PARADISE ON FIRE: HOW HAWAIʻI DEVELOPED ONE OF THE WORST WILDFIRE PROBLEMS IN AMERICA

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Hawaiʻi is experiencing a massive wildfire problem that has grown in size, rate, and frequency. As a Hawaiian scholar, I am concerned and passionate about understanding and combating this crisis. My kūpuna cared for and stewarded over the natural spaces on which they were dependent. I share the same kuleana as them in understanding and caring for the natural spaces around me. The aim of this research is to increase awareness about what's causing these wildfires and how Hawaiʻi has developed into a fire-prone state over time. This research will also provide quantitative data as to the rate, growth, and measurement of land that is burned each year to determine the scale of environmental harm and the annual growth of wildfire size and ignition frequency over time.

Introduction

Hawaiʻi is not known for wildfires; larger desert states like California, Oregon, Texas, and Utah are more well known. From 2005 to 2011, Hawaiʻi was engulfed by the flames of one of the biggest wildfire problems out of any state. Wildfires know no boundaries and are readily ignitable from makai[1] to mauka[2] landscapes across the archipelago island state. Wildfires affect everything in their direct and indirect pathways, including infrastructure, economy, agricultural production, native forests and grasses, coral reefs, watershed, wetlands, human

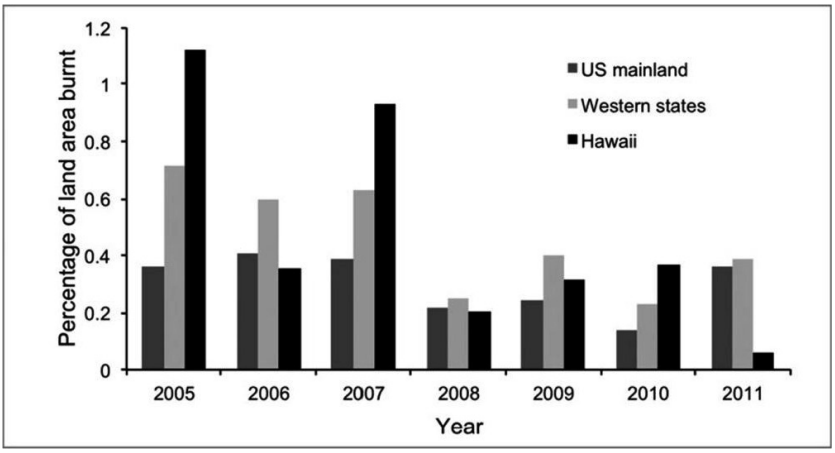

FIGURE 1. **The percentage of land area burned in the US mainland, the westernmost fire-prone US states, and Hawaii from 2005 to 2011. Hawaii (black) is shown burning more than the whole mainland (dark gray) in 2005, 2007, and 2010, including the westernmost fire-prone states (light gray). (Contemporary Scale and Context of Wildfire in Hawaii, *Pacific Journal*, 2015.)**

and animal safety, and cultural resources. Over the past century, wildfires have grown in rate, size, and frequency.

The first portion of this article will identify the scale and magnitude of wildfires in Hawai'i by looking at their history over the past century. It will examine the amount of land burned, size, frequency, intensity of wildfires, and where they are occurring. Following will be a focused look at the role humans have played in causing these wildfires. The third portion of this article will examine the correlation between societal and economic changes that took place from the nineteenth to the twenty-first century and the conversion of Hawaiian landscapes into fire-prone environments. A concluding section will expound upon the role in which invasive grasses and shrubs occupy in fueling and perpetuating the fire cycles in Hawaii today.

Magnitude and Depth of Hawaii's Wildfire Problem

The overall scale at which flames are engulfing Hawaii is nothing less than alarming when you confront the amount of acreage being burned annually. Hawai'i currently burns a larger percentage of land annually than any other US state yet is the forty-seventh smallest state. According to fire ecologist and scientist Clay

FIGURE 2. **Aerial view of the Leilani wildfire. Firefighters continue to battle the Big Island wildfire; 25,000 acres were scorched. (Department of Land and Natural Resources 2022.)**

Trauernicht (Trauernicht et al. 2015), "The mean annual area burned in Hawai‘i from 2005 to 2011 (8,427 ha yr^{-1} [20,823 acres]) accounted for 0.48 percent of Hawai‘i's total land area, which was greater than the proportion of land area burned across the entire U.S. mainland (0.30 percent), and even across the 12 states in the fire-prone, western United States (0.46 percent, includes Alaska) over this same time period." In terms of total land area, Hawai‘i is an island state with significantly less land acreage than any continental state, yet the data show that the annual percentage of land area burned in Hawai‘i surpasses that of any continental state. Figure 1 shows a comparison of the percentage of land burned in Hawai‘i, the westernmost fire-prone US state, and the entire US mainland from 2005 to 2011.

