CHAPTER 7

The Critical Role of Firefighters' Place-Based Environmental Knowledge in Responding to Novel Fire Regimes in Hawai'i

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The "Wicked" Problem of Wildfires in Hawai'i

Human-caused wildfire has become a frequent disturbance across the main, inhabited islands of the Hawaiian archipelago. Over the past decade, an average of more than 1,000 ignitions burn more than 8,000 hectares each year statewide, which as a proportion of total land area is comparable to and in some years exceeds the proportion burned in the western United States (Trauernicht, Pickett et al. 2015). In addition to providing the source for 99 percent of all ignitions in Hawai'i, human activities have dramatically increased the flammability of its landscapes through land use practices that have promoted the spread and establishment of fire-prone non-native grasses. Combined with strong orographic rainfall patterns (rain shadows) and episodic droughts such as those associated with El Niño events, these anthropogenic drivers create potential for frequent year-round, often destructive wildfires. Fire regimes have changed dramatically in terms of recurrence, intensity, seasonality, and the negative effects on Hawaii's native, largely fire-sensitive ecosystems. Importantly, the increasing flammability of Hawaii's landscapes places a disproportionate burden on the fire response professionals who work to contain and suppress theses fires in extraordinarily complex and challenging topographic and environmental conditions, and with very little access to the tools available for fire response in the US mainland.

Contemporary wildland fire management in Hawai'i is focused primarily on suppression efforts. Novel fire regimes wrought by dramatic ecological and social changes, described below, have largely negative impacts on natural resources and local communities. With prevention and fire risk reduction efforts largely incommensurate relative to the prevalence and extent of wildland fire statewide (Trauernicht, Pickett et al. 2015), the responsibility for protecting resources falls squarely on the shoulders of local fire responders. As such, and out of necessity to do their jobs safely and effectively, this group of practitioners has developed a deep understanding of how the drivers of fire—vegetation (fuels), climate and weather, topography, and land use—affect fire behavior and constrain tactical response. This knowledge is especially critical given the high degree to which these drivers vary over space and time in Hawai'i and the lack of fire science available to inform suppression efforts relative to well-studied mainland ecosystems (Weise et al. 2010; Trauernicht, Pickett et al. 2015).

Wildfire response jurisdictions in Hawai‘i are split among multiple county, state, and federal agencies, many of which maintain mutual aid agreements for joint response and resource sharing. Hawaii's four county fire departments (Hawai‘i, Kaua‘i, Maui, and the City and County of Honolulu) provide critical initial response for the majority of wildfires in the state, yet they are primarily trained and equipped for structure fires. The Hawai‘i Division of Forestry and Wildlife is trained and prepared specifically for wildland fire response and is directly responsible for fire suppression on state lands (more than 640,000 hectares or 41 percent of state land area). However, the Division of Forestry and Wildlife employs no full-time firefighters, acting instead as a reserve-style resource with personnel being pulled from their primary forestry duties and mobilized for fire response, typically after county agencies are first alerted. The only full-time wildland fire suppression programs in the state are with federal agencies at Hawai‘i Volcanoes National Park and the US Army garrisons on Hawai‘i and O‘ahu Islands. These federal programs also often assist county and state suppression efforts both with personnel and air support (helicopter bucket drops). Assistance often requires, however, that federal resources be directly threatened during a fire incident. Despite frequent interagency cooperation, suppression efforts are also constrained by Hawaii's geography, which prevents the mobilization and sharing of heavy equipment such as water trucks, brush trucks, and bulldozers among islands during wildfires.

The focus on fire suppression in Hawai‘i stems in part from the relative sensitivity of native vegetation to the effects of fire (D'Antonio and Vitousek 1992; LaRosa et al. 2008). Wildland fires were relatively infrequent in Hawai‘i prior to human settlement, limited to areas of volcanic activity and rare lightning strikes (Burney et al. 1995; Smith and Tunison 1992). Humans, however, have forever altered the fire regime on the islands, beginning with the arrival of the first Polynesian settlers an estimated 800 (Wilmshurst et al. 2011) to 1,000 years BP (Kirch 1986). The use of fire for agriculture and land clearance by Pacific Island peoples has been linked to the expansion of fire-adapted vegetation types in New Zealand (McWethy et al. 2010), Fiji (King 2004), and Micronesia (Dodson and Intoh 1999). Historical accounts describe intentional landscape burning by Hawaiians to access and manipulate key resources such as the indigenous *pili* grass (*Heteropogon contortus* [L.] P.Beauv. ex Roem. & Schult.), for thatching, and other plants for food and fodder (McEldowney 1979; Kirch 1982). The extent of forest conversion by Hawaiians was likely small relative to post-European impacts (Maly and Wilcox 2000) and may also be attributed to factors other than fire, such as seed and seedling predation by introduced rats (Athens 2008).

The most important changes to Hawaii's landscape with respect to fire have occurred within the past century. The rise of the plantation and ranching industries in the late nineteenth and early twentieth centuries led to large-scale clearance of dry, mesic, and wet native forest as well as the introduction of a suite of non-native pasture grasses. Ironically, following the disastrous 30,000 acre Hamakua fire of 1901 on Hawai‘i Island, it was recognition of the value of forests for water provisioning to the plantations that prompted development of a forest warden program and Forest Reserve System by the territorial government (Commissioner of Agriculture and Forestry 1903). Although these changes in vegetation and fire use for sugarcane harvesting likely increased wildfire occurrence,

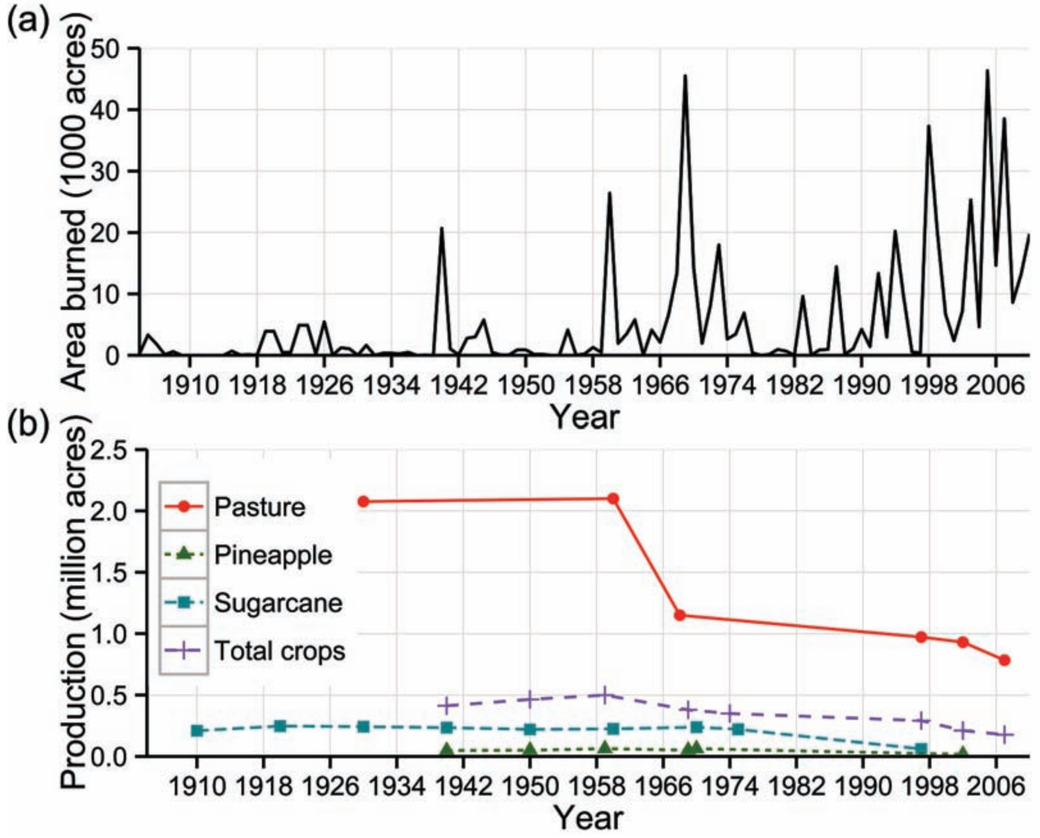

Figure 7.1. Trends in the spatial extent of wildfire occurrence and agricultural production in Hawai'i over the past century. The top graph illustrates the increase in annual area burned statewide for Hawai'i from 1904 to 2012 coinciding with the decrease in area under production for ranching and plantation agriculture depicted in the bottom graph.

plantations and ranches provided infrastructure and resources (people, roads, water, and heavy equipment) and actively assisted government agencies in fire notification and suppression (DOFAW 2010). In terms of actively managed lands, however, these industries have declined by over 60 percent from peak production in the 1950s–1960s, at which time plantations and ranches occupied approximately 5 percent and 50 percent of Hawaii's total land area, respectively (Schmitt 1977; Trauernicht, Pickett et al. 2015; Figure 7.1). Agricultural abandonment not only results in the expansion of fire-prone non-native grasslands and shrublands, or derived savannas (see Veldman and Putz 2011), but also significantly reduces the resources historically provided by agricultural operations for fire suppression.

Widespread expansion of non-native derived savannas—combined with increasing human-caused ignitions in the wildland-urban interface, strong rain shadow effects, and episodic droughts—has resulted in a fourfold increase in area burned statewide over the past century (Trauernicht, Pickett et al. 2015; Figure 7.1). In terms of area burned, wildfire is most prevalent in dry, leeward areas of Hawaiʻi and during the drier summer months. Interannual increases in fire occurrence, however, are strongly driven by drought events, such as those that occur during El Niño episodes (Chu et al. 2002; Dolling et al. 2005), during which large fires can occur in climatically wet areas; namely, windward regions and rainforests. With significant drying trends projected for Hawaiʻi, the relationship between drought and increased fire activity indicates that fire occurrence and impacts will worsen with climate change.

