CHAPTER

Bridging two cultures of fire risk at the wildland-urban interface: The case of Haifa, Israel

1.1

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CHAPTER OUTLINE

1.1.1 Introduction

Fire regimes (or the long-term nature of fires in an ecosystem) (Brown, 2000) are commonly described based on the specific intensity, severity, seasonality, frequency, and pattern of the fire. These characteristics are themselves determined by weather (i.e., temperature, humidity, and wind), climate, vegetation, and topography, as well as by human factors, such as proximity to roads, trails, picnic areas, and habitations (Moreno et al., 2014). Different combinations of these factors give rise to different fire regimes. In Mediterranean ecosystems, fire regimes have changed in the past decades (Spyratos

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et al., 2007), particularly due to an increase in the severity of wildfires developing at the wildland-urban interface (WUI) (Calkin et al., 2014; Mell et al., 2010; Moreno et al., 2014; Radeloff et al., 2018).

The WUI is an area where built structures are in close proximity and intermingle with the peri-urban forest and other vegetated areas (Radeloff et al., 2005). The definition of its depth varies between 50 to 200 m around built-up areas and between 100 to 400 m around forested areas, depending on the system (Modugno et al., 2016). Some authors distinguish an "intermixed zone," where houses and wildland vegetation directly intermingle, and an "interface zone," where houses border wildland vegetation (Radeloff et al., 2018).

The term WUI is nearly exclusively used in the context of fire risk (i.e., a combination of the hazard features—fire in this case—and of the vulnerability of the system), this due to the combination of three elements: the human presence, wildland vegetation, and the narrow distance between them. Together these represent the potential for fire impacts (Stewart et al., 2007). At the WUI, the risk of fires is thus the result of two unmanaged growths: unrestricted and poorly planned urban expansion, and the unmanaged growth of the vegetation (Bar-Massada et al., 2014; Pyne, 2001). The main drivers behind the growth of the WUI are the desire of homeowners to be close to open spaces, in proximity to nature and recreational opportunities, and the search for affordable housing and/or privacy (Ewert, 1993; Hendricks and Mobley, 2018; Stewart et al., 2007). As a result, the spatial expansion of the WUI has been demonstrated to be the most important factor driving the increase in fire-suppression expenditures in the United States (Clark et al., 2016).

In order to take the necessary steps to identify enhanced adaptation strategies, it is fundamental to better understand these new sources of risk. In this chapter, we identify some of the specific elements of the system that co-determine fire risk (and then adaptation) at the WUI, and how these factors differ from those generally characterizing forest-fire risk in the open forest. With this aim in mind, we define risk as the combination of the hazard (wildfire in this case) and the vulnerability of the system. Vulnerability is itself generally described as a combination of: exposure (i.e., "the extent to which a unit of assessment falls within the geographical range of a hazard event"); susceptibility (i.e., "the predisposition of elements at risk to suffer harm"); and lack of coping capacity (i.e., the "limitations in terms of access to, and mobilization of, the resources of a community or a social-ecological system in responding to an identified hazard") (Birkmann et al., 2013, p. 200). As expressed by Priority 1 of the Sendai Framework (SF) for Disaster Risk (Understanding Disaster Risk), it is essential to characterize these components of risk to design tailored adaptation strategies (adaptation being the "longer-term and constantly unfolding process of learning, experimentation and change that feeds into vulnerability" to reduce risk) (Birkmann et al., 2013, p. 196). The chapter contributes to meeting Priority 1 of the SF by identifying the factors and specific characteristics of forest fire risk at the WUI and potential adaptation strategies, starting from the analysis of the available literature and following with an in-depth case study application focusing on the city of Haifa, in Israel. We thus target understanding disaster risk at the local level particularly contributing to the following subtask: "to apply risk information in all its dimensions of vulnerability, capacity and exposure of persons, communities, countries and assets, as well as hazard characteristics, to develop and implement disaster risk reduction policies" (Sendai Framework Priority 1, point 24, letter n).

In Section 1.1.1.1 we describe the social-ecological-technological systems (SETS) framework, which we apply toward a holistic understanding of fire risk at the WUI. We then analyze the literature on the topic to identify and discuss the main known factors contributing to this risk, especially in Mediterranean systems (Section 1.1.1.2). We then look at the available adaptation strategies to reduce sources of fire risk at the WUI, as identified in the relevant literature (Section 1.1.1.3). The subsequent sections focus on the characterization of fire risk at the WUI in the city of Haifa and on the identification and evaluation of potential adaptation strategies. Section 1.1.2 presents the methodology used for studying the target area, Section 1.1.3 the results, Section 1.1.4 the discussion, and Section 1.1.5 the conclusions.

1.1.1.1 The social-ecological-technological systems (SETS) framework

To analyze the literature on factors determining fire risk at the WUI, we adopt the social-ecological-technological systems (SETS) framework (Depietri and McPhearson, 2017; McPhearson et al., 2016a, 2016b). This integrated framework is specifically tailored to analyze environmental problems in the urban context where technological considerations assume an important role, one which is often neglected in the traditional conceptualization of coupled social-ecological systems (SES) (e.g., Folke, 2006; Walker et al., 2004). In the urban context, ecosystem services (e.g., water supply, water purification, water infiltration or urban cooling through the presence of vegetation) are often coproduced by ecosystem functions, human inputs, and technological solutions, as it is rarely possible to rely only on the services provided by unmanaged ecosystems (Depietri et al., 2016). In this way, the SETS framework adds previously overlooked dimensions to the understanding of urban ecosystems. The framework, presented in Fig. 1.1.1, is adopted here to analyze the challenge of fire risk at the WUI, which is indeed a multidimensional problem in which the social, ecological, and technological factors of risk are all important and often interrelated.

