

# Protective Actions in Wildfires: Evacuate or Shelter-in-Place?

Thomas J. Cova<sup>1</sup>; Frank A. Drews<sup>2</sup>; Laura K. Siebeneck<sup>3</sup>; and Adrian Musters<sup>4</sup>

**Abstract:** The decision of whether to evacuate or shelter-in-place (SIP) in a wildfire poses a significant challenge for emergency managers and residents in fire-prone areas. Events such as the 2007 Witch Creek Fire and 2008 Tea Fire in California highlight the option and viability of SIP, as well as the conflict that can occur between first-responders and residents in protecting life and property. In general, anecdotes abound of people choosing SIP over evacuation in wildfires using a variety of means of refuge (e.g., structure, safe area, and water body). We propose a typology of wildfire protective actions that includes all viable forms of in-place shelter and discuss heuristics that have been proposed to guide people through the options. A key distinction is drawn between SIP as a backup plan when evacuation is perceived as too risky and SIP to improve structure survivability. Regardless of the form that SIP takes, the need for this strategy is growing as the wildland-urban interface expands. The paper concludes with a discussion of suggested areas for research and planning.

**DOI:** 10.1061/(ASCE)1527-6988(2009)10:4(151)

**CE Database subject headings:** Fire hazards; Public safety; Evacuation; Planning.

## Introduction

Almost 100 years ago in a Montana firestorm known as the “Big Blow-Up,” Ranger Edward Pulaski ordered 45 men into an abandoned mine in arguably the most famous case of sheltering in a wildfire in American history (Spencer 1958; Pyne 2001). “We reached the tunnel in time... I ordered the men to lie face down upon the ground of the tunnel and not dare to sit up, unless they wanted to suffocate, for the tunnel was filling with fire, gas and smoke . . .,” said Pulaski (1910) (Spencer 1958, p. 112). Legend has it that Pulaski held his crew at gunpoint to prevent them from panicking and fleeing into the throes of the raging fire. While this tale will likely never be eclipsed in its western romance, there are many accounts, some as recent as the 2007 Witch Creek Fire and 2008 Tea Fire in California, where residents threatened by wildfire chose to seek shelter rather than evacuate (CBS 2007; Taxin 2008). In another case in the 2003 Cedar Fire, thousands of patrons of the Barona Casino in San Diego County were told to “stay put” rather than evacuate, as the immediate building surroundings were clear of fuel, yet the exiting roads were at risk of being blocked by the fire (Blackwell and Tuttle 2003; Mutch 2007). Anecdotes such as these highlight both the option and viability of seeking shelter in a wildfire.

While less common than evacuation, the decision to shelter in a wildfire generally occurs in one of the following three situations. The clearest examples occur when sheltering is the only reasonable option: the exiting roads are blocked by fire. This case highlights the importance of shelter as an invaluable backup plan when residents find themselves trapped. Shelter is also advisable when evacuating is perceived as too risky: the exact whereabouts and intensity of a fast-approaching fire are uncertain, and the perceived margin of safety in evacuating is too small. In this case it is generally best to seek shelter rather than risk being overcome by the fire in-transit. The third use of shelter in wildfires occurs when residents choose in-home shelter to improve a structure’s chance of survival by actively defending it against the fire. In recent years it has become increasingly clear that the decision of whether to stay or go in a wildfire is complex and poses a significant challenge for emergency managers and residents alike.

To separate the term “shelter” as a means of direct protection from the effects of wildfire from its more familiar reference to congregate care facilities outside a threat area (e.g., Red Cross), the term *shelter-in-place* (SIP) is used. Although in-place shelter is best known in the context of chemical emergencies (Sorensen et al. 2004), it increasingly appears in wildfire emergency preparedness plans [Rancho Santa Fe Fire Protection District (RS-FFPD) 2004; Santa Barbara County Fire Department (SBCFD) 2004]. Shelter generally refers to a structure, safe area, or water body that offers a degree of protection from the direct effects of fire, and “place” refers to the immediate area at risk. While the use of this term is growing in the context of wildfire, related terms have emerged for specific SIP approaches. In Australia, the phrase, “prepare, stay, and defend” (PSD) refers to the case where residents choose to shelter in their homes. PSD highlights the dual points that protecting one’s home should be made with forethought and viewed as an active endeavor (Handmer and Tibbits 2005). For the purposes of this paper, SIP will be used to refer to all forms of in-place shelter whether the goal is the protection of life or property.

As noted, SIP has garnered increasing attention in wildfire emergency planning, and this has occurred for a number of rea-

<sup>1</sup>Director, Center for Natural and Technological Hazards, and Associate Professor, Dept. of Geography, Univ. of Utah, Salt Lake City, UT 84112-9155 (corresponding author). E-mail: cova@geog.utah.edu

<sup>2</sup>Associate Professor, Dept. of Psychology, Univ. of Utah, Salt Lake City, UT 84112-9155.

<sup>3</sup>Research Assistant, Center for Natural and Technological Hazards and Dept. of Geography, Univ. of Utah, Salt Lake City, UT 84112-9155.

<sup>4</sup>Research Assistant, Dept. of Psychology, Univ. of Utah, Salt Lake City, UT 84112-9155.

Note. This manuscript was submitted on July 7, 2008; approved on November 5, 2008; published online on October 15, 2009. Discussion period open until April 1, 2010; separate discussions must be submitted for individual papers. This paper is part of the *Natural Hazards Review*, Vol. 10, No. 4, November 1, 2009. ©ASCE, ISSN 1527-6988/2009/4-151-162/\$25.00.

sons. Foremost, on-going residential development and escalating losses in fire-prone areas is resulting in the need for innovative strategies to protect life and property. The intersection of fire-prone and residential areas, referred to as the wildland-urban interface (WUI), has become a significant topic of study (Ewert 1993; Haight et al. 2004; Radeloff et al. 2005). A recent analysis by Theobald and Romme (2007) revealed that the WUI in the United States expanded by 52% from 1970 to 2000, and now constitutes an estimated 12.5 million homes on 465,600 km<sup>2</sup>. Second, a new policy called “Stay or Go?” introduced in Australia to reduce the number of last-minute evacuations and improve structure survivability has increased awareness regarding the potential role of in-home shelter in wildfires [Australasian Fire Authorities Council (AFAC) 2005]. Third, many dense, fire-prone communities have relatively poor egress (number, direction, and capacity of exits) which may not allow residents to evacuate in a sudden-onset scenario, leading to a search for viable protective alternatives (Cova 2005).

The decision of whether to evacuate or shelter in a wildfire has emerged as a pressing and challenging problem in research and practice. While initial steps have been made toward raising awareness of SIP as an option in wildfire-prone areas, educational, policy and legal hurdles remain in integrating this option into everyday emergency planning (Community bushfire safety 2008). This paper reviews protective actions in wildfires and provides recommendations for further research and planning. The first section presents a typology of protective actions in wildfires and describes the heuristics that have been developed to guide residents toward the preferable option(s). The next section reviews challenges that lay ahead in terms of forwarding the use of SIP in wildfires. This section is followed by a discussion of the various policy options that exist for SIP in the United States, and the last section provides areas for further research and planning.

## Wildfire Protective Actions

While evacuation has been studied for decades in the context of many hazards (Perry 1985; Vogt and Sorensen 1992; Tierney et al. 2001; Dow and Cutter 2002; Dash and Gladwin 2007), SIP has received much less attention (Sorensen et al. 2004). Evacuation research is typically divided into a behavioral perspective that focuses on factors that influence public compliance with evacuation recommendations (Mileti and Sorensen 1990; Sorensen 2000), and an engineering perspective that focuses on traffic flow modeling and analysis (Southworth 1991; Cova and Johnson 2002; Church and Sexton 2002; Wolshon and Marchive 2007; Chen and Zhan 2008). A current thread of evacuation research seeks to better integrate these two perspectives by incorporating behavioral elements into the modeling process to improve evacuation time estimates (Lindell 2008). While research on evacuee behavior in wildfires is just beginning (Cohn et al. 2006; Mozumder et al. 2008), many of the findings regarding situational, demographic, and warning factors from other hazards applies to the wildfire case (Lindell and Perry 2004; Kumagai et al. 2004; McCaffrey 2004). Similarly, much can be gleaned from the research that has been done regarding SIP in the context of other hazards (Sorensen et al. 2004), as well as broader theoretical frameworks regarding protective actions in general (Lindell and Perry 2004).