The pattern of agricultural abandonment in Hawaii's wildland-urban interface effectively creates landscape-scale wicks of fire-prone grasslands that connect developed areas with high-ignition densities to upland forested areas critical to watershed functioning and native species conservation. The impacts of wildfire on valued resources are especially acute in Hawaiʻi given the sensitivity of native ecosystems to fire disturbance (LaRosa et al. 2008) and postfire invasion by fire-adapted non-native species (D'Antonio and Vitousek 1992), as well as the small land area and tight linkages between terrestrial and marine ecosystems. Unlike wildland-urban interface issues in the continental United States, where fire risk to people and infrastructure increases as development pushes into fire-prone ecosystems, fire risk in many of Hawaii's residential areas has increased as the surrounding landscapes change with agricultural abandonment and the expansion of fire-prone vegetation. Further, the rezoning and division of agricultural lands for new developments complicates access for fire response, and no legislation exists at the state level to ensure that the design of new residential areas reduces wildfire risk.

Hawaii's contemporary fire regime also differs from that of the US mainland in that wildfires occur year-round and are associated with completely novel ecosystems and fuel types. Hawaii's derived savannas are typically dominated by non-native grasses such as *Pennisetum clandestinum* Hoscht. ex Chiov. (*kikuyu* grass), *Pennisetum setaceum* (Forssk.) Chiov. (fountain grass), *Melinus minutiflora* P. Beauv. (molasses grass), and *Megathyrsus maximus* (Jacq.) B. K. Simon and S. W. L. Jacobs (Guinea grass), which attain extremely high fuel loads (e.g., 15 to 30 metric tons/hectare (Beavers et al. 1999; Castillo et al. 2003; Ellsworth et al. 2014) and ignite and burn at high intensities even under low fire-risk weather conditions (moderate relative humidity) (C. Trauernicht, personal observation; Figure 7.2). Weather and climate conditions related to fire occurrence, such as rainfall and wind, are incredibly variable over short temporal and spatial scales in Hawaiʻi, yet these gradients are poorly captured by available weather stations (e.g., Giambelluca et al. 2013; Weise et al. 2010). Importantly, novel fuel types and high environmental variability mean that many of the available tools for fire risk assessment and prediction, including the National Fire Danger Rating System and fire behavior models such as BEHAVE and FARSITE, were developed for mainland US ecosystems and perform poorly in Hawaiʻi (Beavers et al. 1999; Benoit et al. 2009; Weise et al. 2010). In addition, fire response agencies in Hawaiʻi lack access to the impressive array of interagency support available on the mainland because the major federal land management and fire suppression agencies (the US Forest Service and Bureau of Land Management) do not own land in the state. Another critical factor that must be calculated into operational response is protection of cultural and natural resources. Hawaiʻi has the dubious distinction of being the "endangered species capital of the world" (DOFAW 2015). Also threatened are the cultural resources found throughout the islands, including aboveground and subsurface archaeological sites, burials, and culturally significant areas for gatherings, rituals, and a suite of other

Figure 7.2. An experimental fire in guinea grass illustrating high fire intensity (4–5 meter flame lengths) despite relatively benign fire weather (70 percent relative humidity, 5 mph winds) (photo by Clay Trauernicht, 2013).

cultural practices. These factors have forced firefighters to develop sophisticated place-based understandings of local environmental conditions and fire behavior to do their jobs safely and effectively.

The objective of this chapter is to present how firefighters are responding to the "wicked" problem—in that, it is multifaceted, unique, and not readily solvable (Xiang 2013)—of wildfires in Hawai'i through adaptive, place-based knowledge. Based on the first author's prior ethnographic research and community engagement with *paniola* or *paniolo* (Hawaiian cowboys), taro farmers, salt collectors, fishers, plant-gatherers, and other cultural practitioners, and the second author's extension work with firefighters, we made a few assumptions. The first is that, like cultural practitioners, wildland firefighters possess an intimate knowledge of their natural surroundings, especially in terms of fuels, weather, topography, and fire behavior, and they are able to recognize variability and change. For example, native practitioners and professional firefighters similarly stress the growing unpredictability of managing and utilizing resources due to extreme weather events and climate change. The second is that firefighters respond to environmental fluctuations and change in Hawaii's diverse ecosystems with place-based knowledge that is an amalgam of personal experience, the experiences of native Hawaiians, and newly introduced resource management understandings and practices. Consequently, there exists an informal (oral) knowledge network—an oral history or narrative—linking the state's firefighters.

For several decades, anthropologists and ethnobiologists have been studying fire's evolutionary and cultural significance and how (usually Indigenous and Native) peoples use fire to manage resources and influence fire ecology (Welch et al., chapter 2, this volume). For more than forty years, social scientists in the United States have investigated the human dimensions of wildland fires with regard to applied topics such as public perceptions of, public education on, and community engagement in fuels management, controlled burns, postfire recovery, homeowner mitigation measures, and wildfire planning and policy, to name a few (Toman et al. 2013). Anthropologists (as well as ethnobiologists, geographers, sociologists, and other social scientists) have explored the applied significance of indigenous anthropogenic fire regimes and environmental stewardship. Applied research has been undertaken to promote biocultural diversity and restoration, and improve public and private sector land management, fire prevention, and mitigation programs. A few studies demonstrate how the reestablishment of Native American burning practices can help to foster tribal integrity and ecological restoration. For instance, certain fire management practices encourage the growth of culturally valued taxa, such as fungi and plants with edible berries, and wildlife that also provides a range of ecosystem services (Anderson 2006; Anderson and Barbour 2003). In particular, anthropologists have elucidated how fire use and control are deeply embedded in cultural identity, notably the Kodi of eastern Indonesia (Fowler 2013; and chapter 9, this volume) and the Xavante in the *cerrado* biome of Brazil (Welch 2014). At the same time, these authors explore the extent to which Indigenous groups may be culpable for deforestation and global warming, or conversely, whether they are in fact enhancing biodiversity and/or producing negligible survival emissions. These investigations are critical to reframing international conservation narratives that sometimes cast Indigenous groups as responsible for "overspending" global carbon budgets, leading to calls for suppression of anthropogenic burning.

Our research is also informed by integrative and adaptive knowledge and resilience in socioecological systems (Berkes and Folke 1998; Berkes et al. 2002), as well as the integration of Indigenous fire use schema into conventional resource management programs. Recognizing that federal fire management relies on national narratives at the expense of place-based sustainability science, Ray and her colleagues (2012) have proposed a solution that draws from the traditional ecological knowledge of Athabascan forest users in Alaska. Lake and Long (2014) describe successful collaborations between national forests and native tribes. Ryan and his colleagues (2012) have provided guidance to federal fire agencies on how to better understand, avoid, and mitigate potential detrimental effects of fire suppression and postfire rehabilitation activities on cultural and archaeological resources; the authors describe the effects of fire on tangible biocultural and physical resources such as plants and animals (foraged, hunted, or herded), ceramics, lithic artifacts, petroglyphs and pictographs, subsurface deposits, and more. Welch (2012) takes a community and landscape approach to also consider the value of intangible cultural resources to Indigenous peoples. Conceptual, oral, and behavioral beliefs and practices such as origin stories and histories tied to specific places or landscape features are interdependent and key to successful heritage management. All of these authors present several ways to actively involve Native people in the development of collaborative management plans.

Little attention has been paid to the environmental observations and strategies of firefighters. A small body of social science literature exists on wildland firefighters, such as Desmond's (2007) ethnographic exploration of how wildland firefighters understand and habituate to risk and death, Klein's (2000) analysis of decision-making in high-risk professions (e.g., Klein 2000), Desmond's (2007) exploration of the cultural construction of masculinity and gendered dimensions of wildland firefighting, and Eriksen's (2014) argument that wildfire management is a means through which conventional gender roles and power relations are perpetuated. With this chapter, we hope to contribute to the dialogue on fire ecology, management, climate change, and the value of firefighters' place-based knowledge in heterogeneous and fragile island ecosystems, and also point out the practical value of incorporating firefighter place-based knowledge into applied programs such as firefighter education, "best practices" and training guides, resource allocation, operational procedures, natural and cultural resource protection and management, planning, and policy.

Study Overview and Methods

The findings presented in this chapter grew out of a larger project conducted at the University of Hawaiʻi at Mānoa's Department of Natural Resources and Environmental Management. The wildland fire extension specialist, Clay Trauernicht (coauthor of this chapter) was principal investigator of the project Challenges to Rapid Wildfire Containment in Hawaiʻi. The project sought to identify factors limiting rapid initial attack and suppression by fire response agencies in order to better inform resource allocation and investment decisions to improve the capacity of wildfire suppression. The goal of the social science component of the project was to draw on the expert knowledge of Hawaii's fire and emergency response community via in-depth interviews with incident commanders (ICs) and chiefs and fire managers from the Hawaiʻi Division of Forestry and Wildlife, as well as from county and federal fire departments. The study results were synthesized and presented in a report with recommendations to multiple stakeholders and policymakers (Trauernicht, Gollin et al. 2015).

The social science research component of the Challenges project was performed by the senior author of this chapter, Lisa Gollin. Interviews were conducted from December 2014 to June 2015. Judgment, or expert sampling (following Bernard 2011), was used to identify and invite fire leaders and decision-makers to participate in the project. Fifteen ICs were interviewed on the islands of Oʻahu, Hawaiʻi, Maui, and Kauaʻi. The Maui participants also discussed fire response on the islands of Molokaʻi and Lānaʻi, which are within their response district. All but three of the ICs are originally from Hawaiʻi. The two who were originally from the continental United States had spent most of their firefighting careers in Hawaiʻi. Participants included individuals from various government fire response agencies, as well as one fire science educator with the Hawaiʻi Community College Fire Science Program who was formerly an IC with the National Park Service. Five of the participants were retirees: three from county fire departments and two from the Division of Forestry and Wildlife.