1.1.1.2 Forest-fire risk at the wildland urban interface in Mediterranean ecosystems

Mediterranean ecosystems, characterized by wet, mild winters, and dry, hot summers, are particularly fire prone (Pereira et al., 2017; Pyne, 2009). Expanding suburbanization and abandonment of traditional rural lifestyles, accompanied by a reduction in traditional agrarian activities, have further increased fire risk in these areas (Galiana-Martin et al., 2011). More recently, the WUI has become the focus of attention as an area particularly prone to fires, not least because of the high exposure of people, buildings, and infrastructures. Fire-related losses, land abandonment, and urban sprawl are highly interdependent in Mediterranean ecosystems (Darques, 2015), where the distribution of large burned surfaces are often found in close vicinity to cities (Modugno et al., 2016).

Based on a selection of studies from the literature addressing wildfire risk at the WUI, Table 1.1.1 lists the main factors contributing to wildfire risk in Mediterranean ecosystems as resulting from the combination of hazard features (a) and vulnerability of the system (itself a combination of exposure, susceptibility, and lack of coping capacity; b, c, and d, respectively). The components of risk are characterized according to the three dimensions of the SETS framework (i.e., social, ecological, and technological), depicting fire risk at the WUI as a distinctly multidimensional problem. Depending on the context, each of the listed variables and factors plays a unique role in creating fire risk. For instance, although ecological factors (e.g., type of trees, the continuity, density, and homogeneity of the forest) leading to fire regulating services or disservices (see Depietri and Orenstein, 2019) often play a major role in causing fire risk in large and sparsely inhabited forests, at the WUI the social (e.g., education and age of the population), economic (e.g., income and insurance), and technological

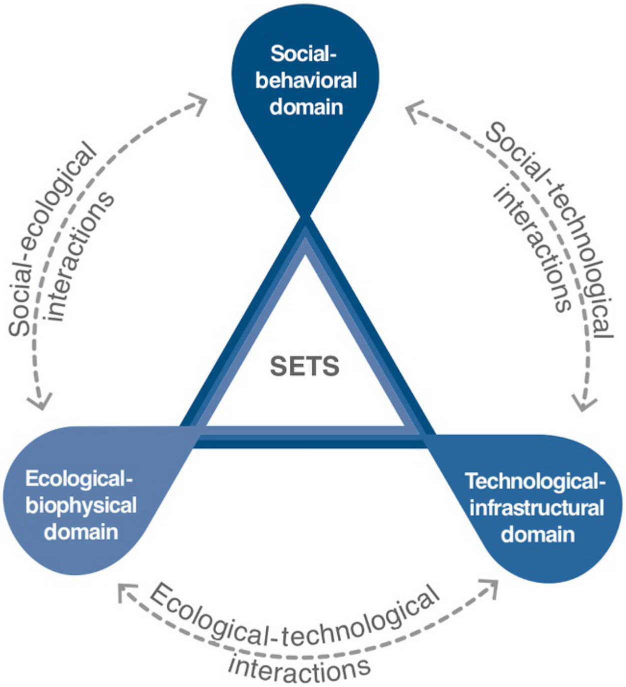

FIG. 1.1.1

The social-ecological-technological systems (SETS) framework.

Source*: Depietri, Y., McPhearson, T., 2017. Integrating the grey, green, and blue in cities: nature-based solutions for climate change adaptation and risk reduction. In: Kabisch, N., et al. (Eds)., Nature-Based Solutions to Climate Change Adaptation in Urban Areas, Theory and Practice of Urban Sustainability Transitions. Springer, Cham, pp. 91–109. doi:10.1007/978-3-319-56091-5_6.*

(e.g., flammability of the built-up area) components also significantly contribute in determining the vulnerability of the system, and consequently its risk. As depicted in Table 1.1.1, it emerges that in the urban context, the technological component is important to the understanding of fire risk, in contrast to the focus on the ecological dimension in the open forest.

1.1.1.3 Adapting to forest fires at the WUI: State of the art

Based on the characterization of fire risk at the WUI depicted in the previous section, adaptation strategies can be identified to address this new configuration of risk. These strategies are unique to the WUI context, rather than simply variations of those usually adopted to prevent and combat forest fires in the open forest. At the WUI, adaptation strategies for dealing with fire risk need to target all the social, ecological, and technological dimensions of the system at risk, as exemplified in Table 1.1.2.

While current approaches for managing wildfire risk focus primarily on forest management and fire suppression (Mahmoud and Chulahwat, 2018), at the WUI additional efforts are needed to define zoning guidelines for the management of vegetation (including buffer zones) and building codes (Pyne, 2001). According to the literature reviewed, strategies in these areas must consider that when people

Table 1.1.1 Factors determining vulnerability and fire risk at the WUI, classified according to the three SETS framework categories (i.e., the social, ecological, and technological) and to the components of risk: hazard (a) and vulnerability in its three components of: exposure (b), susceptibility (c), and coping capacity (d).