Disaster struck again on the Big Island only a year later in August 2022, "just south of Waikōloa Village, the resort area, and mauka of Highway 190 near the Puu Lani Subdivision, a 17,000-acre wildfire has left a charred landscape" (Department of Land and Natural Resources 2022). That fire, called the "Leilani wildfire," started on military training grounds and threatened nearly 7,000 civilians who resided in Waikōloa Village (see Fig. 2).

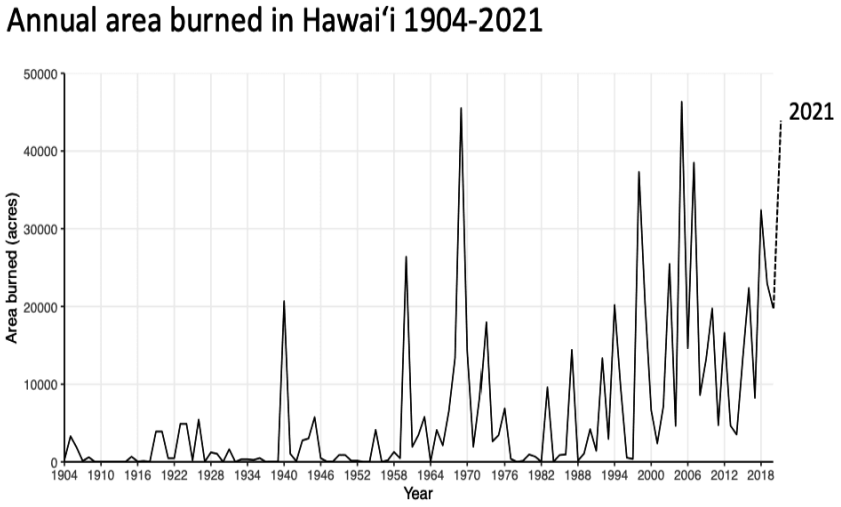

FIGURE 3. **Annual area (acres) burned in Hawaii from 1904 to 2021, showing an overall consistent rise over the past century 1. (Trauernicht and Hawaii Wildfire Management Organization 2021.)**

Hawai'i has been burning a significant portion of its land annually because of risk factors such as human population, climate change, and natural landscape change. Wildfires have drastically become more frequent, especially in the past decade. From 2012 to 2021, Hawaii has seen an overall consistent rise in the amount of land burned annually, as represented in Figure 3, where land burned from under 20,000 acres in 2012 to over 30,000 acres in 2018 and 2019 and then over 40,000 acres in 2021. There have even been incidents of wildfires burning a higher percentage of land within a single burn than the majority of fire-prone western states have annually. This was seen on July 30, 2021, when "the Mana Road Fire burned 1 percent of the Hawaiian Islands' land area in a single incident. For context, a year's worth of fires in California burn, on average, 0.7 percent of the state's land area" (Trauernicht 2021). The Mana Road fire (see Fig. 4) spread at a rate of one hundred acres per hour and consumed 40,000 acres of Hawaiian land.

Examining the rate and frequency of wildfires requires a look at the historical context of wildfires in Hawai'i. Taking a step away from recent years and looking at the past century, "total area burned statewide increased more than fourfold from 1904 to 1959 to peaks in the 1960s–1970s and mid-1990s to present" (Trauernicht et al. 2015). The University of Hawai'i at Manoa and the Hawaii Wildfire Management Organization formed a joint program called

FIGURE 4. **The Mana Road fire burning on the Big Island, 25th Infantry Division, Hawaii Fire. (Gabbert 2021.)**

the Pacific Fire Exchange, which is dedicated to making wildfire science available that is specific to the Pacific region. Shown below are data provided by the Pacific Fire Exchange that charts the amount of area burned (in acres) annually from 1904 to 2021.