### Typology

A first step in examining protective actions in wildfires is to develop a typology of the set of available options from the perspec-

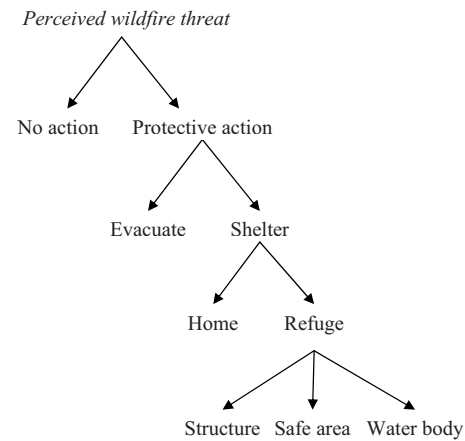


Fig. 1. Wildfire protective-action decision space

tive of both emergency managers and households. Lindell and Perry (1992) define a protective action (or option) as one taken to reduce the impact of a hazardous event to a threatened population. For emergency managers, this includes evacuating or controlling access to threatened areas, whereas for households the primary choice is between evacuation and in-place protection. One approach to this task is to categorize the options according to the primary goal. For example, evacuation is a life-saving option, as the goal in taking this action is solely to reduce the potential for loss of life or injury. As noted, in-place shelter can either be viewed as a life-saving option, as in the case where a resident shelters using a means of refuge (e.g., vehicle in a parking lot), or it can embody the dual goals of protecting life and property, as in the case of sheltering in (and defending) one’s home. The following classification of protective options relies on this distinction between protecting life and protecting life and property.

Fig. 1 shows a simple decision tree that begins with the initial decision of whether to take protective action. On the left side under protective action is the decision to evacuate, which generally involves questions of where, when, and how an evacuation will take place. Immediately below the decision to adopt in-place shelter is the choice of whether the shelter will be a home or not. This division is also based on the difference between the goal of protecting life (using a shelter other than one’s home) or life and property (sheltering in or near one’s home). While it is possible that the goal in selecting in-home shelter is solely the protection of life, the dual goals of protecting life and property are generally viewed as inseparable when selecting in-home shelter, as the best strategy for protecting life is also to protect the structure. On the other hand, when in-place shelter other than a home is the option, the goal is solely to limit loss of life or injury, which leads to the choice of shelter type (e.g., structure, safe area, and water body).

### Dynamics, Timing, and Triggers

A significant challenge in wildfires relates to the highly dynamic context in which protective decisions must be made, and decision makers must adapt to the changing situation. This means that the preferable protective option can change in short order. For example, the prevalent wind direction may suddenly reverse, and a community that was issued a voluntary evacuation recommendation may be thrust into a SIP-only scenario. From the perspective of the tree in Fig. 1, this means that the preferable option must be reassessed when conditions that led to a given option change. While the most common form of dynamics has to do with the fire

itself, there are many other factors that can change. For example, a power line may fall or a vehicle may flip, blocking an exit or reducing its capacity. In the context of in-home SIP, the decision to defend a home may suddenly appear less viable if a power failure reduces household water availability. Consequentially, the main implication of the highly dynamic nature of this decision-making context is that the most preferable protective option at the community and household scale must be continually reassessed against other options as the scenario factors change.

Another important dimension regarding the simple tree in Fig. 1 is the timing of the decision to select an option, particularly in relation to the arrival of a fire (Sorensen 1991). In short, how much time is available to select a protective action before it is no longer viable—a significant amount, a moderate amount, or little to none? The option to leave with significant time available is generally called an “early” evacuation, and the option with little to no time available is referred to as a “late” evacuation (Packman 1995). Similarly, the timing of the decision to seek shelter is also important—will it be made well in advance of the arrival of the fire, somewhat in advance, or at the last minute? In general, SIP takes much less time than evacuation, but its effectiveness varies with the protective qualities of the shelter (Lindell and Perry 1992). While the time at which a given protective option is selected is critical, timing has more to do with selecting the best option from within this tree rather than introducing an additional option (i.e., an early evacuation is preferable to a last-minute dash to a shelter).

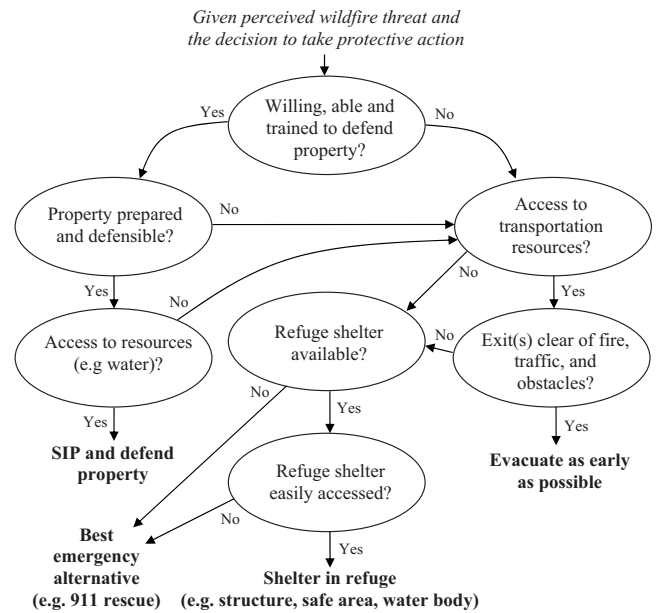
Because the point in time at which a protective measure is taken is so important, incident commanders use *triggers*, or agreed upon events that represent the point at which a protective action should be taken or recommended (Cook 2003; Cova et al. 2005). A common example is to set a trigger point that is based on the anticipated event of a fire crossing a road, river, or ridgeline toward a community. While most triggers are set on-the-fly during an event, they can also be set long before any event and therefore used to educate community residents on different scenarios and the timing and action that would be taken in each case (Dennison et al. 2007).

### Independent Options

A second key point regarding the tree in Fig. 1 is that the options are not mutually exclusive at either the household or community scale. At the household level, some family members may choose to evacuate while others remain behind to defend a home. At the community scale, households with the sole goal of protecting life may choose to evacuate, while others with the added goal of defending their property may select in-home shelter. For example, in a given event, some families might evacuate, some might SIP, and some might separate and select both options. The breakdown of households that adopt these varying strategies generally depends on the threat scenario, the available options, differences across individuals, and the warning context (e.g., official recommendations).

### Protective Heuristics

Given the options depicted in Fig. 1, the next step is to discuss heuristics (rules of thumb) that have been developed to provide guidance as to which option maximizes protection in a given scenario. In other words, what advice has been developed to assist people in selecting from these options? One of the most frequently noted heuristics is, “a structure provides more protection



**Fig. 2.** Example wildfire protective action flowchart that depicts salient decisions that arise in choosing between evacuation, in-home shelter, and refuge shelter

than a vehicle, and a vehicle provides more protection than nothing (or clothing).” The goal of this heuristic is to rank the standard categories of protection from radiant heat. Another heuristic developed in Australia is, “structures protect people and people protect structures (Handmer and Tibbits 2005).” This heuristic highlights the notion that a structure generally provides the best protection from the effects of fire, and this protection can be enhanced if someone actively prepares the structure in advance of the fire’s arrival and extinguishes embers that may land on or near the structure during the fire. Another heuristic developed in Australia focuses on the timing of the protective decision: “Leave early or prepare, stay and defend (property).” The goal of this heuristic is to reduce the likelihood of a last-minute (or late) evacuation by constraining the available options to leaving well in advance of a fire’s arrival or actively defending one’s home.

### Decision Aids for Wildfire Incident Command and Residents

As noted, the context in which wildfire protective decisions are made is complex, dynamic, and uncertain. Paveglio et al. (2008) noted that a key need in analyzing evacuation-SIP decisions in wildfires is the development of decision aids and associated tools similar to the ones used in chemical emergencies (Sorensen et al. 2004). These decision aids would have application in training emergency managers as well as educating homeowners. In most wildfire scenarios, emergency managers will use their access to better information and expertise to make protective recommendations, but there are still cases where households may have to assess the situation with little or no guidance from officials.

