Burned Area
Learning Network

State of the knowledge about post-fire response

This synthesis identifies some of the important publications and ideas that have emerged across the spectrum of post-fire work. The specific focus of this research ranges from the effectiveness of emergency stabilization treatments to how people and communities respond to wildfire. Rather than a comprehensive codification of knowledge, this review is designed to provide a summary highlighting the most recent research in this rapidly evolving field. The goal is to share areas where science has advanced and where gaps remain.

This synthesis is part of building the Burned Area Learning Network (BALN). The goal of the BALN is to accelerate learning by peer to peer knowledge sharing to improve social and ecological outcomes following wildfire. Through our collaborative efforts we seek to improve the accuracy and utility of short and long-term post-fire risk assessment; increase worker safety during burned area assessment and restoration; improve inter- and intra-agency relationships; and develop new science-based cooperative strategies for post fire response.

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Introduction

Over the last 16 years, wildfire burned an average of 4.6 million acres annually in the coterminous U.S. (NIFC 2017). Many of recent wildfires have burned large areas at high severities creating both acute and chronic impacts. Loss of homes and post-fire flooding are examples of the profound effects of wildfire can have on people, communities, and economies. Large, severe wildfires can also completely change ecosystem composition, structure, and function. A recent analysis found over 12 million acres of former forestland are treeless because of wildfire (Sample 2017).

As the climate gets warmer (and in many areas drier) large, severe fires are likely to become more common (Westerling and Bryant 2008, Mitchell et al. 2014, An et al. 2015, Bowman et al. 2017). In fact, this pattern is already visible. An examination of wildfires in the western U.S. between 1984 and 2011 showed both the number of large fires and the acreage burned increased significantly (Dennison et al. 2014). Regional studies have documented an increase in burn severity in both California and the southwestern U.S. (Dillon et al. 2011, Miller and Safford 2012).

The increase in large, severe wildfires means that addressing burn areas and post-fire issues is an important topic that will continue to grow in prominence in the near future.

Impacts of large, severe wildfires

The increasing frequency of large, severe wildfires results in devastating human and ecological impacts (Williams 2013). The list of communities impacted by wildfire grows longer each year, but recent notable examples include the 2013 Black Forest Fire which killed two people, destroyed 489 homes, caused $420 million in insured losses, forced the evacuation of 38,000 people, and cost $9.2 million to suppress (McGhee 2014). California’s 2013 Rim Fire destroyed 11 homes, cost $127 million to suppress, caused private property losses that could be as large as $265 million, and a loss of environmental benefits that could be as large as $736 million (Batker et al. 2013). New Mexico’s 2011 Las Conchas Fire destroyed 63 homes, cost $48 million to suppress, caused massive flooding, destroyed archaeological sites, forced the shutdown of Albuquerque’s drinking water intake, and devastated the traditional homelands of Santa Clara Pueblo (EPSCoR 2012). Initial reports suggest the 2015 Valley Fire, which killed four people, destroyed 1,958 structures, caused over $1.5 billion in economic losses, and more than $925 million in insured losses (Aon Benfield Analytics 2015).

The full cost of wildfire that includes fatalities, injuries, property losses, post-fire flooding, air and water quality damages, healthcare costs, business impacts, and infrastructure shutdowns is anywhere from two to 30 times greater than the suppression costs (Dale 2009). For example, the 2010 Schultz Fire cost between $123 and $137 million dollars after the fire was contained because of post-fire flooding, reduced property values, habitat destruction, and other post-fire expenses (Combrink et al. 2013). Property losses due to wildfire in the U.S. were over one billion dollars in 2012, and only a little more than half were insured losses (Gardner 2014).

