Title

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Journal

Environmental Management, 52(6)

ISSN

0933-0437

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Publication Date

2013-12-01

DOI

10.1007/s00267-013-0165-y

Peer reviewed

Accepted version of publication in Environmental Management.

Perspectives on disconnects between scientific information and management decisions on post-fire recovery in Western US

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Environmental regulations frequently mandate the use of “best available” science, but ensuring that it is used in decisions around the use and protection of natural resources is often challenging. In the Western US, this relationship between science and management is at the forefront of post-fire land management decisions. Recent fires, post-fire threats (e.g. flooding, erosion), and the role of fire in ecosystem health combine to make post-fire management highly visible and often controversial. This paper uses post-fire management to present a framework for understanding why disconnects between science and management decisions may occur. We argue that attributes of agencies, such as their political or financial incentives, can limit how effectively science is incorporated into decision-making. At the other end of the spectrum, lack of synthesis or limited data in science can result in disconnects between science-based analysis of post-fire effects and agency policy and decisions. Disconnects also occur because of the interaction between the attributes of agencies and the attributes of science, such as their different spatial and temporal scales of interest. After offering examples of these disconnects in post-fire treatment, the paper concludes with recommendations to reduce disconnects by improving monitoring, increasing synthesis of scientific findings, and directing social science research toward identifying and deepening understanding of these disconnects.

Keywords: Risk, policy-relevant science, uncertainty, best available science
Acknowledgments: We gratefully acknowledge the support of the Bren School of Environmental Science & Management at the University of California, Santa Barbara. This paper is the product of an interdisciplinary PhD seminar on the science and management of fire. The first 11 authors were participants. Anderson and Tague were the faculty leads.

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I. Introduction

Public management agencies are tasked with using the latest and best scientific information in making decisions on natural resource management (Ryder et al. 2010; Glicksman 2008; Kessler et al. 1992; Sullivan et al. 2006). Often the ability to use the "best available" science requires balancing ecological, economic, and political factors and is the subject of political and public debate (e.g., Daily et al. 2009; Policansky 1999; Sarewitz 2004). These debates frequently identify situations where at least some stakeholders argue that "best available" science was not used in agency decisions.

This paper seeks to more systematically identify disconnects between science and management and their sources. We use post-fire treatment, an important and sometimes controversial response to the threats posed to human and ecological resources after wildland fires, to identify where further research ought to be conducted to establish the existence of disconnects and to work towards addressing underlying causes. By focusing on the United States Department of Agriculture Forest Service (USFS) in the western United States, we illustrate how agency decisions and decision-processes can fail to incorporate natural science, but our insights are broadly applicable to other agency-science relationships. We aim to identify causes of disconnects that are not simply a resistance to the use of science, which might stem from individual motivations, but rather are due to structural attributes of science or the social and political decision-making setting. We do not intend to exhaustively identify disconnects in historic post-fire land management decisions, but rather to highlight areas where understanding the attributes of post-fire science and land management might lead to new insights into why disconnects occur.

There is a rich literature on managing fire risk and on broader forest policy, but we focus on post-fire management where little is known about relationships among political, economic, and ecological factors. In particular, much of the prior work focuses on the development of forest management plans (e.g. Noss et al. 2006; Dombeck et al. 2004) and decision tools that can be used to support planning (e.g. Calkin et al. 2011; Bettinger 2010). In addition, social science has addressed stakeholder involvement and public perception in wildfire policy and management, particularly when decision-making is controversial (McCaffrey et al. 2012; Thompson and Calkin 2011). Reiner (2012) identified institutional barriers to effective fire risk management and Canton-Thompson et al. (2008) addressed social-economic pressures faced by managers in the context of fire suppression. In the areas of fire prevention (Anderson and Anderson 2012; Anderson et al. 2013; Tidwell and Brown 2010) and fire suppression (Busenberg 2004; Donovan and Brown 2005), scholars have documented that political and economic factors, in addition to or in conflict with ecological imperatives, play a role in management actions, but such research has not been done for post-fire management.

