeloff et al. 2005; Theobald and Romme 2007).

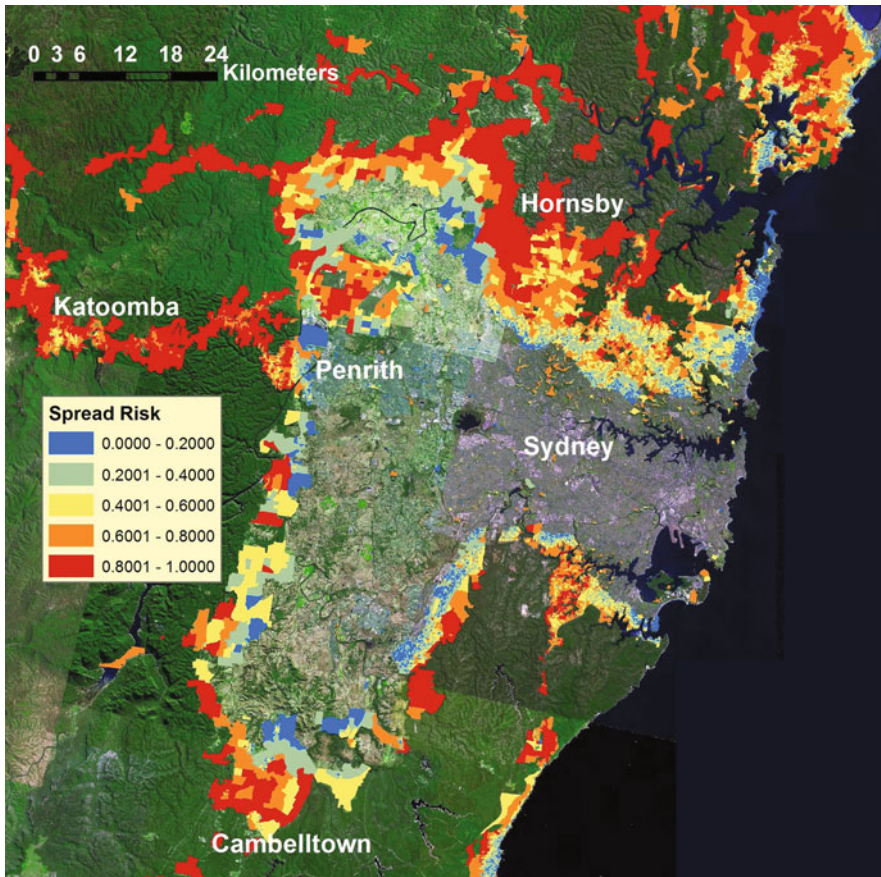
The evolution of improved fuel-based vegetation data and spatial fire history has allowed for large-scale assessment of the likelihood of a future fire impacting areas of human development. Assessments like those by Ager et al. (2010, 2015, 2017) and Haas et al. (2013, 2014) are based on fire simulation models such as the Fire SIMulation model (FSim) (Finney et al. 2011) that develop a large set (>1000) of spatially explicit future potential fire perimeters under a range of different weather conditions to establish the likelihood that any given point on a landscape will burn at given flame length intervals. These burn probability maps can be categorized by the likelihood of fire in any given area and then interacted with the relative density of human population or built structures facilitating the development of spatially explicit wildfire hazard maps at relatively fine scales (e.g., 90 × 90 m pixels) (Ager et al. 2010; Haas et al. 2013; Salis et al. 2013). Figure 2 demonstrates the interaction of population with expected burn probability prior to two of the most damaging 2017 California fires (Tubbs – 5600 structures burned 22 fatalities; Nuns, 1200 structures destroyed 3 fatalities).

Fire history mapping can also be used to develop statistical models of the likelihood of fires reaching different parts of the WUI, as in this example from Price et al. (2015) showing wildfire risk proximate to Sydney, Australia. Similarly, an ignition likelihood map can be made from statistical analysis of past ignition points. Generally, these analyses highlight proximity to roads and population centers as the main drivers of human ignitions. These maps are important tools in helping to prioritize and direct mitigation investments in those areas where wildfire impacts will likely be the highest.



WUI Risk Assessment at the Landscape Level, Fig. 2
A wildfire risk map representing modeled probability of wildfire multiplied by population affected near Santa Rosa California including major 2017 wildfire events.