Participants were interviewed individually or with one other participant at their offices, fire stations, or homes. Semistructured, structured, and open-ended questions were asked about basic biographical information and firefighting experience; the most critical information needed upon receiving the call to a fire; initial attack and containment procedures and issues; wildland fire behavior characteristics in different fuel types, weather conditions, and terrain; agency coordination in each participant's jurisdiction and areas of mutual aid; availability of personnel and equipment; electronic resources (e.g., a Likert ranking of online, real-time, and software modeling programs); and recommendations for improving resource allocation and best practices.

Based on the assumptions noted above, as well as themes that emerged from pilot interviews, Gollin added a new section to the questionnaire. The questions explored "rules of thumb" or "size-up"[1] assessments (the latter term a common firefighting term we heard throughout the interviews) based on experiential indicators of fire behavior rather than standard tools; sensory cues and observations of the natural surroundings, such as odors, sounds, animal behavior, cloud formations, and observations of environmental or climate change over the course of the participant's career; and how managers factor protection of Hawaii's biocultural diversity into fire mitigation. Participants with firefighting experience on the mainland were asked about how fire ecology and suppression in Hawai'i differ from that on the mainland.

Results

Location and Oral Transmission of Knowledge

The findings presented in this chapter are primarily drawn from the Environmental Observations and Place-Based Knowledge section of the interview protocol. Nevertheless, we note that environmental observations and place-based knowledge were addressed throughout the interview, starting with the first question on initial attack: "When you receive a call to respond to a wildfire, what are the immediate questions you need answered in deciding the actions to be taken?" Thirteen of the participants (87 percent) stated that location was the first question to be answered to coordinate a successful response, and it was cited as most critical for two reasons: first, to determine if the fire is in an area of primary response or automatic aid (secondary response); and second, but of no less importance, to guide operational strategies informed by what a few participants referred to as "the slide projector of past fires in the area"—prior site-specific knowledge of vegetation, weather, terrain, and fire behavior. The following statement from a Maui participant is a typical response: "We don't even have to ask what the fuel type is if we know the location. Like if it's at Lahaina Luna School, I know it's in cane grass [*Arundo donax* L.] and that it's going to hit the big trees eventually."

Another theme that arose from the interviews was the institutional memory of Hawaii's fire response community. Interisland and interagency collaboration on fires as well as cross-agency trainings, meetings, conferences, and more provide opportunities for firefighters to share iconic fire stories and suppression strategies.[2] There is an intergenerational knowledge network, with stories and tactics being passed down from the handful of senior commanders who have trained most firefighters on the islands. For example, the phrase "your slide projector," referring to the experiential catalog one brings to a fire, was traceable to a senior forestry commander who, by several accounts, was one of the most influential fire educators on the islands. Throughout the interviews, participants often cited the sources of their knowledge, often mentioning two recently retired forestry division ICs, one on O'ahu and the other on Hawai'i Island, both of whom were interviewed for this study. Participants across agencies and islands described these two men variously as the "brain trusts" or "icons" of Hawai'i wildland firefighting; in the words of a Kaua'i fire chief discussing the O'ahu retiree, "You know that [guy] is the man with the white hat."[3]

Place-Based Knowledge: Environmental Cues, Senses, and Surroundings

The place-based knowledge of Hawaii's firefighters is not a defined body of knowledge, but rather the result of diverse influences. By extension, while standard firefighting jargon permeates the language, the lexicon of Hawaii's firefighters also includes regional and local terms (which we attempt to sort out and explain throughout the chapter). Wildland firefighting place-based knowledge derives from a mix of Native Hawaiian ecological knowledge and cultural practices, ranching and farming resource management practices,[4] an individual's genealogical connection and/or familiarity with an area and its microenvironments, "talk story"(Hawaiian pidgin for exchanging stories and casual conversation) with other fire responders, and an individual's sensory acumen or "perceptual expertise" (Klein 2000, 45). Participants identified a number of environmental cues used in decision-making and to assess fire danger. The incident stories and examples shared for the Challenges project reflect this layering of personal and collective knowledge. Figure 7.3 presents the environmental cues that firefighters use, listed in order from most to least mentioned. Participants generally discussed cues from the fire science framework of the three principal environmental elements that affect wildland fire behavior: fuels, weather, and topography. They also spoke of concomitant phenomena such as smoke behavior, and sensory cues such as odors or the sound of fire; a few participants said they include animal behaviors in their sizeup assessments.

Relative humidity and wind are the two primary weather parameters influencing fire spread and determining whether containment will be successful. Wind feeds the fire, determining intensity and spread. Rain (or the wind dying down) starves it but feeds fuel loading on longer time scales that affect future fires. In Hawai'i, relative humidity, as with wind, fluctuates rapidly in time and space, especially under the influence of the islands' patchy and intermittent precipitation events and rugged terrain. Participants emphasized that relative humidity varies considerably, even in nearby locations such as neighboring ridgetops.[5] Topography is the most stable element of the fire behavior environmental triangle, but the rugged and varied terrain in many parts of Hawai'i places real physical constraints on the ability of firefighters to suppress fire safely and effectively. Importantly, the steepness and exposure of terrain differentially and dramatically affect fire activity. Fires move quickly up steep slopes and burn more intensely on drier, south-facing slopes, and terrain has complex effects on wind direction.[6] Fuel types are also relatively stable, but fire behavior is unpredictable given the other environmental variables in Hawaii's diverse and changing biogeographic setting. (Novel fuel types are considered in more detail in the next section.)

The environmental cues identified by participants and depicted in Figure 7.3 are not discrete categories. Environmental factors are interrelated and dynamic. An example is the relationship between wind, smoke, and fire activity; a firefighter may use the lean of a smoke column to determine wind direction and therefore where the fire is heading. As discussed in the introduction, many of the standard tools (e.g., fire modeling software, fire danger rating systems) were not designed for island geography, weather systems, and microclimates. As the fire science educator and former National Park Service IC remarked in his interview, "All of those [online, real-time, fire behavior modeling] programs you mentioned don't really fit here. It's a lot more complex and it's just something we deal with."[7]

The following observations provided by participants shed light on the critical role of place-based knowledge and sensory information from the natural surroundings in making decisions about fire management and suppression.

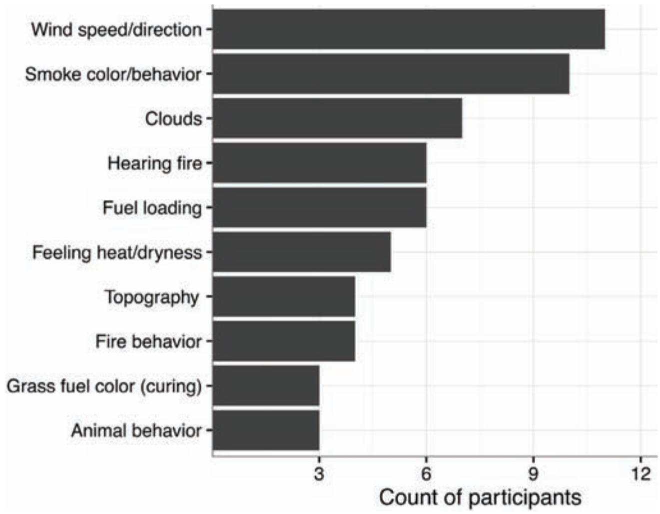

FIGURE 7.3. Environmental cues used by firefighters in Hawaiʻi to determine fire danger and guide decision making.

Wind

Wind (direction, speed, and microclimatic variation) was identified as the most critical variable in determining the course of a fire and operational response by most participants and was discussed more than any other environmental element. Eleven participants shared stories about wind characteristics and response tactics. Seven discussed cloud formations in relation to wind. In the words of a protection forester who runs the fire management program for Hawaiʻi Island:

> When you see thunder clouds forming, have fast moving clouds, or lenticular clouds, then you know you have the possibility of strong winds. Feeling the air drying out in your nose and mouth. The wind and terrain will determine which direction the wind is going to go. Wind more than terrain.

Particularly salient was understanding the diurnal and seasonal wind changes characteristic of an area. The chief of the Hawaiʻi Island fire department provided this example:

> Growing up here I know that . . . the Nīnole Loop at night, the wind always shifts from mountain to the ocean coming back up. Starts at about sunset. The wind goes [up from the] ocean and then at night mauka [mountain] to makai [ocean]. We were relieved by a crew. I remember mentioning that the winds shift at night. That worked out for the first day. But the second crew didn't pay attention and they left an apparatus out on the roadway. The wind shifted. [The fire] turned back and destroyed the vehicle.

Figure 7.4 is a schematic of the Maui Island wind system drawn by the forest management supervisor for the islands of Maui, Lānaʻi, and Molokaʻi. It displays how the prevailing trade winds from the northeast shoot through the saddle of central Maui between the west Maui Mountains and Haleakalā on the east creating, in his words, "an eddy effect . . . like water in a stream funnels between rocks." He explained that the swirling winds form along the higher elevations and affect fire behavior in the Kula Forest Reserve. While his home was untouched by an August storm a short distance from Kula, the reserve sustained major damage in one gulch where he estimated winds to be 90 to 100 mile per hour. "It mowed down a 400 acre swath. It snapped the large trees to the ground. You can look up on the ridge and see there is no longer a tree line in that area. That's a microclimate!"