II. Background

The number of wildfires in the western U.S. is increasing (Hudson 2011; Pierce et al. 2004; Westerling et al. 2006), and the size and severity of these fires create significant challenges for agencies responsible for post-fire recovery (Robichaud 2005; Westerling et al. 2006). Recent fire seasons underscore this. In 2012, more than 9 million acres burned, the second worst season on record (NICC 2013), and the 2013 firefighting budget was depleted in August with at least two months of fire season remaining (Fears 2013). While wildfire acts as an important disturbance event in natural ecosystems, uncharacteristically short return intervals and high intensity of fire within a system can cause soil degradation, soil erosion, loss of biodiversity, local species extinction, an increased risk of flooding, and damage to natural and human environments (Beschta et al. 2004). Post-fire management goals include promoting return of the landscape to a prior state, reducing the risk of damage by flooding or erosion, and altering subsequent fire frequency and/or severity. Management encompasses small-scale immediate responses (e.g. decision to seed immediately after a specific fire), medium scale planning for smaller jurisdictions (e.g. collaborative watershed planning), agency decisions regarding longer term strategies (e.g. stewardship contracting), and long term planning processes and policy (e.g. federal budget documents specifying priorities).

There are three reasons why post-fire management is an especially fruitful area to explore possible science-agency disconnects. First, decisions must often be made in the face of uncertainties and complexities in the scientific information available. There is debate over whether human intervention, such as post-fire logging or re-seeding, are necessary or useful in promoting recovery (McIver and Starr 2001; Beschta et al. 2004; Donato et al. 2006) and there is disagreement as to the effectiveness of different treatments for specific locations (Robichaud et al. 2009; Schoennagel et al. 2004). Complicating matters, the temporal and spatial scale of both the science and the management of post-fire recovery varies. Second, recognizing the difficulty of incorporating science into management decisions, the USFS in 1998 created the Joint Fire Science Program (JFSP) , which has sought to coordinate fire research between agencies and scientists (Joint Fire Science Program 2000). Although post-fire rehabilitation is not included explicitly within the JFSP implementation plan, the existence of the JFSP makes the USFS a best-case scenario since it is likely to have fewer disconnects than other agencies that utilize science. Third, decisions made during the period following a fire are often highly visible given the attention focused on the wildland-urban interface, making political and public factors especially relevant.

A. Post-Fire Treatments

Following wildfire a wide variety of treatments are available for managers. Table 1 summarizes post-fire land treatment options and describes their methods, purpose, effective duration, effectiveness at meeting the intended purpose, and implementation cost per spatial unit.

B. Burned Area Emergency Response (BAER)

Burned Area Emergency Response (BAER) is the process by which post-fire assessment and treatment across federal lands is accomplished (USDA Forest Service 2011). BAER focuses on responding to emergency conditions that exist after a fire such as soil erosion and flash flooding. During and following fire containment, a BAER team comprised of experts from a variety of disciplines (e.g., pedology, hydrology, forestry, ecology, cultural resources, engineering, etc.) assesses the need for emergency response by investigating burn severity and the risk of damages. Treatments are ranked using a "cost-risk analysis" worksheet that considers the probability of the threat occurring, costs if the threat occurs, the probability that a treatment will be successful, and treatment cost. Because BAER's explicit goals are to focus on small-scale responses immediately following fire containment, long-term treatments (see Table 1) such as salvage logging may fall outside of BAER and onto individual management agencies.

C. Agency decision-making: focus on the U.S. Forest Service

While the executive and legislative branches of the U.S. government have the power to alter agency action through legislation, directives, and appropriations, the legislative mandates that have been handed down still allow the USFS to maintain significant autonomy (Kunioka and Rothenberg 1993), in part because agencies that have the technical knowledge to support their proposals with scientific information are less likely to face congressional control (Ellison 1995). This is particularly true with post-fire management. Of the nearly 1,000 reports [including congressional hearings and US Government Accountability Office (GAO) documents] pertaining to the USFS in the last ten years, only two have been in response to post-fire treatment. Additionally, post-fire treatments receive minimal discussion in the budgets proposed by the USFS (USDA 2011, 2012). USFS policy is mostly dictated by the National Forest Management Act of 1976 (NFMA) and the National Environmental Policy Act of 1969, but agency planning rules are regularly revised, even as recently as 2012. Initially, NFMA led to a multiple use perspective in managing forest resources, but this has given way to priority protection of ecosystems in some circumstances (Hoberg 2003). Conflicts in choosing between various objectives occur often, particularly with respect to commodity and motorized use, but also between multiple use management and ecosystem management (Martin et al. 2000).