Fig. 2 depicts a flowchart that includes some of the salient decisions that are commonly addressed in selecting a wildfire protective action. This diagram can serve as a starting point for developing normative decision tools for protective actions in wildfires, and this should not be confused with descriptive diagrams that articulate how people actually make protective decisions in emergencies (Gladwin et al. 2001). The diagram begins at

the point at which a household perceives a threat and has decided to take protective action. An initial decision is whether a household is willing, trained and able to defend its property. If this is the case, then the focus might turn to the degree to which the property itself is defensible and whether the necessary resources are available. If so, then one option might be in-home SIP with the idea that the property will be defended to the best ability of its occupants, an option in widespread use in Australia and under increasing consideration in California (Saillant 2009). If the answer to one of these three questions (i.e., willingness, defensibility, and resources) is “no” or “uncertain,” then the focus turns to whether there is the means and access to evacuate the area ahead of the wildfire. If this is the case, then evacuation may be the preferred option. However, if the answer to either of these questions is “no” or “uncertain,” then a search for high-quality, easily accessed refuge shelter is a viable back-up option. If there is no sign of refuge shelter, then the final option might be an emergency rescue by family members, neighbors or officials (or a re-evaluation of the prior options) to identify the best remaining option.

Figs. 1 and 2 reveal three distinct protective options used in wildfires: evacuation, in-home shelter, and refuge shelter. The heuristics developed to date were designed to help guide emergency managers and households toward one of these options. For example, the heuristic, “a structure provides more protection than a vehicle, and a vehicle provides more protection than clothing,” yields the protective option ranking (at the time of a fire’s impact): in-home shelter, refuge shelter (structure), and evacuate by vehicle. While this is a reasonable ranking for a household with a defensible structure and the willingness, training and resources to defend it, this guideline might mislead a resident in an ignition-prone structure into believing that defending it is the best option. The preferable option for this household is likely to evacuate as early as possible, or to seek the best available form of refuge if evacuation is perceived as too risky. The same point holds for residents who are not suitably trained, equipped, or physically and mentally able to defend a home. The heuristic, “leave early or prepare, stay and defend,” does not address the option of refuge shelter, and instead rates the options of evacuating (early) and in-home shelter as equally viable. This heuristic works well for households residing in an ignition-resistant structure clear of fuel that are well-prepared and equipped to defend a home, or ones with ample time and the means to evacuate, but it does not provide guidance for cases where one of these two cases is not met. These cases include residents who are not able to evacuate or defend a home (e.g., latch-key children and disabled), or cases where the exiting roads are compromised (e.g., traffic, obstacles) and a home is not defensible (e.g., ignition-prone structure, no available water, extreme fire behavior, health conditions). In these cases, seeking proximal refuge shelter or assistance from family, neighbors, or officials may be the preferable option.

In addition to guiding future protective decisions, Fig. 2 can also be used to determine why a particular protective option was taken in a past event. For example, the decision of some residents to abandon their vehicles and evacuate on foot with the assistance of officials in the 2007 Angora Wildfire in California is puzzling because this option is so risky given the lack of protection against the direct effects of fire (CNN 2007). However, the other three options (e.g., evacuate early by vehicle, in-home shelter, and refuge shelter) were not available to all households because the exiting roads for some residents residing in ignition-prone structures surrounded by fuel were blocked at the onset of the fire, and there was no viable and easily accessible refuge shelter. Fire fighters

therefore had to rescue some residents at the last minute while others sought help from neighbors. While many residents were able to evacuate on their own using a vehicle, others, such as an ignition-prone daycare facility that did not have the means to transport the children to safety, were rescued by emergency responders (J. Morgan, personal communication, El Dorado County Sheriff’s Office (EDSO)—Office of Emergency Services, 2008). In general, the structures in this community were fire-unsafe and ignited each other (Murphy et al. 2007), so in-home SIP was not a viable option. However, the fact that there were no fatalities or injuries indicates that the actions taken to protect the residents were effective.

## Decision Factors

Although the flowchart in Fig. 2 highlights salient decisions in selecting a protective action, it oversimplifies the decision process and conceals a significant challenge associated with this process: the many factors that influence the decisions depicted by the ovals. In other words, what factors in a given scenario would be valuable to know to select the best protective option? For example, the first question of whether a household is willing, able and trained to defend a home relies on information regarding a host of fire and household-related factors (e.g., fire intensity and spread rate, household demographics, preparedness, health). The question regarding the degree to which a home is defensible can also be nontrivial and depends primarily on fire intensity, a home’s ignition zone (Cohen 2000; Sharfran 2008) (i.e., the density and type of fuel immediately surrounding the structure), as well as the construction of the home itself (e.g., ignition-resistant roof, siding, deck). In regards to evacuation, salient factors include fire intensity, the time available before the fire impacts the community, and exit availability (e.g., number, direction and capacity). The remaining flowchart decisions require knowledge of the whereabouts and quality of refuge shelter, as well the geography and fuel context of the routes to this shelter, all factors that may be dynamic and highly uncertain to many residents, particularly renters and transient populations (Drabek 1996).

## Incident Commander Perspective

A second challenge arises in making protective decisions at the community scale. Although the flowchart in Fig. 2 was originally developed to illustrate the decision-making process to households, it can be applied at the community scale by viewing each decision (oval) as applying to a set of homes. In general, incident commanders (ICs) are charged with guiding residents toward one (or more) of these options. This raises the specter of significant variation in household construction, demographics, environmental context, and preparedness within a WUI community. For example, some homes can be highly ignition-resistant while others are veritable tinderboxes. Along the same lines, there can be significant variation in household demographics, health, special needs and preparedness. This complicates the task of identifying a single “best” protective action for a community and may make this goal unattainable. However, this variation, particularly in terms of home ignitability, is generally lower in newer, more-homogenous WUI communities over those where structures were incrementally added over decades (Cova 2005). Also, new WUI subdivisions tend to be significantly more fire-safe and therefore represent a more fertile ground for SIP policy development.

**Table 1.** Factors That Affect Protective-Action Decisions in Wildfires from an Incident Commander Perspective

	Factor	Description	Change
	Fire hazard		
1	Terrain characteristics	Slope, hills, ridges, valleys, and canyons	Static
2	Wind direction	Cardinal direction of wind	Dynamic
3	Wind speed	Wind speed in mph	Dynamic
4	Fuel moisture	Water content in fuel	Dynamic
5	Humidity	Relative humidity	Dynamic
6	Temperature	Air temperature	Dynamic
7	Forecast weather	Predicted temp, wind, and humidity	Dynamic
8	Fire spread rate	Fire advancement in m/min	Dynamic
9	Fire intensity	Rate of fuel consumption	Dynamic
10	Fire direction	Cardinal direction fire is moving	Dynamic
11	Percent contained	0–100% of perimeter suppressed	Dynamic
12	Distance from fire to community	Miles or kilometers	Dynamic
13	Spotting and branding	Embers, spotting ahead of fire	Dynamic
14	Fire suppression resources	Fire fighters, fire engines, and bull dozers	Dynamic
	Community context		
15	Housing density	Structures per unit area	Static
16	Fuel in/around community	Type, pattern, and density	Static
17	Fuel along exiting roads	Distance from road, type, density	Static
18	Structure flammability	Shingle/tile, wood/plaster, . . .	Static
19	Defensible homes	Number, location, quality	Dynamic
20	Number of structures at risk	1, . . . , $n$	Dynamic
21	Number, capacity of exiting roads	1, . . . , $n$ , vehicles per hour	Dynamic
22	Direction of exiting roads	Cardinal direction of exits	Dynamic
23	Shelter/safe zones	Number, location, type, and accessibility	Dynamic
24	Livestock in community	Type and amount	Dynamic
	Warning and evacuation time		
25	Community preparedness	Evacuation plan, notification methods, . . .	Dynamic
26	Population at risk	Total number of persons threatened	Dynamic
27	Time to warn population	Hours and minutes	Dynamic
28	Special needs populations	Elderly, young, disabled, . . .	Dynamic
29	Law enforcement personnel	Number, type, experience, . . .	Dynamic
	Decision-making context		
30	Legal/regulatory context	Regulatory context	Static
31	Political context	External pressure/influence	Dynamic

Note: “Change” is in reference to a 24-h period.