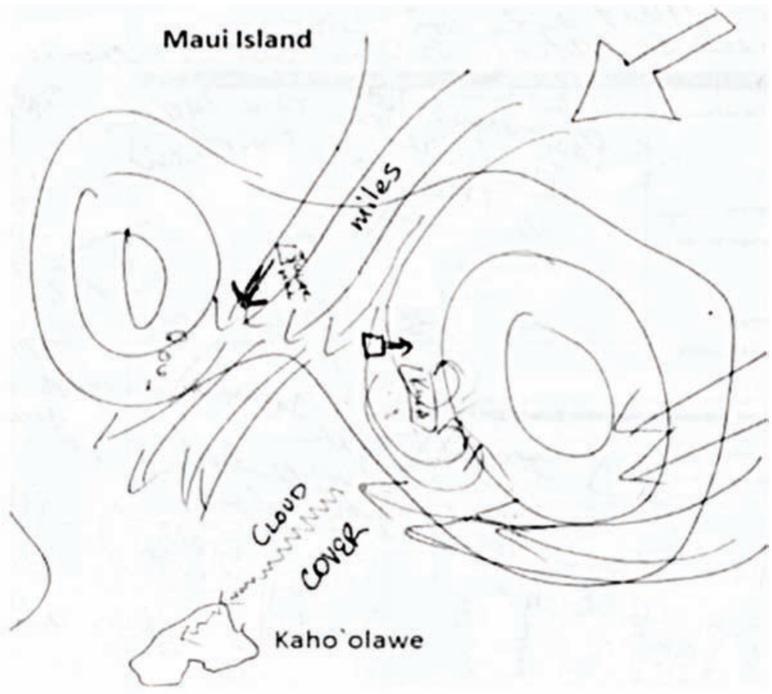

Figure 7.4. Illustration of the Maui wind system (drawing by Lance DeSilva, 2015).

The forest management supervisor emphasized that knowledge of wind speed and direction is critical to protecting the habitat restoration exclosure (an area enclosed to keep unwanted flora and fauna out) of the endangered *nēnē* (Hawaiian goose, *Branta sandvicensis* Vigors) from fire on the ridges of the western mountains where firefighters typically battle light, flashy grasses with strong winds. The Maui forestry IC explained that winds blowing on the west side are of minimal consequence "because the fire will back into the strong wind and it won't move too much."

If a fire starts east (mauka) of the nēnē pen, he said the trade winds are likely to steer the fire toward the fenced exclosure. He further described how the trade winds that shoot through the saddle of central Maui help to form the "Hawaiian cloud" that used to form rainstorms on the eastern island of Kahoʻolawe (referring to the *nāulu* rains and cloud bridge that once existed between Maui and Kahoʻolawe).[8]

The fire science professor and former federal IC shares the following story with his students. As a "burn boss,"[9] he would always spend a few days in an area ahead of a prescribed burn to become familiar with it and strategize. For a burn in the coastal area of west Hawaiʻi, he consulted with older fishers at Kawaihae Harbor who pay close attention to the lunar cycle and other natural cycles and weather patterns to determine which fish are running and the best time and places to catch them. They told the IC that within a couple days of the new moon, the winds die down at night, making it the best time for fishing, and they suggested he refer to the Hawaiian fishing calendar. He did, and planned the burn accordingly. On the day of the prescribed burn, the wind was howling ferociously, even into the evening. The IC began to doubt his decision. At 8:00 p.m. (as per the fishing calendar) the wind died down, allowing them to execute a "95 percent perfect burn." He tells his classes, "We didn't have to waste any of [the] taxpayers' money. The take-home message? Local knowledge is important!"

One retired firefighter who worked for the Hawaiʻi Fire Department and served as president of the Hawaiʻi Wildfire Management Organization discussed wind speed and fire behavior on volcanic terrain. When fire burns toward a *puʻu*, or cinder cone, the winds "will be squirrely as they blow over [it] because they won't keep on going the same direction. They will accelerate as they approach it and then . . . wrap around the sides and do all kinds of swirly things."

Relative Humidity

Four of the project participants discussed humidity in relation to sensory perception and knowledge of place. The educator and former National Park Service IC with years of experience fighting fires on the mainland shared the differences between relative humidity and fire activity in the continental United States versus Hawaiʻi. Whereas fire danger thresholds for relative humidity range from 15–30 percent on the mainland (NOAA n.d.), he discovered that Hawaiʻi can have very high intensity fires at much higher relative humidity:

> We can have fires here at 95 percent humidity. But at 95 percent humidity, they are not doing anything. What I found is that 60 percent [relative humidity] is the cutoff. . . . You start to see increased fire activity and more difficulty with the alien grasses.

The same participant had become so attuned to relative humidity, he said, "I can tell how many days it's been since there's been rain." Although the air may always feel moist to someone not accustomed to Hawaii's wet weather, the IC can feel what is unseasonably dry under these humid conditions. He recounted taking technicians from the mainland to service one of the remote automatic weather stations. "I told them, you need to check that again because I think that's not the right humidity. They checked again and their sensor was off. I was more sensitive than their sensor."

Smoke

Reading smoke—its form, velocity, color, and odor in relation to fire characteristics—is a standard subject taught in fire science programs and training modules. Eight of the participants discussed a color code for smoke particularly in relation to Hawaii's fuel sources. A chief with the Kauaʻi Fire Department said, "The color of smoke is either black, brown, gray, or white depending on what's burning." He went on to explain that dark or black smoke indicates that heavy fuels such as cars, tires, or forest hardwoods are burning, while white smoke indicates lighter, flashy green fuels. The fire chief of the US Army's Pōhakuloa Training Area on Hawaiʻi Island uses smoke color and plume size to help evaluate whether he has the resources on hand to fight the fire, and if the fire will be an extended attack: "White, flowing smoke that means you have a convection pattern going in the sky and it's already creating its own weather. When you are at that point, it's beyond IA [Initial Attack]. If you see an anvil, it's beyond IA."

The fire chief developed his own rule of thumb to ascertain if his company has the resources available to put out the fire or if they need to request assistance. When he is a mile away from the fire, he holds up his thumb to the smoke column. If it is wider than his thumb, the fire is beyond an acre and beyond the 300 gallon water-holding capacity of a brush truck. "It's usually ten to fifteen minutes before I can get another brush truck. That's when we . . . call for more water, resources. We call it an 'all hands' fire."

Firefighters also note the direction the smoke column is leaning to ascertain wind direction. A Maui battalion chief described another smoke characteristic: "If there are explosive puffs, [the wind and fire are] moving quickly. If it's lazy billowing, slowly."

A few of the firefighters mentioned that where they lack access maps, sometimes the smoke plume is the only way to locate the fire from a distance.

The retired fire management officer from Oʻahu who worked for the Division of Forestry and Wildlife (and who is considered one of Hawaii's wildland firefighting icons) is an old hand at smoke reading. He described how his knowledge of fire and smoke behavior came not only from formal fire science education, but also from watching the harvesting of sugarcane using backfire operations when he was growing up. He noticed that dispersed smoke aggregates in a column "because the fire is drawing a lot of oxygen, so everything is going to be drawn in the direction of the main fire. When the fires meet, it's all done."

Backfiring is a suppression strategy in which fire is intentionally set along the inner edge of a fire line to consume fuels and reduce the intensity and/or slow the progression of an approaching wildfire. The retired firefighter recalled a fire early in his career, one of his first backfire operations. Another firefighter was sitting at the bulldozer line in the safety zone where the backfire would be lit, casually smoking a cigar. When the cigar smoke suddenly changed direction toward the main fire approaching from the distance, "we knew it was the perfect time to set the backfire."

Olfactory cues are used by structural and wildland firefighters to identify what kind of fuel the fire is burning and to locate its source. It is common in structural fires for stations to receive "odor-of-smoke" calls. Firefighters familiar with this type of fire are able to recognize the difference between, for example, the distinctive sharp, pungent odor of an electrical fire and the burnt food smell of a stove fire (Sheridan 2014). Many wildfire ICs are able to identify the predominant fuel type by its smell, which is particularly useful for predicting fire behavior and protecting endangered native flora and fauna when visibility is obscured by clouds, inclement weather, dense smoke, or nightfall. The Hawaiʻi Island Pōhakuloa Training Area fire chief has become astute at differentiating vegetation types by smell, such as the mixture of nutty, woody, and "sweet maple bacon" of burning *kiawe* (mesquite, *Prosopis pallida* [Humb. & Bonpl. Ex Willd.] Kunth). He explained:

> Upon arrival, you can usually smell if something is wet and burning as opposed to if it's dry and burning. How accurate that is can potentially tell you what is burning. . . . You can tell the different types of fuels that are burning. You can tell if what's burning is in [native] mamane [*Sophora chrysophylla* (Salisb.) Seem.], naio [false sandalwood, *Myoporum sandwicense* A.Gray] or koa [*Acacia koa* A.Gray]. Mamane and naio are very oily and have a very pungent smell when they burn. Whereas if it's a hardwood like ʻōhiʻa [*Metrosideros* spp.] or koa, it has a more woody smell—a more pleasant smell.

Terrain/Topography

Four of the firefighters that were interviewed discussed topography in relation to fire behavior and access issues. The corrugated folds of the island chain's tall mountains contribute to the landscape-scale "wicking" system, in which uncontained fire in lowland shrub and grasslands can quickly become an upland forest fire. A retired Oʻahu county fire captain described how fire accelerates as it burns uphill, putting firefighters in danger and community assets—homes, structures, native forest—in the path of the fire: "You are always watching out for uphill situations or what we would call box canyons where the valley comes to a tight V which would almost in essence create a chimney-type effect."

The Big Island (the nickname for Hawaiʻi Island) is the youngest, most mountainous, and only volcanically active island in the archipelago. Active lava flows ignite wildfires along the flanks of the Kīlauea Volcano,[10] but inactive flows across the island pose a unique challenge to firefighters who have to navigate the porous and rough terrain of old lava fields. Interviewees from the Big Island explained that long dead lava fields serve a useful function because they can sometimes be used as natural fire breaks where vegetation is sparse. The fire science educator and former federal IC pointed out this contradistinction, "For most of the island you can't cut line because of the lava. You don't have soil. On the mainland, that's the Holy Grail."[11]

He uses an alternate technique to cutting line by hand that firefighters refer to as "black lining," which refers to the process of igniting pockets of unburned fuels between the fire line and the main fire.