Social	Ecological	Technological
(a) Hazard		
Intentionally or accidentally set fires	Biomass (fuel) quantity and height, vegetation type, age and structure, presence of natural firebreaks (e.g., ponds, rivers, assemblages of little flammable vegetation) Weather, climate Soil characteristics Landscape diversity, spatial and structural patchiness Topography, elevation	Proximity to roads and picnic areas (i.e., ignition probability) Flammable material outside of residential units (e.g., piles of wood, dead vegetation, garbage, construction material, flammable liquids or gas)
(b) Exposure		
Density of the population	Biomass of the vegetation; concentration of animal species with restricted mobility or limited habitat	Density of built-up areas, number of dwellings; infrastructure of different types (e.g., roads, railroad tracks, energy infrastructure) Houses, buildings and infrastructure design and location with respect to topography (slope inclination) Recreational and aesthetic amenities
(c) Susceptibility		
Income, employment status Mobility Homeowner behavior Legislation, law enforcement	High concentration of high biomass, invasive and little adapted plant species; endangered animal species	Flammability properties of residential units (e.g., external and internal walls and roofing materials) Flammable material located inside residential units (e.g., nylon curtains, rugs, polyurethane furniture)
(d) Coping capacity		
Early warnings Availability of evacuation plans	Well adapted and local plant and animal species	Fire and smoke detectors Fire suppression and firefighting; availability of stock of water tanks, trucks, planes, fire brigades Availability of spark arresters

Table 1.1.2 Possible adaptation strategies for addressing fire risk at the WUI, compiled from the literature and classified according to the three components of the SETS framework.

Social	Ecological	Technological
Adaptation		
Preparing and administering education programming and raising awareness	Administering prescribed burns (in the more distant forested areas form the buildings)	Constructing or improving access roads for emergency vehicles
Preparing and distributing evacuation plans	Mechanical thinning, spacing, "limbing," and trimming, reducing stand and canopy density; maintenance of tall trees and big trees of fire-resistant species, while reducing and clearing young trees	Reducing flammability of structures by constructing with noncombustible materials
Provide individual landowners and residents who are at risk with knowledge of the regulations and best practices regarding building codes	Removing "ladder" fuels and surface vegetation	Removing flammable material (e.g., garbage or construction materials) from around buildings
Providing government incentives and regulations for better urban planning	Maintaining biodiversity and local species; removing invasive species	Implementing land-use plans for building density and location
Providing and maintaining insurance policies	Increasing landscape diversity and patchiness (e.g., through grazing or other agropastoral activities)	Providing fire hydrants, automatic sprinkler systems, cisterns, and other water sources
Reducing socioeconomic inequalities	Creating buffers (around built-up structures) and firebreaks	Securing propane tank storage Installing spark arresters and smoke and fire detectors Constructing watchtowers

build or purchase homes near forest areas, for the improved access to physical, mental, and aesthetic benefits, they also have expectations that their homes will be protected from fire. This situation sometimes precludes certain fire management strategies at the WUI, such as prescribed burns, due to concerns that the fire might escape control, leading to loss of life and property. On the other hand, residents might oppose strategies that are too invasive and might cause a significant change or an alteration of the peri-urban forest, affecting it's cultural value (Depietri and Orenstein, 2020). So, context-specific strategies are needed.

Reducing flammability of buildings is an important strategy for reducing fire risk at the WUI, and this is generally less relevant in open forests (Mell et al., 2010). Flying embers are the principal cause of house ignition at the WUI. Noncombustible materials are recommended to avoid ignition of buildings via embers. Other solutions, like removing wooden roofs, cleaning up garbage and construction materials around homes, building a defensible space, and facilitating access to firefighters, by widening the network of roads between buildings and the forested areas, are all important strategies for dealing with fires at the WUI (Pyne, 2001). According to Syphard et al. (2014), the most effective strategy is that of reducing woody cover by up to 40%, immediately adjacent to structures. While these and other context-specific strategies need to be envisaged in the WUI, the management of the forest should not be neglected in order to reduce fire risk in these areas. Yet, traditionally, the majority of wildfire suppression expenditures at the WUI has been directed toward fire suppression, and less has been invested in forest management policies (Schoennagel et al., 2009) or in technological solutions to reduce susceptibility.

Spatial patterns of urban development at the WUI affect fire risk. Higher-density urban development, for instance, reduces the cost of fire protection and overall fire risk, as most fire-related damage occurs in low-density housing areas (Radeloff et al., 2005). Clark et al. (2016, p. 656) found that "policies to control the spatial pattern of WUI development can be nearly as effective as policies that completely restrict WUI development." Isolated development, which increases fire risk, could be restricted by means of higher fees and taxes relative to those imposed on dense development, to account for higher fire-risk expenditures in these areas. Fire insurance policies could also have higher premiums for isolated development in high-risk areas (Clark et al., 2016).

We note, as Pyne (2018) suggests, that dealing with wildfires at the WUI requires merging two (now separate) approaches to deal with fire risk: one traditionally employed to deal with fires in open forests, and directed toward managing the vegetation, and another applied when dealing with fires in, and immediately outside, buildings. In the Haifa case study that follows, we investigate concretely how the risk from forest fires at the WUI is characterized and dealt with and how, to this end, combining two existing cultures of fire risk is needed to deal more effectively with this new threat.