### Factors Influencing Protective-Action Decision Making

To shed light on the perspective of a wildfire incident commander (IC), an initial step is identifying and evaluating factors that affect IC protective-action decision making. An initial list of 31 factors was created with the help of experienced wildland fire fighters (Table 1), and their relative importance in decision making was assessed through interviews with ICs (Drews, F. A., Cova, T. J., Musters, A., and Siebeneck, L. K. “Decision making of wildland fire incident commanders.”). The factors identified are organized into four groups: fire hazard, community context, warning and evacuation time, and policy context. The primary fire-hazard factors include direction, spread rate, intensity, wind and terrain context, but humidity, fuel moisture, and forecasted weather are also important factors in predicting fire behavior. One factor that ICs immediately raised as important is “spotting and branding”—the case where the wind transports embers ahead of a fire front that

ignite spot fires and structures. The principal geographic fire factor is the distance from the fire to a community, and in conjunction with the fire spread rate and direction, the time available before a fire impacts a community can be estimated.

The factors associated with the community context (15–24) can be considered characteristics of a community without its residents. These include the number, density, and flammability of structures, as well the fuel along the exiting roads, an important factor in determining whether a fire might block the exits. The factor “shelter/safe zones” is included to underscore the additional SIP option of refuge shelter, and this factor could be subdivided into the quality, distribution, and capacity of available protective shelter. The warning and evacuation factors (25–29) focus on the challenge of moving people to safety and include the population at risk, available law enforcement personnel, the estimated time to warn people, special needs populations, and the

level of community preparedness. The policy factors are associated with the legal and regulatory context in which incident commanders make decisions, as well as the political context, which represents possible external pressures on emergency managers from elected officials.

In considering these factors, it is important to highlight both their dynamic and uncertain nature in making protective-action decisions. Table 1 lists the factors that typically change in a 24 h period as “dynamic” and the ones that are constant as “static.” The table shows that all the warning/evacuation factors, all but one fire factor, and the majority of the community factors can be dynamic over this time period. The factor of “defensible homes” is considered dynamic because residents can improve the survivability of a structure in the hours leading up to a wildfire (e.g., clearing brush or applying foam). In most scenarios, many of these factors will not be known to a decision maker (IC or resident), or they will be known with some degree of uncertainty (i.e., there may be ignition-prone structures and special needs populations in a community). While scouts on the ground and in the air can gather information for emergency officials regarding a fire’s location, intensity, and movement, these factors are often obscured by smoke and topography to many residents, particularly in areas of high relief. It is easy to see why fire fighters on the ground are frequently drawn into assisting residents in taking protective action rather than their primary task of fire fighting—they know more about the scenario factors and have a greater understanding of how they might affect a given household’s circumstances.

## SIP Challenges

Increasing community awareness regarding SIP as an option in WUI communities raises a number of issues and challenges. This is not surprising as the evacuate-shelter debate in the context of chemical emergencies spans decades and remains largely unanswered without consensus (Sorensen et al. 2004). The focus of research and planning in chemical protective actions is the same key questions of whether a shelter will provide adequate protection and whether there is enough time to evacuate—questions that can rarely be answered with certainty in many scenarios. Thus, the barriers to a general SIP policy are complex in the context of any hazard, but the wildfire case is becoming increasingly critical to address given the rapid residential development in fire-prone areas.

## Learning from Experience

One approach to shedding light on the best protective option in wildfires is to examine past cases where evacuation or shelter was used either successfully or unsuccessfully by one or more households. This approach has been applied in Australia and serves as the basis upon which their current policy has been developed (Handmer and Tibbitts 2005). One key finding from this research is that last-minute evacuations can be dangerous, and some fatalities have been attributed to failed attempts to leave a home at the last minute as a fire approaches (Wilson and Ferguson 1984). In addition to the bushfire fatalities in Australia that have been analyzed, there are cases in the United States (Mutch 2007), and more recently Greece (*U.S.A. Today* 2007), that support the idea that a last-minute dash can be fatal. This lends further support to the Australian efforts to reduce the use of this option with the heuristic, “leave early or prepare, stay and defend.”

Reconstructing the events that led to the protective choices and outcomes of individuals in past fires can be very insightful, but this approach also has limits. For example, if a resident died while evacuating, would s/he have lived had the choice been to defend a home? Similarly, if a resident died while defending a home—would s/he have survived if the option had been to evacuate or seek refuge shelter instead? While there are cases where it is reasonable to assume that a resident would or would not have survived with an alternative strategy, it is important to note that this is an assumption. The same issue also arises in examining the manner in which a given protective action is adopted. For example, would a resident have survived had s/he left a few minutes earlier or sheltered in a different manner (e.g., pool over garage)? Two cases where it is safe to assume that someone would have survived include: (1) substituting a last-minute evacuation or SIP with an early evacuation or (2) substituting an evacuation with SIP when the shelter was never at risk.

Recent fires have produced a range of outcomes in terms of identifying the most appropriate option available at the time of the fire. In the 2003 Cedar Fire in San Diego County, it was discovered that most of the residents near the San Vicente Reservoir that chose in-home shelter did not die, while some that fled at the last minute did (Mutch 2007). This example lends support to the idea that in-home SIP can be superior to evacuating at the last minute when the structure is defensible and relatively clear of fuel, and its residents are active in defending the property. In the 2007 Witch Fire (also in San Diego County), over half a million people were evacuated, and the two fatalities in this event were a Poway couple who did not evacuate (Moore 2007). A reasonably safe assumption in this case is that there would have been no fatalities if this couple had evacuated early. In another recent case, three fatalities occurred in Utah in the 2007 Neola Fire when a farmer attempted to defend his property with the help of two visitors, but they misjudged the fire’s spread rate and intensity (*Deseret News* 2007). In this case, the assumption is that evacuating (or seeking in-place shelter) would have been preferable to defending the property as the fire approached. This case also highlights the challenge of training civilians to make decisions regarding extreme fire behavior they have never encountered. Fire is notoriously difficult to predict, and “burnover” remains a leading cause of fatalities, even among experience wildland firefighters [National Wildfire Coordinating Group (NWCG) 2007].

Another limitation in analyzing past wildfire fatalities arises in ascribing them to different protective strategies post hoc. In this case, there may be ambiguity in regards to the original intent of the deceased regarding their protective strategy. For example, if person’s remains are discovered in a vehicle down the road from their home in the wake of a fast-moving wildfire, this fatality could either be classified as a failed last-minute evacuation or a failed attempt to defend a home (or both). In the case of a failed last-minute evacuation, it is possible that the individual planned to leave but overestimated the available time before the fire’s impact. In the case of a failed attempt to defend a home, the person may have underestimated the intensity of the fire and/or the protection offered by a structure and fled at the last minute. However, ascribing the case to the category of a failed attempt to defend property is only possible with knowledge of the original intent of the homeowner (e.g., prior intent communicated to family or friends). For this reason, the only recorded cases of failed attempts to defend a home are those where victims were found inside or very near their home. This can lead to biased assessments of the success or failure of a given protective action in past

fires and highlights one of the many challenges of observational analysis (i.e., evacuation may be deemed more dangerous than defending a home).

The case where a person or household abandons the goal of defending a home at the last minute before a fire's impact also raises the broader issue of whether promoting the option of defending a home might induce late evacuations (Saillant 2009). This is related to the issue of homeowner inexperience, in that they may not be able to develop realistic expectations of what they are facing when deciding to SIP and defend a home. For example, most WUI homeowners have never experienced an ember shower in low visibility or the roar and radiant heat of a firestorm up close. Even with proper training, health, equipment, and mindset, it is asking a lot of civilians to not misjudge fire behavior and override their flight instinct when a fire crosses their property. The 2006 Esperanza Fire in Southern California served as a reminder that even very experienced fire fighters can misjudge extreme fire behavior [United States Forest Service (USFS) 2007]. Nonetheless, a growing number of cases support the notion that defending a home is a viable option when the right conditions are met.

