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# Fuel Breaks and Fuels-Management Strategies for Pacific Island Grasslands and Savannas

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## Objectives of This Guide

Fuels management is any method of altering vegetation to reduce fire hazard and thereby reduce wildfire intensity and risk. This guide outlines key factors for landowners and natural resource managers to consider when deciding where and how to implement fuel breaks and other fuels management strategies. Fuels management is a central part of wildland fire risk reduction, but most available resources focus on forests and temperate rangelands (e.g., Green 1977; Moriarty et al. 2015; Dennis, n.d.). This guide focuses instead on tropical grasslands and savannas, the vegetation/fuel types that burn most frequently on Hawai'i and other Pacific Islands such as Guam, Yap, the Northern Marianas, and Palau. It draws on relevant fire science as well as in-depth discussions with fire managers working in the Pacific region.

Specifically, this guide will help managers to do the following:

- Identify different types of fuel breaks and other fuel-management options.
- Distinguish how strategies for fuel-break implementation affect potential fire behavior.
- Understand how site-level factors influence decisions about fuel break placement.
- Have informed discussions with fire management and fire response experts.

## Key Notes and Findings

- Fire planning is an important first step because it may identify actions that are of higher short-term priority than fuels management.
- Fuels management is NOT intended to stop or extinguish oncoming fires.
- The structure and condition of fuels has quantifiable and predictable effects on potential fire behavior.
- Tying fuel breaks in to existing road networks is especially critical.
- Fuel breaks are most effective at ridge tops or at the base of slopes.
- A common rule of thumb cited by fire managers is that the break should be 3x wider than the maximum height of the vegetation.
- For grassland and savanna fuel types specifically, a minimum width of 40–60 feet (12–18 meters) was most consistently recommended.
- When asked how wide they make the breaks that they manage, the most common answer from fire managers was 50–100 feet (15–30 meters).
- Lack of regular maintenance was identified as the biggest cause of fuel-break failure in nearly all discussions with fire managers.
- It is important that woody debris be removed from the fuel break.
- The presence of woody vegetation along fuel breaks greatly increases ember production.
- Grassland and savanna fuel breaks may require as many as 2–4 treatments per year.
- Vegetated or green fuel breaks are a long-term strategy.

## Integrated Fire Planning

Fuels management should be part of a broader fire management or fire preparedness plan. Such plans outline specific objectives, such as human safety and the protection of valued societal and natural resources, and organize information so that it can be easily communicated to fire responders. Good fire plans prioritize assets and valued resources, identify multiple hazards, and indicate potential fire risk-reduction actions. **Fire planning is an important first step because it may identify actions that are of higher short-term priority than fuels management**, such as improving water availability and access for fire trucks or establishing evacuation procedures. In addition, developing a fire preparedness plan is an excellent opportunity to identify and discuss with local fire agencies existing hazards and resources at risk. In-person discussions and field visits allow fire agencies to become familiar with your management area and to provide feedback about which risk-reduction projects should be prioritized. Guidelines for fire preparedness planning are available on the Pacific Fire Exchange website (http://www.pacificfireexchange.org/research-publications/category/pre-fire-planning).

## Wildfire Risk, Hazards, and Fuels Management

Wildfire risk is determined by the probability that a fire will occur and the potential impact, or loss, that the fire can impose on valued resources and assets (Hardy 2005). Hazards are the existing or potential conditions and situations that contribute to this risk. Multiple hazards increase fire risk, including drought, high winds, steep terrain, and human-caused ignitions, as well as fuels, the live and dead vegetation available to burn**.** Fuels management is any method of altering vegetation to reduce hazardous conditions and thereby reduce wildfire risk. **Fuels management is NOT intended to stop or extinguish oncoming fires** (Finney and Cohen 2003)**.** Instead, it reduces the chances of a wildfire igniting in the first place; creates safer, more defensible spaces where firefighters can protect resources during wildfires (Moghaddas and Craggs 2007, Syphard et al. 2011, Moriarty et al. 2015); and can increase the chance that assets will survive a fire (Gibbons et al. 2012).

### *Pacific Island Fuel and Fire Types*

Vegetation/fuels are the only hazard that can be directly altered by humans to reduce fire risk. At a basic level, fuels can be divided into **fine fuels,** which are leaf litter, grasses, other herbaceous plants, and small shrubs, and large or **coarse fuels**, which are larger shrubs, trees, and dead woody debris (see Rothermel and Deeming 1980, Duff et al. 2017). The arrangement of live and dead vegetation over a landscape, or the fuel bed, often comprises a mix of fine and coarse fuels. However, the most fire-prone areas in Hawai‘i and western Pacific Islands like Guam, Palau, Yap, and the northern Marianas, are grasslands and savannas dominated by fine fuels, including native and nonnative grasses, small shrubs, and ferns. **These grass-dominated fuel types quickly cure with dry weather, ignite easily, and**


**Figure 1. Flame length is the distance the flame front “leans” with the wind. These photos illustrate the difference in flame lengths between a head fire driven by the wind and a backing fire moving into the wind in the same fuel type (guinea grass, *Megathyrsus maximus*).**

**provide conditions for very fast-moving fires** (Cheney and Sullivan 2008). In contrast, coarse fuels like trees and larger shrubs typical of forested areas cure more slowly and require more energy to ignite. Once ignited, however, coarse fuels can burn longer and at higher intensity, especially under severe drought.

Fine and coarse fuels types are often mixed on Pacific Island landscapes, so fuels management must consider how the properties of both fuel types influence fire risk. However, it is rare to get "crown fires" burning treetop to treetop on Pacific Islands and in tropical ecosystems in general (Pausas and Keeley 2008). Instead, Pacific Island grasslands and savannas primarily carry **surface fires** spreading through fine fuels. These fires occasionally "crown," or burn up into individual tree canopies, but more commonly tree morality is caused by the fire damaging live cambium tissue around the trunk, akin to girdling.

