Research Article

Emergency Post-Fire Rehabilitation Treatment Effects on Burned Area Ecology and Long-Term Restoration

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ABSTRACT

The predicted continuation of strong drying and warming trends in the southwestern United States underlies the associated prediction of increased frequency, area, and severity of wildfires in the coming years. As a result, the management of wildfires and fire effects on public lands will continue to be a major land management priority for the foreseeable future. Following fire suppression, the first land management process to occur on burned public lands is the rapid assessment and emergency treatment recommendations provided by the Burned Area Emergency Response (BAER) team. These teams of specialists follow a dynamic protocol to make post-fire treatment decisions based on the best available information using a range of landscape assessment, predictive modeling, and informational tools in combination with their collective professional expertise. Because the mission of a BAER team is to assess burned landscape and determine if stabilization treatments are needed to protect valued resources from the immediate fire effects, the evaluation of treatment success generally does not include important longer term ecological effects of these treatments or the fates of the materials applied over the burned landscape. New tools and techniques that have been designed or modified for BAER team use are presented in conjunction with current post-fire treatment effectiveness monitoring and research. In addition, a case is made to monitor longer term treatment effects on recovering ecosystems and to make these findings available to BAER teams.

Keywords: BAER treatments, burn severity map, mulching, native seed, remote sensing, seeding, treatment monitoring, values-at-risk

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INTRODUCTION

Wildland fires are natural earth system processes that have affected atmospheric composition, climate, and the evolution and spread of new plants and biomes for over 350 million years (Scott 2000, Bond and Keeley 2005, Scott and Glasspool 2006). Until very recently, post-fire recovery of burned landscapes occurred with little or no human intervention. However, in the past two decades, increased resource management and continued community development into fire-prone wildland areas (often referred to as the wildland-urban interface) has resulted in an increasing amount of research, management, and funding of post-fire stabilization and rehabilitation to protect public safety and other values-at-risk (e.g., water quality, irrigation systems, roads, buildings, habitat, and culturally significant sites). As the ecological resources of wildland areas (e.g., sources for clean water and carbon sequestering capacity) are recognized and valued, the longer term consequences of post-fire treatments on the environment and ecological recovery are becoming more important in the post-fire treatment decision-making process.

The number and severity of wildfires in the western United States has increased in the past decade (National Interagency Fire Center 2008) and the rise is likely to continue (Flannigan *et al*. 2000, Brown *et al*. 2004), the southwestern United States likely to be especially hard hit. Using the combined forecasts of 15 climate models and applying a derived measure of climate responsiveness, Diffenbaugh *et al*.(2008) found that the strongest US "hot spot" (area where the models predict climate will be changing the most) stretches across the southwest from southern California to western Texas (Kerr 2008). The model predictions of hotter dryer conditions, which exacerbate fire conditions, may already be emerging as there has been a strong trend of drying and warming in the southwest for the past decade (Westerling *et al*. 2006 ,Kerr 2008). At the same time, the number of people living in wildland-urban interface continues to grow, increasing the risks to human life and safety, natural resources, infrastructure, and homes and buildings. These risks stem from the direct threat of wildfires and the secondary effects (increased runoff, flooding, erosion, and debris flows) of those fires (Stewart *et al*. 2003). When there are significant values at risk for loss and damage, letting nature take its course is rarely accepted public policy for fire suppression or post-fire rehabilitation efforts (Calkin *et al*. 2007). Although protection of public safety often requires rapid suppression of wildfires and mitigation of secondary fire effects, the general public will strongly advocate for additional restoration efforts to enhance post-fire recovery to bring the burned area back to its pre-fire condition as quickly as possible.

Most post-fire stabilization and short-term rehabilitation treatments are used to mitigate the post-fire effects on physical ecosystem components, such as soil, water, and hydrologic processes (Robichaud *et al*. 2000). Long-term rehabilitation and restoration activities are often more focused on the biotic components of the ecosystem, such as recovery of native communities and habitat, maintenance of biodiversity, re-establishment of timber or grazing species, and control of invasive weeds (Hessburg and Agee 2003, Beschta *et al*. 2004).