III. Disconnects Between Post-fire Management and Science

Using post-fire management as a case study, this paper identifies circumstances where characteristics of agencies and science or their interaction may impede the use of science in decision-making. Processes such as BAER are explicitly designed to make use of the best available science and do so by engaging science advisors and a variety of science based tools and databases (Robichaud and Asmun 2012). In many cases, BAER effectively does so. Despite this intention, however, disconnects still occur. We propose that disconnects occur on a spectrum ranging from those derived from the attributes of the agency, like its incentives to respond to public opinion or political overseers, to those derived from attributes of science, such as a lack of synthesis (Figure 1). Unclear, conflicting or limited synthesis of scientific findings may make incorporation of science into decision-processes challenging, particularly given the need for an immediate response to fire. In between the two ends lie a continuum of disconnects created by the interaction of agency and science attributes, including differences in systems of incentives, time horizons, and institutional frameworks.

A. Disconnects and Agency Incentives

1. Direct Financial Incentives

Agencies may face financial incentives to choose one management strategy over another when revenue from the production of commodities is at stake. Safeguards are in place in many of these instances, but they always require scrutiny to determine whether financial incentives counteract the scientific mandate.

For example, the USFS receives direct revenue from timber sales, which goes to special off-budget accounts. The USFS therefore may have an incentive to favor salvage logging over other post-fire treatments (Saylor 2007). Such logging occurred as far back as 1938 in response to hurricane damage in Massachusetts (Foster and Orwig 2006) and the USFS has regularly used fire as a motivation to harvest timber (Hutto 2006). For example, after the Biscuit fire in Southern Oregon and Northern California in 2002, the USFS carried out a plan, contested by environmental groups, that included extensive salvage logging (Preusch 2004). As recently as 2003, the Flathead and Kootenai National Forest Rehabilitation Act directed the USFS to implement proposed post-fire salvage logging without the normal public input and legal requirements (Kreiter 2006) and the merits of salvage logging continues to be debated (CRS 2012). Post-fire salvage logging is often prescribed using "emergency exemptions," which allow the USFS to circumvent traditional requirements for public disclosure of environmental impacts based upon the economic value of burned trees (Karr et al. 2004). While stewardship contracting has offered opportunities to engage private companies in ecological restoration, the financial incentives remain as a source of disconnect between management decisions and the science of post-fire recovery.

2. Budget Constraints

Budget constraints more broadly may also be a reason why "best available" science is not used. The Forest Service is subject to yearly budget oversight and must operate within its appropriations. As Table 1 illustrates, different post-fire management treatments have varying costs. As a result, managers may be forced to use a less expensive treatment or to use less treatment in order to stay within their budgets. At times, the budget for a given fire's post-fire treatment is even a specific line item in the budget (e.g., after the 2012 Colorado fires), reducing the discretion that managers can exercise in allocating post-fire treatments. How economic incentives and constraints are balanced against scientific considerations has not been rigorously evaluated for post-fire management in the Western US. This suggests a role for social science research to evaluate past post-fire decision-making in order to understand these tradeoffs.

3. Political Pressure

A third source of disconnects may come as the result of political pressure that is inherent to most agencies. Pressure can come from the public (Carsey and Rundquist 2009; Potoski and Talbert 2000), elected officials (Balla et al. 2002; Bickers and Stein 2000), or internally. Members of the public who are affected by fire demand emergency relief spending to prevent further damage (e.g., flooding). For example, after the Booth and Bear Butte Complex and Biscuit fires in Oregon, over ninety percent of those surveyed supported post-fire erosion control, replanting, and seeding (Olsen and Shindler 2010). While individuals who interacted with the agency via public participation were often dissatisfied with the process (Germain et al. 2001), Sabatier et al. (1995) found that the USFS does appear to respond to public demands.