### *How Do Fuels Influence Fire Behavior?*

Fire behavior describes how fire moves through fuels in the landscape. Fire behavior is affected by factors beyond human control, such as wind, relative humidity, and topography; however, **the structure and condition of fuels has quantifiable and predictable effects on potential fire behavior** (Rothermel and Deeming 1980, Cheney and Sullivan 2008). This knowledge is useful to both identify hazardous fuels and to understand how fuel treatments reduce wildfire risk.

We will consider three fundamental characteristics relevant to fire behavior:

- **Ignition potential** – the probability that vegetation will combust and carry fire.
- **Rate of spread** – the speed at which fire moves through fuels over the landscape.
- **Fire intensity** – literally the energy released by the fire, but most commonly measured indirectly as fire temperature or flame length (Figure 1).

### *How Does Fuels Management Influence Fire Behavior?*

There are five fundamental properties of fuels that alter ignition potential, rate of spread, and fire intensity (see Box 1): (1) fuel structure and continuity, (2) fuel density, (3) fuel moisture, (4) fuel curing, and (5) fuel loading. Different fuels management strategies will have different effects on these properties. By combining the knowledge of how fuels contribute to fire behavior (Table 1) with observations about how fuels management alters the fuel characteristics (Table 2), you can set realistic expectations for how fuel treatments will reduce fire risk.

Ultimately, the methods selected for fuels reduction (see Box 2) will be determined by a combination of factors, including the dominant fuel types, management goals and preferences, and logistical constraints such as the availability of funding/labor/equipment/grazing animals and site accessibility. Furthermore, by identifying the areas of highest risk and resources with the greatest vulnerability, you can select fuels management strategies that are more tailored for a given area or resource (Table 1).

For instance, mowing grassy fuels along roadsides and in parks and campgrounds can reduce the risk of ignition by vehicles, machinery, or campfires, as it reduces the fuel load in critical areas most prone to this type of ignition. If a wildfire does ignite, breaking up the continuity of grassy fuels can slow the spread

**Table 1: Changes in fuel characteristics and corresponding effects on ignition potential and behavior, specifically for fine fuels (Cheney and Sullivan 2009). Pluses indicate relative strength of the effect; minuses indicate limited or no effect.**

| Change in Fuels | Reduce Ignition Potential | Slow Rate of Spread | Reduce Fire Intensity |
|---|---|---|---|
| Reduce Height | + | - | ++ |
| Reduce Biomass | - | - | ++ |
| Increase Fuel Moisture | + | + | + |
| Reduce Curing Level | + | ++ | ++ |
| Reduce Continuity | - | ++ | + |
| Increase Compactness | + | ++ | + |

BOX 1

## HOW FUELS INFLUENCE FIRE BEHAVIOR

Fuels management alters five fundamental properties of both fine and coarse fuels: fuel structure and continuity, fuel density, fuel moisture, fuel curing, and fuel loading (e.g., Finney and Cohen 2003; Stephens and Moghaddas 2005). These properties have different effects on ignition potential, rate of spread, and fire intensity.

**Fuel structure**: the physical stature and arrangement of the dominant plants on the landscape, such as the height and relative quantities of fine and coarse fuels. Finer fuels increase ignition potential (think of starting a fire with kindling vs large logs) and typically result in faster rates of spread. Once ignited, coarse fuels may burn at higher intensity, simply because there is more potential biomass available for the fire to consume (see Fuel Loading below). The presence of coarse fuels can increase ember production, which can increase the chances of spot fires igniting away from the main part of the fire.

**Fuel continuity:** both the vertical and horizontal connectedness of fuels across the landscape. Dense understory and mid-story vegetation, also known as ladder fuels, increases vertical continuity and can allow fire to spread from the surface up into tree crowns, increasing fire damage to canopy trees and the potential for high-intensity crown fires. Horizontal fuel continuity increases the potential for fires to spread across large areas and is a major concern in Hawai'i's grasslands and Pacific Island savannas. This can vary among grass species, depending on characteristics such as whether they grow as bunches or form mats/sod. Greater horizontal connectivity of fine fuels allows for head fires (the fire's advancing lead edge) to rapidly expand in size, which result in faster rates of spread (Cheney and Sullivan 2008)

**Fuel density**: how loose or compact the fuels are. Loosely packed or upright fuels dry out more quickly and provide more oxygen, resulting in fires that spread faster and burn at higher intensity. Tightly packed fuels, for example in the litter layer, have less available oxygen and therefore are less likely to ignite. They also burn more slowly, at lower fire intensity (Schwilk 2015). Slower-burning fuels, however, can result in severe fire damage, especially to soils, by increasing the fire residence time, or how long the fire burns in place.

**Fuel moisture**: simply the water content of live and dead plant material. As you could probably guess, drier fuels are more likely to ignite, spread faster, and burn at higher intensity than moister fuels. The moisture content of dead fuels, in particular, fluctuates rapidly due to changes in relative humidity, causing fire risk to change within the course of hours. Even after heavy rainfall, dead fuel moisture in grasses will adjust back to ambient moisture conditions within several hours (Cheney and Sullivan 2008). The moisture level at which fuels cannot ignite, known as the moisture of extinction, varies among plant species.

**Fuel curing:** the percentage of standing dead vs. live vegetation, specifically for grassland fuels. Higher curing levels (i.e., greater percentages of dead plant material) result in more intense and faster moving fires. For example, experimental fires in grasslands are difficult to sustain with curing levels of less than 25–35% (Cheney and Sullivan 2008).

**Fuel loading**: a measure of the quantity or biomass of vegetation available to burn. All other factors being equal, higher fuel loads will result in higher-intensity fires, which are, therefore, more difficult for firefighters to suppress. Contrary to widely held belief, experimental grassland fires indicate that higher fuel loads do not create faster-moving fires (Cheney and Sullivan 2008). Rate of spread is influenced more by fuel moisture, arrangement, and curing level in fine fuels.