The firefighters from the Big Island have a simple topography typology for lava. The spiky broken shards of lava known in Hawaiian as *ʻaʻā* is treacherous to walk on, but bulldozers—the primary tool for cutting line in this environment—can be used to create fire breaks. However, bulldozers cannot be used on *pāhoehoe*—a smooth, unbroken, billowing, elephant skin–like lava. It is too tough and, most critically, there are lava tubes, cave-like subsurface channels, some of which are large enough to, in the words of the Pōhakuloa Training Area fire chief, "swallow equipment":

> The lava tubes in ancient times were used as areas of refuge. . . . Any time you get into the pāhoehoe lava, there's a good chance there's lava tubes in the area. You look for skylights [formed when a section of lava tube roof collapses] and other indicators. Normally, lava tubes run from mauka to makai rather than north to south. So, if you find a skylight, you have a pretty good idea of where the tube might be. [The lava] is going to follow the path of least resistance. We've had dozers fall into tubes. Now we try and put crews in front of the dozer so that we have eyes ahead.

Firefighters use many perceptual cues to guide their responses. Sensory cues provide critical information, particularly when visibility is poor. For example, the sound of a fire can indicate where the fire head is and how the fire is rolling. Six interview participants discussed such auditory cues. The federal fire chief described the sound and feel of a fire that is growing in ferocity:

> When a fire is getting ready to run, you got the wind going. If you're developing a line in front of a fire and all of sudden you feel a strong wind drawing across your face and the fire is behind you, that's not a good sign. Because it means that the fire is sucking that in, and it means that it's rolling. You hear people referring sometimes to . . . the fire as sounding like a freight train. Your audio cues will tell you how the fire is going. When you hit the fire with water, you're going to hit the seat of it, and it will sound like a hiss. You are going to hear that. If you have a duff fire and you hit it with a straight stream, you're going to hear a really low rumbling in the ground.

Two of the ICs (one from Hawaiʻi Island, the other Kauaʻi) noted that animal evacuation patterns, such as that of wild pigs in the mountains or mice, rats, and even cane spiders in lowland fields, can serve as forewarning that the fire front is heading in their direction. The Hawaiʻi Island IC described how the heat of the fire drives everything in front of it: "If you're cutting line and all of a sudden you have all these pigs running past you, you know the fire is coming your way."

Another participant from Hawaiʻi Island and a retiree of the county fire department used ʻ*io*, the endemic Hawaiian hawk (*Buteo solitarius* Peale), as a guide. He said that when he sees hawks catching thermal updrafts, soaring high in the air, "The fire is likely to be able to allow a big column of smoke and heat to rise because it's an unstable weather pattern. There is no trade wind inversion overhead. So the fire is likely to get a good head of steam going."[12]

Ecological Succession: Grasses, Shrubs, and Fire Behavior

The spread of fire-prone invasive grasses and, increasingly, pyrophytic environments was the consensus topic of concern for project participants. Division of Forestry and Wildlife ICs—responsible for managing and protecting native ecosystems and cultural resources on state lands—were more likely than county firefighters to discuss forest conversion due to fire. An IC with the Oʻahu Island Division of Forestry and Wildlife commented, "If you have an area that is burned forest, then it comes back as grass. It very rarely recovers 100 percent to what it was before. It's irreversible."

Many others echoed that statement. A Maui forestry IC discussed ecological succession in Honuaʻula. When he began his career, land formerly cultivated in sugarcane and pineapple at the lower elevations had come to be dominated by cane grass and other non-native species. There were stands of large eucalyptus trees climbing up the mountains. Native forest was on the ridgetops. A fire burned in Honuaʻula on his second day on the job. The responders were able to put it out before it reached the native forest. It burned through the cane grass and stopped. Then it rained, and it took only a week for the grasses to grow back. The next year there was another fire. This one advanced up into the eucalyptus trees but did not touch the native forest. Grasses then grew in place of the eucalyptus.

> Everything burns: grass, timber, natives—or really, grass, grass, native. And now the natives are being replaced by grasses. It's a new vegetation succession. You can still see eucalyptus trees, but it's sparse. And it's an annual, or really every other year fire regime. It used to be dark with natives above the timberline. Now when you look at it, it's light [with grasses] all the way up the hill.

Counterintuitively, some grasses can be as dangerous when they appear green and alive as when they appear brown and dead (see molasses and kikuyu below). For the Hawaiian Islands, there are no curing guides, which use the color of prominent grass species to help firefighters assess the percentage of dead material and decreasing live fuel moisture to determine potential fire risk, intensity, and spread.[13] Several participants do use a heuristic code. The retired Big Island IC (another of Hawaii's wildland firefighting icons and repositories of knowledge) used the curing colors of fountain grass (green-yellow-golden-brown-gray) as an indicator of when to expect more fires: "We always used to joke about grasses. I used to drive along this corridor from Kona to Waimea where it's covered with fountain grass. I used to always tell the boys when I would see it gray, you better start packing your bags because we're going out on a fire soon."

Table 7.1 presents fuel types and associated fire behaviors of the most problematic non-native grasses and, for comparison, the native grass pili and native fern *uluhe* (*Dicranopteris linearis* [Burm.f.] Underw.). Species are listed from most to least challenging for fire response based on project participants' responses to free-listing exercises and follow-up questions. The results underscore what is novel about Hawaii's changing fire regimes. For example, firefighters often use previously burned areas as a safety zone (or, as they call it, "the black") from which to fight fire. Grasses generally burn quickly and "clean," leaving no unconsumed fuel to allow the fire to burn back over the same ground. In Hawai'i, burned grasslands do not reliably provide a safe spot for firefighters.[14]

Some of the non-native grasses listed in Table 7.1 result in what firefighters refer to as a "dirty burn" in which the fire does not consume all the fuels in an area, leaving partially burned spots susceptible to reigniting. Certain grasses can reignite quickly (within hours or days), even when they have high moisture content (appear largely green) in high humidity or precipitation. One of the ICs with many years of experience on the mainland and in Europe quickly learned that in Hawai'i, because of the constantly shifting winds, and aspect and slope of its upland terrain, "If you drive into the black to fight the fire, soon you will have the fire back around you."

Guinea grass is considered the most difficult to suppress. It has a high fuel load, grows tall, and has exceptionally high flame lengths. A Big Island forestry IC described Guinea grass as "a whole other animal," and he approaches a Guinea grass fire from "a different angle . . . paralleling it because the radiant heat is so high." When dry, it burns fast but can still lead to a dirty burn. One retired O'ahu fire captain noted that the Guinea grass often reburns:

> A lot of times the clump in the center might not burn. It's ironic, you take the ash from the fire and that goes on the ground and then we shoot water on it and we're basically fertilizing it to grow again. . . . Sometimes Guinea grass doesn't burn completely. I think that has to do with the wind, how fast it's moving through. The drier parts are usually the ends of the grass versus the clump which is down by the moisture. The moisture goes from the ground and lessens as you get to the top of the grass, so there are situations where the clumps will still be green and still present after the fire. So, they can burn again or dry out again. Ideally, you'd attack these fires from the . . . black, but that's not always possible.

Fountain grass and buffel grass (*Cenchrus ciliarus* L.) are tussock grasses and, as one firefighter noted, they "can burn themselves out except if it's windy." According to a Maui participant, buffel grass may throw embers but does not tend to create spot fires because "if it does throw embers, it's most likely not going to ignite again."

Fountain grass, a popular landscaping ornamental, now covers vast expanses of west Hawai'i Island and has created a fire regime alien to the islands' dryland ecosystems (Blackmore and Vitousek 2000). Unlike buffel grass, it has high fuel loading. According to the federal IC working in the high-altitude plateau of the Pōhakuloa Training Area, where fountain grass is ubiquitous,[15] it has a "dualphasic burn": the top burns in the morning, then dries up and heats the bottom; when the wind switches directions in the afternoon, as it typically does, it reignites the grass that burned in the morning. "You get a hot fire that kind of kills everything in the ground," he said. "Then up where we are, you get a leaching of phosphorous which allows nothing to come back."

Cane grass resembles sugarcane and can grow up to 20 feet tall. A number of participants noted that cane grass holds moisture, meaning "it never fully burns out" and can throw embers that are carried by the wind and easily ignite elsewhere and reburn through the black. Molasses grass grows in mats and is found mainly in disturbed, dry to mesic open areas. Firefighters say it can create a high-intensity fire that is easily wind driven. Molasses grass no more than a foot high can put out a 15 foot flame and, as the fire science educator noted, it "has a resin in it that makes it burn hotter when it's green than when it's dry. It's really sticky stuff, like molasses."

Kikuyu is an important range and pasture grass. In Hawaiʻi, as in other parts of the tropics, it is also an inexpensive and easy to maintain golf course turf grass. The firefighters said kikuyu grass is slow burning, but the dense thatch of subsurface stolons and stems makes kikuyu fires difficult to extinguish: "For mop-up [postfire cleanup], it's the biggest headache." They pointed out that a lush green carpet of wet kikuyu grass can be deceptive. Although it may appear to be defensible space—a buffer zone against fire—kikuyu can end up in a dirty burn. A retiree from the Big Island explained:

> Kikuyu grass . . . will easily go 6 feet down and into the cracks of the rocks. They are deep-seated fires and they can run horizontally. In a kikuyu pasture the roots can easily go so far underground and spread underneath a 20 foot firebreak. . . . It can burn underground for a couple of days and pop up on the other side and the fire is off and running again.

Frequently mentioned non-native trees and shrubs were kiawe, *koa haole* (*Leucaena leucocephalum* [Lam.] de Wit), ʻ*opiuma* (*Pithocellobium dulce* [Roxb.] Benth.), and eucalyptus (*Eucalyptus* spp. L'Hér.). Koa haole and kiawe, both introduced for cattle forage, are widespread throughout the islands. Each part of a koa haole tree has its own burn characteristics: the trunk and branches burn slowly but often survive after a fire moves quickly through a stand. An Oʻahu retiree said such fires can move "so fast that the plant will still be alive and in three weeks you'll notice new branches sprouting. The leaves will burn off quickly unless it's dead but the main stem will burn for a while. It throws a lot of embers. The seeds hold a lot of heat and then land and start fires."