In addition to public pressure, agencies may face pressure from legislators who seek electoral rewards for providing emergency assistance spending (Cheng et al. 2007; Cole et al. 2012; Healy and Malhotra 2009). For example, all seven Colorado Representatives signed a letter to appropriators asking for emergency funds for post-fire restoration after the 2012 fire season. Representative Jared Polis (D-CO) subsequently issued a press release applauding the House appropriations bill for including “$48,256,765 for flood prevention funding—the exact amount requested by the House congressional delegation.” Robichaud et al. (2000) note that the public and elected officials expect post-fire treatment to occur, regardless of whether it is actually needed, which can drive unnecessary spending on treatments such as seeding.

These political pressures emphasize action immediately following fire, with less attention paid to evaluating the subsequent effectiveness of the action. The USFS spent $192 million for over 110 emergency soil stabilization and over 40 rehabilitation treatment plans following the 2000 and 2001 wildland fires (GAO 2003). Despite the monitoring requirements of BAER, neither the USFS nor the GAO could determine whether emergency stabilization and rehabilitation treatments were achieving their intended results. As noted by GAO (2003), “Most land units do not routinely document monitoring results, use comparable monitoring procedures, collect comparable data, or report monitoring results to the agencies’ regional or national offices.” In 2006, the GAO issued another report directing the USFS to report back to Congress on the status of current and future post-fire rehabilitation projects and to conduct additional monitoring to evaluate the effectiveness of projects. Currently, a review by the GAO is pending to assess the extent to which the USFS followed their recommendations for monitoring of post-fire treatment. Although experimental monitoring has become more common in recent years (Hubbert 2006; Robichaud et al. 2013), widespread systematic monitoring of the effectiveness of various treatments is limited or not reported. This lack of effectiveness monitoring makes it difficult to discern whether responsiveness to the public and elected officials is resulting in activities that facilitate post-fire recovery.

B. Disconnects in Scale

One of the main disconnects between agencies and science stems from the differing scales, both time and spatial, at which agencies and science operate. Agencies often face short-term (within 3 years after fire) incentives, while recent ecological literature frequently emphasizes the importance of long-term (decadal) ecological research in understanding landscapes and the effect of human activities on them (Driscoll et al. 2012). Management practices are also often limited in spatial scope by jurisdictional boundaries and administrative rules that may not correspond to the broad range of spatial scales considered by ecology.

1. **Time Scale**

Science literature on post-fire effects spans both short-term behavior, such as increased erosion following fire, and long-term consequences for forest structure, function and subsequent fire regimes (Veblen 2003; Whitlock et al. 2003). However, long time scales are frequently incongruous with that of the current political system, where incentives operate over shorter time scales (Besley and Case 1995; Koontz and Bodine 2008; Nordhaus 1975). Constrained by the public and lawmakers, forest agencies are often required to implement solutions that address immediate risks (Carroll et al. 2004). Management agencies in the U.S. implement the majority of their post-fire practices immediately after a fire disturbance and many of their "long-term" management practices last fewer than five years (GAO 2003). For example, in the aftermath of 2012 fires in New Mexico, recovery money was mostly spent on controlling the short-term risk of flooding and erosion and $25 million was spent within a month of the fire (Bryan 2012).

Post-fire ecosystem-management projects require long-term planning and long-term financial commitments (Stein and Gelburd 1998). As of the FY 2013 Department of Interior Wildland Fire Management Budget Justification, long term targets for restoration of burned acres had not yet been developed and scientific funding rarely extends beyond a decade, not long enough to encompass fire patterns at the landscape level (Falk et al. 2007).