For more details on Pacific Island fuel types, please see PFX Fuels Training Module: http://www.pacificfireexchange.org/research-publications/category/fuels-wildfire-behavior-a-training-module

of fire. Reducing the fuel load can lower fire intensity which can reduce potential damage to valued resources and increases the ability of firefighters to put the fire out (Cheney and Sullivan 2008, Moriarty et al. 2015).

## Fundamentals of Fuel Treatment and Fuel-Break Design

Despite the different approaches to fuel treatments (see Box 2), all treatments share the same purpose: to reduce the potential for vegetation to ignite and/or reduce the speed and intensity at which vegetation burns. **Fuel breaks are intended to literally serve as a line of defense in the space between ignition sources and valued resources**. Importantly, and especially for grassland fires that move rapidly over large areas, fuel breaks and fuel treatments disrupt the horizontal continuity, or connectedness, of vegetation, which can slow fire spread. Planned and implemented over whole watersheds or even larger landscape units, networks of fuel breaks can effectively fragment fuels into compartments that slow fire progression and provide multiple opportunities for firefighters to contain fires (Loehle 2004, Duguy et al. 2007, Oliveira et al. 2016).

In addition to bigger picture planning, deciding exactly where and how to establish fuel breaks can greatly influence fuel-break effectiveness. Fuel treatment placement depends both on an understanding of the resources/assets to be protected and on how the existing

**Table 2. Fuel treatments and corresponding effects on fuel characteristics. Pluses indicate relative strength of the effect; minuses indicate limited or no effect. *Some vegetated and shaded fuel breaks may increase total biomass, or the quantity of vegetation, but effectively reduce the biomass of more fire-prone fine fuels.**

| Treatment | Reduce Fuel Height | Reduce Biomass | Increase Fuel Moisture | Reduce Curing Level | Reduce Continuity | Increase Compactness |
|---|---|---|---|---|---|---|
| Mowing | ++ | + | + | + | - | - |
| Herbicide | ++ | + | - | - | - | - |
| Grazing | ++ | ++ | - | + | ++ | ++ |
| Green breaks | + | +* | ++ | ++ | ++ | + |
| Shaded breaks | + | +* | ++ | - | + | - |
| Burning | ++ | ++ | - | - | ++ | - |

BOX 2

## FUELS MANAGEMENT TERMINOLOGY

**Fuels reduction**: any strategy that reduces the quantity of potentially combustible plant material deemed to pose a fire hazard. Fuels can be reduced across entire land areas or management units, around specific resources or known areas of frequent ignitions, or as linear fuel breaks designed to limit fire spread. Methods of fuels reduction include prescribed burning, mechanical removal (mowing, mastication/chipping), application of chemical herbicides, targeted livestock grazing, or combinations of treatments.

**Fuel break**: an area where the quantity of fuels is reduced and maintained as a strip or linear feature on the landscape or around a valued resource. The vegetation remaining in a fuel break will still carry fire but can reduce the intensity and slow the forward rate of spread of the fire. The objectives of fuel breaks are to reduce fire intensity and rate of spread; improve access; create safer, more defensible space; and buy time for fire responders.

**Fire break**: an area where fuels are completely removed to mineral soil, also typically as a linear feature. Fire breaks can actually stop the spread of fire, depending on the vegetation, fire break width, and wind conditions. For example, high winds and the presence of trees and shrubs increase the chance that embers will ignite spot fires ahead of the main fire and "jump" the break (Wilson 1988). Fire breaks are not typically recommended for fuels management because they cost more to establish and maintain and are much more prone to erosion than fuel breaks. Roads, however, often serve and are managed as fire breaks. Otherwise, fire breaks are more commonly established as short-term barriers to contain prescribed fires or during wildfire suppression operations. Australia has developed a comprehensive guide to fire break establishment (DFES, n.d.).

**Vegetated fuel breaks**: also called green strips or green breaks. A fuel break where the types of plants are altered within the break to reduce the potential for intense, fast-moving fires. In temperate areas, vegetated fuel breaks are often planted with low-statured, fire-resistant herbs and shrubs and may also incorporate forage species to support managed grazing (e.g., Moriarty et al. 2015). In some parts of the world, succulent and/or thick-leaved plants such as agaves are planted in rows to slow the spread of fire. Green breaks incorporating low-flammability trees and understory plants are used in China (Cui et al. 2019).

**Shaded fuel breaks**: in the tropics, including Hawai'i and other Pacific islands, areas where canopy trees are planted at high enough density as to limit the growth and increase the moisture content of grassy fuels, thereby preventing combustion through shading and competition. By contrast, in temperate forests shaded fuel breaks are areas where large trees are left on the landscape to provide some canopy cover but are thinned to prevent the spread of crown fires, fires through the forest canopy (Agee et al. 2000). In both types of shaded fuel break, mid-story shrubs and low branches (i.e., ladder fuels) are removed to limit the spread of fire upwards into tree canopies.

hazards and landscape features influence potential fire behavior (Figure 2). A good starting place to begin planning for the allocation of time and funding necessary for effective fuels management is to consider ignition risk relative to the location and "footprints" of the resources/ assets you want to protect.

### *Preventing and Containing Ignitions vs. Resource Protection*

If ignitions are highly concentrated in your management area, for example along access roads or in campgrounds, establishing fuel breaks in those areas may be an effective strategy for protecting valued resources that lie outside those areas. **Most fires on oceanic islands are human caused, and ignition risk is typically highest near roads and other areas commonly accessed by people.** These high-risk areas also often align with access points for fire response agencies. Therefore, fuels management along roadsides and in parking areas can both minimize the chances of fire starting accidentally (e.g., from sparks from trailer chains or the catalytic converters on cars, campfires, etc.) as well as create a safer environment for fire response operations. Ignition-density maps are currently available for Hawai'i state (http://www.pacificfireexchange.org/research-publications/category/wildfire-ignition-density-maps-for-hawaii).