The Burned Area Emergency Response (BAER) process focuses on short-term mitigation of the secondary (physical) fire effects and stabilization of the burned area. However, in the past decade, recovery of ecological functions, especially in terms of restoring native vegetation and controlling invasive weeds, has become a major concern for BAER assessment teams (Beyers 2004). In addition, erosion mitigation treatments often include direct seeding or large-scale applications of surface-covering materials (mulches), both of which can impact vegetation recovery on post-fire landscapes (Beyers 2004, Kruse *et al*. 2004, Hunter *et al*. 2006). In this paper we describe: 1) some methods and tools used by BAER teams for post-fire assessments and treatment decisions; 2) questions concerning post-fire rehabilitation treatment effects on burned area recovery, which have become apparent during treatment effectiveness monitoring; and 3) a rationale for concertedly determining the environmental effects of post-fire rehabilitation treatments and taking those findings into account during the BAER treatment selection process.

POST-FIRE ASSESSMENT AND TREATMENT RECOMMENDATION PROCESS

A BAER team is assembled whenever a fire may pose a threat to life, safety, or structures (e.g., roads, buildings, irrigation ditches), managed resources (e.g., timber, cover for grazing, cultural sites) and environmental resources (e.g., water quality, spawning habitat, biodiversity). These *ad hoc* teams include soil scientists, hydrologists, foresters, ecologists, engineers, archeologists, and other specialists as dictated by the location of the fire and values-at-risk. Once assembled, their tasks are to: 1) assess the fire-induced changes in the burned area; 2) estimate the risk for loss or damage posed by the post-fire conditions to the identified values-at-risk; 3) recommend cost effective treatments to reduce the risk where possible and economically justified; and 4) implement selected treatments. BAER teams work under strict time constraints to accomplish these tasks within weeks of fire containment, as protection of public safety and burned area stabilization need to be put into place as rapidly as possible. Given the time limitations for post-fire assessment and treatment recommendations, the methods and tools used by BAER teams must efficiently provide reasonable estimates and accurate information for decision-making. As the impacts of various treatments on ecological processes and environmental recovery are determined, these data need to be readily available for efficient use during the BAER process.

Assessment of Fire-induced Changes in the Burned Area

Burn severity is a qualitative classification of fire effects on the physical, biological, and ecological characteristics of the burned area, and is generally designated in discrete categories of unburned, low, moderate, and high (Lutes *et al*. 2006). Because the degree or magnitude of nearly all secondary fire effects is directly related to burn severity (DeBano 2000, Robichaud 2000, Moody and Martin 2001, Moody *et al*. 2005), the initial task of most BAER teams is to assess burn severity across the burned area. The first step in this process is to obtain the Burned Area Reflectance Classification (BARC) map. This map is produced from satellite imagery and generally reflects changes in vegetation and increased mineral soil exposure immediately after the fire. BAER teams, when evaluating the need for post-fire stabilization treatments, are particularly interested in fire effects on ground cover and soil properties that will impact post-fire soil hydrological functions. These include: 1) loss of protective surface cover on the soil; 2) formation or enhancement of soil water repellency; 3) change in soil structure due to consumption of fine roots and other organic material that increase micro and macro pores; and 4) change in bulk density due to collapse of aggregates and clogging of voids by ash (Certini 2005). These fire-induced soil changes have the potential to decrease infiltration and increase flooding and erosion, which have downstream effects on water quality and aquatic habitat. Consequently, BAER teams verify and adjust the burn severity designations on the BARC map to reflect the effects of the fire on the soil. This field-validated map is called the soil burn severity map and highlights areas where increased runoff and peak flows, flooding, erosion, and sediment delivery to streams threaten values-at-risk. Field verification of soil burn severity may include a general inspection of ground parameters (e.g., amount and condition of remaining duff and litter, amount and color of bare mineral soil, depth and color of ash), testing for soil water repellency and reduced infiltration, and examination of changes in soil structure.