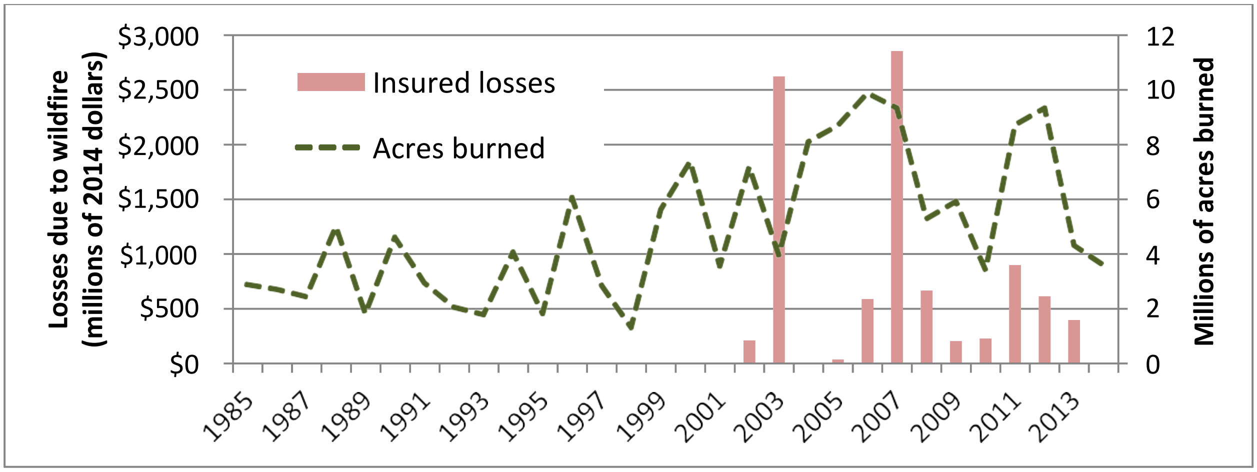

Figure 1 Insured losses from wildfire with acres burned (Gardner 2014, NIFC 2015)

Though the insured losses from wildfire vary a great deal each year, the number of structures lost to wildfire shows growing impact in WUI. The decadal average number of structures lost to wildfire has increased tenfold since the 1960s (ICC 2008, NICC 2014). Wildfire can have immeasurable impacts on communities. Often, people whose homes are destroyed by wildfire do not rebuild after wildfire, causing long-term community change (Alexandre et al. 2015).

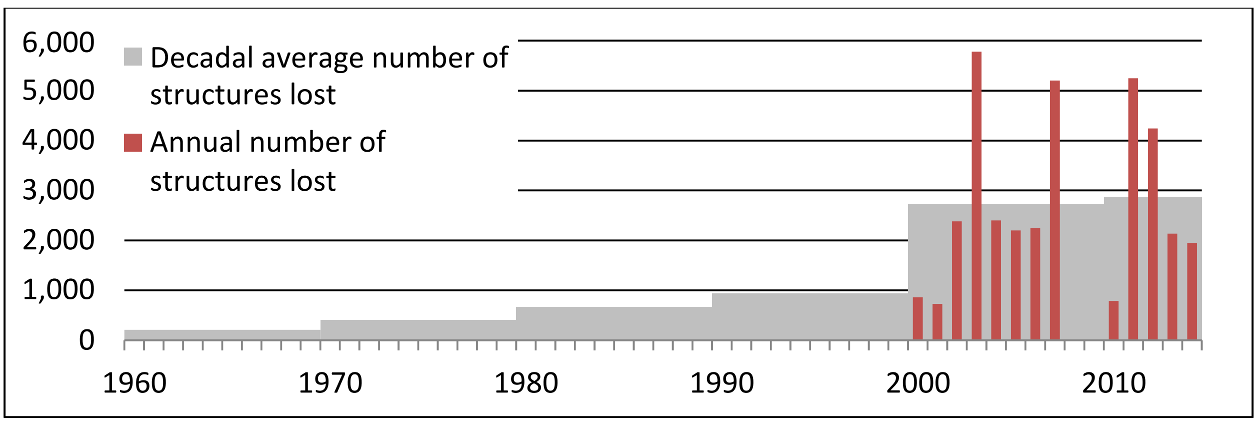

Figure 2 Number of structures lost to wildfire (ICC 2008 and NICC 2014)