When funding is limited and valued resources are remote and/or have small footprints, such as communications infrastructure or populations of endangered species, establishing smaller-scale fuel breaks around these resources may be more feasible. An anecdotal example is the use of weed matting to suppress grasses within a ~10 ft perimeter around the last *Gardenia brighamii* individual on O'ahu. While the intention was to suppress weeds, the weed mat also prevented the tree from sustaining fire damage during the 2016 Nanakuli Fire. If the protection goals are broader, for example critical watershed forests, large habitat areas, or residential developments, fuel breaks and other fuels reduction strategies will need to be designed to take advantage of topography and landscape features to maximize effectiveness and reduce the costs of implementation and maintenance.

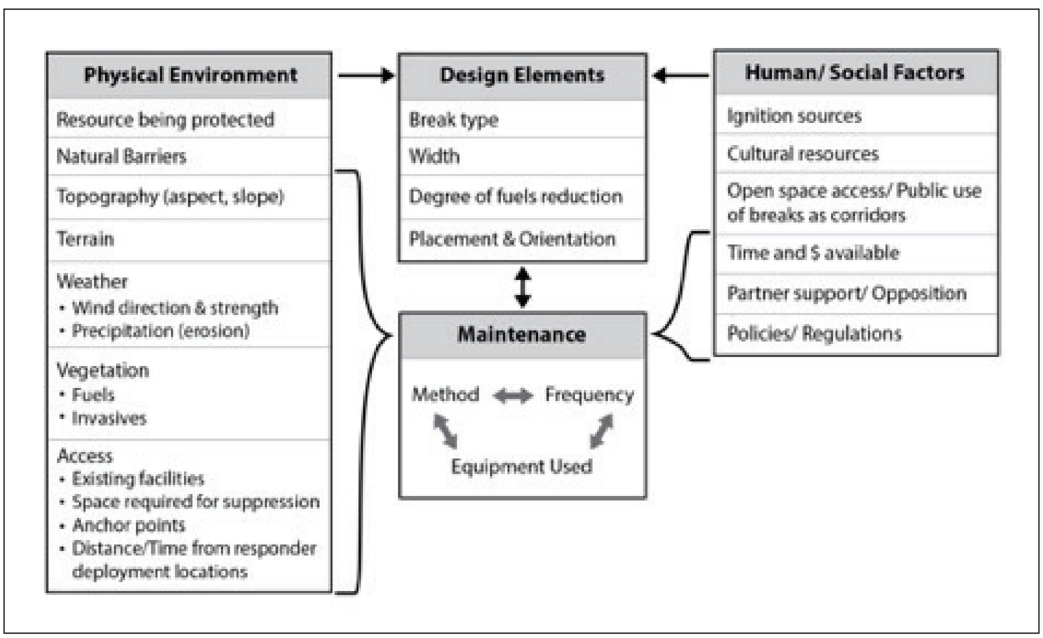


**Figure 2. There are many aspects of the landscape, built environment, climate, valued resources, and social interactions that must be considered for effective fuels management. Integrating fuels management into a broader fire management or fire preparedness plan for a given property or management area is highly recommended.**

**Figure 3. This access road in Makaha Valley, O‘ahu, was intended to serve as a fuel break but failed due to the lack of vegetation management along the edges.**


**Figure 4. Fires burn more intensely moving upslope and on drier south-facing slopes.**

### *"Anchor Points" and Existing Breaks*

**Effective fuel breaks must be "tied into" natural or built landscape features that provide a safe area of unburnable fuels or a barrier to fire spread**. These features are called "anchor points" by firefighters and used as a starting place from which to clear vegetation to contain a fire (i.e., build a "fire line"). Therefore, identifying anchor points, even if they are not used as part of a fuel break, can also be of great help to firefighting operations. Examples of anchor points and natural fuel breaks include paved or dirt roads and parking areas, land parcels where vegetation is regularly mowed or maintained, rivers and streams, barren lava flows, and cliffs or rocky outcrops**.**

Tying into existing road networks is especially critical, as fuel breaks can be used as access points and defensible spaces by fire response agencies. Reducing fuels along roadsides can provide an effective barrier to fire spread (Oliveira et al. 2015) by preventing the fire from "jumping" the road (Figure 3; see Fuel Break Width, below) and, importantly, increasing firefighter safety. Looking at these features and using them strategically as anchor points and/or part of a fuel-break network can help reduce the length and area of fuel breaks that need to be established and maintained and therefore reduce costs.

### *Landscape Placement and Orientation*

In addition to tying into anchor points, **the placement of fuel breaks must also take into account the effects of wind and topography on fire behavior**. Fire will spread most rapidly in the direction that the wind is blowing. Therefore, fuel breaks are generally situated perpendicular to prevailing winds in order to slow the forward progression of the fire's leading edge, or head fire (Finney 2001). Fires also spread more quickly and burn more intensely as they burn upslope, as uphill fuels effectively get cured by the radiant heat of the approaching fire (Figure 4, Butler et al. 2007). This behavior increases the chances that a fire will jump or cross a fuel break placed mid-slope. In addition, due to greater sun exposure and drier fuel conditions, fires will often burn more intensely and rapidly on south-facing slopes in the Northern hemisphere. **Fuel breaks are therefore most effective at ridge tops** (see Figure 5) **or at the base of slopes**. If a fuel break must be placed mid-slope, especially where a fire may be approaching the break from below, anticipate increasing the fuel break width (see below).

### *Fuel Break Width*

The most frequently asked question about fuel breaks is "How wide should they be?" The easiest answer is "As wide as possible." Unfortunately, there is very little experimental work on fuel-break effectiveness to provide specific dimensions for tropical grasslands and savannas (but see Cui et al. 2009). To inform this guide,

**Figure 5. Grassland fuel breaks in southern Guam (left) and Pu‘u Wa‘awa‘a, west Hawai‘i Island (right, photo by E. Parsons). Note the placement of the fuel breaks in the left-hand image along the ridgetops. The fire that was contained in the photo also likely approached the break as a backing fire into the wind (see Figure 1).**

we discussed this question with nine wildland firefighters and fire managers from Hawai‘i and Guam**. A common "rule of thumb" is that the break should be 3x wider than the maximum height of the vegetation**. This recommendation is useful because it is adaptable to both grassland and forested areas, where the fuel break width can be adjusted based on the structure of the vegetation.