### **Implicit Goals**

Another challenge posed by in-home SIP is that it can be difficult to separate the decision to protect life from the decision to protect property. This represents a hurdle in formulating and setting policy because educating residents on the option of defending one's home may lead people to take risks that they would not otherwise take if they were solely concerned with protecting life. For example, if a household is ordered to evacuate, they would do so solely with the goal of protecting life. However, assume that the household is presented with the option of evacuating early or defending property, and they decide to defend it. This choice yields an implicit tradeoff between protecting life and protecting property, as they are foregoing the opportunity to leave the threat area safely with an early evacuation (life protection) in hopes of also saving their property. A common solution to this tradeoff is to send some family members out of the threat area (e.g., children) while one or more household members remains behind to defend the home, and this decision reveals a household's perception that evacuation is the best option for protecting life. However, in the case where evacuation is not an option because the exits are blocked, or the margin of error is too small to assure that it is a safe option, the goals of protecting life and property no longer represent competing objectives, and the tradeoff disappears. For this reason, a policy that highlights defending one's home as a viable option when early evacuation is possible risks criticism that the protection of property is to some degree being traded against the protection of life. In the long run, this may be borne out through a rise in a loss of life for homeowners that forego evacuating early to defend their home, but then misjudge the fire's spread rate and intensity, overestimate their capabilities or the protection offered by the structure, or make any number of other errors.

### **Supporting In-Home SIP**

One way to minimize the potential loss of life from having an increasing number of WUI residents defend a home over evacuating early would be to only allow households to take this option that meet high structural, home ignition zone, health, equipment, and training standards—effectively rating (or certifying) house-

holds to defend their property [Wildland Fire Management Section (WFMS) 2004]. Implicit within the associated heuristic, "structures protect people and people protect structures," is the recognition that the structure by itself is not fire proof, as its chance of survival improves by having at least one person defend it. This underscores the risk that a homeowner is taking in potentially falling short of effectively fighting off the fire. In other words, classifying a structure as defensible does not mean that the residents have the capability and resources necessary to successfully defend it, and this may require including the household demographics as well as training, water availability, and equipment to the point where it is actually the household that is being certified rather than the structure. One problem that can arise with this task is that many of these factors are dynamic during an event (e.g., water availability, personal injury, and equipment malfunction), which can affect a household's chance of success. This can make it very difficult to make evacuate-SIP decisions in advance without knowledge of the scenario.

As an example, it is easy to imagine two houses of identical ignition-resistant construction and fuel surroundings, one with an able-bodied, highly trained head of household, and one with a partially disabled head-of-household. Despite an identical ignition context, given the notion that one household cannot exercise the "people protect structures" part of the phrase, it follows that the "house protects people" part of the phrase would be compromised. This also holds for all cases where the head-of-household is not home at the time of the fire (Proudley 2008), resources are compromised (e.g., water unavailable because of a power failure), or fire behavior exceeds anything anticipated. Given the variation in household demographics, available resources, household construction and fuel context, a more honest heuristic may be, "structures can protect people, and people can protect structures."

### **SIP Policy Options**

Moving toward an expanded SIP policy in the United States is a challenging but necessary next step. The geographic variation in building construction types, fire regimes, fuel patterns, demographics, and attitudes is immense. However, the potential advancement in policy in this area is becoming increasingly necessary and actively considered (Saillant 2009). In general, wildfire policy formulation is local and varies by jurisdiction, but in some cases it may vary on a scale as fine as an individual subdivision [Rancho Santa Fe Fire Protection District (RSFFPD) 2004]. Because there are many states with relatively low wildfire risk, the most appropriate scales for setting model policies are likely the community, local and state levels rather than the federal level.

### **SIP as Plan B**

A first step in increasing awareness regarding SIP as a viable protective option is to highlight it as an essential back-up plan in any wildfire community preparedness education program (SIP as Plan B). There are a significant number of WUI residents that are unaware of how valuable and effective SIP done properly can be when evacuation is not an option. The 2008 Tea Fire in California recently highlighted this when an estimated 800 students on the Westmont College were instructed to SIP in the campus gymnasium (Taxin 2008). Along this line, residents need to be aware that evacuation may not be possible in all scenarios, or the circumstances may be uncertain regarding the availability of clear

exiting roads to the point that they may be advised to “stay put” rather than evacuate. Just as WUI households are told to have an evacuation plan, they should also be trained to assess their proximal refuge shelter (e.g., structures, safe zones, neighborhood pools)—essentially a SIP plan. In many cases, the best refuge may be a home if it has been well prepared and the right fire conditions are met. Given that the best option in a given scenario can vary by household, communities may need to consider a “comprehensive wildfire protective plan” rather than an “evacuation plan” which presupposes for all scenarios that evacuation is the best option for everyone.

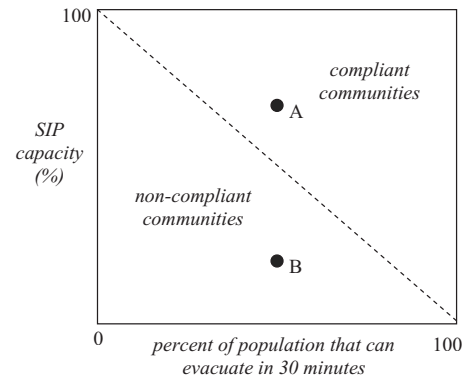
### SIP as Plan A

A more challenging policy problem arises in the case where early evacuation is an option, but residents wish to SIP and defend their property (SIP as Plan A). This option requires an expert assessment of a structure, home ignition zone, household demographics, special needs, equipment, training, and a host of fire-related factors to arrive at an answer to the question of whether a household has a reasonable chance of defending a home in a given scenario. In prior events, tension has arisen between residents who wish to defend their property and fire fighters who quickly assess that they have not met many (or any) of the necessary conditions to successfully defend a structure. This reveals the conflicting goals of the fire fighter charged with protecting life while fighting the fire and the homeowner who wishes to protect property at any cost. However, our interviews with incident commanders in the western United States indicate that a significant portion are amenable to the idea of residents defending their home if conditions regarding the structure, home ignition zone, equipment, and training are met to their satisfaction (Drews, F. A., Cova, T. J., Musters, A., and Siebeneck, L. K. “Decision making of wildland fire incident commanders.”). This is particularly the case where a household that is not in the immediately area threatened by the fire wishes to defend it against a remote ember attack. A few counties have recently highlighted defending a home as an option in their educational materials for residents [Santa Barbara County Fire Department (SBCFD) 2008; Ventura County Fire Department (VCFD) 2008].

Regardless of the policy that is developed, it is important that it not be based on limiting the available protective options or funneling a community toward one option over another in advance. For example, the city of Rancho Santa Fe in San Diego County developed an advanced plan to SIP [Rancho Santa Fe Fire Protection District (RSFFPD) 2004]. This presupposes that SIP is the best option in all cases, and a better plan would be to alert residents that evacuation may be recommended but ensure that the community is designed to facilitate SIP as well. In the 2007 Witch Fire, an evacuation was recommended for this community and all homes survived regardless of whether a resident was there to defend it or not (Weisberg and Pierce 2007). In some sense this is the best case for a community—residents can stay or go—but in either case the structures are very likely to survive.

### SIP in Low-Egress Communities

The greatest need for moving SIP forward as a protective option may lie in WUI communities where the minimum evacuation time is very high due to constraints imposed by the exiting roads (Cova 2005). This can be generalized to the following rule: the more likely a community may not be able to evacuate in an urgent scenario, the greater the need for SIP as a backup plan. Fig. 3



**Fig. 3.** Hypothetical standard that relates the percent of people in a community that can evacuate in 30 min with the minimum recommended SIP capacity

shows one manner in which this relationship might be codified—as the percent of people that can evacuate in 30-min declines (i.e., an urgent evacuation becomes more problematic), the minimum required SIP capacity rises accordingly. Communities A and B can each clear about 50% of their population in 30 min, but Community A is compliant in that it has excess SIP capacity where Community B falls short of the recommended minimum access to protective shelter. Although this approach advocates SIP as a backup plan (Plan B), some of the best refuge shelter may be well-prepared homes. In general, there is a need to move beyond encouraging SIP preparedness in these communities toward SIP standards and codes.