2. Spatial Scale

Wildfire knows no boundaries, whereas the management of post-fire often is limited to jurisdictional responses, presenting a mismatch in the appropriate spatial scale of response. For example, discontinuous treatment measures may be delimited within fire-affected landscapes by federal boundaries or state and county lines. In some cases, such as the need for erosion control for vulnerable downstream aquatic ecosystems, there may be universal ecological principles for post-fire management. However, it is well documented in the literature that fire regimes in the western U.S. vary over space and time, making a universal management approach impractical for most restoration goals (Noss et al. 2006). Yet, static political boundaries can prevent post-fire management from being spatially adaptive.

Management agencies have more recently attempted to embrace ecosystem-based managerial practices (Butler and Koontz 2005) but are inhibited by administrative boundaries and jurisdictional limitations (Koontz and Bodine 2008). As a result, some management collaborations, such as the Wildland Fire Use Plan for the Bob Marshall Wilderness Complex in Montana (Hann and Bunnell 2001), have emerged to propel ecosystem-based management across spatial boundaries. The advancement of ecosystem-based management practices has the potential to address fire at the scale at which it occurs while meeting multiple science and management objectives simultaneously. But such management faces obstacles when it crosses jurisdictional boundaries. For example, after a fire in Santa Barbara, California, authorities required landowner permission to hydromulch on private lands. Michael Harris, Emergency Operations Chief for Santa Barbara County said, "In two of the fires, we've had big swaths of private land and government land, and obtaining permission to hydromulch was fairly straightforward, but in another fire in which we had very much smaller parcels, it became very difficult to get a large number of property owners to agree to hydromulching" (Snider 2011).

IV. Disconnects Related to the Synthesis of Science

While the previous sections have focused on disconnects that derive from agency characteristics or the interaction of these and characteristics of science, attributes of science alone can also create disconnects. Limitations of science can prevent synthesis or lead to scientific uncertainty. For example, post-fire treatment effects are often confounded by spatial and temporal variability among treated areas. Although research and monitoring have begun to provide data on the effectiveness of post-fire treatments (Table 1), they are often focused on individual effects rather than the combined effects of multiple treatments and lack long term evaluation (Covert 2010; Davidson et al. 2009; Dodson and Peterson 2010; McCullough and Endress 2012; Robichaud et al. 2009). Up until very recently many studies either contained little quantitative data or lacked untreated control sites with which to compare treatment effectiveness (Beyers 2004). Furthermore, the focus of science research is not always explicitly or efficiently directed at resolving science-related management questions.

From the perspective of agencies, considerable effort is often needed to interpret complexities, caveats, uncertainties, and contingencies in existing work and to synthesize a growing body of scientific research. The need for immediate responses in post-fire management, combined with limited resources can make updating management based on scientific recommendations difficult. In the case of post-fire management, BAER and the USFS often incorporate scientific uncertainty into decision-making. For example, rather than provide a single number, the BAER Treatments Catalog provides summary tables that allow managers to prioritize treatments based on field conditions (Napper 2006). Decision-making support tools (reviewed by Hyde et al. 2013) clearly synthesize existing information but whether or not the information they provide is precise enough to lead to decisions that are appropriately tailored to local site conditions has not been evaluated. To do so would require substantial data collection on post-fire management decisions and their environmental consequences. New monitoring approaches and an increasing number of studies across a range of conditions can lead to significant advances and reduce science-based uncertainty. A recent review, for example, took advantage of the increase in data quality and improved experimental design (Peppin et al. 2010). They found that the majority of early studies that showed seeding treatments were effective were from the lowest data quality categories. The highest data quality studies reviewed were nearly all published after 2000, and none found seeding treatment to effectively reduce erosion. They also found that seeding treatment effectiveness may vary by ecoregion. Over the last thirteen years, the JFSP has facilitated research and review of various post-fire rehabilitation treatments, including assessments of monitoring programs. Additional studies and their synthesis could be used to develop a framework for assessing what is likely to work within a particular watershed and under what conditions.