Kiawe, or mesquite, is a culturally valued fuelwood for *imu* (underground ovens) used to cook *ʻahaʻaina* (Hawaiian feasts) foods such as pig, taro, and sweet potatoes.[16] It is also widely favored for barbecues. Firefighters discussed how difficult it is to fully extinguish pitoven fires, which can smolder underground and reignite weeks or months later and start or restart wildland fires. A few interviewees had seen fellow firefighters severely injured by falling into ash pits. They also provided other examples of the many potential problems characteristic of kiawe. For example, the large amount of leaf and bean pod detritus under the tree is highly flammable, can burn for a long time, and create spot fires. Also, the wood is so dense that tree cutters with chainsaws have a difficult time felling kiawe in the path of fire. According to one Oʻahu firefighter, "It's almost impossible for us to put out every kiawe stump. It's just not a wise use of the time."

Kiawe stumps are always in danger of burning, however, and potentially rekindling the fire. Two of the Maui participants discussed how ʻopiuma, introduced as a shade tree in pastures, burns hot and easily rekindles, and was increasingly becoming a fire hazard in leeward areas of Maui and on Molokaʻi. Eucalyptus, many species of which are now found on all the major Hawaiian islands, takes over fallow fields and native habitats, resprouts prolifically after burning, and, as noted by a Big Island fire chief, has its own fire regime: "We've seen crowning type fires that we've never had before."

For the most part, project participants did not bring up native plants. Where grasses are concerned, exotic grasses pose the greatest fire threat. Native grasses such as pili, unlike

Figure 7.5. Wildfire burning through *uluhe* fern (*Dicranopteris linearis* [Burm.F.] Underw.) in native forest on Oʻahu, 2015 (courtesy of the Hawaiʻi Division of Forestry and Wildlife).

alien grasses, burn "slow and clean." In fact, the Big Island IC who established that fire risk rises when relative humidity falls below 60 percent in alien grasslands had determined that the cutoff is 40 percent for pili grass, suggesting that areas where pili grass remains the dominant fuel have a lower potential for burning. There is one notable exception. The native fern uluhe (Figure 7.5) has taken forestry division firefighters by surprise. Uluhe dominates many upland forests, draping the mountains in dense, thick foliage that often provides continuous vegetative ground cover up to 10 feet deep between emergent trees.

An Oʻahu forestry IC explained that under certain conditions, "it can burn as aggressively as Guinea grass or fountain grass. . . . The top layer is green, maybe one foot, but the bottom layer is brown. In the Koʻolau (mountain range) the bottom layer is wet and moist, but in between, the middle layer is all dead." He shared a video on his phone of an uluhe fire in central Oʻahu where the fire was so fierce, it created its own wind:

> See how the smoke is going backwards. It's not even a wind-driven fire. It's burning that good without the wind at its back driving it. You can imagine how bad it would've been with winds. That was at six at night in January! The temperatures are cooler. It's not two in the afternoon. The humidity is recovering.

One of the retirees considered part of Hawaii's wildfire fighting "brain trust" described a suppression strategy that he came up with to manage uluhe fires:

> We would construct a hand line by going direct, meaning constructing the line as close as possible to the fire's edge.That way you are eliminating the dry dead fuel from being burned and the potential for reburn is significantly reduced.

Environmental Change over Participants' Careers

In the words of a thirty-year forestry division veteran, "Firefighters are deeply in-tuned

Table 7.1. Novel fuel types and corresponding fire behavior and characteristics described by project participants.

	Species	*Fire Behavior Descriptions*
Non-native grasses	Guinea grass (*Megathyrsus maximus*)	Large flame height; High intensity; High rate of spread; Large fuel loads; Continuous fuel loads; Tall fuel bed; Embers/spotting; Low visibility; Requires large fuel breaks; Reburns 'through black'; Dangerous; Smolders/continues burning
	Fountain grass (*Cenchrus setaceus*)	High intensity; High rate of spread; Burns clean; Requires more water to extinguish; Reburns 'through black';
	Buffel grass (*Cenchrus ciliarus*)	Low intensity; Low flame height; High rate of spread; Flashy; burns clean; Easy to extinguish; Cures rapidly
	Molasses grass (*Melinis minutiflora*)	Large flame height; High intensity; Large fuel loads; Burns clean
	Cane grass (*Arundo donax*)	Low rate of spread; High fuel moisture; Embers/spotting; Reburns 'through black'
	Kikuyu grass (*Pennisetum clandestinum*)	Lower rate of spread; Large fuel loads; Smolders/continues burning; Difficult to extinguish; Matting/burns into ground; Difficult mop up
Native species	Uluhe (*Dicranopteris linearis*)	High rate of spread; Reburns 'through black', cures rapidly
	Pili grass (*Heteropogon contortus*)	Low flame height; Low intensity; Low rate of spread; Easy to extinguish; Requires lower RH (<40%) to ignite
Non-native trees & shrubs	Eucalyptus (*Eucalyptus* spp.)	Crown fires; Increased fire risk; Increased fuels (downed woody debris)
	ʻOpiuma (*Pithocellobium dulce*)	High intensity; Difficult to extinguish
	Kiawe (*Prosopis pallida*)	High intensity; Smolders/continues burning; Difficult to extinguish; Large quantities of surface fuels; Difficult to cut
	Haole koa (*Leucaena leucocephalum*)	High intensity; Ignites easily; Dangerous; Cures rapidly; Embers/spotting

to the environment, and must be in order to do our job." Figure 7.7 presents fire-related environmental changes observed over the course of participants' careers. The most common observation was the expansion of fire-prone grasses into native dry and mesic woodlands and the resulting emergent fire regimes.

The "brain trust" IC provided an example from Puʻuanahulu, where "fountain grass has burned off the native seed sources" and created grasslands where there were once native *ʻōhiʻa* shrubs (possibly *Metrosideros polymorpha* Guadich. or *Eugenia* sp. L.; mamane; and *aʻaliʻi* [*Dodonaea* spp. Mill.]). He remarked that younger firefighters believe the area to be natural grassland, being unaware that it was formerly a native and endemic shrubland. Some grass species, especially fountain grass, are capable of colonizing barren lava flows. On the Big Island, firefighters count on younger lava fields as natural fire breaks and to establish safety zones. *Kīpuka* (clear places or green oases within a lava bed) generally do not ignite if composed of pili and other natives. A Big Island forestry IC predicted that by the end of his career, as fountain grass colonizes lava substrate, "we won't be able to use lava flows as barriers."

FIGURE 7.6. Fountain grass (*Pennisetum setaceum* (Forssk.) Chiov.) colonizing lava substrate. Non-native grasslands and shrublands cover approximately 25 percent of land area in Hawai'i (photo by Lisa Gollin, 2015).

Several interviewees talked about droughts becoming longer, and how leeward-windward areas of the islands are uncharacteristically wetter or drier and more fire prone due to unprecedented fuel buildup from torrential rains followed by protracted hot and dry spells. Following are some of the statements made by ICs from each of the major Hawaiian islands where the interviews were conducted:

- "What used to be west O'ahu's fire problem is now central and west O'ahu's problem and in some regards even out to the Kahuku area of the North Shore."
- "Now more and more, you're getting a lot of heavy rains and long periods of drought."
- "The island is getting a lot drier. The average rainfall might be the same, but you are getting it all at one time or not at all. It's not well distributed."
- "In the last years it's been more wet than what we've seen in a long while. There are areas that are green that should be brown now."
- "I've seen places burn before I never thought would ever burn. I notice less trades and increases in Kona(s) [warm, southerly winds]."

The firefighters on the Big Island discussed the seven-year drought that generated unprecedented fires in the rainforests. One IC discussed the 2002 Kupukupu fire (named after the fern *Nephrolepis cordifolia* [L.] K.Presl), the primary fuel carrying the fire). He explained that this winddriven forest fire was different from past fires because when the lava flowed into the rainforest, the understory vegetation ignited rather than trees. He further described how unusually dry conditions and erratic winds had dried the ferns, which ignited and drew the fire into the forest at such high temperatures that the radiant heat made it impossible for firefighters to work on the ground:

- "I had to use bucket work." He said they battled flames 150 feet high at the fire's leading edge, which he characterized as "extreme fire behavior."

Seven interviewees discussed how rapid development in wildland-urban interface areas is changing the face of wildland firefighting.[17] For example, a Maui forestry IC recalled a conversation with a senior forestry IC about converting the Division of Forestry and Wildlife from a wildland agency to a "WUI [wildland-urban interface] agency because we have to work not in, but around, structures more and more."

The Big Island fire science educator offered three reasons fires are getting bigger across the islands. The first is climate change. The second is that firefighters have become more successful at suppressing fires, which naturally leads to fuel buildup. "The third," he said, "is that we have more people building homes out in the woods." This expansion into the wildland-urban interface means more human-caused ignitions. In the past, he recalled, they would have let a fire burn, "but now that there are homes there, we have to go put the fire out."

Somewhat paradoxically—given that Hawaii's ranching and plantation past is largely responsible for the contemporary widespread conversion of native ecosystems and environmental disturbance, and resultant higher-intensity fire regimes—several participants lamented the loss of the former agricultural infrastructure because they offered several presuppression and suppression services (see the section below on ungulates). Farmers and ranchers were once de facto first responders and partners with fire response agencies. A Hawai‘i Island fire chief (and the son of a Hilo sugarcane processing superintendent) recalled:

> When I first started [firefighting] there was still cane agriculture. It was managed very well because that's how they grew crop, it was by fire. So they had fire breaks, knew the language, had equipment. So the first thing we'd do if there was a fire was to call the plantation to see if it was a normal cultivation fire or something else. Access was easy. . . . Where there was cane there wasn't rubbish underneath, nothing for the fire to go through. Everything was harvested and cleaned up and replanted.