1.1.2 Studying forest fires at the WUI in Haifa

1.1.2.1 Case study description

The city of Haifa sits on and develops around the northwest slopes of Mount Carmel (elevation 0–525.4 m above sea level) (Fig. 1.1.2). It has a population of about 281,000 inhabitants and is the third largest city in Israel. It is adjacent to the Carmel National Park, whose vegetation consists of different associations of *Pinus halepensis*, *Pistacia palestina*, *Cistus* sp., and *Quercus calliprinos* (Wittenberg and Malkinson, 2009). Similar vegetation is found in the city where the forest penetrates the built-up areas through a network of undeveloped wadis (or dry riverbeds). Most of the forests of the Carmel-Haifa region are the product of afforestation efforts carried out by the Jewish National Fund (or the Keren Kayemeth LeIsrael, KKL) since the beginning of the last century. In many areas, these planted forests are uniform, dense, monocultured, and even-aged, all characteristics that increase fire risk (Amir and Rechtman, 2006; Osem et al., 2008). The region has, in fact, been periodically affected by forest fires that have mostly occurred within the area of the Carmel National Park (such as the major fires in 1989, 1995, and 2010). A new risk of fires at the WUI has recently become evident due to a large urban fire in Haifa in November 2016. This fire was the first major fire in Israel exclusively urban (Tessler et al., 2019). The fire spread through the vegetated areas of the city, destroying 527 apartments in 77 buildings, leaving 1600 people homeless. The dry weather conditions facilitated the formation of a fast-spreading and intense fire, which proved difficult to extinguish. The event made clear to local authorities that the city needs to adapt to a new type of fire regime, not a fire spreading from the adjacent forest of the Carmel National Park, as had previously been considered, but one that originates

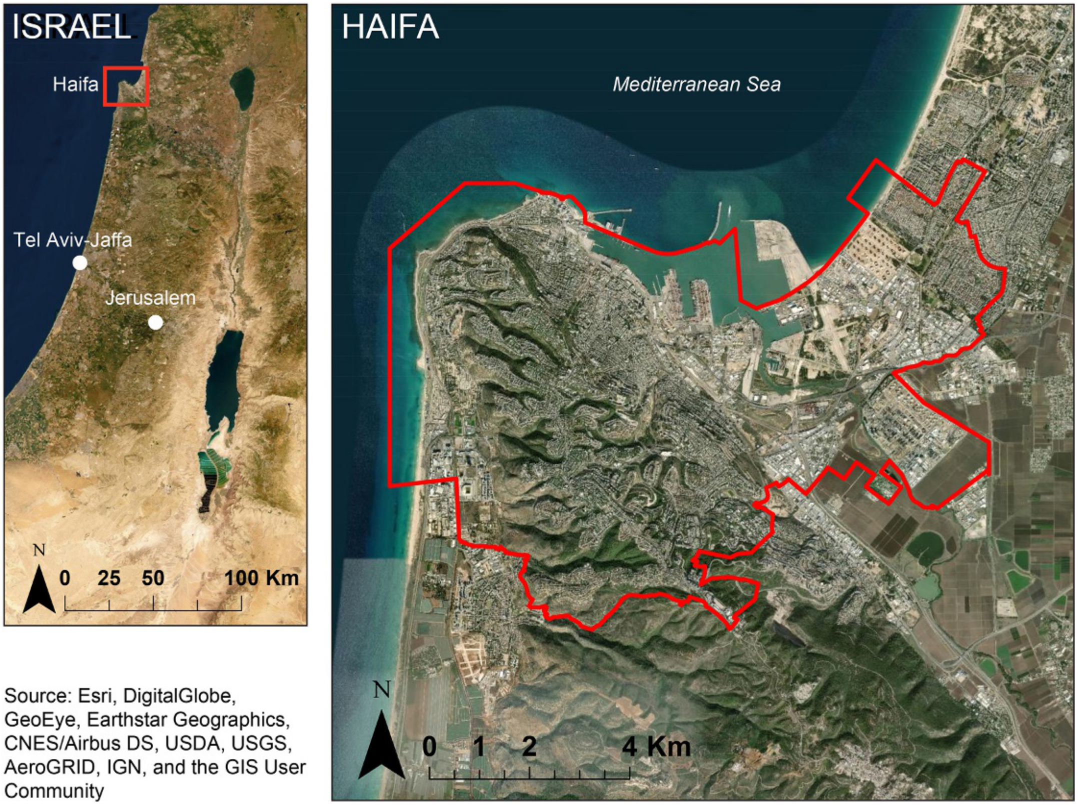

FIG. 1.1.2

Location and satellite map of the city of Haifa.

within the city itself, at the WUI. This requires rethinking fire risk and the development of new strategies for the urban context of Haifa, different than those that had been designed to deal with fire risk in the open areas of the Carmel National Park.

1.1.2.2 Methodology

We began our study of the target area, Haifa, by reviewing professional committee reports produced following the 1989 and 2010 Carmel National Park fires, which provided recommendations for reducing fire risk in the park area (also see Pereira et al., 2017). Next, we conducted 13 in-depth interviews with experts in the field of fire ecology, management, and risk reduction, regarding the factors at play in the context of fire risk in Haifa. The experts included academics, independent experts, and local authorities, and were identified as the community of specialists most informed regarding the case of Haifa and fire risk. Interviewees were asked to identify areas particularly at risk from wildfire within the city and to indicate and comment on the factors of risk for those areas. Areas at risk (up to five for each respondent) were mapped using the online software Scribblemaps (https://www.scribblemaps.com/).

The software allowed respondents, together with the interviewer, to draw polygons on a satellite image of Haifa around areas of high risk. In the second part of the interview, the experts were asked to discuss the relevance to the urban and peri-urban context of five preselected fire-adaptation strategies that had been recommended by the postfire commissions to deal with fire risk in the Carmel National Park. These included: (1) thinning of the vegetation; (2) creating firebreaks and buffers; (3) introducing grazing; (4) removing pine trees; (5) diversifying the landscape and introducing patchiness through other activities, such as planting fruit trees. The experts were asked to assess these strategies to ascertain whether the recommendations given for dealing with the open forest fires in Carmel National Park were also applicable to the case of reducing fire risk at the WUI of Haifa, in the aftermath of the 2016 fire event. They were also asked to provide any additional comments, which often provided complementary and previously unconsidered information for the characterization of fire risk in the city. The interviews were carried out in English and lasted between 60 to 120 minutes. They were then transcribed and analyzed using Atlas.ti (https://atlasti.com/), a qualitative data analysis and research software for identifying common and recurring themes in the transcription of interviews.