Efforts to improve the remote sensing of soil burn severity are ongoing (Lentile *et al*. 2006, Robichaud *et al*. 2007a). The images from new sensor technologies and higher resolution sensors, including images from various satellite platforms (Hudak *et al*. 2007) and airplane mounted sensors (e.g., hyperspectral imagery), are being analyzed for potential use in refining the post-fire soil burn severity map and mapping soil water repellency (Lewis *et al*. 2006, Robichaud *et al*. 2007a, Lewis *et al*. 2008). These higher resolution sensors are also being tested for remote identification of invasive plant species within a burned area. As this process is refined, remotely sensed images can be used to determine the post-fire spread of invasive species and patterns of vegetation recovery within varied burn conditions.

Recently, Robichaud *et al*. (2008a) have developed a technique to use the hand-held Mini-disk Infiltrometer™ (MDI; Decagon Devices, Inc., Pullman, Washington) to sample infiltration to assess soil water repellency (Figure 1). A burned area sampling plan was developed specifically for BAER teams using the MDI to assess fire-induced soil water repellency. The basis of this sampling plan was a stratification of the burned area based on soil burn severity and slope aspect. These factors, derived from data sets acquired in conjunction with remote sensing of soil water repellency (Lewis *et al*. 2006, 2008), focus field sampling to provide a reasonable assessment of fire-induced soil water repellency in the short time frame available to BAER teams.

Figure 1: Using a mini-disk infiltrometer to assess soil burn severity and reduced infiltration after a fire.

Identifying Values-At-Risk and Estimating the Potential for Loss or Damage

Areas of high and moderate soil burn severity with downstream values-at-risk are generally the focus of BAER team evaluations. BAER teams determine if reducing the threat (e.g., stabilization of hillslopes to reduce erosion; upsizing water passage structures on roads to avoid washouts) are justified to protect public safety and reduce risk of damage or loss to identified constructed and ecological resources. To accomplish this, BAER teams often use predictive models to estimate the runoff, peak flow rates, erosion, and debris flows that are likely to occur in these burned areas, and to relate those predictions to the necessity to protect values-at-risk.

There are several models for predicting runoff, peak flows, and erosion; however, only a few have been adapted to the post-fire environment. For example, the Water Erosion Prediction Project (WEPP; Flanagan and Livingston 1995) has been adapted to provide estimates of hillslope erosion for burned forests, rangeland, and chaparral areas (for examples, see the Forest Service WEPP interfaces at http://forest.moscowfsl.wsu.edu/fswepp/) (Elliot 2004). The Erosion Risk Management Tool (ERMiT) was developed specifically for use by BAER teams (Robichaud *et al*. 2006a), and has been used extensively in the southwest during the past three fire seasons (P. Robichaud, Forest Service, personal communication). This web-based application uses WEPP technology to estimate hillslope erosion in probabilistic terms on burned and recovering forest, range, and chaparral lands with and without the application of erosion mitigation treatments. User inputs are processed to combine rain event variability with spatial and temporal variabilities of soil burn severity and soil properties. Based on multiple WEPP runs, ERMiT produces a distribution of event (rain or snow melt) sediment delivery rates with a probability of occurrence for each of five post-fire years. In addition, event sediment delivery rate distributions are generated for post-fire hillslopes that have been treated with seeding, straw mulch, and erosion barriers (Robichaud *et al*. 2007b, c).

Not all potential post-fire threats can be modeled to estimate the magnitude or extent of the threat in relation to values at risk. Professional judgment and monitoring data from past fires are often used to predict severity of potential threats for which predictive models have not yet been developed (e.g., the spread of invasive weeds in burned areas) or have not been adapted for use in post-fire environments or the specific environment being assessed. In addition, professional judgment and monitoring data are often essential to validate or adapt model predictions for the specific environment being assessed.

Recommend Cost Effective Treatments to Reduce Risk where Justified

As threats are being evaluated, BAER teams consider the potential effectiveness of post-fire treatments to reduce the risk of resource damage or loss. Economic justification, such as benefit and cost analyses, has always been a part of the Forest Service BAER assessment process, while the US Department of Interior agency BAER teams have used a ranking system to justify use of post-fire treatments (Calkin *et al*. 2007). The process of treatment justification can, in the end, support a no-treatment option as the best, most cost-effective decision.