**For grassland and savanna fuel types specifically, a minimum width of 40–60 feet (12–18 meters) was most consistently recommended.** This recommendation is based on observed fire behavior such that the break is at least 2x wider than the maximum head fire flame lengths that fire managers have seen in these fuel types (see Figure 1). In other words, the fuel break needs to be, at the very least, wider than the length of the forward "lean" of a wind-driven grass fire so that the break is not "breached" or crossed by the flames coming into contact with fuels on the other side of the break. The presence of woody fuels (trees and shrubs) within 65 feet (20 meters) of the fuel break significantly increase the odds of a breach (from ember or firebrands carried by the wind; Wilson 1988), and should be removed or compensated for by increasing the fuel break width. **When asked how wide they make the breaks that they manage, the most common answer from fire managers was 50–100 feet (15–30 meters)**. As stated above, fuel breaks may need to be wider in areas where other factors have an important influence, such as midway on slopes or in areas exposed to frequent high winds.

## Fuel Break Establishment and Maintenance

**Lack of regular maintenance was identified as the biggest cause of fuel break failure in nearly all fire manager discussions.** Securing the resources to both establish and maintain fuel breaks is critical, considering that vegetation in tropical grasslands and savannas can recover very quickly following fuels reduction treatments. There are a variety of options for fuels management (Box 2), each differing in their effects on fire behavior (Table 2) as well as the costs and logistics involved.

Most commonly, managers treat fuel breaks using a combination of mechanical and chemical means. Where large machinery is available and able to access sites, mowing is an efficient means to establish fuel breaks in grasslands. Plowing, disking, and other means of overturning soil will technically create a *fire break*, in which mineral soil is exposed and erosion becomes a concern, along with the need for frequent maintenance or hardening of the surface (Box 2). In more remote areas or difficult terrain, weedwhackers are typically used to cut vegetation. Chemical herbicides are frequently used, either following mechanical treatment or on their own, including glyphosate and imazapyr, as well as pre-emergent herbicides to prevent the vegetation from growing back. It is important to recognize that fire risk will increase immediately following initial fuel treatments, as dead vegetation is more likely to ignite than live vegetation (Castillo et al. 2003). In addition, when woody fuels like shrubs and small trees are being treated**, it is important that woody debris be removed from the fuel break**, as this material can significantly increase fire intensity. According to fire manager discussions, **to maintain fuel break effectiveness in grasslands and savannas, fuel breaks may require as many as 2–4 treatments per year**, with more treatments required in wetter areas or during wetter years.

In addition to reducing the overall quantity of vegetation, changing the vegetation structure within and along the edges of the fuel break can reduce fire risk. In particular, **the presence of woody vegetation along fuel breaks greatly increases ember production** and therefore the probability that the fuel break will be "breached" by embers or burning fuels carried by the wind (Wilson 1988). Haole koa, or tangantangan (*Leucaena leucocephala*), for example, is well known among Pacific Island firefighters for heavy ember production due its burning seed pods. It is therefore recommended that woody vegetation be reduced or removed from within and along the edges of fuel breaks to the greatest extent possible. If this not possible, it is recommended that the lower branches and foliage of remaining trees, called ladder fuels, be removed to a height of 6–10 ft (2–3 m) to reduce the likelihood of the canopy burning and producing embers. It is also prudent to widen the fuel break where trees and shrubs are present (see Fuel Break Width, above).

## Alternatives to Conventional Fuel Breaks

### *Green Breaks, Shaded Fuel Breaks, and Restoration*

Strategically altering vegetation composition to make it less prone to burning, also called fuels conversion, is another strategy to reduce fire risk. Areas where grasses or other fire-prone vegetation are replaced with less flammable vegetation are often called "green breaks" or "greenstrips." Green firebreaks are widely used in China (Cui et al. 2019), where low flammability multi-layered vegetation (i.e., trees, shrubs, and herbaceous plants) is planted in 10–20 m wide strips around forests and plantations. **Plant species in green breaks may have multiple uses, but they are primarily intended to disrupt fuel continuity, physically block wind, absorb radiant heat, and directly halt the fire front** (Cui et al. 2019). Similarly, rows of pineapple have been shown to slow and even the halt the spread of savanna fires in Brazil (Xaud et al. 2009).

**Shaded fuel breaks on the Pacific Islands are a type of vegetated fuel break in which trees are planted to suppress grass growth and increase the moisture of understory vegetation through canopy shading.** This is in contrast to shaded fuel breaks in temperate continental forests, in which canopy trees are retained as part of conventional fuel breaks, but at much lower density to prevent fires spreading up into and through the forest canopy (Agee et al. 2000). Research shows that woody plants can slow fires and reduce fire intensity by reducing fine fuel loads. In Florida, high densities of the invasive tree Christmas berry (*Schinus terebinthefolius*) reduced both fire intensity and tree mortality in Everglades savannas (Stevens and Beckage 2009). Increasing the cover of broadleaf trees in European forests also significantly reduced fire intensity (Freijaville et al. 2016). In Australia, closed-canopy groves of the conifer *Callitris intratropica* actually exclude low-intensity grass fires in tropical savannas (Figure 6; Trauernicht 2012) and create densely packed leaf litter which is virtually impossible to ignite (Scarff and Westoby 2006).