A. Time Lags in Assimilation of Science by Agencies

One reason limitations of science might cause disconnects is that agencies are slow to incorporate changing science. In a classic paper, Hannan and Freeman (1984) argue modern societies tend to favor organizations that "reproduce a structure with high fidelity" and that "selection tends to favor stable systems." Recent institutional analysis has pointed out that agencies face "institutional friction" *(Jones 2001; Jones and Baumgartner 2005)*. Even when change could yield better results, the risk of unexpected negative outcomes can deter organizations from adopting new ways of solving problems (Choo and Bontis 2002). Wright (2010) found targeting individual managers who were "early adopters" could shorten the lag between the production of science and its incorporation into management.

Although there generally tends to be a time lag between when new science is released and when it is widely incorporated, managers certainly respond to advances in science. For example, managers switched from contour felled logs to mulch treatment when research showed that the proportion of ground cover was most important in determining erosion (Robichaud et al. 2010). However, when multiple objectives are considered, such as reducing post-fire erosion risk and maintaining species diversity, it can be challenging to determine the applicability of research results to a local area (Barbour 2007).

B. Model Limitations

In recent decades, post-fire management decision-making, such as BAER, has used and provided decision support tools (Hyde et al. 2013). Although these models are fairly widely used, managers often use different techniques to determine the input parameters, making the estimation of post-fire flow inconsistent across USFS regions (Foltz et al. 2009). The advantage of such models is that they can codify a broad collection of research on treatment effectiveness and associated contingencies. For example, ERMiT, a simplified version of the Water Erosion Prediction Project (WEPP), estimates erosion risk in particular locations and the potential for different treatments to reduce it (Robichaud et al. 2009). The disadvantage of models, however, is that underlying assumptions may be hidden from users and may codify out-dated science if they lack a formal procedure for updating models with new peer-reviewed research.

V. Recommendations and Future Research

This paper identifies a range of situations that have or are likely to lead to disconnects between post-fire decision-making and science. We have shown that when management decisions do not align with "best available" science, the culprit is not usually agency intentions. Some disconnects between current science and decision-making may be inevitable, and in some cases even desirable. Lags between recently published science and decision-making practices, for example, may be necessary to maintain stable and effective decision-making. However our discussion identifies a number of situations where disconnects may negatively influence outcomes. Identifying and ultimately resolving these disconnects is likely to improve post-fire management from both agency and science perspectives. To move toward this goal, we recommend more systematic monitoring of existing post-fire treatments, scientific synthesis of post-fire treatments, and a social science research agenda that considers the political and economic drivers of potential disconnects.

Even in the face of budget cuts, we suggest that additional efforts from both science and agencies are needed to expand the data available for synthesis. Our recommendation echoes the 2006 and 2003 GAO reports that argued for a coordinated post-fire treatment monitoring system. We recommend that management agencies make the systematic monitoring of post-fire treatments across agencies a higher priority, including allocating budgetary resources for sufficient monitoring. Science can lead in the design of monitoring techniques and protocols and implement experiments that provide data for synthesis (Lentile et al. 2006). We note that current National Science Foundation networks of long term observatories such as the Long-Term Ecological Research network (LTER), National Ecological Observatory Network (NEON), and Critical Zone Observatory network (CZO) are developing monitoring data protocols and information management systems that may contribute to these efforts (Baru et al. 2012; Michener et al. 2011).

Responsibility for disconnects, also lies with the science community. In our review of post-fire management literature, it was clear that synthesis studies that examine the effectiveness of a specific post-fire treatment under a variety of site conditions, such as Robichaud et al. (2010), provide critical information for managers. These types of reviews help to reduce scientific uncertainty and clarify contingencies. Studies such as this, however, remain relatively scarce. Science-based assessments of the broad range of post-fire treatments (Table 1) under different site conditions and for a range of different post-fire treatment objectives are needed. However, the diversity of post-fire treatments, site conditions, and management objectives also makes this type of synthesis challenging without a large number of case-studies where post-treatment effects are monitored. The already strong linkages between the science community and management through JFSP, BAER, and other agency networks can facilitate this, and we recommend that they emphasize meta-analysis of past post-fire decisions and, where possible evaluation of their environmental consequences. An adaptive management framework, where there is ongoing evaluation of the consequences of past decisions to improve future decisions can facilitate this but requires funding to be effective (Cundill and Fabricius 2009). We also note that continued updating of BAER processes, and in particular models that codify science based information, is essential for integrating results from these research efforts. Translating these synthesis studies into education materials can further demonstrate to the public why decisions are made.