Benefit and cost analyses of post-fire treatments are complex economic processes; it has been particularly difficult to estimate the monetary value of many non-market resources (e. g., habitat continuity, biodiversity, archeological sites, water quality, recreational use) that are often identified as values-at-risk in post-fire assessments. Recently Calkin *et al*. (2007) developed a resource valuation framework that provides a standardized values-at-risk valuation process specifically for BAER team treatment decision-making. The inputs to this valuation tool include estimates of the probability that the threat will occur, the probability that the treatment will be successful, and the cost of the treatment.

In the case of hillslope erosion, ERMiT can be used to determine the probability of the threat occurring and the probability of treatment success for seeding, mulching, and erosion barrier installation. However, estimating these probabilities for other threats and mitigation treatments is dependent on data from past wildfire treatment monitoring and the professional judgments of the BAER team. The Burned Area Emergency Response Treatments Catalog (BAERCAT) presents instructions, monitoring tools, and references that BAER teams may use to identify appropriate post-fire emergency treatments (Napper 2006).

Monitor Treatment Installation and Effectiveness

Given the high cost of many post-fire stabilization and rehabilitation treatments, it is important to monitor treatment installation as well as effectiveness. For example, agricultural straw mulches applied to burned hillslopes to slow runoff and reduce erosion must provide 60 % to 70 % ground cover to be effective, but if the mulch is too thick it can inhibit natural vegetation recovery (Beyers 2004). To get the most treatment effectiveness for the money spent, installation specifications must be clearly delineated and monitored for compliance.

After the treatments are in place, monitoring treatment effectiveness is essential to determine if treatments are functioning as desired, to compare various treatments, to identify conditions that enhance or limit treatment effectiveness, and to determine long-term ecological impacts. For example, a post-fire treatment monitoring plan was initiated on the 2008 Trigo Fire in the Ciboles National Forest in New Mexico to compare treatment effectiveness of straw mulch, seeding, and no treatment (control) options that were applied within the burned area. These data can also be compared to monitoring data from other fires and ecosystems to reveal treatment and environmental factors that enhance or limit treatment effectiveness. In addition, monitoring allows new post-fire treatments and application technologies to be tested and compared to those currently available. Some post-fire treatments have unintended consequences, such as the introduction of invasive species through the use of agricultural straw mulch (Robichaud *et al*. 2003), which can be documented through treatment monitoring.

Monitoring the effectiveness of post-fire rehabilitation treatments demands a quick response to measure the potentially largest runoff and erosion events that occur in the first post-fire year. In addition, a commitment of several years is required so that treatment effects can be evaluated through the initial recovery period and compared with the natural recovery process that occurs in the burned, but untreated, control areas (Robichaud 2005). Quantitative methods, such as the use of sediment fences to measure hillslope erosion (Robichaud and Brown 2002) and instrumented sediment dams with weirs for measuring runoff and sediment yields from paired catchments, have been developed for some post-fire treatment monitoring (Robichaud 2005, Robichaud *et al*. 2008b).

Monitoring post-fire treatment effectiveness requires commitment of funds and personnel that may extend beyond the first three post-fire years—the time frame typically allocated to initial recovery. Recovery rates vary by climate and geographic area as well as size and severity of the burn. DeBano *et al*. (1996) found that following a southwestern US wildfire, sediment yields from a low severity fire recovered to normal levels after 3 years, but moderate and high severity burned watersheds required 7 yr and 14 yr, respectively. Although post-fire recovery of the soil may take decades, the vegetation generally proceeds through post-fire successional stages more rapidly. Changes and growth of post-fire vegetation provide the perturbation and organic inputs that contribute to soil recovery. The effects of erosion mitigation treatments on this recovery cannot be determined if the site is not monitored beyond three years or if vegetation and other site factors are not included in the monitoring protocol.