We also supplemented the information derived from the interviews with transcripts from public lectures given at a postfire symposium held at the University of Haifa in November 2017, where local authorities, city fire department officials, military personnel, and academics gathered to discuss their institutions' perspectives on fire risk, fire prevention, and firefighting activities, focusing particularly on their experiences from the 2016 Haifa fire and its aftermath.

1.1.3 Results

1.1.3.1 Factors and configuration of fire risk in Haifa

In the initial part of the interviews, we focused on factors contributing to hazard intensity and exposure and less on susceptibility, which, as illustrated in Table 1.1.1c, is represented primarily by the social dimension. There was a consensus among the interviewees that, in the case of fires at the WUI in Haifa, the three main factors determining hazard intensity were: the type, location, height, and density of the vegetation; the orientation of the wadi or the green area with respect to wind direction; and the slope of the wadi and its inclination, especially with respect to the location of the built-up area (which increases exposure). Fig. 1.1.3 indicates the green areas of Haifa specified by the respondents as particularly at risk of fire due to different combinations of these three factors of risk. Most of these areas are concentrated in the southern parts of the city, where there is a prominence of wadis (ephemeral river beds) with an east-west orientation and dense tree growth, and where residential structures and infrastructure are built on the upper slopes of the wadis. Those areas that did not burn in the 2016 fire continue to be characterized by a high concentration of pine trees. Despite these specific areas, the respondents stressed that most of the city is, in fact, at risk from wildfire.

1.1.3.1.1 The hazard

The presence of dense forested areas and tall trees near infrastructures and buildings was considered to be a primary source of risk. Furthermore, while the factors were listed in a different order of relevance by the individual respondents, vegetation characteristics emerged as the primary factor for which intervention and manipulation is possible in order to reduce fire risk in the city.

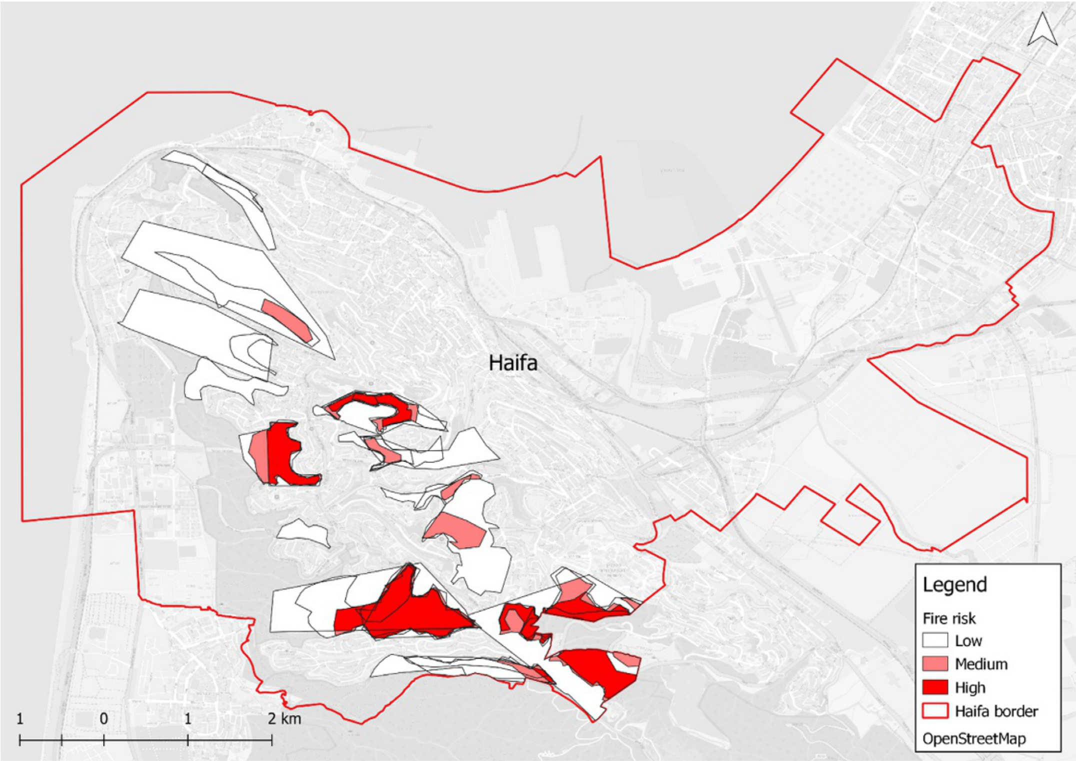

FIG. 1.1.3

Areas at high fire risk as indicated by fire experts.

Source: Depietri, Y., Orenstein, D.E., 2020. Managing fire risk at the wildland-urban interface requires reconciliation of tradeoffs between regulating and cultural ecosystem services. Ecosyst. Serv. 43 (in press).