Disasters, including wildfire, often have a disproportionately negative impact on the most vulnerable such as the poor, the elderly, and people with disabilities (Buckland and Rahman 1999, Morrow 1999). An examination of the 2002 Rodeo-Chediski Fire showed that when fire hits, working class residents are more vulnerable than their richer neighbors (Collins and Bolin 2009). In addition, research from Oregon suggests that poor households are more likely situated in areas with minimal or non-existent fire response capabilities than wealthy households (Lynn and Gerlitz 2005). A national mapping effort found that nearly 10% of all housing in places with high wildfire potential also exhibits high social vulnerability (Wigtil et al. 2016). Even where wildfire mitigation programs exist, socially vulnerable communities are less likely to participate (Collins 2008, Ojerio et al. 2011).

Recent Research on Post-Fire Issues

Because of the increase in large, severe wildfires post-fire response and management of burned areas are active topics for scientific research and management discussions. The specific focus of this research ranges from the effectiveness of emergency stabilization treatments to how people and communities respond to wildfire. The following sections identify some of the important publications and ideas that have emerged across the spectrum of post-fire work. Rather than a comprehensive codification of knowledge, this review is designed to provide a summary highlighting the most recent research in this rapidly evolving field. The goal is to share areas where science has advanced and where gaps remain.

Stabilization treatments (Burned Area Emergency Response)

One of the first responses to large wildfires on US Forest Service land is through the Burned Area Emergency Response program. On lands managed by the Department of Interior, similar efforts fall under emergency stabilization and burned area rehabilitation (please see the accompanying document title ‘Burned Area Emergency Response - Federal Policy Overview’). It is worth noting that BAER focuses on identification of imminent threats and mitigation of unacceptable risks. A recent review of over three decades of reports on post-fire stabilization treatments found five trends:

1. Post-fire treatment justifications different by region and revealed local concerns;
2. Post-fire responses generally reflected expansion of the WUI;
3. Road work was the most frequently recommended post-fire treatment type;
4. Seeding was the most common treatment but its use declined over time; (6)
5. Use of straw mulch steadily increased over time; and
6. The greatest post-fire expenditures were for land treatments applied over large areas to protect important resources such as municipal water sources (Robichaud et al. 2014).

Another review highlighted that research showing the proportion of exposed mineral soil is the primary factor controlling post-fire hillslope erosion and that dry mulches can be highly effective in reducing post-fire runoff and erosion (Robichaud et al. 2010). A review of post-fire management from an ecological restoration perspective identified a number of practices as generally inconsistent with efforts to restore ecosystem functions: seeding exotic species, livestock grazing, placement of physical structures in and near stream channels, ground-based logging, removal of large trees, and road construction (Beschta et al. 2004).

An assessment of post-fire treatments identified the post-fire peak flow estimation is an important factor that specialists use to select road treatments (Foltz et al. 2009). In general, BAER specialists use U.S. Geological Survey methods for larger watersheds (great than five square miles) and Natural Resource Conservation Service Curve Number methods for smaller watersheds (Foltz et al. 2009) (see the section ***Post-fire flooding*** for more discussion of post-fire flooding).

A key part of the post-fire response is understanding where to focus efforts. Soil burn severity and canopy mortality maps play a central role in responding to post-fire risks. Researchers have worked to assess the effectiveness of current mapping and identify opportunities for improvement. Studies of canopy mortality mapping efforts reaffirm their ability to accurately characterize fire severity (particularly high severity) (Miller and Quayle 2015, Lydersen et al. 2017). As new research efforts seek to facilitate integration of these severity maps with runoff models through an online spatial database that rapidly generates properly formatted modelling datasets modified by user-supplied soil burn severity maps (Miller et al. 2016b).