Two or three years after a fire, land management goals generally shift from stabilization of burned areas to long-term productivity and ecological restoration. Further monitoring, resource management, and restoration is done through the land agencies in charge of the burned area. Hence, the longer term effects of BAER treatment decisions may not be evaluated or reported. In addition, most BAER treatments are selected to mitigate threats to hillslope stability and to protect structures (roads, water crossings, etc.), and the evaluation of these treatments is measured in terms of how well it mitigates the threat for which it was selected. If long term treatment effects and environmental consequences are to be taken into account as BAER teams make treatment decisions, the information first needs to be collected and analyzed, and then integrated into the tools and databases used by the BAER teams during the post-fire assessment process, and then explicitly included in the treatment selection process.

POST-FIRE TREATMENT SUCCESS

Treatment success depends not only on the treatment, but on the threat being treated. Until recently, broadcast seeding after fires was the most common and widely used post-fire erosion mitigation treatment (Figure 2) (Robichaud *et al*. 2000), and it is still extensively used in some regions. When the seeded plants (typically grasses) germinated, their roots stabilized the soil and the vegetation protected the soil surface from raindrop impact. However, careful examination of post-fire treatment monitoring and research studies showed that seeded plants seldom produce effective cover the first year after a fire when erosion potential is highest (Beyers 2004). In addition, some studies have found that unseeded control sites have the same amount of vegetative cover as seeded sites in the first three post-fire years (e.g., Robichaud *et al*. 2006b, Groen and Woods 2008). More recent research has shown that seeding can suppress native plant recovery (Beyers 2004, Kruse *et al*. 2004, Hunter *et al*. 2006). Purposefully using this inhibiting effect, seeded grasses have been applied to suppress noxious weeds or less desirable species (Beyers 2004). Specialized seeding to enhance native populations or control non-native species is increasing. Thus, if seeding with native species is used to mitigate the spread of invasive plants, it may be quite successful and yet be inadequate for mitigating post-fire erosion during the first years after a fire.

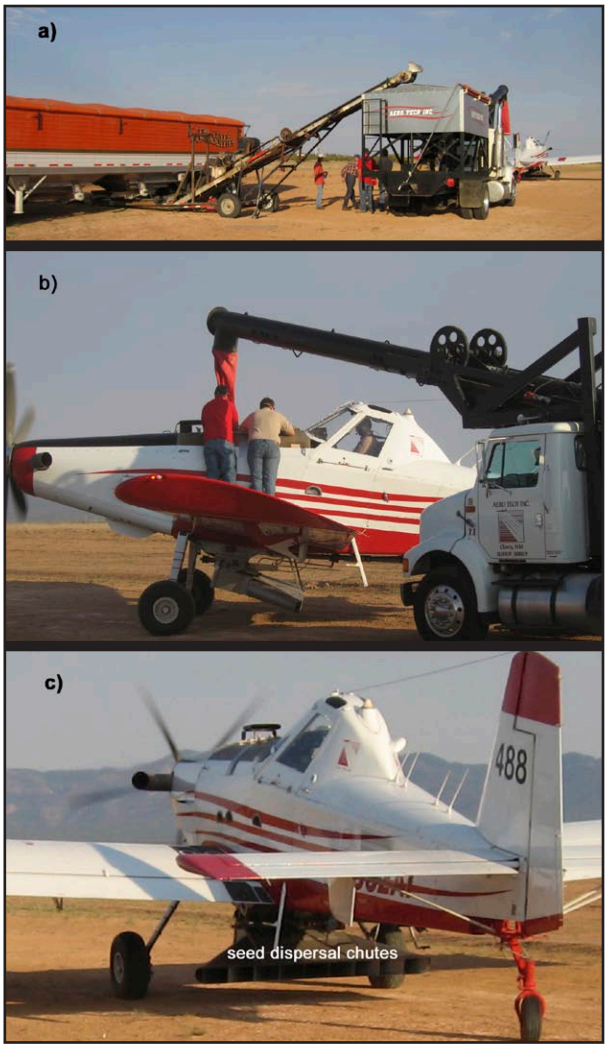

Figure 2: The staging area for aerial broadcast seeding treatment on 2400 ha burned at high and moderate burn severity on the 2008 Trigo Fire in New Mexico. a) Preparing the seed mix—50 % annual rye grass and 50 % native perennial (mountain brome and slender wheatgrass) by weight. b) Loading the seed mix into the seed hopper of the airplane. c) Airplane taxiing for take-off with seed dispersal chutes visible under the fuselage.