Now those fallow sugarcane fields are filled with Guinea grass. One Kaua‘i fire chief says he has watched fuel loads of Guinea grass "double, even triple" in some fallow fields. Participants also said they missed being able to draw on farmers' and cowboys' expertise regarding local terrain (including locations of archaeological sites), weather, and fuel types. For example, ranch bulldozer operators partnering with firefighters knew where the lava tubes were in pāhoehoe lava fields because they had "been over that ground on horseback [and] knew the ground intimately."

The increase in lightning fires in upland forests was specifically noted by Big Island participants. According to one, fifteen years ago lightning-strike ignitions were unheard of on the island. During his first six years as a federal fire commander on Hawai‘i he had heard of two lightning ignitions. "And in the past seven years, it is well over ten or eleven. . . . We're having these lightning strikes because it's a change in the different types of fuels that is not only fire-tolerant, but depends on fire to reproduce."

Protection of Cultural and Natural Resources

Although the primary responsibility of Division of Forestry and Wildlife firefighters remains wildlife fires, all fire response agencies must factor protection of natural and cultural resources into their suppres-

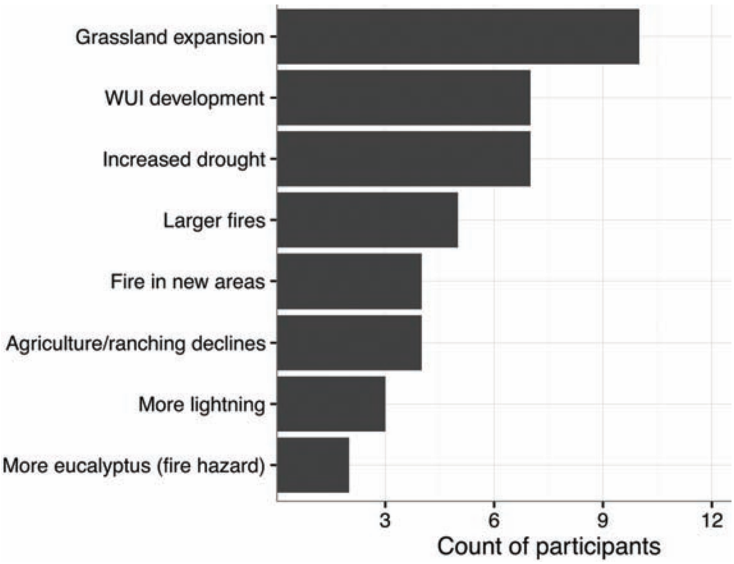

FIGURE 7.7. Changes in Hawaii's environment identified by project participants as having an effect on fire occurrence and suppression.

sion efforts. Fire is generally not a threat to archaeology sites and historic properties. In fact, it can be used as a tool to uncover, clean, and revegetate cultural sites.[18] Interviewees stressed that suppression efforts can do more harm than fire to *heiau* (ritual and religious structures, places of worship), petroglyphs, habitation sites, burials, and other cultural sites. If firefighters do not know where these sites are located, they can damage or destroy them when they are using bulldozers, bucket drops from helicopters, and hoses. A bulldozer can obliterate rock alignments, and the force of water from a bucket drop or hose can easily damage a wall. The former National Park Service IC would tell the helicopter pilots, "Go low and slow. If you're building line, you have to identify these critical areas." A Maui IC said he puts a scout in front of the bulldozer to walk the line and expressed the need to have "eyes on everything" to avoid archeological sites.

The leeward Waiʻanae Coast of Oʻahu (the most flammable region of the island) is a perfect example of a natural and cultural resource hot spot and was mentioned in several interviews. Low-lying coastal areas are ideal for bulldozer operations because they are flat, grassy, and offer easy access. However, they cannot be used in many of these areas because of dense concentrations of archaeological sites. In the uplands, special tactical considerations must be made for threatened and endangered species.[19] Helicopters are the best, and sometimes only, tool for combating fire in the mountains. The ocean is a close source for bucket dips, but agricultural reservoirs and portable dip-tanks are often used to decrease travel time. One participant said saltwater does not necessarily harm native flora,[20] although it does harm fauna. Knowledge of the location and value of cultural and biological resources is clearly critical, but these resources often pose difficult choices for ICs. One participant with extensive experience in Waiʻanae explained that ICs choreograph an intricate "air show" to avoid critical habitats, such as the exclosures for the endangered *kāhuli* tree snail (*Achatinella* spp. Swainson) on the ridges. "We can keep this fire to 200 acres," he said, "and treat the exclosure as secondary, or we can have the fire grow to 500 acres and prioritize the snails."

Figure 7.8. White ash rings from burnt *mamane* (*Sophora chrysophylla* [Salisb.] Seem.) and *naio* (*Myoporum sandwicense* A.Gray) trees during the 2010 Mauna Kea fire (photo by Jay Hatayama).

Also, as emphasized by many participants, the most important issues for all ICs are team safety, human safety, and public health.[21]

While destructive to native habitats, non-native feral ungulates—horses, cattle, sheep, and goats—provide controversial but critical ecosystem services, including fire presuppression. A number of ICs talked about the beneficial role of grazers in reducing fuels. An example repeated by ICs on Hawai'i Island was the Mauna Kea Fire of 2010 (Figure 7.8). Sheep had been removed by order of the federal government to protect the critical habitats of *palila* (Hawaiian honeycreeper, *Loxioides bailleui* Oustalet), mamane trees, and other endemics. According to interviewees, grass fuel loads grew out of control and primed the area for the 1,300 acre fire. As one of them noted, "The forest is still there with the ungulates. But one fire goes through the forest and it's gone. The ungulates have been here since the early 1800s and are now part of the environment."

There is clear evidence that feral ungulates degrade native ecosystems (Mueller-Dombois and Spatz 1975; Murphy et al. 2014; Scowcroft and Conrad 1992), but conservation-based decisions often do not factor in the consequences of their removal for increased fire risk.

Conclusions

In Hawai'i, the local heterogeneity of wildland fire triangle factors (fuels, weather, topography), the spread of pyrophytic savannas and grasslands in the nation's "homogenocene" (Samways 1999) hot spot, the rise of anthropogenic ignitions in wildland-urban interfaces, and increasingly warming, drying conditions present a unique set of challenges for fire suppression and management. In this chapter, based on interviews with fire commanders, we have focused on how fire decision-makers use place-specific environmental knowledge to guide operational responses. To a lesser but equally important extent, we have identified the critical role of local networks in transmitting knowledge. The collaborative dynamics of Hawaii's firefighting community and the knowledge network that has developed across fire agencies and islands are key to survival on multiple levels. Fire agencies overcome infrastructure, equipment, and personnel constraints through creative inter- and intra-agency and island cooperation built largely on personal bonds. In the words of a federal IC who fought fires around the mainland United States and in Europe before his thirteen years in Hawai'i, "I've never seen a more diverse group, different agencies working together and not worrying about what patch they're wearing, worrying about the fire and working together to put the fire out."

Additionally, working together on fires and attending trainings and conferences both support the informal exchange and generational transmission of knowledge and experience between senior commanders and firefighters and strengthens institutional memory.

Indigenous or Native ecological knowledge and resource management systems interpret and respond to ecosystem variability and disturbance (e.g., new crop diseases, climate change) through the complementary use of long-held or revitalized traditional practices (e.g., floral, faunal, air temperature, soil temperature, and moisture indicators in agroecosystems) and conventional science (Tengö and Belfrage 2004). Similarly, the adaptive knowledge of Hawaii's firefighters is dynamic. It draws on native Hawaiian local ecological knowledge, ranching and plantation management practices, technical and analytical training, and new developments in fire science to respond to changing fire regimes. An individual's experience, background, personal and/or family connections, familiarity with place, sensory acumen, and intuition all come into play in decision-making. Several examples were mentioned in the interviews:

- using the Hawaiian moon calendar and consulting with fishers to determine when the wind will die down and be the safest time for a prescribed burn
- spotting lava tube skylights themselves or consulting cowboys familiar with their locations when cutting a fire break through pāhoehoe lava to avoid lava tubes and *pōhaku ki'i* (pictographs)
- gauging relative humidity when sensors are malfunctioning
- knowing that the wind is likely to reverse direction at certain places during the night
- understanding how fierce winds and rain will differentially impact the fire behavior of native versus non-native grasslands, and when and where being "in the black" really constitutes a safety zone

Like fishers, salt collectors, hula and medicinal plant gatherers, and other cultural practitioners, firefighters are environmental ground-truthers contributing their observations and insights on climate change. One example is the dramatic and relatively recent uptick in lightning fires on Hawai'i Island. New climatology research using a novel storm model, for example, has demonstrated an increase in lightning strikes and the initiation of more wildfires in the United States due to global warming (Romps et al. 2014).

Heuristic devices or rules of thumb employed by Hawaii's firefighters have grown out of collective knowledge and personal perceptual expertise critical for making life or death decisions under immense time pressure. Examples include re-operationalizing strategy when firefighters hear a sound like a freight train (which indicates a fire is about to run), identifying a fuel source by the smell or color of smoke, and calling for backup when a distant fire plume is wider than one's thumb. Klein's (2000) model of naturalistic decision-making by fire ground commanders, emergency room medical personnel, military commanders, and other professionals in high pressure vocations highlights perceptual expertise. For instance, experienced nurses use certain cues to determine if a premature infant has developed a life-threatening infection (e.g., irritability, skin color). Many of these cues are covered in nursing education, but many others are not and may, in fact, be contrary to how sepsis presents in healthy neonates or adults. New nurses tended to miss signs of sepsis, resulting in higher death rates in preterm infants. Septic deaths were reduced significantly after perceptual indicators of infection in preterm neonates were compiled from experienced nurses and incorporated in training material (Klein 2000, 43).

In tactical training, fire commanders learn that decision-making is both analytical and intuitive. One interviewee estimated that the knowledge a commander brings to a fire is 30 percent didactic and 70 percent experience: "You just know from the intuitive cache in your brain what steps to take." He described how this worked for him when he drove around Maui: "I look at an area and think if I got a call right now, what would I do? So I play situational games."

