Introduction
Wildfires are a growing threat in Hawai‘i that degrade natural resources, threaten human safety, and are extremely expensive to contain. Prior work has outlined the historical increase in wildfire statewide and the negative impacts that wildfires have on native species and habitat, and has given recommendations for reducing threats to timber plantations (Trauernicht et al. 2015, UH Extension Publication RM-18). In this document we provide protocols for monitoring the long-term impacts of wildfire on vegetation and soils. This type of information is critical for tracking post-fire recovery as well as assessing the effectiveness of post-fire responses such as erosion control, weed control, and replanting efforts.

After a wildfire is contained and controlled, among the first concerns for landowners and managers is the direct or immediate effects of the fire, such as tree mortality and soil exposure. But important indirect effects of fire, such as soil loss and vegetation change, require tracking these processes over time. Monitoring is a simple and effective tool that can provide baseline information (i.e., post-fire assessment) as well as shaping short-, medium-, and long-term responses in terms of vegetation recovery and the effects of post-fire response.

This guide provides methods for monitoring changes in soil and vegetation after a wildfire occurs. There are countless techniques described in the scientific and professional literature for natural resource monitoring. However, the majority of these have never gained broad appeal or implementation simply because they are too technical or time consuming. The techniques presented below aim to avoid both of these pitfalls.

Initial Post-Fire Severity Assessment vs. Long-Term Monitoring
Initial post-fire assessments document the immediate severity of wildfire effects on soils and vegetation. These provide critical baseline information and can help prioritize site rehabilitation efforts as well as indicating where longer-term monitoring should be conducted—for example, comparing recovery in areas of high vs. low burn severity. On federal lands, post-fire assessments are often conducted by specialized Bare Area Emergency Response (BAER) teams. Although there are no BAER teams based in Hawai‘i, local resources are available to provide guidance, including the Hawai‘i Wildfire Management Organization and the University of Hawai‘i Cooperative Extension Program. In contrast to initial assessments, however, many of the post-fire monitoring techniques we outline below provide methods for tracking site recovery over time.

A technique to rapidly assess fire intensity in the post-fire environment is to use standing woody vegetation (shrubs and trees) to measure scorch height, or the maximum height from the base of the tree to height of the tree crown at which leaves have survived the fire (Figure 1). Scorch height indicates the height at which heat from the fire was hot enough to scorch and kill leaves.
and provides an indirect measure of fire intensity. Scorch height is most easily measured 1–2 weeks after a fire has occurred, when leaves are brown and dead below the scorch height and live and green above. A good sampling strategy is to take scorch height measurements from 5–10 trees at multiple locations throughout the burn site to identify areas of high and low burn severity.

Soil burn severity is another important factor that indicates potential for erosion and will typically vary within a burn area. Large areas of exposed, bare earth where plants and leaf litter have been completely consumed indicate high burn severity at the ground level and higher erosion risk. Another indicator of high soil burn severity is a change in soil appearance, often indicating a physical change, from rough texture to a smooth, shiny surface that repels water and increases downslope erosion. This can be compared at different locations within the burn site by pouring a small amount of water on the soil and recording the time it takes for the water to be absorbed into the ground. For a detailed guide to initial assessments of fire severity on soils and vegetation, we recommend the Hawai‘i Post-Fire Response Assessment Guide, produced by the Hawai‘i Wildfire Management Organization (HWMO; available at HawaiiWildfire.org or PacificFireExchange.org).

Why Monitor
Monitoring requires time and effort, so it is important to identify the purpose of any monitoring program. A useful way to approach this is to ask how you will use the results. Are you monitoring just to document change, or will the results potentially influence management decisions? If you intend to monitor to inform or assess the impacts of management actions, how certain do you need to be? Increasing confidence in the results, for instance, may require increasing the number of sites and/or the frequency at which sites are monitored. Some common monitoring aims include the following:

- To describe and document resource conditions and trends (it is the most objective means of achieving this).
- To determine the effectiveness of management practices.
- To document progress of movement toward desired conditions.