When post-fire hillslope erosion is directly measured, research and monitoring consistently find ground cover (e.g., needlecast, litter, vegetation, mulch treatments) to be the most significant factor in reducing hillslope erosion (Pannkuk and Robichaud 2003, Wagenbrenner *et al*. 2006, Groen and Woods 2008, Larsen *et al*. 2009). Covering bare mineral soil to reduce raindrop impact, promote infiltration, slow runoff, and shorten runoff flow paths has the greatest post-fire hillslope erosion mitigation effect.

The success of mulching, as well as its high cost, has created a strong interest in post-fire mulch types and mulch application technologies. Agricultural straw mulches (Figure 3a) are readily available and less expensive than other mulches, but they can be contaminated with weed seeds and are easily blown into deep piles, leaving large areas of unprotected soil (Beyers 2004; Kruse *et al*. 2004; K. Hubbert, Hubbert & Associates, unpublished report available at <http://www.fs.fed.us/psw/publications/4403/BAEREffectivenessMonitoringSoCA.pdf>).

Use of forest materials, such as pulverized forest floor materials (litter, leaf detritus, etc.) (Figure 3b), wood chips made from burned trees, and manufactured wood strand products such as WoodStraw™ (Forest Concepts, Auburn, Washington; Figure 3c), eliminate the seed contamination issue and are more resistant to displacement by wind (Beyers *et al*. 2006, Foltz and Copeland 2007). In addition, the use of native materials for post-fire mulching may be more ecologically benign because it limits the amount of foreign material being introduced into the environment. Little is known about the ecological consequences of applying wood chips or wood strand products, some of which are decay resistant compared to straw, on the physical, biological, and nutrient soil components where they are applied.

On a burned site in Arizona, USA, Beyers *et al*. (2006) evaluated the erosion mitigation effectiveness of wood chips, rice straw, and