Figure 3 shows the annual area burned (acres) from 1904 to 2021, indicating a strong overall trend of an increasing amount of land burned annually from 1904 to 2021. While this is close to the present, it still doesn't account for incredibly large wildfires, such as the previously mentioned Mana Road fire and the Leilani wildfire.

In 1901, the first large wildfire recorded in Hawaiian history burned 30,000 acres over the span of three months on the Hamakua coast of the Big Island. The fires caused so much destruction to land that a system and data collection policy was developed, leading "to the establishment of Hawai‘i's Forest Reserve

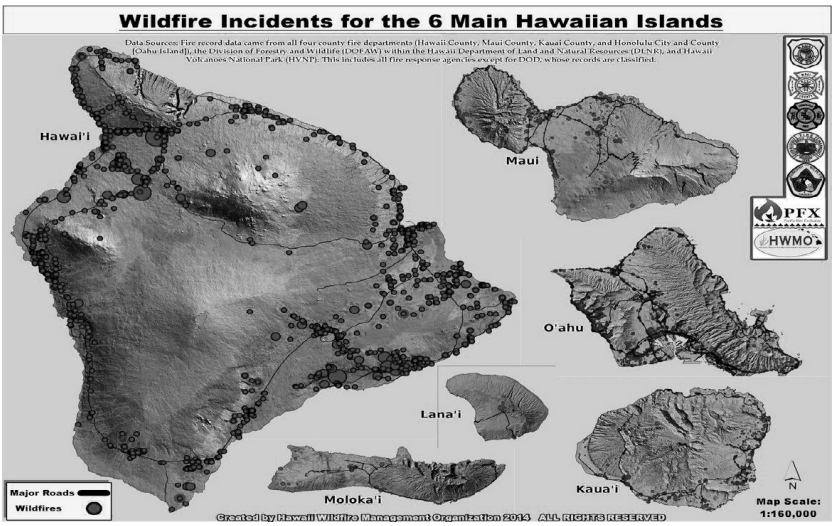

FIGURE 5. **Map showing wildfire incidents that have taken place among the six main Hawaiian Islands from 2000 to 2012. (Hawai'i Wildfire Management Organization 2021.)**

System, the integration of wildfire into government forest management policy, and the initiation of annual wildfire reporting in 1904" (Trauernicht et al. 2015). Since 1904, wildfires have been documented and recorded by the Hawaii Division of Forestry and Wildlife, county fire departments, and the Hawaii Wildfire Management Organization. The map shown in Figure 5 was created by the Hawaii Wildfire Management Organization using records from multiple sources to show where these wildfire ignitions took place specifically from 2000 to 2012. Figure 5 is important because it is showing us visually where these fires are and how big they are. The many red circles littering the coasts in the map show an incredible number of fires taking place within a twelve-year span and give us an idea of which communities are dealing with wildfires.

Human Error

The wildfire crisis in Hawai'i is caused primarily by human activity on many levels. Human error is responsible for almost all wildfire ignitions in Hawai'i; rarely do natural occurrences like lightning or lava cause wildfires. Humans completely changed Hawaiian landscapes to become more fire prone by

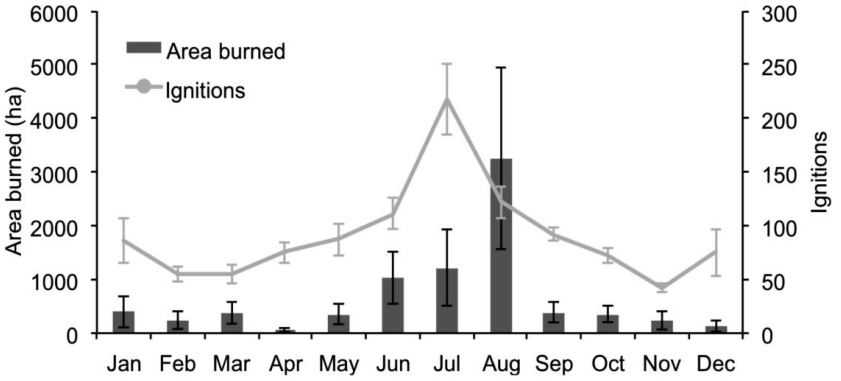

FIGURE 6. **Average area burned in hectares (dark gray bars) and the amount of wildfire ignitions that took place each month during 2005–2011. This shows year-round ignitions with peaks in June, July, and August. (Contemporary Scale and Context of Wildfire in Hawaii, *Pacific Journal*, 2015.)**

introducing invasive plant species that are extremely flammable and that dominate the terrain pre- and postburn. The abandonment of sound and proven Native Hawaiian land management practices enabled residential, commercial, and military development to convert Hawai‘i to a fire-prone state through landscape changes and increased human interactions within the Wildland Urban Interface[3] (WUI).