Figure 1. Scorch height is measured as the maximum height from the base of the tree to height of the tree crown at which leaves have survived the fire and provides an indirect measure of fire intensity and a method for assessing severity of fire effects on vegetation.
• To allow for adaptive management strategies—that is, the process of modifying management practices based on scientifically derived and objectively collected quantitative monitoring data (Ringold et al. 1996).
• To meet state and/or federal requirements for post-fire response funding.

What to Monitor
What and where to monitor are probably the most important points to determine when developing a monitoring program. Taking the time to thoroughly consider these questions will pay dividends later by ensuring that the most pertinent data are collected and that time is most efficiently allocated. What to monitor depends on overall management objectives, but these questions can be helpful to ask:

• What vegetation is growing back following fire?
• What is the success rate of out-plantings?
• What type of soil movement (i.e., erosion) is occurring?
• What is the status of the forest (density, composition, mortality, etc.)?

Where to Monitor
Consider monitoring in the following areas: high fire-severity areas; high erosion-source areas; areas with endangered, threatened, or candidate species; and riparian or wetland areas. In some cases, these areas may occupy a small proportion of the landscape. The merit of devoting a disproportionate amount of effort toward monitoring such sites needs to be weighed cautiously. Focusing on such areas may detract from an overall monitoring program designed to address resource concerns over a much larger area. Areas that are representative of the bulk of the burned area/forest should typically be included. Monitoring sites should not be located near roads or heavy public use areas. It should be noted that no one knows and understands an area better than the manager, and his/her experience should weigh heavily in the selection of monitoring sites.

How Much to Monitor
The question always arises: “How many monitoring sites should I have?” Unfortunately, there are no universal guidelines to determine how many monitoring sites an area should have. Differences in the size and heterogeneity of the site can combine to make strict guidelines difficult. It is recommended that you have at least one monitoring site for each vegetation type in the burned area. However, establishing multiple sites will provide a more robust picture of recovery over the long term by capturing variability across the burn area. The number of sites you establish will ultimately depend on what is feasible in terms of time and resource availability, as well as how you plan to use the results. In determining how many monitoring sites to establish, and where, it is recommended, at least initially, that you plan on spending no more than two to three days every six months monitoring your area. As you become more comfortable with the monitoring program and procedures, this time investment can be increased or decreased as appropriate.

Monitoring sites should be representative of the larger area for which management decisions will be made. Effort invested in monitoring a vegetation type should be proportional to the area it represents on the burned landscape. For example, if 20% of the burned area is vegetated by eucalyptus, then approximately 20% of the monitoring sites should be located in eucalyptus habitat. One or two additional sites can be added for special habitats (e.g., T&E species, riparian areas). However, these sites should not interfere with monitoring more representative sites or with the ability to complete such monitoring on a regular basis. Again, starting monitoring programs as soon as possible after the fire is necessary to establish baseline conditions.

When to Monitor
Another frequently asked question is, “When should I monitor?” Ideally, an initial survey of the burn area would be completed as soon as possible. Over the longer term, the answer is, “It depends.” On the mainland, if vegetation is of interest, monitoring is generally conducted at the beginning and end of the growing season. Although there is no dormant season in Hawai‘i, there tend to be fairly distinct wet and dry seasons that roughly correspond to summer and winter months (see Rainfall Atlas of Hawai‘i; http://rainfall.geography.hawaii.edu/). Given the influence of rainfall on growing conditions and erosional processes, monitoring vegetation and soils at the beginning and end of the wet season would be ideal. However, if resources are limited, monitoring should be conducted at the end of the wet season.
Precipitation
Precipitation should be recorded onsite if possible to help explain changes observed in vegetation and soil data, as well as to determine whether irrigation may be necessary for revegetation efforts. Often this is not possible, so using the closest automated weather station will suffice (see National Climate Data Center http://gis.ncdc.noaa.gov/map/viewer/ for online access to statewide weather station locations and data). Monthly data points are ideal.