### SIP and Voluntary Evacuations

In terms of other directions for forwarding SIP practice in the United States, an analogy can be drawn between the Australian recommendation to “leave early or prepare, stay and defend” and a voluntary evacuation order in the United States. In both cases, the decision of whether to stay or go rests with the household. For this reason, more liberal use of voluntary evacuation orders would move a jurisdiction toward the option of letting homeowners decide what to do, an important element of the Australian approach (McCaffrey and Rhodes 2009). The difference with the Australian message is that it adds both a recommendation regarding the timing of an evacuation (early), as well as one regarding a homeowner’s role in actively preparing and defending a home. In the United States, a voluntary evacuation order is often upgraded to a mandatory order as a fire inches closer to a community, so the more common use of a voluntary order is to gradually reduce the number of evacuees in a community as a fire approaches should the need arise to clear everyone later. If a jurisdiction wishes to allow some residents to defend their property, the modification might lie in the ordinance that governs the issuance of mandatory and voluntary evacuations. For example, if the required conditions (or criteria) under which a “mandatory” evacuation order can be issued were narrowed, this would lead to more residents receiving a voluntary evacuation order and therefore being allowed to remain at their home and defend it. This direction comes with new risks and therefore holds the potential to be more controversial than SIP as a backup plan because it would allow some residents to forego evacuating (early) in the hope of defending their home (Wallace 2004).

## Evacuate and SIP Plans

Given that evacuation is not likely to work in all scenarios, as well as for all residents (and neither is SIP), an obvious direction to explore is combining the two approaches. A possible wildfire scenario in a densely populated WUI community is one where some, but not all, residents can evacuate early. This might occur because a fire ignited too close to a community to allow enough time for everyone to evacuate, or the response of some households is delayed to the point where evacuation is no longer an option (e.g., prolonged warning or preparation time). In this case, the most preferable option might be for some households to evacuate, some to SIP, and some to split and adopt both options. In the context of a plan that allows a mix of both evacuation and SIP, the idea of “evacuation time” would need to be replaced with “protection time.” This would allow communities where dire scenarios exist to develop a plan that allows for the entire community to be protected in less time using both evacuation and SIP. As an example, a community protection plan where two hours is available prior to the fire’s arrival might be a straightforward evacuation of the entire community, but a 1-h protection plan might involve some robust households choosing a form of in-place protection to reduce the traffic load while others evacuate early, leading to the case where everyone is either clear of the area or harboring in some form of shelter within 1 h.

## Research and Planning Needs

There are many needs in research and planning regarding wildfire protective actions in general and SIP in particular. Foremost, raising the notion of SIP as an option in wildfires leads to the difficult question of assessing the cases when it eclipses evacuation as the better option, whether from the perspective of a household or a community, as well as whether the better option is in-home SIP to protect property or refuge SIP. This problem lies at the heart of a broader research and planning agenda regarding protective actions in wildfires. The following list of research and planning needs are designed to highlight areas that might lead to an improved understanding of wildfire protective actions in general and SIP in particular:

1. *Advancing protective action theory with wildfires as a special case.* There is a need to develop theoretical and conceptual frameworks to reason about protective actions both in terms of selecting the preferable option (or options) as well as assessing the benefit and cost of each one. Lindell and Perry (1992, 1994) developed the protective action decision model as a conceptual framework for understanding protective actions, but it has not been widely tested. There is also room to advance this theoretical framework in terms of tailoring it to the wildfire case. For example, a significant difference between chemical evacuate-SIP decisions and wildfire evacuation-SIP decisions is that WUI residents have the added opportunity to defend their property against the threat where this issue does not arise in chemical releases.
2. *New methods for determining the quality and accessibility of wildfire shelter.* The focus of the work of Cohens (2000) on the home ignition zone and structural survivability was primarily saving the structure rather than using it to protect life in regards to SIP. However, the same factors that improve a structure’s survivability also improve its viability as in-place shelter (Community bushfire safety 2008). In addition to home defensibility, there is a need to develop methods for determining the quality, capacity and accessibility of refuge shelter in a community, as well as the potential value of this shelter based on a community’s circumstances. This varies widely across WUI communities where some have a substantial amount of high-quality SIP options, and some have almost none.
3. *New methods for incorporating shelter in wildfire planning.* As noted, it is better to develop a comprehensive wildfire protection plan for a community that includes all protective options rather than channeling residents down one path in advance of an event. The same can be said for developing plans that work for all residents regardless of their home ignition zone, structure, demographics, special needs, and equipment and training. This is a planning topic as much as a research topic because it is challenging to assess both how a comprehensive (or mixed) protective plan would work in addition to its benefits and costs in different scenarios.
4. *Case studies of where and when shelter was used successfully or not.* Despite the limitations of observational studies regarding the outcome of past fires, there is still significant value in conducting empirical studies in regards to protective actions in general and shelter use in particular. SIP is used more common than is widely known in the U.S. when considered in all forms. This includes recommendations from incident commanders to stay put, as well as cases where residents choose to voluntarily defend their home or SIP by other means.
5. *Protective-action decision theory.* What are the factors that influence the decision to evacuate or seek shelter and how are they combined? This question represents a significant research challenge in and of itself. Certainly all aspects of the fire including location, direction, and behavior to forecasted winds, fuel patterns, lead time and topography all need to be included. However, there is also a need to consider many aspects of the human dimension including warning systems, quality and accessibility of in-place shelter, preparedness measures, exiting roads, fire-fighting resources, demographics, legal and regulatory context, among many others. Table 1 depicts an initial cut at articulating some of the factors that enter into the decision of whether to evacuate or seek shelter from an emergency manager’s perspective, but much more needs to be done in this area.
6. *Uncertainty and incompleteness.* How does uncertainty vary across the factors noted in the prior research area? While some of these factors are nearly constant and known with great certainty, others are dynamic and uncertain. This uncertainty can also vary by decision maker in that one resident may be able to clearly assess an approaching fire while others with limited visibility may not. Similarly, while a resident may have very detailed knowledge of a community’s exits, a visitor may have little knowledge of their surroundings. Unfortunately there are a number of factors that fall in the category of dynamic and uncertain to many decision makers, especially from the point of view of residents. While incident commanders may be able to send scouts on the ground and in the air to gather information about an advancing wildfire, residents are often in smoke-obscured areas with little information about the dynamics of the fire (e.g., direction, intensity, and spread rate) or surrounding traffic (e.g., pattern, delay).
7. *Community protective action adoption.* There are many questions regarding the degree to which SIP can viably be adopted in different jurisdictions as well as the receptiveness

of a community to this option. What options are available to which residents and in what percentages? There are likely to be community members that are very receptive to in-home or refuge SIP as a viable option, while others will prefer evacuation whenever possible. Others will not be able to evacuate without assistance, yet some will be amenable to having all options available. Understanding which options are available to which households, communities and jurisdictions is a significant geographic challenge at multiple scales.

8. *Timing wildfire protective actions.* There are many issues that arise as to which protective action should be issued and when. In many cases the “when” question is as important as the action being taken. Prior research supports the idea that a late evacuation is dangerous (Krusel and Petris 1992; Handmer and Tibbits 2005), but there is little research on what constitutes early and late in different scenarios or across households. The binary early-late division seems simple enough in the case when there is substantial time (early) or almost none (late), but a significant gray area exists in the middle where it is easy to make errors in timing. Research on modeling wildfire protective-action trigger points (Cova et al. 2005; Dennison et al. 2007) as well as empirical studies on the timing of protective actions in past wildfires (Kim et al. 2006) may be able to shed light on developing strategies for educating incident commanders and residents on when it is too late to evacuate or seek proximal refuge shelter.
9. *“Compliance” with stay or go recommendations.* One challenge with recommending more than one protective option to residents is that it can be difficult to assess “compliance” with the recommendation. In a traditional evacuation context, compliance is defined as the percentage of people that adopt a recommended protective action. For example, Dombroski et al. (2006) provide a method for comparing compliance with either an evacuation or SIP recommendation in the context of a radiological emergency. However, a recommendation to “evacuate or SIP” would lead to 100% compliance in all cases because these two categories exhaust the universe of protective options. If the recommendation is to, “evacuate early or SIP,” then evacuating too late could be viewed as one form of noncompliance. In the Australian case where residents are told to “leave early or prepare, stay and defend,” noncompliance could be defined as either a late evacuation or failing to properly prepare and defend a home. Under the assumption that some means for precertifying WUI residents to defend their homes exists, then noncompliance might be defined as defending a home without proper training and certification. In any case, to bring wildfire protective recommendations in line with the wealth of research on compliance for other hazards, a suitable definition of compliance for recommendations that allow more than one option will need to be developed.
10. *Fire behavior in WUI communities.* While significant progress has been made toward understanding structure ignitability in WUI communities (Cohen 2000), more research is needed on examining fire behavior within communities, as well as the effectiveness of fuel treatments and fire suppression efforts. This would depend on fuel characteristics in and around a community, construction type, housing density, and local fire fighting resources to yield the expected fire behavior in and around the structures in the community. This same line of research could explore the viability and capacity of safe areas (e.g., size and shape), as well as the design and landscaping of communities to provide areas of SIP refuge.