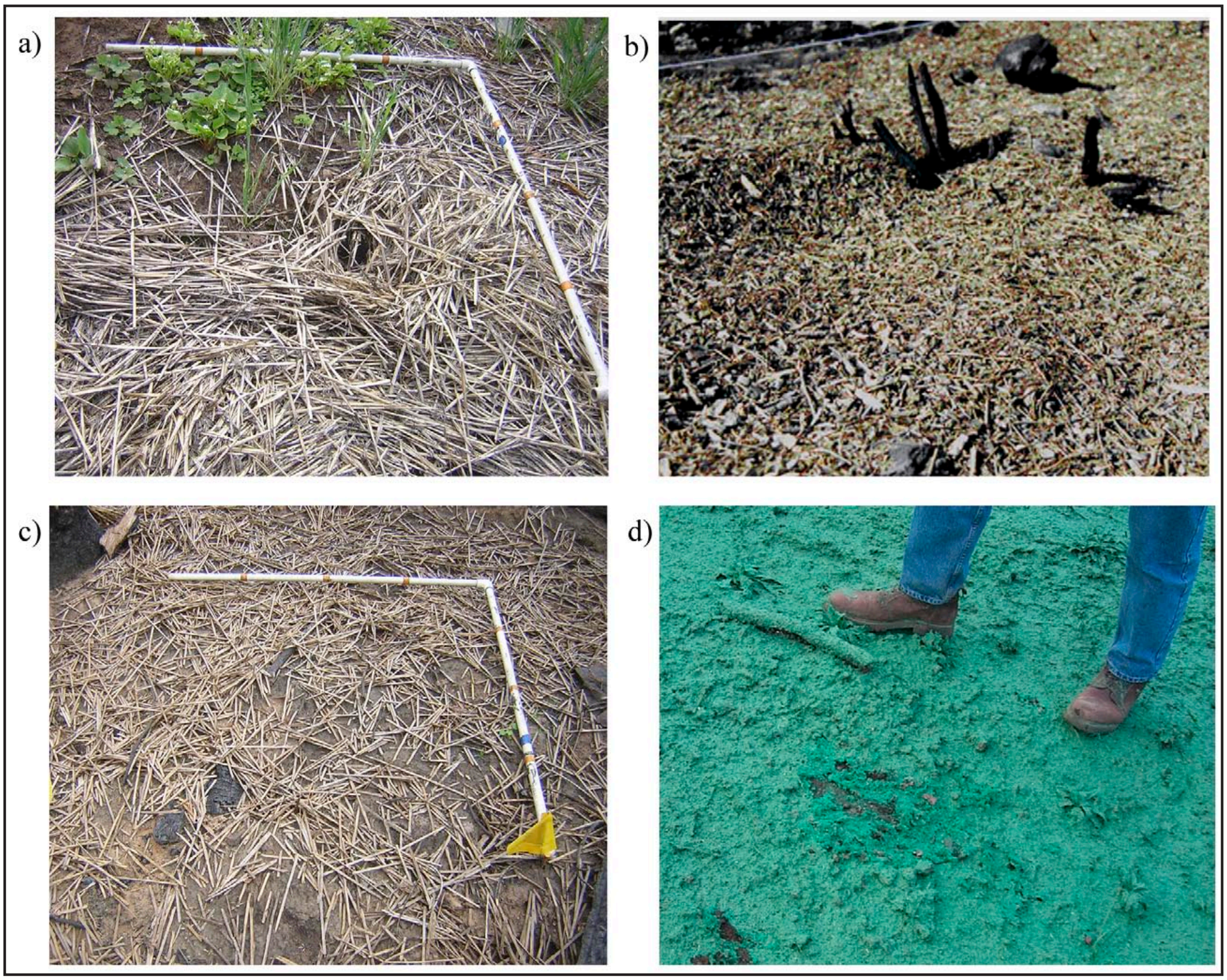

Figure 3. Mulches for post-fire treatment on burned areas: a) agricultural straw (wheat), six months after aerial application on the 2005 School Fire, Washington, USA (PVC frame is 1 m on a side); b) heterogeneous mix of wood chips, small twigs, and pine needles made from shredded forest-clearing debris; immediately after application following 2002 pine forest wildfire in Alicante, Spain (photo credit: Susana Bautista); c) WoodStraw™, six months after aerial application on the 2005 School Fire, Washington, USA (PVC frame is 1 m on a side); and d) hydromulch, immediately after aerial application on the 2002 Hayman Fire, Colorado, USA.

straw pellets containing flocculent, finding that wood chips provided the greatest total ground cover and greatest reduction in erosion over several post-fire years. However, the costs for production and transportation of wood-based mulches in the quantities needed for post-fire hillslope treatments make these treatments twice as expensive as agricultural straw. Beyers *et al*. (2006) reported that burned sites in Arizona and California treated with thick or decay-resistant mulches, such as rice straw and wood chips, had slower recovery of vegetation cover than sites treated with straw pellets and hydromulch. Similar vegetation responses have been observed after three years of monitoring the erosion response to three different mulch treatments (hydromulch, wheat straw, and WoodStraw) combined with four species of native grass seed that were applied after the 2005 School Fire on the Umatilla National Forest in southeastern Washington, USA. The sites mulched with wheat straw had slightly less vegetative cover than the untreated control sites; and vegetative recovery was stronger in areas where the straw was evenly distributed and less dense as compared to areas where the mulch was in thicker clumps. WoodStraw mulched sites had significantly less vegetative cover than the control sites. The initial aerial application of WoodStraw resulted in thicker, denser coverage in the larger spaces between tree canopies, and little decomposition or redistribution occurred in the three intervening years. Although overall vegetative cover was less than in other sites, tree seedling germination appeared to be highest on the WoodStraw sites (P.R. Robichaud, unpublished data).