Unfortunately, as with conventional fuel breaks, experimental evidence for the effectiveness of shaded fuel breaks on actual fire behavior in the Pacific is largely anecdotal. In the Western Pacific islands of Yap and Palau, most savanna fires self-extinguish at the edges of moist high-canopy forest (Figure 7). In Hawai‘i, canopy shading by secondary forest and outplanted trees significantly reduces nonnative grass biomass (Figure 6; McDaniel and Ostertag 2010). These observations indicate that **shaded fuel breaks have promise for suppressing fires in Pacific Island grasslands, but there is limited information available on specifics such as fuel break width, planting density, and species selection**. Foresters on the island of Yap, for example, plant a mix of nonnative trees in their shaded fuel breaks such as Honduran mahogany (*Swietenia macrophylla*) with native trees like *Calophyllum inophyllum*, *Pterocarpus indica*, *Inocarpus fagifer*, and large shrubs like *Scaevola taccada*. Fuel break size and planting densities also vary project to project. The shaded fuel breaks on Yap are being put in 8 trees wide with 8-foot spacing between trees.

Following the Broomsedge Fire in Hawai‘i Volcanoes National Park in 2000, a “vegetated fuel barrier” using native species was proposed to protect an area of critical habitat from future fires (Loh 2007), but the high planting density required to reduce fuels (>1300 plants per hectare) limited the park’s ability to establish the fuel break (R. Loh, personal communication). This example illustrates how **trade-offs between fuel-break size and available plant material/labor inputs must be considered relative to the scale at which fire risk needs to be managed in the landscape**. Costs of grass removal and tree planting in restoration sites at Pu‘u Wa‘awa‘a on Hawai‘i, for example, ranged from $5,500 per hectare ($2226/acre) at moist high-elevation sites to more than $13,000 per hectare ($5,260/acre) at drier low-elevation sites (Wada et al. 2017).

**In Hawai‘i, there is some evidence that ecosystem restoration with native species can exclude grasses and reduce fire risk**. Grass removal, typically using weedwhackers and herbicide, followed by high-density outplanting with native species has been shown to reduce the quantity of grassy fuels on Maui, O‘ahu, and the Big Island (Madeiros et al. 2014, Ellsworth et al. 2015, Zhu 2019). Experiments on Hawai‘i Island indicate the native shrub aweoweo (*Chenopodium oahuense*) was effective at limiting growth of nonnative fountain grass (*Pennisetum setaceum*) and also had high moisture content, indicating low flammability (Cordell 2017).

There is limited information available for selecting either native or nonnative “low-flammability” plants for green breaks in Hawai‘i and other Pacific Islands. Fire managers in New Zealand have identified several low-flammability species from plant genera found elsewhere in the Pacific, including *Coprosma* and *Pittosporum* (Wyse et al. 2016). More work needs to be done on this topic, but general, trait-based guidelines (from Doran et al. 2004; see also Alam et al. 2019) to identify low-flammability plants include the following:

- High moisture content in leaves and branches (arguably the most important)
- Broad, thick leaves to retain moisture
- Low content of chemicals like oils and resins
- Open, loose branching patterns
- Few dead leaves and branches retained on and below the plant.

Thick-leaved succulent plants such as aloe, sempervivum, and yuccas are commonly recommended for home landscaping to reduce fire risk (e.g., Doran et al.

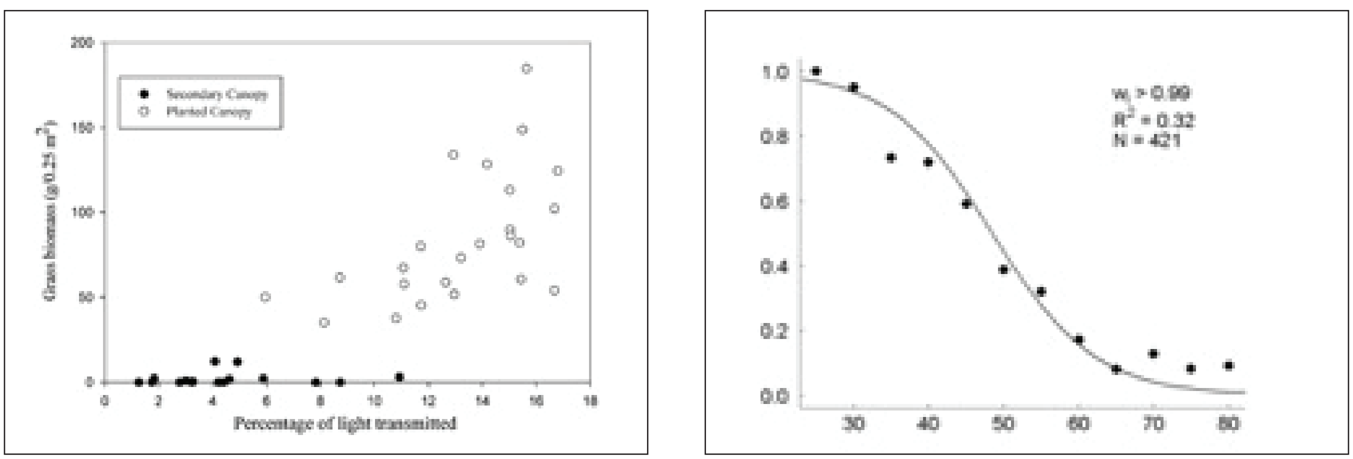


**Figure 6. The left panel shows that grass biomass (i.e., fuel load) decreases as shading by canopy trees increases (or the “Percentage of Light transmitted” decreases), both with planted native trees (“Planted Canopy”) and by naturally regenerated, non-native trees (“Secondary Canopy”) at Hakalau, Hawai‘i Island (r=0.854, P=0.000; McDaniel and Ostertag 2010). The right panel shows how increasing tree canopy cover of *Callitris intratropica* reduced the probability of burning in a tropical savanna in Australia (from Trauernicht 2012). (add Probability of burning to vertical axis and Percent canopy cover to horizontal axis)**


**Figure 7. Savanna fires on Pacific Islands often self-extinguish at the edge of closed-canopy forest, illustrating how canopy shading affects fire spread by increasing fuel moisture and reducing fine-fuel availability. Fires are more likely to burn into forests during droughts.**

2004). There are few native succulents in Hawai‘i and other Pacific Islands, but it may be worth considering nonnative, non-invasive succulents such as *Aloe* spp. and *Yucca guatemalensis* for green breaks. Many other succulents, such as agaves, other *Yucca* species, dragon fruit, and night-blooming cereus cacti are considered to be high risk by the Hawaii Pacific Weed Risk Assessment (WRA; https://sites.google.com/site/weedriskassessment/).