While research and planning in this area is advancing (Spyratos et al. 2007; Syphard et al. 2007), there is more opportunity to advance the science of fire behavior in and around communities and its relation to protective actions in wildfires.

## Conclusions

Ongoing residential development in the WUI is precipitating the need for new approaches to public safety in wildfires. Evacuation is the most common form of protective action in a wildfire, but WUI communities and households face a growing number of scenarios where evacuation may be too risky or not feasible. The best strategy is to build communities, raise awareness, and develop emergency plans that offer all options for protection, as plans that channel residents to either evacuation or SIP in advance reduce the latitude of incident commanders and residents. Given that WUI communities vary in many regards from structure ignitability to demographics and special needs, a possible direction to explore is comprehensive (or mixed) protective plans where some households (or household members) evacuate early while others adopt in-place protection in either a home or by means of proximal refuge shelter. Although in-home SIP is being actively pursued in Australia as well as some initial counties in California (Saillant 2009), there are many households and communities in the WUI where this option is not feasible or desired, and a greater deal of attention should be placed on refuge SIP in all its forms in cases where evacuating or defending a home are too risky.

There is a significant division between SIP as a backup plan in cases where evacuation is not possible and in-home SIP as a strategy for improving structure (home) survivability. In the former case, there is less potential for controversy, as it is becoming increasingly clear that many WUI communities and households cannot evacuate across the continuum of scenarios they might face. However, in the case where early evacuation is an option but households choose in-home SIP to protect their property, an implicit tradeoff is introduced between protective life and protective property. Pursuing this second option of allowing residents to forego early evacuation to protect property will require research into issues surrounding structure defensibility, timing protective actions, health issues, training residents to fight fires, special populations, among many other areas. There are a significant number of unknowns in moving in this direction that may take quite awhile to resolve. However, there are many opportunities for improving protective action decision-making and options in WUI communities in the United States, and the need for this is clearly growing.

## Acknowledgments

This work was supported by NSF under Grant No. CMMI-065372. The writers thank Phil Dennison, Dave Lemberg, Mike Lindell, Bill Mills (Boulder High Class of '65), Christina Randall, Dave Theobald, Lee Wensel, Dave Williams, and the anonymous reviewers for valuable comments.

## References

- Australasian Fire Authorities Council (AFAC). (2005). “Position paper on bushfires and community safety.” (<http://www.afac.com.au>) (Nov. 28, 2008).

- Blackwell, J. A., and Tuttle, A. (2003). *California fire siege 2003: The story*, California Department of Forestry and Fire Protection and U.S. Forest Service, Sacramento, Calif.
- CBS. (2007). "Pool plunge saves couple from wildfire: They stay under rock in water for almost four hours, watching home burn to ground." *The early show*, (<http://www.cbsnews.com/stories/2007/10/30/earlyshow/main3429071.shtml>).
- Chen, X., and Zhan, F. B. (2008). "Agent based modeling and simulation of urban evacuation: Relative effectiveness of simultaneous versus staged evacuation strategies." *J. Oper. Res. Soc.*, 59(1), 25–33.
- Church, R. L., and Sexton, R. M. (2002). "Modeling small area evacuation: can existing transportation infrastructure impede public safety?" (<http://www.ncgia.ucsb.edu/vital/research/pubs/200204-Evacuation.pdf>) (July 2, 2008).
- CNN. (2007). "Blaze near Lake Tahoe 'spots' across fire line." (<http://www.cnn.com/2007/US/06/26/wildfires/index.html>) (Nov. 12, 2008).
- Cohen, J. D. (2000). "Preventing disaster: Home ignitability in the wildland-urban interface." *J. For.*, 98, 15–21.
- Cohn, P. J., Carroll, M. S., and Kumagai, Y. (2006). "Evacuation behavior during wildfires: Results of three case studies." *West. J. Appl. For.*, 21(1), 39–48.
- Community bushfire safety*. (2008). Handmer, J., and Haynes, K., eds., CSIRO Publishing, Australia.
- Cook, R. (2003). "Show low Arizona inferno: Evacuation lessons learned in the Rodeo-Chediski fire." *NFPA J.*, 10–14.
- Cova, T. J. (2005). "Public safety in the urban-wildland interface: Should fire-prone communities have a maximum occupancy?" *Nat. Hazards Rev.*, 6(3), 99–108.
- Cova, T. J., Dennison, P., Kim, T., and Moritz, M. A. (2005). "Setting wildfire evacuation trigger-points with fire spread modeling and GIS." *Transactions in GIS*, 9, 603–617.
- Cova, T. J., and Johnson, J. P. (2002). "Microsimulation of neighborhood evacuations in the urban-wildland interface." *Envir. Plan. A*, 34, 2211–2229.
- Dash, N., and Gladwin, H. (2007). "Evacuation decision making and behavioral responses: Individual and household." *Nat. Hazards Rev.*, 8(3), 69–77.
- Dennison, P. E., Cova, T. J., and Moritz, M. A. (2007). "WUIVAC: A wildland-urban interface evacuation trigger model applied in strategic wildfire scenarios." *Natural Hazards*, 40, 181–199.
- Deseret News*. (2007). "Killer Utah fire still raging." (<http://deseretnews.com/dn/view/0,1249,680195569,00.html>) (Oct. 18, 2008).
- Dombroski, M., Fischhoff, B., and Fischbeck, P. (2006). "Predicting emergency evacuation and sheltering behavior: A structured analytical approach." *Risk Anal.*, 26(6), 1675–1688.
- Dow, K., and Cutter, S. L. (2002). "Emerging hurricane evacuation issues: Hurricane Floyd and South Carolina." *Nat. Hazards Rev.*, 3(1), 12–18.
- Drabek, T. E. (1996). *Disaster evacuation behavior: Tourists and other transients*, Institute of Behavioral Science, Univ. of Colorado, Boulder, Colo.
- Ewert, A. W. (1993). "The wildland-urban interface: Introduction and overview." *J. Leisure. Res.*, 25, 1–5.
- Gladwin, C. H., Gladwin, H., and Peacock, W. G. (2001). "Modeling hurricane evacuation decisions with ethnographic methods." *Int. J. Mass Emerg. Disasters*, 19, 117–143.
- Haight, R. G., Cleland, D. T., Hammer, R. B., et al. (2004). "Assessing fire risk in the wildland-urban interface." *J. For.*, 102(7), 41–48.
- Handmer, J., and Tibbits, A. (2005). "Is staying at home the safest option in bushfires? Historical evidence for an Australian approach." *Environ. Haz.*, 6, 81–91.
- Kim, T. H., Cova, T. J., and Brunelle, A. (2006). "Exploratory map animation for post-event analysis of wildfire protective action recommendations." *Nat. Hazards Rev.*, 7(1), 1–11.
- Krusel, N., and Petris, S. (1992). "Staying alive: Lessons learnt from a study of civilian deaths in the 1983 Ash Wednesday bushfires." *Fire Management Quarterly*, 2, 1–17.
- Kumagai, Y., Carroll, M. S., and Cohn, P. (2004). "Coping with interface fire as a human event: Lessons from the disaster/hazards literature." *J. For.*, 102(6), 28–32.
- Lindell, M. K. (2008). "EMBLEM2: An empirically based large-scale evacuation time estimate model." *Transp. Res., Part A: Policy Pract.*, 42, 140–154.
- Lindell, M. K., and Perry, R. W. (1992). *Behavioral foundations of community emergency planning*, Hemisphere Press, Washington, D.C.
- Lindell, M. K., and Perry, R. W. (2004). *Communicating environmental risk in multiethnic communities*, Sage Publications, Thousand Oaks.
- McCaffrey, S. M. (2004). "Thinking of wildfire as a natural hazard." *Soc. Nat. Resour.*, 17(6), 509–516.
- McCaffrey, S. M., and Rhodes, A. (2009). "Public response to wildfire: Is the Australian stay and defend or leave early approach an option for wildfire management in United States?" *J. For.*, 107(1), 9–15.
- Mileti, D. S., and Sorensen, J. H. (1990). *Communication of emergency public warnings: A social science perspective and state-of-the-art assessment*, Federal Emergency Management Agency, Washington, D.C.
- Moore, S. (2007). "Bodies are found on burned hilltop." *New York Times*, Oct. 26, (<http://www.nytimes.com/2007/10/26/us/26dead.html>).
- Mozumder, P., Raheem, N., Talberth, J., and Berrens, R. P. (2008). "Investigating intended evacuation from wildfires in the urban-wildland interface: Application of bivariate probit model." *For. Policy Econ.*, 10(6), 415–423.
- Murphy, K., Rich, T., Sexton, T. (2007). "An assessment of fuel treatment effects on fire behavior, suppression effectiveness, and structure ignition of the Angora Fire." *Rep. No. RS-TP-025*, United States Department of Agriculture (USDA).
- Mutch, R. W. (2007). "Faces: The story of the victims of the Southern California's 2003 fire siege." *Wildland Fire Lessons Learned Center*, (<http://www.wildfirelessons.net/documents/FACES.pdf>) (July 2007).
- National Wildfire Coordinating Group (NWCG). (2007). "Wildland fire fighter fatalities in the United States—1990–2006." *Rep. No. PMS-841*, NWCG—Safety and Health Working Team.
- Packman, D. R. (1995). "Evacuation in wildfires: The Australian experience." *Wildfire*, June, 25–30, ([http://www.nweg.gov/pms/pubs/pms841\\_all-72dpi.pdf](http://www.nweg.gov/pms/pubs/pms841_all-72dpi.pdf)) (Nov. 21, 2008).
- Paveglio, T., Carroll, M. S., and Jakes, P. J. (2008). "Alternatives to evacuation—Protecting public safety during wildland fire." *J. For.*, 106(2), 65–70.
- Perry, R. W. (1985). *Comprehensive emergency management: Evacuating threatened populations*, JAI Press, Greenwich, Conn.
- Proudeley, M. (2008). "Fire, families and decisions." *The Australian Journal of Emergency Management*, 23(1), 37–43.
- Pyne, S. J. (2001). *Year of the fires: The story of the great fires of 1910*, Viking, New York.
- Radeloff, V. C., Hammer, R. B., Stewart, S. I., Fried, J. S., Holcomb, S. S., and McKeefry, J. F. (2005). "The wildland-urban interface in the United States." *Ecol. Appl.*, 15(3), 799–805.
- Rancho Santa Fe Fire Protection District (RSFFPD). (2004). *Sheltering in place during wildfires: A modern approach to living safely in a wildland-urban interface community*, Rancho Santa Fe Fire Protection District, Rancho Santa Fe, Calif.
- Saillant, C. (2009). "Southern California fire chiefs debate stay-and-defend program." *Los Angeles Times*, Jan. 13.
- Santa Barbara County Fire Department (SBCFD). (2004). *Living with wildfire: A guide for homeowners in Santa Barbara County*, Santa Barbara Fire Department, Santa Barbara, Calif.
- Santa Barbara County Fire Department (SBCFD). (2008). *Your wildfire action plan: Should I stay or should I go?* Santa Barbara County Fire Department, Santa Barbara, Calif.
- Sharfran, A. P. (2008). "Risk externalities and the problem of wildfire risk." *J. Urban Econ.*, 64(2), 488–495.
- Sorensen, J. (2000). "Hazard warning systems: Review of 20 years of progress." *Nat. Hazards Rev.*, 1(2), 119–125.
- Sorensen, J. H. (1991). "When shall we leave? Factors affecting the timing of evacuation departures." *Int. J. Mass Emerg. Disasters*, 9, 153–165.
- Sorensen, J. H., Shumpert, B. L., and Vogt, B. M. (2004). "Planning for protective action decision making: Evacuate or shelter-in-place." *J.*