Social science data-driven research on the connections between management and science in actual post-fire decisions would facilitate an assessment of how often and under what conditions the use of “best available science” is problematic. Our paper highlights why disconnects may occur and thus argues that this type of post-decision data collection and analysis is needed. We argue for social-science that investigates how external forces, internal structure, and institutional culture may influence outcomes. Understanding how and why these disconnects between science and management occur can identify places where improvements can be made.

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Figure 1: Possible drivers of disconnects between science and management.

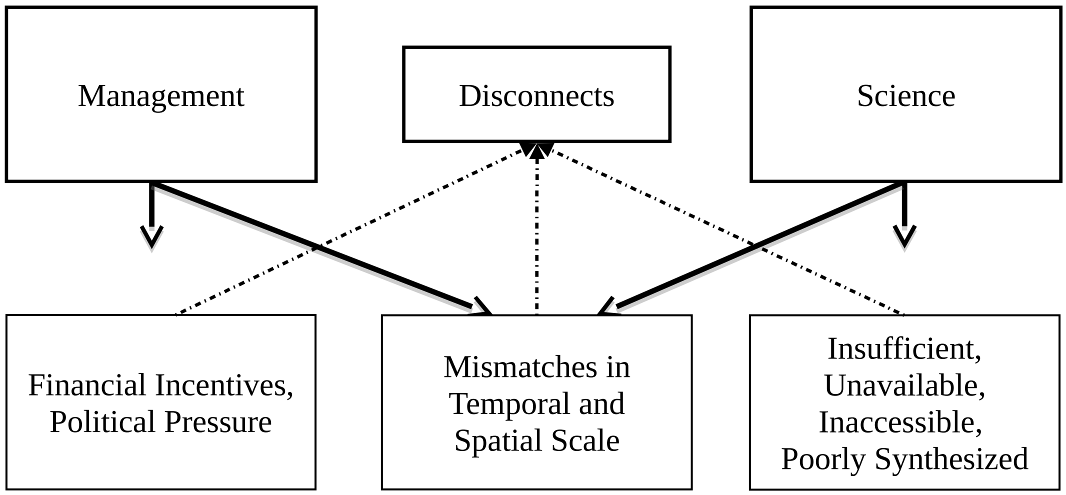

Table 1: Post-fire land treatment options and their reported purpose, effective duration, effectiveness, cost, and most recent review literature.

Treatment	Details	Purpose	Duration	Effectiveness	Cost	References
Seeding	Broadcasting seeds to encourage vegetative growth. One of the most widely used treatments.	Erosion control	1 year	Often not effective, but effectiveness might vary depending on seasonal and regional differences in rainfall regime; may reduce nutrient loss	$20-$170 per acre	Beyers 2004; Napper 2006; Peppin et al. 2011; Peppin et al. 2010; Wagenbrenner et al. 2006*; Gómez-Rey et al. 2013*; Miller et al. 2013*
		Re-establish vegetation	>1 year	Slight majority of studies suggest seeding hinders native plant recovery, and effectiveness depends on the rainfall regime		
		Non-native plant control	1 year	Evenly mixed results		
Herbicide	Aerially applied herbicide after fire disturbance	Non-native plant control	1-3 years	Mixed results		DiTomaso et al. 1997*; National Park Service 2007*; Steers and Allen 2010
		Encourage marketable conifer species	1 year	Effective in reducing shrub cover and encouraging conifer growth		
Salvage logging	Harvesting of lumber remaining post-fire	Timber revenue and reduce fuel loads	>5 years	Net economic gain/loss unknown; short term increase in fuel load from slash or possibly from shrub growth; slight medium to long term fuel reduction when slash removed; increased surface runoff and soil damage primarily from road construction, but level depends on management activities and scale; negative effects on ecosystem diversity; mixed effects on individual species; lower onsite carbon storage	Unknown	Karr et al. 2004; Lindenmayer et al. 2008; McIver and Starr 2001; Peterson et al. 2009; Redding and Leach 2012; Powers et al. 2013*
Mulch – Straw and wood chips	Straw/wood chips mulch with weed-free material helps provide temporary cover to erosion-vulnerable areas, applied with helicopter to large areas, or by hand for smaller treatment sites.	Erosion control	<3 years	Reduces sediment yields by at least 95%; more effective for larger or intense storms as compared with other treatments; wood chips are less likely to be removed by wind; may reduce nutrient loss	$250-$930 per acre (helimulching); $500-$1,200 per acre (hand application)	Napper 2006; Robichaud et al. 2013; Robichaud et al. 2010; Wagenbrenner et al. 2006*;
		Moisture retention to re-establish	<3 years	The effectiveness depends on distribution and thickness of mulch layer; too thick of an application may delay vegetative growth; straw mulch has		