As described in Haas et al. (2013). (Figure provided by Jessica Haas (US Forest Service, Rocky Mountain Research Station))



WUI Risk Assessment at the Landscape Level, Fig. 3 A wildfire risk assessment of communities around Sydney, Australia. As described in Price et al. (2015)

The application of landscape simulation models allows us to not only examine the likelihood that any point on the landscape may burn but also the characteristics of those fires that may impact areas of human development (Haas et al. 2014; Ager et al. 2017). An emerging application allows us to map out the extent of areas on the landscape where wildfires may ignite and influence an established area of interest (e.g., a community boundary) (see Ager et al. 2015). Examining the WUI fire problem beyond the community boundary is critically important since many of the most destructive WUI fires ignite fairly distant (10's of kilometers from the WUI) from human settlement and burn across large landscapes. This information can improve community planning efforts that to date have largely focused only on the immediate areas surround-

ing human development and not considered the broader landscape characteristics that can have a significant influence on a wildfire impacting a community (Ager et al. 2017). Additionally, those characteristics and condition of the landscape beyond the immediate settled area are typically very important for the livelihoods of residents due to natural resource extraction and/or recreation-based economies, provision of clean water, and general quality of life and desirability of residential settings. Thus a wildfire can have a huge impact on a given community without burning a single home (Fig. 3).

Coordinated planning and action to mitigate fire risk at the landscape scale are very challenging due to multiple ownerships with differing goals, management strategies, mandates, and understanding of the WUI fire problem (Calkin

et al. 2014). Further, communities at risk to wildfire vary in their capacity to undertake planning and mitigation efforts, social cohesion necessary to undertake collective action, and level of support from external government entities. Finally, there are substantial differences among countries regarding the roles and responsibilities of the individual homeowner versus government entities from local through national levels for wildfire risk mitigation activities. Risk assessments are powerful tools to help prioritize among the range of risk reduction options available including prevention, landscape hazardous fuel treatment, suppression, home ignition zone (HIZ) mitigation, zoning requirements, evacuation planning, and insurance programs (Ager et al. 2015).

Examining the Problem as a Social-Ecological System

Although the specific factors that drive the increase in recent loss vary around the world and are largely driven by the local ecology and human community characteristics, there are several common features (Moritz et al. 2014). It is necessary to examine how social and ecological change at the landscape scale has occurred over time along with the characteristics of the management response to the WUI fire problem to understand both drivers of wildfire risk and opportunities to reduce future loss (Gill 2005).

In many parts of the world, human use of fire has been the primary driver of the “natural” fire regime due to indigenous peoples’ use of wildland fire (e.g., Australia and much of North America). In other areas (e.g., Mediterranean Europe), a large majority of the landscape has been directly impacted by a range of human activities for millennia, and the use of fire as a tool for agricultural and pastoral purposes is responsible for the majority of fire on the landscape. While in some remote areas (e.g., mountainous regions of North America), lightning-ignited wildfire remains the dominant force on the landscape. As human settlement patterns and economic activity change over time, factors that drive wildfire ignition (Mann et al. 2016;

Ganteaume et al. 2012) and the use of fire to achieve human desires change as well. For more information the reader may see the contribution on ignition sources.

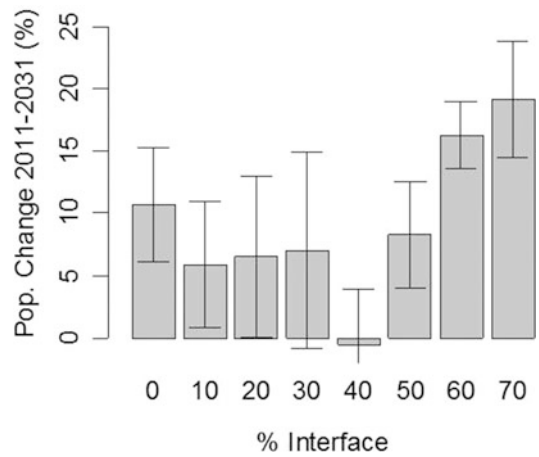
Weather is a driving force of wildfire and an important factor to consider in risk assessment. Fuels must be sufficiently dry to burn and this depends on temperature and humidity. Wind speed is a critical factor in determining the rate at which fire spreads. Climate change has increased both the ambient temperature which increases the rate at which fuels dry and the frequency, scale, and severity of drought events although the impact of climate change on wind speed is uncertain. Scientists have demonstrated that recent climatic shifts have significantly increased the duration and available burnable area of forested ecosystems around the globe (Jolly et al. 2015). Under these more frequent extreme weather conditions, the suppression efforts are overwhelmed by the intensity and rate of fire spread resulting in damages and losses at the WUI (Cohen 2000; Calkin et al. 2014; Tedim et al. 2018). Given the emerging influence of climate on fire, it is important to recognize that our future experiences with wildfire are likely to differ substantially from our historical experience and need to be considered in risk assessments.