Highly flammable Aleppo pines, especially those close to buildings, were of utmost concern to the experts. As mentioned, although occurring naturally in small numbers in the area, the widespread distribution of this species of pine in the region is mostly due to historical afforestation activities (Ne'eman et al., 1997). The species was selected for afforestation in the past because it grows quickly, requiring minimal care and water (Stemple, 1998). However, it proved to be invasive, spreading rapidly and contributing to fire risk. Most of the experts interviewed stressed that, the higher the density and the number of tall and mature Aleppo pines, the greater the risk. This species of pine is very flammable and produces fires of high temperatures. Burning cones can be propelled hundreds of meters, which further facilitates the spread of fire to nearby but disconnected forested areas. For some of the experts, the spread of Aleppo pines is the primary driver of more frequent catastrophic fires in Haifa and the Carmel. This represents one aspect of the ecological dimension of the hazard, when we apply the SETS framework to the case of Haifa.

Other biophysical and meteorological factors include the west-east orientation of the wadis, which increases fire risk by interacting with the dry and hot "Sharav" wind, a meteorological condition that greatly increases the occurrence and intensity of fires as it blows from the east. This wind can cause a rapid drop in humidity (to as low as 5%) and a rapid increase in temperature in a very short period of time (raising the temperature by up to 10°C in a span of a few hours).

Wildfires also burn faster and more intensely when climbing up a slope than when spreading along flat ground. According to the experts, a fire on a steep slope will burn with longer flame lengths. Furthermore, the wadis themselves produce a channel effect that leads to an even faster-moving fire. Some experts suggested that considering only the fuel load and the inclination of the slope would suffice in determining areas at high fire hazard. However, some important factors are less predictable, such as the precise wind direction, which can become chaotic once it reaches the urban fabric and the network of wadis.

Other important factors of risk to consider are the proximity of the forest to a road or to areas developed for outdoor activities. Areas of high interest for recreational activities (such as picnic areas) and areas within 50 m from a road were considered to be at higher risk due to the increased chance of inadvertent ignition. The presence of waste (which includes household trash, construction waste, vegetation clippings, and discarded furniture and tires) in the wadis and around buildings could increase fire intensity. These factors fall within the social-technological component of the SETS framework.

1.1.3.1.2 Exposure

If a built-up area, such as a residential area, is located upslope and the slope is steep and densely forested, the exposure and risk of damage from a wildfire increases. The widespread absence of buffer areas between the built-up areas and the forested areas further increases exposure of buildings and people to fires in Haifa. The steep slopes often hamper the construction of roads around the buildings, which, in the words of some experts, greatly increases the exposure of these areas as it makes them virtually indefensible once a fire erupts.

1.1.3.2 Approaches for adapting to fire risk at the WUI in Haifa

As mentioned, prior to the 2016 WUI fire in Haifa, policy makers and managers considered the risk of wildfires as coming primarily from the Carmel National Park, from the south and east of the city. This is in fact where most major fires had occurred in the past and they rarely reached the WUI of Haifa. However, the November 2016 fire, which started within the city and spread through its undeveloped vegetated corridors, made the local authorities and experts aware that the city should be prepared to deal with this new type of fire regime.

Experts were asked about the effectiveness of different ecosystem-based strategies to reduce wildfire intensity and exposure in Haifa among the five management options listed in the methodology section. Here we analyze how their recommendations also differed from those of the post-1989 and post-2010 fire commissions.

1.1.3.2.1 Thinning

Thinning was deemed an important option, but not enough if implemented in isolation. Thinning at the WUI, according to respondents, should be practiced especially to prevent fires from reaching tree canopies and for clearing the vegetation around the buildings. Canopy fires are indeed very difficult to stop, according to the experts. Further, on the steep slopes of Haifa's wadis, the distance between trees should be increased because the fire climbs faster there. Thinning is an effective practice to slow down fires in these cases. Low vegetation should be removed at the end of the summer to prevent ground fires from developing into canopy fires. This practice might detrimentally affect the landscape aesthetic value, according to the experts, but it should still be practiced in specific cases. Despite this widely shared opinion, thinning has not been systematically implemented in the city, even though the 2016 crisis helped create opportunities to advance intensive fire management practices in the context of restoration processes (see Tessler et al., 2019).

1.1.3.2.2 Firebreaks and buffers

In contrast to the recommendations for the Carmel Forest fire risk management, respondents in our research were wary regarding the effectiveness of firebreaks to reduce fire risk at the WUI of Haifa. In 2016, the fire jumped from one side of a road to the other and from one wadi to another. In these conditions, firebreaks would have been of little help. Also, considering that maintenance of firebreaks requires substantial and continued investment and that they affect the aesthetic, recreational, and ecological value of the green areas of Haifa (see also Depietri and Orenstein, 2020), respondents were understandably reticent to recommend them as an appropriate management strategy. Overall, firebreaks were considered the least cost-effective and desirable strategy among the five suggested to deal with wildfire risk in the city.

Buffers around the urban area, with roads to improve the access of firefighters at the precise interface between buildings and the forest, were deemed, in contrast, desirable. Buffers (providing a defensible space) were considered very important to prevent fires from reaching structures. However, some experts feared that a buffer could lead to an elimination of most of the wild vegetation within the city, particularly in the narrowest vegetated areas and wadis. Still, aiming for narrow, defensible buffers, such as the 30 m depth suggested by FEMA (2008), may be proportional to and necessary for the conditions of Haifa. At the same time, defensible buffers accessible by roads for firefighting could provide new recreational opportunities, as the buffers would function as trails or paths for recreational activities. Orchards and gardens could supplant the dense vegetation in these buffer areas and could provide new recreational opportunities for inhabitants to enjoy nature at the WUI. Areas with typical, brush-like *maquis* vegetation would not need significant interventions because of their relatively low flammability. *Maquis* vegetation has high ecological and aesthetic value, it represents the characteristic vegetation of the area and is highly appreciated by city residents (Depietri and Orenstein, 2020).