All wildfires start at ignition, and, unfortunately, most ignitions start with humans. In fact, "more than 99% of known wildfire causes were attributable to human activities, for example, sparks from machinery, cars, and downed electrical lines; campfires; fireworks; and arson" (Trauernicht and Lucas 2016). Natural causes of ignition are rare and exclusive to lava flow, volcanic activity, and lighting strikes. Lightning strikes don't seem to be a major culprit, "accounting for <0.2% of attributed wildfire causes'" (Trauernicht et al. 2015). Natural conditions and weather within an environment are huge determinants of wildfire activity. Things like temperature, humidity, and rainfall all contribute to wildfire ignitions.

Climate and time of year play a critical role in the frequency of ignitions and the overall chance of ignition transpiring. From 2005 to 2011, the majority of wildfire ignitions took place in June, July, and August during the hottest, driest times of the year (see Fig. 6). They also most frequently take place on the drier leeward sides of the islands. Despite peaking during hotter, drier months and most frequently occurring on the drier sides of the island, when looking at

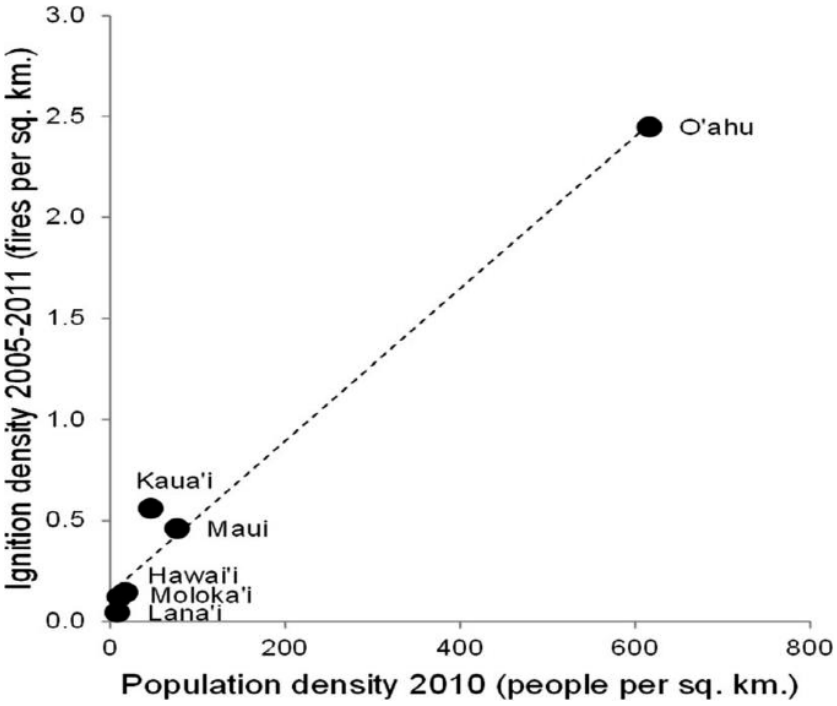

FIGURE 7. **Ignition density from 2005 to 2011 shown in correlation with each island's population density from the 2010 census. (Contemporary Scale and Context of Wildfire in Hawaii, *Pacific Journal*, 2015.)**

Figures 5 and 6, year-round wildfire occurrence is observed on both dry and wet sides of the islands.

There is also a direct connection between population density and wildfire ignitions. Population density increases within the limits of the islands, causing more human interactions to transpire within the WUI. "The Wildland Urban Interface (WUI) is the zone where structures and other human development meet and intermingle with underdeveloped wildland or vegetative fuels" (Department of Land and Natural Resources 2010). The WUI is a vulnerable zone where human development starts to affect undeveloped land and human activities start and carry fires over into wildland. Figure 5 shows wildfire ignitions from 2000 to 2012, where we can see that the majority of ignitions took place along roadside areas. In other words, the more people there are in such a small space as Hawai'i, the more wildfire ignitions occur.