The mental "slide projector" of past fires referred to in a few interviews is not made up of static snapshots but involves what Klein (2000, 45) refers to as a heuristic strategy of mental stimulation involving "the ability to imagine people and objects consciously and to transform those people and objects through several transitions, finally picturing them in a different way than at the start."[22]

The applied significance of these findings suggests that place-based understandings of Hawaii's firefighters can be used to better inform land and resource management practices and fire mitigation programs in the face of climate variability and change. Most of the fire commanders interviewed for the Challenges project referred to climate change implicitly rather than explicitly. Only three respondents used the term *climate change*, and only one used the term *global warming*. Nevertheless, participants did note environmental changes they had recognized over the course of their careers. Observations often related to the intensity, frequency, spread, and seasonality of fires, and their anticipation of more extreme weather and disturbance regimes in the future.

Some participants stressed the need for better development policy and planning. They argued that Hawaii's increasingly incendiary environment be taken into account by restricting new development in wildland-urban interface areas or mandating that planned communities be made fire-safe, meaning that they be surrounded by defensible space, fire breaks, and adequate access. Two of the ICs recommended that golf courses surround resorts and residential communities rather than being located at their centers, as is currently most common. And the use of kikuyu grass on golf courses may need to be reconsidered. Although golf courses may seem to planners and developers to offer a green buffer or safe zone, from a firefighting standpoint, kikuyu turf grass can lead to dirty burns and extended fires.

Participants in the Challenges project also urged research and development of new prevention and response procedures based on past Hawaiian and agricultural resource management practices, including more controlled burns, letting fires run their course where assets are not threatened, using ungulates for prescribed grazing to reduce fuels (Elmore et al. 2005; Blackmore and Vitousek 2000), and revegetating with native plants. They also asked for more locally informed public outreach prevention and mitigation programs.[23] For example, the place-based knowledge of Hawaii's seasoned firefighters could be compiled and shared through training courses and guides, as well as through multiagency activities such as training and conferences. This suggestion is especially crucial because Hawaii's firefighting community will become further challenged by the loss of retiring ICs and chiefs with long-term knowledge who, in the words of one interviewee, "know how to put the pieces together in an operational picture—know which way the fire is going, what it's going to be doing, and what is necessary to stop it."

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Notes

1. Sizeup, a term used universally by firefighters, is a quick initial assessment of environmental conditions in relation to available resources in order to set operational priorities.
2. In the words of one of the participants, "The more opportunities we can get the people together . . . before the fire, after the fire, when there is no fire, and do more training together and do more sit-downs together then we can speed up those relationships. . . . Find the reasons to get together whether, hey, we got a new truck we're blessing [Hawaiian blessing of new fire engines] or we're doing new training on this new truck."
3. In the words of a Hawaiʻi Island federal IC, "You want to talk about a loss. You know they say [in] government service no one is irreplaceable? That's not true. . . . I'd say about 30 percent of the brain trust of wildland fire response is with those two guys."
4. For consideration of how the alteration of the landscape and cultural practices that followed the introduction and expansion of cattle in the late 1800s were accommodated by the existing Indigenous Polynesian system of natural resource values and management practices, see Maly and Wilcox's (2000) history of range management in Hawaiʻi, Traditional Polynesian and Western Resource Management: Conflict and Assimilation.
5. A Hawaiʻi Island participant said, "We have so many mini microclimates. For example, Volcano and the golf course. Volcano Village is 2 miles down the road from Volcano Golf Course. Volcano Village can have 15 inches of rain in a month and the golf course will only have 5. You can have a 60 percent difference in rainfall in a 2 mile area." A Maui Island participant said, "We can be on one ridge and the [relative humidity] could be 20 percent on the windward side, and on the leeward side of the mountain the [relative humidity] could be 8."

6. An example of terrain challenges as described by an Oʻahu participant:

   > On Oʻahu our landscape is dramatic. On the Big Island you have more sloping land. Topographically it's a problem. We don't have a lot of roads. We don't have access. We have steep slopes with rolling rocks, burning embers, and debris that can create spot fires. . . . On mild slopes we could scratch a line. But now we have to dig trenches to catch rolling embers and pine cones. Topography sucks on Oʻahu. If it was nice and flat and we didn't have arch[aeology] sites, we could utilize heavy equipment as well. If you have arch sites, you can't bring dozers there. If there are not access roads, you can't pump water out of a truck. So we have to carry backpack pumps and fly blivets. And helicopters are expensive.

7. There was general consensus among participants that instruments that work well for the mainland are often insufficient for Hawaiʻi. A statement that typifies responses is: "You can go online and see what the weather, wind speed, temperature, et cetera was an hour ago. That's all online. But things change so rapidly here. There are so many microenvironments here, that's hard to put online."

   An Oʻahu participant made the point that firefighters should have sufficient "qualitative indicators" in their experiential toolkit to not have to rely fully on "quantitative indicators."

   Discussing the Keetch-Byram Drought Index (KBDI), he described how it is useful for preplanning, but not for suppression:

   > You can tell already everything is pretty dry, dead. It's not brown, it's gray, grass is dry, fire is burning strong. . . . There are all these qualitative indicators. Under eucalyptus there is no understory. There are all these twigs and leaves so fire smolders through that stuff. I've seen 18 inch flame heights. That's an indicator that the KBDI is high. [KBDI] is quantitative, while when you are out there you have all of these qualitative indicators. For example Maui, when the KBDI is above 600, they take their fire packs with them everywhere they go. So they use it more for preplanning than suppression. From a suppression side, after so many years of experience, hopefully, managers can tell from qualitative indicators than KBDI. That's the slide [projector] mentioned earlier.

8. Nāulu, meaning a "sudden shower" (Pukui and Elbert 1986, 263), can also refer to the sea breeze particular to certain locations, including a nāulu that blows off the coast of Maui influencing Kaʻaholawe Island's weather system. The Hawaiian language includes numerous place-specific terms for elements of the natural environment: winds, cloud formations, rain, ocean currents, and so on.
9. "Burn boss" is standard firefighter terminology for the person who supervises a prescribed burn from start (ignition) to finish (mop-up).
10. We note that lava fire starts are relatively infrequent compared to human ignitions.
11. Cutting line refers to carving a path by hand or bulldozer through exposed soil to block the fire's access to more fuel.
12. There is a prominent temperature inversion in the trade wind that streams over the eastern tropical oceans, including the Hawaiian Islands. Moist air extending above the surface is trapped by dry, warm air above. The inversion forms where the sinking dry, warm air meets the surface flow of cooler maritime air. One participant's observation of a Hawaiian hawk catching thermals high up in the air was a signal for him that the cap was off the inversion layer—in other words, the layer was lifting, a key indicator of atmospheric instability and large fire growth.
13. Curing—the process by which grasses die or become dormant and dry out—is a useful indicator for assessing fire danger. For a good example of a curing guide see the CFA Grassland Curing Guide (CFA, n.d.).
14. The key factor in establishing a safety zone, or "black area," is that it has no reburn potential. The black area also must position firefighters at a safe distance from radiant heat and have adequate egress and ingress routes.
15. Another aspect of the conservation conundrum is that invasive alien species sometimes provide critical habitat for native fauna. This is true of fountain grass and the endangered nēnē. It has been found that the nēnē on the Pōhakuloa

Training Area specifically choose taller fountain grass for nest sites and shorter grasses for food and mobility (US Army Garrison 2010).

16. Kiawe, introduced for cattle fodder, has naturalized culturally as well as botanically. It is a highly valued ethnobotanical resource used primarily as a fuel wood for cooking, and also for a variety of other purposes including making flour from the beans, carving, as a source of honey, and, more recently, making beer. From the perspective of plant users in Hawaiʻi, there is often not enough kiawe to meet the demand, especially for barbecue or imu (underground oven) fuel. Kiawe is emblematic of several contested or controversial floral and faunal species labeled "alien" and "invasive" that have been targeted for removal by conservation efforts but, at the same time, are regarded as culturally valuable to native Hawaiians and the diversity of ethnic groups that utilize natural-cultural resources. A signature of kiawe and other culturally naturalized species (e.g., waiawī, or yellow strawberry guava [*Psidium cattleianum* Sabine]) is that they often bear a Hawaiian name (Gollin et al. 2004).
17. The wildland-urban interface is the transition zone where human development (structures and infrastructures) meets or overlaps with undeveloped wild areas and/or vegetation, increasing the likelihood of anthropogenic ignitions and fire spread from one zone into the other.
18. Pili has come to play an important role in conservation and restoration projects, replacing invasive species such as fountain grass in island xeriscapes. One of the participants worked with University of Hawaiʻi researchers on a seven-year study at Puʻukoholā Heiau burning off the alien buffel grass and reseeding it with native pili grass. Now the area looks like it did in depictions from 1790s. According to the participant who served as the project burn boss, native Hawaiian practitioners visiting the restored site commented that the wind blowing through the pili sounds different and is more pleasing than wind through buffel grass.
19. Three of the five protected Natural Area Reserves Systems (NARS) on Oʻahu are in Waiʻanae.
20. The firefighting and natural resource management communities do not fully agree that saltwater is harmful to native flora. The use of saltwater (as well as foaming agents) to extinguish wildland fires is a concern for natural resource programs.
21. A forestry IC stated that while the job of the Division Of Forestry and Wildlife may be "to protect the last gardenia on earth," the first order of concern for an IC, "even if it is the last gardenia on the face of this earth," is to never "put my men [in a situation] if I know it's going to be detrimental to them."
22. One of the commanders interviewed for Klein's (2000) study of naturalistic decision-making remarked, "To be a good fire ground commander, you need a rich fantasy life" (14).
23. In their overview of Social Science Findings in the United States, McCaffrey et al. (2015, 23) make the point that situational characteristics such as local ecological conditions are a key consideration for many residents, who have a higher likelihood of adopting fire risk reduction measures they view as appropriate to the local ecological context.

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