1.1.3.2.3 Removing pine trees

Little doubt was expressed among the experts that management priority should be given to the removal, or significant reduction, of Aleppo pine trees from most of the green areas of Haifa, and particularly from areas close to buildings. This strategy was considered by some respondents as the most cost-effective ecosystem-management strategy among those suggested. Pine trees should be removed from within a minimum of 10 to 15 m of houses and these areas should be planted, instead, with non- or little flammable, low vegetation (e.g., shrubs) and irrigated plants. Respondents specified that there should be at least 3 m distance between each tree canopy in general, and even further apart in the case of pine trees. As Aleppo pines tend to resprout very easily, intensive management of vegetation would be required in the first few years right after the occurrence of a fire or after the mechanical removal of these trees.

Removing pine trees may face some community opposition, considering that Haifa residents feel that these trees are a natural part of the history and landscape of the city. Respondents recommend that pines be replaced with carob and oak trees, which are local species, and they are shorter and less flammable than pines. Oak trees located very close to buildings should nonetheless be thinned, although different, less strict standards should be applied in their case. Cypress trees are being considered for planting to reduce fire risk in Haifa, as they are less flammable than pines and can slow down the spread of fire.

1.1.3.2.4 Landscape patchiness

Orchards, olive trees, and fruit trees, experts agreed, could be planted in some areas of the wadis to increase landscape patchiness and diversity. These interventions could at the same time improve recreational opportunities (e.g., picnic areas) and increase the aesthetic value of the landscape. However, it may be a challenging practice to implement due to the topography of the city. It would require terracing wadi slopes and would entail additional investments in long-term management. Such strategies can nonetheless be implemented synergistically with the creation of buffer zones.

1.1.3.2.5 Grazing

Experts had some concerns regarding the introduction of domestic grazing in the urban context, mainly due to the need to pay shepherds and due to the potential inconveniences associated with raising herds of domesticated animals within the urban setting, including dangers to traffic and the smells that it might generate. In this regard, fences would need to be erected.

In any case, goats and sheep would be preferable to cattle, as cattle cause more disturbances to the soil, increase dung production, and create other nuisances. Cattle are still more suitable for removing herbaceous vegetation, while goats primarily feed on woody vegetation. The most efficient use of grazing would be to maintain potential firebreaks, but, as noted earlier, that would be of little relevance in Haifa, where firebreaks were considered by experts as ineffective. Local nature enthusiasts were positively predisposed to introducing grazing into Haifa's wadis, as reported in a companion study (Depietri and Orenstein, 2020).

1.1.3.2.6 Other strategies

Removing flammable garbage and construction material from close to buildings was considered as important for reducing fire risk in Haifa. Overgrowth of invasive species that colonize the disturbed environment around buildings, especially after a fire, should also be removed. In private gardens and lots, owners should be required, through regulations and incentives, to care for their lots and gardens and reduce the concentration of flammable vegetation and materials. Insurance schemes that consider owners' efforts to reduce fire risk on their property are deemed to be important mechanisms to lower aggregate fire risk in the city.

Besides these measures that focus on ecological aspects of the landscape, socio-economic and technological measures can be implemented to reduce risk. In Haifa and the Carmel National Park, fires do not start because of natural causes (e.g., lightning); they are only ignited by human activities. Most fires in the region start within 50 m of a road or close to army training camps. Therefore, a respondent suggested the importance of education and of awareness regarding fire risk as fundamental to insuring an adequate public response. People should be aware that they live in a fire-prone environment and should know how to prevent fires and how to react in the event of fire. Fire prevention and preparedness, through awareness campaigns, mechanisms for alerts, and evacuation plans, are important strategies for reducing losses.

Firewatchers and patrols should be organized to keep the city's most sensitive areas under control. Outdoor smoke and heat detectors placed in the forest at the WUI (a technological solution) are also potentially effective strategies to detect fire at its very onset, alerting firefighters at the very initial stages of fire propagation by sending real-time signals to the fire department. Firefighters would then have better chances to prevent the fire from spreading, especially in the case of favorable weather conditions. In urban areas, one cannot drop fire retardants or resort to aerial firefighting, as is done for fires in the open forest. The fire needs to be dealt with at much smaller spatial scales, sometimes from building to building. The time to react to fire spread is also much shorter when compared to that when dealing with fires in the open forest, and authorities need to act quickly to evacuate homes, schools, hospitals, and commercial areas.

According to the fire department of Haifa, in case of fire, there are more losses that occur in apartment buildings than in offices because fire regulations are currently too flexible for residential structures in the country. Typically, building codes only apply to new developments or to buildings undergoing comprehensive improvements or repairs, leaving existing buildings at risk. The maintenance of buildings is indeed poor regarding fire readiness. Technological solutions to diminish flammability of buildings are necessary. The fire department representative suggested during a lecture in 2017 that there are new technological developments that can be adopted to reduce fire risk in buildings, for example, windows that break at high temperatures so that smoke can flow out of the buildings. The use of flame-retardant building materials is also important in this context. Fireproof elevators could be made mandatory in high-rise buildings. Safe rooms with filters for smoke, sprinklers, smoke detectors, and escape routes should become an integral part of building construction. Also, new chemicals are available that can be added to water to make the liquid more effective in extinguishing fires. Finally, the fire department suggested the need to have smaller, but more widely distributed, fire stations across the city and to enlarge the firefighting crews (including volunteers). Evacuation centers should be clearly identified and made available during a fire event.