Figure 7 illustrates the correlation between population density and ignitions per square mile for Oahu, Hawai‘i, Moloka’i, Maui, Kauai, and Lana’i from 2005 to 2011. Note how Oahu has the highest population density, which correlates to the highest ignition density.

Societal Change and Abandonment of Comprehensive Land Management Practices

One of the things that has most contributed to the wildfire problem seen today is the many societal and economic changes that have taken place in Hawai‘i since the cessation of subsistence culture and society. Through proper stewardship of watershed-based land divisions, Kūpuna, “lived close to the land, developing systems and ways to protect, preserve, and restore the ocean and the land resources” (Department of Commerce and Consumer Affairs 2004). During this time, fire was present only as a tool used to burn pili grass and serve other agricultural functions. According to Trauernicht et al. (2015), “There are accounts of larger-scale, intentional land-scape burning to manage plant resources such as the native pili grass (*Heteropogon contortus*) for thatching.” These types of tools and agricultural methods were common in Polynesia.

The most notable event in the history of land tenure took place in 1848 with, the Mahele, when King Kamehameha III gathered with 245 *Ali’i*[4] and *Konohiki*[5] to divide up all 4 million acres of land. The Mahele made it possible for an individual to own title to land and “is the single most important event in the history of land title in Hawai‘i. It essentially abolished the feudal system and gave rise to an allodial system of land tenure. Private ownership of most of the property in Hawai‘i began with the Great Mahele” (Department of Commerce and Consumer Affairs 2004). Land could then be purchased as a result of private ownership, changing Hawaiians’ relationship with the living systems that surrounded them. Private landownership and capitalism replaced the feudal system under a sovereign monarch, leading to the end of subsistence culture throughout Hawaii.

By the mid 1800s, both ranching and plantation agriculture had established a foothold in Hawaiian society. According to a research paper published by the University of Hawai‘i on wildfires, “The development of Hawai‘i’s agricultural economy from the mid-nineteenth to early twentieth centuries accelerated population growth and likely had significant impacts on the number of wildfire ignitions” (Trauernicht et al. 2015). As plantations and other agriculture grew, labor opportunities drove immigrants to Hawai‘i to work, contributing to the rise in population. According to the US Department of Commerce (2022), in 1950, the population of Hawai‘i had grown to 493,437. As shown in Figure 7, there is a direct correlation between population and wildfire ignition frequency.

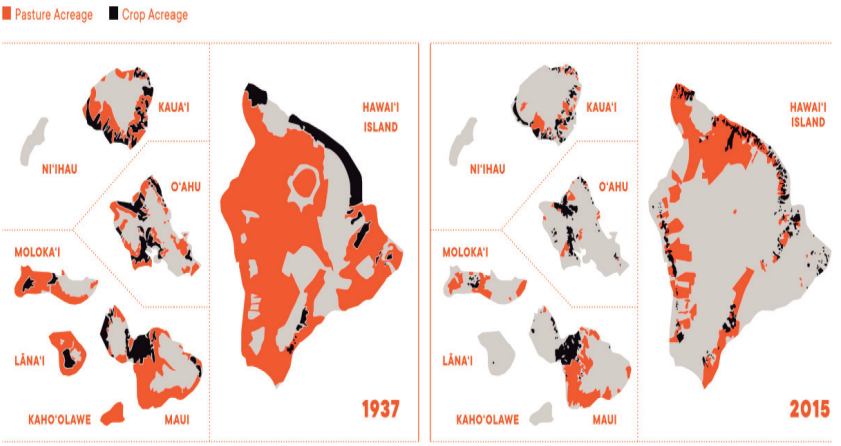

FIGURE 8. **Loss of suitable pasture and agricultural land from 1937 to 2015. (Hawaii Department of Agriculture Statewide Agricultural Land Use Baseline, 2015.)**

The scale to which ranching and plantation agriculture rose and fell greatly contributed to the transformation of Hawaiian land into fire-prone landscapes and can be seen in Figure 8. In 1937, over 50 percent of Hawaiian land was used for ranching and another 5 percent for sugarcane. Consequently, ranching declined in Hawai'i in the mid- to late twentieth century. Over 2 million acres in Hawai'i were classified as "grazing lands," and by 2015, only 750,000 acres of land were classified as "pasture" (Department of Land and Natural Resources 2017), resulting in a 62.5 percent decrease in ranching and agricultural land from 1937 to 2015. By 2015, 90 percent of the remaining suitable agricultural land was fallow, unmanaged, and overrun with non-native invasive grasses, shrubs, and trees.