		vegetation		potential to include non-native seeds		Wohlgemuth et al. 2006*; Gómez-Rey et al. 2013*
Mulch – Hydromulch	Applied to large areas by aerial delivery or ground to provide ground cover. Adheres to the surface soil layer, and may be mixed with seed to re-establish vegetation.	Erosion control	<3 years	Less effective than straw/wood chips mulch; effective during low intensity rainfall; ineffective against intense rainfall	$2,000-$3,000 per acre by aerial application; or $1,675-$3,000 per acre by ground application	Robichaud et al. 2013; Robichaud et al. 2010; Napper 2006; Wohlgemuth and Robichaud 2006*; McCullough and Endress 2012*
		Moisture retention to re-establish vegetation	<1 year	Effective at retaining moisture but the degree to which it may enhance infiltration is not known. Little impact on native plant recovery.		
Soil binders [e.g. polyacrylamide (PAM)]	Chemical adhesive used to bind soil particles. Spread over soil surface as a liquid or as pellets that dissolve during rain events.	Erosion control and increase infiltration	<1 year	Has a preference for binding with ash that typically blows away with the first wind and less with coarse grains; ineffective during large or intense rainfall events; moderately effective during low intensity rainfall events	~$500 per acre	Robichaud et al. 2010; Napper 2006
Log erosion barrier	Felled tree trunks laid parallel to slope strike to reduce erosion by providing a flow barrier, improving infiltration, and trapping water and sediment.	Erosion control	>1 year	Less effective than mulching; ineffective against intense storms and after storage space becomes full; moderately effective during large storms. Often used in the 1990s, however after circa 2000, rarely used due to research suggesting limited effectiveness	$420-$1,200 per acre	Robichaud et al. 2010; Cerdà and Robichaud 2009; Napper 2006; Wagenbrenner et al. 2006*
Straw wattles, fiber rolls	Rolls of hay, woodchip or other fibrous material bound with twine used to create flow blockage thereby slowing overland flow, increasing infiltration, and trapping sediment.	Erosion control	>1 year	Ineffective during high intensity rainfall; moderately effective with large rainfall events	$1,100-$4,000 per acre	Robichaud et al. 2010; Cerdà and Robichaud 2009; Napper 2006
Silt fences	Geotextile fabric that prevents the passage of sediment. Installed vertically with wooden posts or metal T-posts, firmly sealed and anchored below ground level. Used infrequently as a BAER treatment. Commonly used to protect at risk high value areas.	Erosion control	>1 year	Effective when properly installed; upon partial filling with sediment must be cleaned out to maintain effectiveness	$50 per roll, labor costs and other effort may increase cost to between $150-$250 for each fence	Cerdà and Robichaud 2009; Napper 2006

* Citations marked with asterisks are not syntheses, but contribute information to the knowledge of the treatment's effectiveness.