Hydromulch (Figure 3d) is more expensive to manufacture and apply than dry mulch counterparts. Aerial hydromulch operations require a water source at the staging area and, because the hydromulch is carried as wet slurry, larger aircraft are required. However, hydromulch is designed to adhere to the soil surface, is not easily displaced by wind, and protects seeds that are often included in the mix. Although the use of aerial hydromulch as a post-fire hillslope treatment is relatively new and not often used, preliminary treatment effectiveness data from post-fire monitoring studies have shown hydromulch to have limited effectiveness in reducing post-fire sediment yields. Aerial hydromulch treatments after the 2002 Hayman Fire in Colorado, USA, reduced erosion 18 % in the first and 27 % in the second post-fire years, which was much less than the reductions measured in the straw mulch treated catchment (P.R. Robichaud, unpublished data). Following the 2003 Cedar Fire in southern California, aerial hydromulch was applied in two different patterns—100 % coverage and 50 % coverage in 30 m contour strips. The first post-fire year, with rainfall well below normal, the 100% coverage watershed had about half the sediment yield of the control sites, while there was no difference between the 50% coverage and control watersheds. During the second post-fire year with rainfall twice the normal average, the two treated watersheds produced very similar sediment yields, which were about 40 % less than the untreated control (Pete Wohlgemuth, Forest Service, unpublished report). Although most hydromulch used for post-fire erosion mitigation had decomposed rapidly (seeming to disappear within the first year in most cases), there is little knowledge of the fate of mulch components or their effects within the ecosystem. Most studies of secondary effects of post-fire erosion mitigation treatments have focused on vegetative recovery after treatment (Beyers 2004, Beyers *et al*. 2006). Few studies have examined the effects of treatments on soil and water; however, one such study was initiated after the 2002 Hayman Fire. Soil microbial activity, as measured by wood decomposition rates, is being compared in treated and untreated burned watersheds. Preliminary data from this on-going study show little difference between the hydromulch and control sites (D.

Page-Dumroese, Forest Service, personal communication).

Determining where to apply post-fire rehabilitation treatments and selecting treatments is a dynamic decision-making process. The benefit of using a particular treatment must be evaluated in terms of costs, likelihood of its success, and long-term ecological impact, which all vary by location within the burned area. Because the probability of success of the different seeding and mulching treatments is not known for all environmental conditions, mulching types, and treatment combinations, it is important to monitor BAER treatments over time to continuously expand and refine post-fire treatment information and to make it accessible to BAER teams for future fire treatment decisions.

CONCLUSION

Wildfires and our responses to them will continue to be a significant land management issue for the foreseeable future. This is particularly true in the southwest where the climate is predicted to become hotter and dryer—a trend that has been observed over the last decade (Westerling *et al*. 2006, Diffenbaugh *et al*. 2008). The water shortage in the southwestern US, fueled by extreme weather events, changing precipitation patterns, and earlier mountain snow melt (Westerling *et al*. 2006), will likely become more pronounced, making the hydrological function of watersheds a valued resource and a priority for protection. Ecosystem transitions, influenced by a changing climate, will alter resource management priorities over shorter time frames than we have seen in the past. In addition, the trend for community expansion into the wildland-urban interface will continue to make protection of public safety a high priority.

The Burned Area Emergency Response (BAER) program is an effective mechanism for making timely decisions to protect valued resources from long-term damage by secondary fire effects and will likely continue in its current or similar form well into the future. Thus, if new priorities and new information are going to impact post-fire assessment and treatment selection, they must be readily accessible and easily used by BAER teams within the BAER program protocols. We have presented some tools, techniques, and current research results that are designed to assist BAER teams in making effective and timely decisions based on the best science available.

As we continue to examine treatment effectiveness, it has become increasing apparent that the ecological effects of post-fire rehabilitation treatments need to be determined and taken into consideration when treatment decisions are made. For example, the effects of various mulches on vegetative cover, species diversity, and tree germination need to be established along with the treatment's effectiveness in reducing runoff and erosion. Research to support the BAER program mission includes: 1) development of predictive watershed process models that integrate disturbance regimes, hillslope and channel processes, and probabilities of event occurrence with GIS input and output; 2) expansion and refinement of remote sensing tools for assessment and monitoring of burned areas; and 3) development of mulches and mulch-making technologies that use on- or near-site natural materials and manufacturing processes. However, if we want to avoid today's solutions becoming tomorrow's problems, we must also evaluate longer term ecological consequences of post-fire treatments and ensure that they are included in the treatment decision-making process.

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