The reason the rise and fall of ranching and agriculture in Hawai'i has contributed to wildfires is because the non-native plants that have dominated the remaining fallow land are the primary fuel sources for the wildfires that are occurring. According to researchers at the University of Hawai'i, "Unmanaged, fallow agricultural lands in Hawai'i typically become dominated by nonnative grasses" (Veldman and Putz 2011), making agricultural abandonment a primary driver of the current dominance of fire-prone, nonnative grasslands statewide" (Trauernicht et al. 2015).

While the presence of non-native ungulates[6] negatively affects native ecosystems in diverse ways, they do a great job at preventing wildfires. "Domestic and non-native ungulates can reduce fine and woody fuel loads through grazing

and browsing, and increase the discontinuity of the fuel bed, therefore affecting the frequency, intensity and severity of wildfires" (Archibald and Hempson 2016; Belsky 1992; Kellner 2011; Trauernicht 2013; Zhu et al. 2021). Grazing on non-native grasses and shrubs by domesticated livestock reduces the primary fuel load for wildfires and decreases their intensity and rate of spread. During Hawaii's peak era of ranching and plantation agriculture from 1929 to 1937, the frequency of wildfires that occurred was dramatically less than is seen today. A noticeable difference in the severity and frequency of wildfire activity is observed (see Fig. 2) from the mid-twentieth century, when ranching and agriculture started to decline, to the present day.

Wildfire and Fuel Loading Cycle

The wildfire and fuel loading cycle is the driving force behind the rapid non-native grassland dominance of native Hawaiian ecosystems. These invasive species can outcompete and outlive native Hawaiian plant species in the case of wildfire and provide an incredible source of fuel to wildfires. Such plants are fountain grass (*Pennisetum setaceum*), Guinea grass (*Megathyrsus maximus*), Formosa koa trees (*Acasia confusa*), buffel grass (*Cenchrus ciliaris*), and molasses grass (*Melinis minutiflora*). Currently, "Wildfires in the region are exacerbated by invasion of fire-prone grasses and shrubs, which now make up 25% of Hawai‘i 's land area" (US Forest Service, n.d.). Invasive grass species are dominant in Hawai‘i and cover nearly one-quarter of all land.

These invasive grasses possess intrinsic qualities that make them a perfect and readily available fuel source for wildfires. When studying what physical properties make invasive grasses and shrubs such a fast-growing and potent fuel source, researchers at the University of Hawai‘i at Manoa (UHM) found that "intrinsic fuel properties associated with type conversion from forest to grassland can include increased flammability due to lower fuel moisture (Brooks 2004), total curing of grass (Andrews 2006), and higher ratios of surface area to volume (Hoffmann 2012), followed by competitive superiority for above- and belowground resources in the postfire environments (Veldman and Putz 2011; Ammondt and Litton 2012; Invasive grasses change landscape structure and fire behaviour in Hawai‘i 2009). These qualities allow invasive grasses and shrubs to cover immense space and burn easily. They are perfectly built for wildfire, so how does that affect wildfire behavior?

In 2014, a study by researchers at UHM sought to better understand how invasive grasses affect potential fire behavior in open grasslands versus grass-invaded native forest. Their method of collecting data "quantified fuel load and moisture in non-native forest and grass-land (*Megathyrsus maximus*) plots (n = 6) at Makua Military Reservation and Schofield Barracks, and used these field