It is important to keep in mind that **vegetated fuel breaks are a long-term fire management strategy**. Additional fuels management will be required over the short to medium term to reduce fire risk and protect against the loss of your project's investment while the green break is establishing. Some grass species, such as guinea grass (*Megathyrsus maximus*) and sword grass (*Miscanthus floridulus*), which burn at very high intensities, may threaten well established green breaks and require other methods of control (Figure 8). For example, the Hawai‘i Division of Forestry and Wildlife and the Wai‘anae Mountain Watershed Partnership on O‘ahu have incorporated shade cloth to limit guinea grass regrowth in a vegetated fire break planted with native species (Figure 9). There are also some grass species, such as meadow rice grass (*Ehrharta stipoides*), that grow well under full-canopy shading (McDaniel and Ostertag 2010). This species has fueled several fires under well-established *Acacia koa* canopies in Hawai‘i Volcanoes National Park (e.g., Loh 2007). In general, if understory fuels are heavy enough, high-intensity head fires may cause vegetated fuel breaks to fail; however, they may still be effective along lower-intensity areas of the fire line such as the flanks or backing fire. Knowledge of fire behavior and historical fires is therefore useful in planning vegetated fuel breaks.

### *Landscape-Scale Treatments: Prescribed Fire and Grazing*

In addition to mechanical and chemical fuels reduction treatments, **livestock grazing and prescribed burning can be effective at reducing hazardous fuels in grasslands and savannas** (Taylor 2006, Nader et al. 2007, Castillo et al. 2003). Both of these approaches have the advantage that they can reduce fuels across larger areas at lower cost than mechanical and chemical removal. However, these approaches also require specialized knowledge and infrastructure and may potentially conflict with other land-management goals.

Prescribed burning can be highly effective at reducing fuels (Castillo et al. 2003), but it requires specialized training, fire suppression capacity, and adequate infrastructure such as water and temporary fire breaks to contain the fires. Prescribed fire may be unsuitable for certain areas where topography creates unsafe conditions for controlling fires or the risk of escaped fires is deemed too high. Unlike continental areas with fire-adapted ecosystems, the ecological applications of prescribed fire on Pacific Islands are limited given the sensitivity of native vegetation to

**Figure 8. A line of *Chenopodium oahuensis* (from lower left corner to center of photo) planted by the Honolulu Board of Water Supply as a green break in Makaha Valley was killed in the 2018 West Oʻahu Fires not by direct flame contact but by radiant heat. The break was designed to slow fires approaching along the slope from the left; however, this fire jumped an access road below, burning upslope through guinea grass and haole koa on the right. Despite low survival of the plants, the fire did not breach the green break, due in part to limited grass establishment (preventing direct flame contact) as well as "tying" the green break to rocky landslide debris.**

**Figure 9. A combination of outplanting and weed-matting is integrated into a vegetated fuel break at Waiʻanae Kai Forest Reserve on Oʻahu. The roadside break provided defensible space for firefighters during the 2016 Waiʻanae Fire. Note the slight fire damage to the canopy of the *Acacia koa* tree on the right side of the road, indicating the radiant heat produced by the mix of guinea grass (*Megathyrsus maximus*) and haole koa (*Leucaena leucocephala*) shrubs that burned on the left. (Photo by Ryan Peralta)**

fire damage (e.g., Smith and Tunison 1992). However, prescribed burning is used in Hawaiʻi by the US Fish and Wildfire Service to improve native waterbird habitat at James Campbell National Wildfire Refuge, by the US Army Wildland Fire Program Schofield Barracks to reduce fuels, and by Maui County Fire Department for both fuels reduction and wildland fire training.

Targeted grazing and browsing by cows, sheep, or goats is widely practiced for fuels management in the continental US and Europe (Taylor 2006, Nader et al. 2007, Ruiz-Mirazo 2011). The most obvious effects of grazing are reductions in fuel loads and continuity through consumption and trampling (e.g., Castillo et al. 2003; Diamond et al. 2009; Strand et al. 2014). There is also evidence that grazing reduces the quantity of dead fuels relative to live fuels, thereby increasing the curing level, compared to ungrazed areas (Strand et al. 2014, Evans et al. 2015). Wild or feral ungulates can also reduce grassland fuel loads (Zhu 2019); however, effective fire risk reduction requires intentional management of animals at adequate stocking rates to strategically reduce fuels. For example, grazing for fuels reduction in high-risk areas, such as roadsides, has long been practiced by ranchers in Hawaiʻi (F. Rice, K. Wood, personal communication). Ample evidence from both research and anecdote indicates that targeted grazing can effectively limit fire intensity and the potential for fire to spread in Hawaiʻi (Figure 10; see Litton and Trauernicht 2016).

Targeted grazing requires access to animals, of course, but it also requires fencing, water, and the knowledge of how to care for and control animals so that fuels reduction occurs where and when it is most needed. There are also trade-offs between fire risk reduction and long-term forage quality and production. Overgrazing may effectively limit fire, but it also increases erosion and contributes to the establishment of unpalatable plants that can ultimately prohibit the use of livestock over the long term (Thorne and Stevens 2007). In addition, protecting native species or other resources like crops and tree plantations from livestock may require establishment and maintenance of additional fencing.