Photo Points
Photo points are a simple, inexpensive, and effective method for monitoring vegetation change. They allow managers to visually assess changes in plant composition and structure over time and can even be quantified for statistical analyses of environmental change (Michel et al. 2010). It is recommend to establish multiple photo points within a site and take a minimum of two photographs at each point—one landscape-level photo and one ground-level photo—each time data is recorded (e.g., bi-annually or at start and end of wet season). Using a dry-erase board or equivalent, record the date (e.g., MM/DD/YY) and monitoring site in each photo (Figure 2). For the ground-level photo, create a 3-foot square with two folding carpenter rulers or PVC pipes and place at the corner of a fixed point (see ground-level photo below). To avoid casting a shadow on the plot, stand on the north or south side directly above the square created by the folding carpenter rulers and take the photograph.

To be able to draw conclusions and detect trends over time it is important to be able to return to the same site and take the photo from the same perspective and same direction year after year. Numerous options are available for permanently marking plots (e.g., PVC posts, steel T-posts, coordinates from a GPS). To increase the value of the photographs, strive to take quality pictures. Avoid facing east or west to minimize variation due to sun position. In addition, attempt to take subsequent photographs at the same time of day to avoid problems associated with shadows. Try to include in the photograph some landmark, such as a rock outcrop, big tree, or ridgeline, so the same photo (orientation/direction) can be re-taken each year. Bring past photographs along to try to duplicate the shot. If no landmarks are available, take a compass reading and record the bearing. It is critical to document and describe the photo point location so someone else can find it the next year. Handheld
GPS units are useful for locating the general area, but not the exact location.

**Erosion Photo Points**
Erosion site photo points document trends over time at key erosion areas. Photo points can be used to record erosion at sites such as gullies, stream banks, culverts and road cuts. The procedure outlined above for photo points should be followed. Additionally, a pole marked in 1-foot increments should be placed within each erosion site photo to provide scale. As noted above, it is important that erosion site photo monitoring occur as soon after the fire as possible and take place before and after the wet season if possible.

**Hillslope Erosion**
Measuring hillslope erosion has historically been a costly, time-consuming practice. An easy-to-install, low-cost technique using silt fences is described in the following publication: *Silt fences: an economical technique for measuring hillslope soil erosion* by Robichaud and Brown (2002). In it are discussed equipment requirements, installation procedures, and analysis methods for measuring hillslope erosion. The use of silt fences is versatile; various plot sizes can be used in different settings to determine effectiveness of various treatments. Silt fences are installed by making a sediment trap facing upslope such that runoff cannot go around the ends of the silt fence (Figure 3). Silt fences are more than 90% efficient, making them suitable to estimate hillslope erosion.

**Measuring Change in Soil Surface Level**
The direct measurement of change in soil level is appropriate in the case of localized erosion where rates are expected to be high and the direction of the erosion can be predicted (e.g., high-severity burn sites with moderate to steep slopes; Hudson 1993). Erosion pins are a widely used method consisting of a pin/stake driven into the soil such that the top of the pin gives a baseline from which changes in the soil surface level can be measured (see figure below; Hudson 1993). Alternatively called pegs, spikes, stakes, or rods, the pins can be of wood, iron, or any material which will not rot or decay and is readily and cheaply available; Hudson 1993). The pin should be a length which can be pushed or driven into the soil to give a firm and stable baseline: 12 inches is typical; less for a shallow soil, more for a loose soil. A small diameter of about 0.25 inches is preferable, as thicker stakes can interfere with the surface flow and cause scour. If it is not possible to drive the pin completely into the ground, a metal file can be used to mark the pin to indicate the starting surface level of the soil. In some cases a metal washer is slipped over the pin to give a better base from which to measure to the top of the pin. However, this is not recommended, as the washer can bias the flow of water. For monitoring purposes, a 5’ x 5’ square grid (or larger depending on time and resources) with 5-foot spacing can be constructed at strategic areas of interest (e.g., high-severity burn sites with moderate to steep slopes). Ideally, similar to erosion photo points, erosion pins should be established as soon after the fire as possible and changes in soil surface level would be recorded at the beginning and end of the wet season.