- Hazard. Mater.*, 109(1–3), 1–11.
- Southworth, F. (1991). “Regional evacuation modeling: A state-of-the-art review—Oak Ridge National Laboratory.” *ORNL*, TM-11740, (<http://eme.ornl.gov/CSEPPweb/data/Evacuation%20Documents/Evacuation%20Models/ORNL46280.pdf>) (Aug. 20, 2008).
- Spencer, B. G. (1958). *The Big Blowup: The Northwest's great fire*, Caxton Printers, Ltd., Caldwell, Id.
- Spyratos, V., Bourgeron, P. S., and Ghil, M. (2007). “Development at the wildland-urban interface and the mitigation of forest-fire risk.” *Proc. Natl. Acad. Sci. U.S.A.*, 104(36), 14272–14276.
- Syphard, A. D., et al. (2007). “Human influence on California fire regimes.” *Ecol. Appl.*, 17(5), 1388–1402.
- Taxin, A. (2008). “Santa Barbara fire doesn’t spare Westmont College.” *The Mercury News*, Nov. 14.
- Theobald, D. M., and Romme, W. (2007). “Expansion of the U.S. wildland urban interface.” *Landsc. Urban Plann.*, 83(4), 340–354.
- Tierney, K. J., Lindell, M. K., and Perry, R. W. (2001). *Facing the unexpected: Disaster preparedness and response in the United States*, Joseph Henry, Washington, D.C.
- United States Forest Service (USFS). (2007). “Esperanza fire accident investigation report: Riverside County, California.” ([http://www.fire.ca.gov/fire\\_protection/fire\\_protection\\_memorial\\_esperanza.php](http://www.fire.ca.gov/fire_protection/fire_protection_memorial_esperanza.php)) (Oct. 26, 2006).
- U.S.A. Today*. (2007). “Greek wildfires bring stories of death, survival.” ([http://www.usatoday.com/weather/wildfires/2007-08-28-greek-wildfires\\_N.htm](http://www.usatoday.com/weather/wildfires/2007-08-28-greek-wildfires_N.htm)) (June 7, 2008).
- Ventura County Fire Department (VCFD). (2008). *Wildfire action plan: Your first weapon against wildfire*, Ventura County Fire Department, Santa Barbara, Calif.
- Vogt, B. M. and Sorensen, J. (1992). “Evacuation research: A reassessment.” *Rep. No. ORNL/TM-11908*, Oak Ridge National Laboratory.
- Wallace, G. (2004). “To go or not to go: Can that ever be a legitimate question in fire country?” *Home & Fire*, Summer, 9–15, ([http://www.firewise.org/resourecs/files/Resources\\_for\\_Life/To%20Go%20or%20Not%20To%20GO.pdf](http://www.firewise.org/resourecs/files/Resources_for_Life/To%20Go%20or%20Not%20To%20GO.pdf)).
- Weisberg, L., and Pierce, E. (2007). “Shelter in place kept flames at bay.” *San Diego Union Tribune*, (<http://www.signonsandiego.com/news/metro/wildfires/20071202-9999-1n2shelter.html>) (Dec. 2, 2008).
- Wildland Fire Management Section (WFMS). (2004). “When wildfire threatens: Should residents stay or evacuate?” *National Fire Protection Agency*, ([http://www.firewise.org/resources/files/Resources\\_for\\_Life/](http://www.firewise.org/resources/files/Resources_for_Life/)) (May 2, 2008).
- Wilson, A. A. G., and Ferguson, I. S. (1984). “Fight or flee? A case study of the Mount Macedon Bushfire.” *Australian Forestry*, 47(4), 230–236.
- Wolshon, B., and Marchive, E., III. (2007). “Emergency planning in the urban-wildland interface: Subdivision-level analysis of wildfire evacuations.” *J. Urban Plann. Dev.*, 133(1), 73–81.