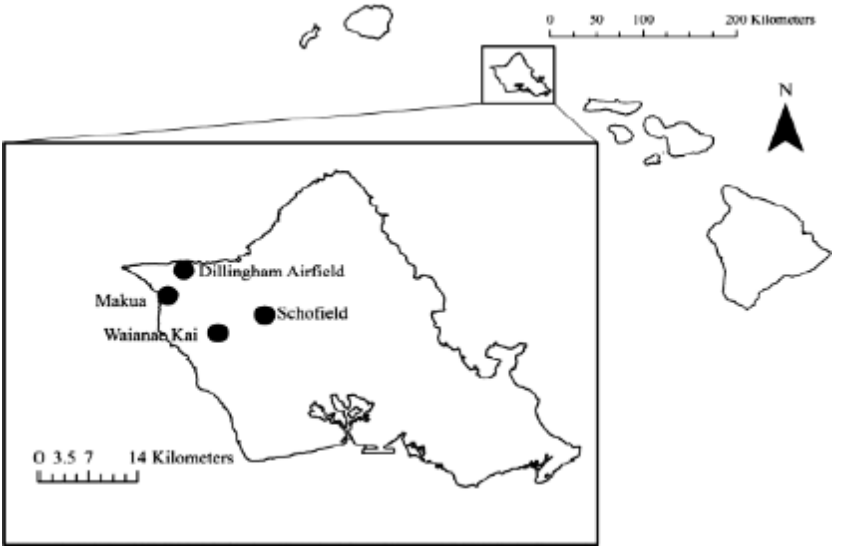

FIGURE 9. **Open grassland and grass-invaded native forest sites where fuel loads were quantified and fire modeling took place for the 2014 UHM study on fire behavior. (*Journal of Applied Vegetation Science*, Department of Natural Resources and Environmental Management UHM, 2014.)**

data to model potential fire behaviour using the BehavePlus fire modeling program" (Ellsworh et al. 2014). At each of these sites (see Fig. 9), they examined three open grassland plots and three non-native forest plots. The understories of all these plots were dominated by *M. maximus* (both open grassland and forest). Within each of these 50 × 50-m plots, they measured the total fuel loads (dead and living grasses, shrubs, and trees), mean fuel height, fuel composition, and moisture levels. Using these data, they found that "mean surface fuel height was 31% lower in forests (72 cm) than grasslands (105 cm; $P < 0.02$), which drove large differences in predicted fire behaviour. Rates of fire spread were three to five times higher in grasslands than forests, and flame lengths were two to three times higher in grasslands than forests" (Ellsworh et al. 2014). These data show a large increase in wildfire intensity in areas that are more dominated by *M. maximus* (open grassland) than forest and that can be directly associated with type conversion of landscape from forest to non-native grassland.

This same study also sought to understand and measure the landscape conversions taking place at the two locations that they quantified invasive fuel loads. In Hawai'i and other parts of the tropics, the commonly accepted

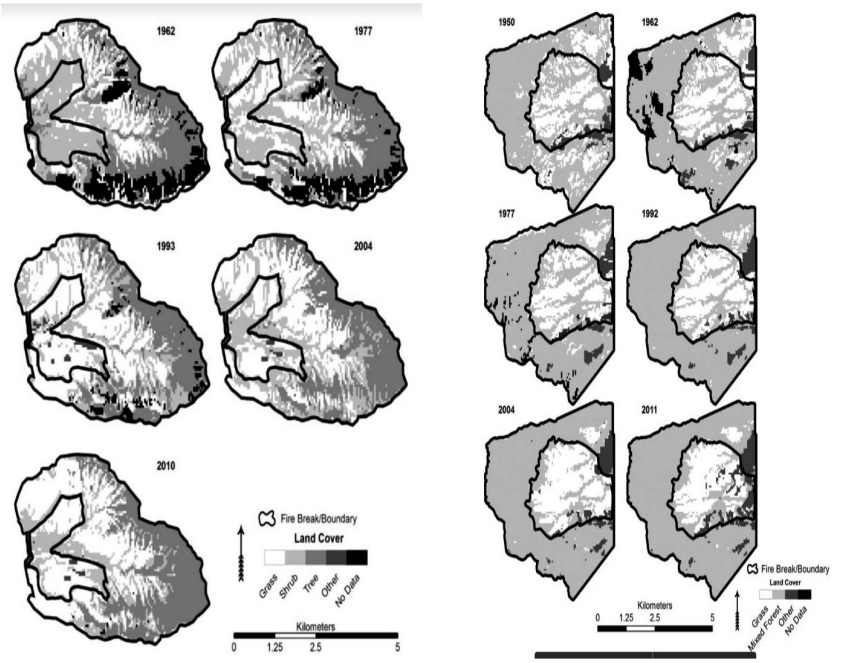

FIGURE 10. **(Left) Makua Military Reservation land cover change from 1962 to 2010 and (right) Schofield Barracks land cover change from 1950 to 2011 showing dramatic decrease in native tree cover and increase in grass and shrubs cover. (*Journal of Applied Vegetation Science*, Department of Natural Resources and Environmental Management UHM, 2014.)**