### *Patch Mosaics*

"Patch mosaics" are mixtures of different habitat or vegetation patches across the landscape. Patch mosaics are often discussed in the context of habitat quality

**Figure 10. The 2018 West Oʻahu Fires stopped burning along the edge of a grazed pasture. There are many anecdotal accounts of grazed areas stopping fires in Hawaiʻi, and research supports these observations.**

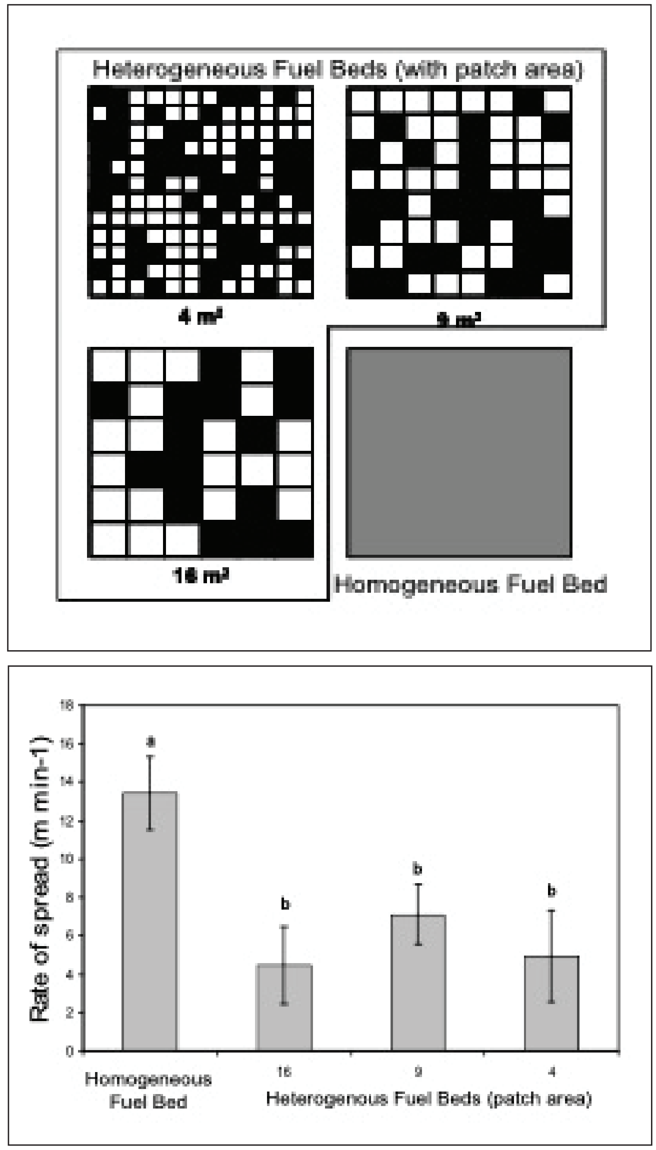


**Figure 11. Experimental grassland fires where fuels were mowed in patches (above, black areas) illustrate how increasing the heterogeneity or patchiness of fuels resulted in rates of fire spread that were 2–3 times slower than homogenous, or continuous, fuel beds (below) (Engle 2009).**

for wildlife and plant species. But mosaics are also relevant to fire because increasing the "patchiness," or heterogeneity, of vegetation conditions can also influence fire behavior, especially in grasslands and savannas.

Grass fires burn more intensely and more rapidly with homogenous, continuous fine-fuel beds that allow wide head fires to develop (Cheney and Sullivan 2008; Figure 11). Therefore, **any actions that disrupt the continuity and increase the patchiness of grassy fuels can reduce the rate of fire spread and fire intensity** (Loepfe et al. 2010, Kerby et al. 2007, Viedma et al. 2009). For example, intentional or prescribed burning under wetter conditions in tropical and subtropical savannas results in smaller fires that disrupt fuel continuity and decrease the potential for large, destructive fires that get set under drier conditions later in the year (Haynes 1985, Slocum et al. 2003). Altering patterns of ignitions during prescribed fire can also help to increase patchiness. Grazing can increase patchiness and thereby disrupt fuel continuity and decrease rates of spread and fire intensity (Kerby et al. 2007, Engle 2009). Similarly, increasing woody cover—be it native or nonnative species—can reduce fire intensity and rates of spread in grasslands (Kaufman et al. 1994, Mandle et al. 2011).

In terms of management applications, the patch mosaic concept indicates that fuels treatments can be applied in patches across the landscape to slow fire spread and reduce intensity (see Figure 11). **Establishing patch mosaics, whether by grazing or fuels conversion, can reduce the size of the treatment area and therefore substantially reduce management costs.** However, for fuels conversion approaches where woody species are planted to disrupt grassland continuity, it is highly likely that planted areas will burn and/or sustain fire damage. Therefore, identifying woody species that can recover through seed germination or resprouting after fire (see

Loh 2007) and that can compete with grasses in the post-fire environment is key to this approach.

## Summary

This guide is intended to help you understand and anticipate the factors that influence effective fuel-break establishment and how the options for fuels management might fit your own management goals. It is also intended to prepare you for an informed discussion with fire experts. There is no substitute for on-the-ground consultation, especially with the agencies that will be potentially responding to an incident on your lands. There is also not a single prescription that works under all scenarios. It is important to understand **that the effectiveness of any type of fuel break will be limited during conditions of extreme fire behavior that may occur during intense drought, hot temperatures, and very high winds.**

One of the key challenges of Pacific Island "problem fuels," and of tropical grasslands and savannas more broadly, is that fuels regrowth is very rapid after treatment. Therefore, conventional fuels management often requires multiple applications per year and must be responsive to "green-up" events that follow rainy periods**. Fuel breaks are only effective when they are regularly maintained, which will require monitoring and integrating management costs into a long-term management plan**. Fuel breaks and fuels management are one component of wildland fire risk reduction. Comprehensive planning to reduce fire risk must also consider other key aspects such as evacuation procedures, access, and water availability for fire responders. Again, FUEL BREAKS ARE NOT INTENDED TO STOP A FIRE. Instead they slow the fire down, reduce fire intensity, and create safer conditions for fire responders to do their job.

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