Fuel type and availability are another factor to consider in risk assessment. Fire suppression response from government entities in the USA may induce behavior that actually increases WUI risk over time. In fact, effective suppression response results in fuel accumulation over the longer term resulting in an increased likelihood that suppression may be ineffective in the future (this has been labeled the wildfire paradox; see Cohen 2008 or Calkin et al. 2015). Therefore, even if in the near term suppression may likely reduce the likelihood of a given fire interacting with the community, it may increase both the likelihood and potential consequence in the longer run. Although significant investment in fuel treatment reduction is often directed toward fire-prone communities, treatment cost and social opposition to many types of treatment

may reduce the effectiveness and efficiency of such programs (Bradstock et al. 2012; Calkin et al. 2014).

Rural abandonment in Mediterranean Europe also influences total wildfire risk. Rural abandonment may reduce the consequences of wildfire by removing a proportion of the population from rural areas. However, it may also induce increased economic hardships for the remaining population, which is also aging and increasingly less able to manage fuels or to perform authorized controlled burning. This results in an overall accumulation of flammable fuel mass that could favor the propagation of intense wildfires and promote the occurrence of extreme fire behavior (Moreira et al. 2011). In parallel, woodlands and shrublands are progressively colonizing abandoned former pastures and cultivated areas. Migration to more densely populated areas may spur additional restrictions on traditional agricultural burning practices and induce farmers into illegal introduction of wildfire that is more likely to escape. Therefore, although rural abandonment reduces the number of people and value of assets at risk if a wildfire were to occur, it simultaneously increases the likelihood and intensity of future wildfires and WUI fires (Moreira et al. 2011).

Another factor contributing to the risk is the population expansion into more remote areas for reduced cost of living and increased amenity values including privacy, recreation opportunities, and aesthetic beauty. As populations expand there is increasing development of primary and secondary homes in areas of high wildfire potential. In the USA in 2010, approximately 10% of the land base in the conterminous USA was defined as part of the WUI with one in every three homes being considered within the WUI (Martinuzzi et al. 2015). Additionally, expansion of housing units inside the WUI has exceeded areas outside the WUI. Expanded human development into previously natural forests and other fire-dependent ecosystems have resulted in increased human-caused ignitions (both deliberate and accidental) and are the primary source of wildfire in many areas (Syphard et al. 2007).



WUI Risk Assessment at the Landscape Level, Fig. 4

Projections for population growth 2011–2031 for 106 local government areas grouped according to the proportion of their area in the WUI as of 2011 (population predictions 2013 by the NSW Department of Planning, WUI definitions by authors using data from the Australian Bureau of Statistics, NSW Department of Lands and Property Information, and Office of Environment and Heritage, 2011–2014)

Since the 1960s, there has been rapid expansion into the forested peri-urban fringes of the major cities in Australia, and this continues apace. Combining population census data with vegetation and historical fire mapping for New South Wales shows that most local government areas dominated by wildland-urban interface have experienced population growth greater than 7% in the past decade and are projected to grow by more than 10% by 2031 (see Fig. 4). Figure 4 shows forecast population growth in NSW Australia is highest in local government areas with high or low proportion of wildland-urban interface (i.e., very urban or on the edge of native vegetation). This is similar to the growth rate for highly urbanized areas but double the rate for areas with intermediate levels of interface. These population trends are probably the main reason that the human impacts of the 2009 Black Saturday fires were so high. The fires in 1939 burned the same area and under similar conditions, but the impact in terms of life and property loss was one third (Teague et al. 2010).