paradigm is that "fire shifts composition from woody communities (forest) to non-native grassland, that these changes persist over long time periods, and that the end result is a landscape that is increasingly dominated by non-native invasive grasses that have a much higher fire risk than the forests that they replaced" (Ellsworh et al. 2014). Researchers at UHM used aerial imagery from 1950 to 2011 to track the large-scale landscape conversions taking place at Makua Military Reservation (see Fig. 10, left) and Schofield Barracks (see Fig.10, right) to understand how these places have changed over time. Here we see the native tree cover disappear and become completely overtaken by grasses and shrubs by 2011.

A significant part of the "competitive superiority" is because they are fire adapted, while the majority of native Hawaiian plants are not. When a wildfire occurs in an area, native plants cannot regenerate and grow back. The

non-native grasses that can grow back do so quickly, overtaking the entirety of said space and then converting it to fire-ready grassland. A great example is this of fountain grass. According to the Department of Land and Natural Resources (2010),

> During a wildfire, most of the above ground portion of the grass is burned, including a highly flammable seed head. The seeds are dispersed by windy conditions that occur during wildfires. Fountain grass roots, which can easily withstand fire, quickly regenerate during Hawaii's rainy winter season. The ash from the fire nourishes the existing Fountain grass rhizomes and provides nutrients for the newly sprouting seeds.

The grasses therefore infiltrate, dominate, and then eliminate native plants. The relationship between these fires and grasses is symbiotic in nature, each continuously fueling each other, creating a dangerous cycle, and ultimately changing landscapes to become more susceptible to fire.

Conclusions

In the past two centuries, Hawai'i has undergone an immense societal, economic, and environmental transformation that has resulted in a devastating wildfire problem. On examination of Hawaii's history, we can see exactly how this development has occurred. In 1848, a feudal system of watershed-based land stewardship was replaced with an allodial system of land tenure that opened up the privatization of land.

From 1848 to 1937, over half of the land in Hawaii was transformed into pasture grazing land and plantation agriculture land. From 1937 to 2015, that amount of land decreased by over 62 percent, and over 90 percent of the remaining land suitable for ranching agriculture lands turned fallow and unmanaged. This land perfectly welcomed invasive grass and shrub plant species that have dominated and transformed Hawaiian ecosystems into fire-prone environments. These grasses and shrubs are the perfect fuel for fires and cover one-quarter of all Hawaiian lands. These grasses fuel a wildfire and fuel cycle with the help of high temperatures, dry climates, and human error.

The issue of wildfires demands immediate attention due to its destructive nature and devastating effects on native species, ecosystems, natural resources, and human lives. Hawaii was once free of frequent wildfires and has since become one of the most wildfire-frequented US states, with over 1,000 ignitions annually burning up to 20,000 to 40,000 acres each year. Putting out

the flames of this fire requires assessment, preparation, and planned action at the state, military, academic, and community levels. This has not gone unrecognized, as there are numerous professionals and people dedicating time, research, and effort to fight this problem on all levels. On an academic level, there are countless professors and faculty from the University of Hawai‘i and other institutions dedicating research, time, and effort in spreading awareness and combating this problem. On a community level, there are countless men and women belonging to county fire departments, the Hawai‘i Division of Forestry and Wildlife, and the US armed forces that have boots on the ground and are risking their lives fighting these wildfires. These contributions to understanding and combating the wildfire crisis in Hawaii are critical to mitigation efforts toward reducing the destruction of lands and opportunities for livable places for Hawaiians.

NOTES

1. Seaward, or toward the ocean.

2. Upland, toward the mountain.

3. Transition zone between wilderness and land developed by humans.

4. Chief.

5. A special class of Ali'i that managed and stewarded over land, water, and human resources.

6. Any kind of typical hoofed animal that grazes or eats grass.

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