**Tree Survival and Mortality**
Different species of trees will respond differently after fire. Some trees may survive low- and high-intensity
burns, but even trees that retain green foliage after a fire occurs may have been killed by girdling and will take weeks to show signs of canopy death. Some trees, such as Eucalypts, may experience “topkill” (e.g., the stem and crown are killed by the fire) but will resprout from the base. Other trees, such as koa (*Acacia koa*) may resprout from root suckers further away from the dead stem. Other species such as ‘ōhi’a (*Metrosideros polymorpha*) will sprout along the exposed trunk and branches. Many other tree species can only regenerate from seeds in the post-fire environment. The percent of tree mortality and topkill can provide an indication of fire severity, and monitoring resprouting vegetation can indicate areas where vegetation is recovering sufficiently and may help in prioritizing areas for rehabilitation via outplanting or broadcast seeding. Similarly, monitoring the resprouting of undesirable species can help inform decisions about invasive species and weed control.

**Understory Vegetation & Cover**

Understory vegetation and cover can be determined using the Rapid Assessment Methodology (RAM; Allison et al. 2007). This technique was designed to quickly and objectively characterize natural resource conditions in order to make management decisions based on quantitative data. RAM is an effective and flexible monitoring tool that fits easily into an adaptive management plan. A RAM transect can be run in approximately 30 to 60 minutes to document ground cover and species composition.

**How to Run RAM or Step-Point Transects:** Use the permanently marked photo point (as described above) as the center of the plot. Avoid stepping in and disturbing ground-level photo points by starting each step-point transect ~10 feet from photo point (see Figure 4). At the start of each transect (designated by the four bold lines below), begin your stride with your left foot, and every time your right foot (specifically, the center of the tip of your boot) hits the ground, record the cover (grass, forb, litter, rock, soil) and the species of the nearest understory plant. Record 15 data points (or 15 paces) for each transect. Summarize data by combining all 60 data points. Cover can be reported at % grass, forb, litter, rock, and soil hits. The number of each understory plant species can also be reported.

**Reference Plots**

In some circumstances, land managers may want to assess whether an area is recovering to pre-fire conditions or to a different vegetation type. “Reference plots” are monitoring sites placed in nearby, unburned areas that were similar to the burned area prior to the wildfire. Establishing reference plots can be a valuable tool for those situations where a return to pre-fire conditions is the overall objective.

**Data Organization and Analysis**

Good record-keeping is a critical part of monitoring programs. Be sure to record the plot number and date every time plots are measured. GPS points and metal tags can be used to clearly identify plots and even landmarks (e.g., trees, rocks, etc.) in the field to assist with re-measurement. Make sure information is clearly written and stored in a secure location. Brands of weatherproof notebooks, such as Rite-in-the-Rain®, can be useful for this purpose. Data should be entered using simple spreadsheet software such as Excel to assist with summaries and analyses, but it is important to keep original records as a backup. You can contact the University of Hawai‘i Cooperative Extension Program for more information on various ways you can analyze the data.

![Figure 4. Step-point transect design.](image)
Conclusions
Because of the diversity of landscapes and management objectives found in Hawai‘i, no single monitoring protocol can be recommended or universally adopted. Rather, a monitoring program must be adapted to site-specific needs and considerations. Developing and implementing a monitoring program or protocol may seem daunting upon first consideration. However, by following the guidelines presented above, a program can be easily established and data readily collected. Remember, the best monitoring program is one that was started yesterday, or better yet, ten years ago.

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References