1.1.4 Discussion

The challenge of forest fires at the WUI brings together two cultures of fire: that of urban fires (which focuses on building types and structures) and that of fires in wildlands, as also suggested by Pyne (2018). In this research, it emerged clearly that the technological component gains a prominent role in determining the vulnerability of the system to forest fire at the WUI, while this is less relevant in the open forest, where prescribed burning, the diversification of the landscape, and the management of the vegetation are traditionally recommended to avoid catastrophic fires. At the WUI, the ecosystem management perspective for open spaces and the urban/indoor fire prevention and response perspective need to merge. This combined perspective became apparent from the analysis of the case of Haifa the drivers of fire risk in Haifa (e.g., location of buildings upslope and near a dense forest; the need to resort to technology to reduce risk).

Applying technological solutions may offer leeway regarding implementation of ecological management solutions, for example by allowing preserving some trees, since they are highly valued by local residents who feel that they contribute to the special forested character of the city (Depietri and Orenstein, 2020). Putting smoke and heat sensors in the open land around the urban areas, a strategy traditionally adopted in buildings, is now suggested as important for dealing with fire risk at the

WUI. Building materials need to be adapted to fire risk, as managing the vegetation alone might not be enough.

It emerged from the case study that some strategies generally considered as effective in the open forest might not be practicable at the WUI (e.g., firebreaks or grazing, which might generate ecosystem disservices). So, while current approaches to managing wildfires focus on fire suppression and managing fuel build-up (Mahmoud and Chulahwat, 2018), these might not be sufficient and more attention needs to be paid to technological and social aspects of the system to understand fire risk at the WUI, as also suggested by Mahmoud and Chulahwat (2018). As mentioned, these include using fireproof materials in buildings, installing automatic sprinkler systems and fire/smoke detectors, and managing vegetation in the ignition zone immediately adjacent to built-up areas.

Fig. 1.1.4 displays how understanding and adapting to fire risk at the WUI is specific to an area where the forest meets the city, and in which two different, traditionally distinct paradigms of risk need to be brought together at the theoretical and practical levels. In the case of Haifa, the fire department tends to approach this source of fire risk as they would with indoor fires, while ecologists and some fire experts tend to focus on ecosystem management or integrated approaches. Bringing together these two cultures of risk to assess and deal with fires at the WUI will require institutional reform and a dedicated cross-sectoral collaboration. An improved collaboration between the fire department and the environmental protection authorities is deemed fundamental to understanding and reducing wildfire risk at the WUI. To this end, an extended process of engaging with multiple stakeholders will be needed. Homeowners are also likely to be required to play a central role in lowering vulnerability to wildfires at the WUI, as also suggested by Mahmoud and Chulahwat (2018). Postfire restoration offers important opportunities to implement these principles. The municipality of Haifa, for instance, did implement some beneficial practices in the burnt areas after the 2016 fire, including reforesting with broadleaf trees, and building unpaved roads to improve access for firefighters (see Tessler et al., 2019).

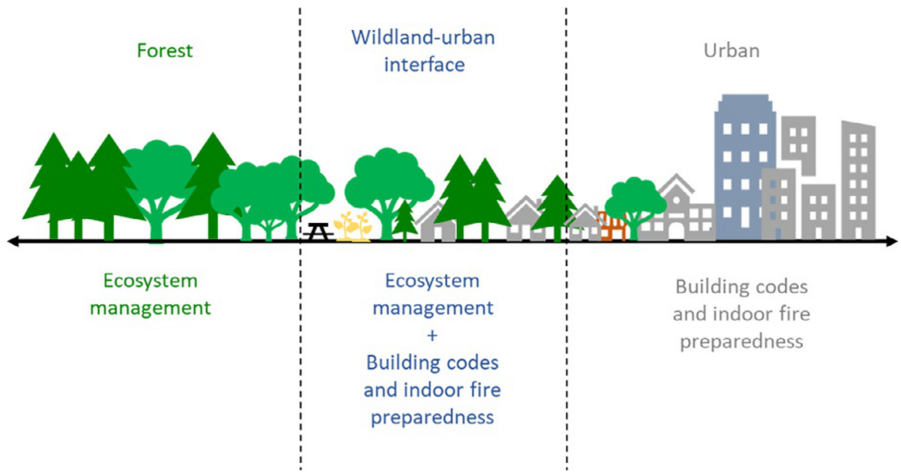

FIG. 1.1.4

Types of landscape and associated prevalent fire-risk reduction strategies. The figure shows that at the WUI two cultures of fire risk need to be brought together to adapt the system.

1.1.5 Conclusions

Understanding forest fires at the WUI requires a multidisciplinary and multisectoral approach in which different cultures of risk—those of urban, indoor fires and those of wildland fires—need to be brought together. By applying the SETS framework to the insights gathered through the literature and the Haifa case study, it becomes clear that the social, ecological, and technological components of risk and adaptation are all relevant when we are dealing with forest fires at the WUI. From our analysis it surfaced that the technological component of the system is fundamental, alongside ecological and social ones, to understand wildfire vulnerability and risk at the WUI. Forest fires at the WUI are more complex phenomena in which urban and forest elements of risk meet and intermingle. Innovative strategies and technological solutions are thus required to deal with this risk, in addition to the traditional management of the vegetation recommended to deal with fires in the open forest.

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