Although a common European framework to define and characterize WUI areas does not exist, mostly due to heterogeneous laws and the scarcity of standardized maps and data, there is evidence that WUI areas are progressively growing, and this is particularly relevant in Southern Europe countries (Tedim et al. 2014). WUI expansion in recreation-based areas and forests, as well as rural abandonment in many Mediterranean EU countries, represents a major social disturbance and influences wildfire risk in several ways. A growing issue is the expansion of WUI areas into coastal zones, which in the case of wildfires can cause entrapments of residents and tourists, due to increased difficulties in evacuating people in crowded areas and panic situations for tourists unaware of wildfire growth and behavior, as dramatically observed in 2018 in the Mati fire (Greece). The spread of WUI areas and related road networks influences risk by increasing the likelihood of fire through increased arson and accidental fire ignition potential in the vicinity of highly valued resources (Mann et al. 2016; Ganteaume et al. 2012). Furthermore, WUI areas represent a priority target for wildfire suppression. Successful suppression actions limit fire on the landscape resulting in wildlands or remote forests with increased fuel loads.

One of the most obvious ways to avoid future WUI fire disasters is by defining high-risk areas and assuring that homes are not built in those areas, or if they are built in those areas, there exists requirements on both construction materials and landscape conditions that reduce the likelihood that the home will be destroyed in the event of fire (Gude et al. 2008). Research in the USA has demonstrated that the characteristics of the home and fuels within 30–60 m of the home largely determine whether or not a home will be destroyed by wildfire (Cohen 2000). The characteristics of fuels around the property are even more important when large wildfires engage numerous homes simultaneously, thus making it impossible for fire responders to protect each home within the broader community (Calkin et al. 2014). The condition of neighboring properties has both an influence on the likelihood

that a structure will burn, but also that mitigation efforts taken by neighbors induce other property owners in the vicinity to conduct risk mitigation activities (Champ et al. 2013). However, many of the characteristics that make homes vulnerable to wildfire are also attributes that make them attractive to people living in at-risk landscapes (e.g., wooden decks and adjacent trees and other vegetation). The reader may see the contributions on WUI risk assessment at the structure level and ignition-resistant communities.

Insurance could also use risk assessment to prioritize and influence insurance strategies (Haldane 2013). The availability and cost of wildfire insurance influence the level of personal loss experienced by the individual homeowner and can therefore alter housing decisions in wildfire-prone areas and/or induce additional mitigation activities. If insurance is inexpensive and widely available, then homeowners may be justified in not undertaking hazard reduction activities. Although it is too early to identify the impacts of home insurance pricing and availability based on wildfire risk assessments, this development could have a major influence on homeowner risk mitigation efforts and development patterns.

Human life and protection of private property are typically the first and second priority of wildfire suppression response (Calkin et al. 2013). As such landscape risk assessments must take into consideration how people in different geographic areas will likely respond to wildfire. At the societal level, countries differ in their view of primary responsibility for protection of human structures from wildfire. As discussed earlier, many fatalities throughout the world are associated with being trapped while trying to flee a fire (Whittaker et al. 2013). Thus there is increasing interest in landscape risk assessment work to identify risk area and where limited egress may result in entrapment and expand the development of safe egress routes in developed areas (see Cova et al. 2013). One of the most pressing problems facing European fire managers when dealing with WUI fires is the management of safe evacuation routes. Historic development patterns can make safe access and egress quite

challenging as demonstrated by the high proportion of fatalities from recent events in Portugal and Spain associated with members of the public attempting to flee oncoming wildfires. Landscape risk assessment can inform effective investment strategies for roadside fuel management, evacuation planning, and improved strategies for homeowners to shelter in place.

Conclusion

Increased development along with increased frequency of severe fire weather has led to an increased wildfire risk consistent with recent observed losses around the globe. This increased risk requires increased investment in planning for and implementing effective and efficient mitigation strategies. A range of landscape scale risk assessments have been developed to better understand primary risk factors that drive potential loss and feasible, culturally appropriate, cost-effective methods to reduce risk and improve the ecological condition of the landscapes within which communities are located.

Cross-References

- [Building Codes and Standards for New Construction](#)
- [Ignition-Resistant Communities](#)
- [Ignition Sources](#)
- [Lessons Learnt from Post-Fire Surveys and Investigations](#)
- [Modeling Approaches](#)
- [Ornamental Vegetation](#)
- [Pre-fire and Post-fire Data Studies in the WUI](#)
- [Wildfires and WUI Fire Fatalities](#)
- [Wildland-Urban Interface](#)

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