Post-fire flooding and debris flows

Post-fire flooding is an area of intense study beyond the emergency stabilization context. This is driven by the drastic increase of runoff or erosion after wildfire, which can be more than 100 times greater than pre-fire conditions (Bladon et al. 2014, Williams et al. 2014). A summary report from the 2014 conference titled *Managing for Future Risks of Fire, Post-fire Flooding and Extreme Precipitation* provides an overview of key issues on the topic (Garfin et al. 2016) and a 2013 report from the Water Research Foundation reviews the effects of wildfire on drinking water utilities and mitigation options (Sham et al. 2013). Of course, post-fire flooding has significant impacts on aquatic ecosystems as well (Bixby et al. 2015).

Recent research in Arizona and California disentangles the changes in water yield due to fire effects and those due to precipitation fluctuations (Hallema et al. 2017). Other research documents the ability of treatments to partially and gradually reverse incising channels to conserve wetlands, soils and associated values (Long and Davis 2016). Another study emphasizes the importance of unburned patches to limit runoff and erosion (Cawson et al. 2013). Research is also helping to better characterize key details of post-fire infiltration (Balfour et al. 2014) and the geomorphic effects of post-fire rainstorms with different spatial patterns (Kampf et al. 2016).

Just as efforts to map fire severity (i.e., the degree to which an area has been altered or disrupted by fire) are improving, mapping and modelling of post-fire flooding and debris flows is an area of active research. For example, Cannon and colleagues (2010) developed a mapping approach to identify the watersheds most prone to the largest debris flows post fire. These models have been implemented in a number of areas in New Mexico (e.g., Tillery et al. 2011, Tillery et al. 2014, Tillery and Haas 2016). Modeling and mapping efforts can contribute to pre-fire treatment prioritizations, wildfire response, and post-fire erosion mitigation.

Moody and colleagues (2013) identified five key research needs around post-fire flooding and debris flows:

1. organize and synthesize similarities and differences in post-wildfire responses between different regions to determine common patterns;
2. quantify functional relations between fire effects and soil hydraulic properties;
3. determine the interaction between burned landscapes and temporally and spatially variable meso-scale precipitation;
4. determine functional relations between precipitation, basin morphology, runoff connectivity, contributing area, surface roughness, depression storage, and soil characteristics required to predict the floods and debris flows; and
5. develop standard measurement methods that will ensure the collection of uniform and comparable runoff and erosion data.

Fuels

As large, severe wildfires increase in frequency, they have started to reburn the same areas. Reburning highlights the importance of understanding post-fire forest development and fuel build up. For example, a study in California found that high- to moderate-severity fire led to an increase in standing snags and shrub vegetation, which in combination with severe fire weather promoted high-severity fire effects in the subsequent reburns (Coppoletta et al. 2016). Research from the Gila National Forest, New Mexico also suggests that where initial fires burned at high severity, there is higher probability of reburning at high severity (Holden et al. 2010). Greatly increased fuel loads have been identified after other fires as well (Keyser et al. 2009).

Even when fire burns with less severity, the post-fire fuel complex is likely to be different than the pre-fire fuel complex (Keifer et al. 2006, Dunn and Bailey 2015). One factor in the new fuel complex is delayed tree mortality and eventual snag fall (Miller et al. 2016a). Snags can create "jackstraws" when they fall together and form pockets of dense, dry fuels, which can burn intensely in subsequent fires (Passovoy and Fulé 2006). Where fire severity is lower, forest and fuel conditions are more likely to be in-line with management goals (or the historic range of variability), but still may require fuel reduction or maintenance work (Stevens-Rumann et al. 2012, Higgins et al. 2015, Huffman et al. 2017).

Salvage

One approach to reducing fuels and recovering some of the timber value lost to a wildfire is salvage, or post-fire, logging. While post-fire logging can remove dead or dying trees that could otherwise increase fire intensities in future fires, the approach has become the focus of significant opposition (DellaSala et al. 2006). A review of post-fire logging studies identified a range of both positive and negative impacts from the practice (McIver and Starr 2000) and a 2008 book on salvage logging concluded that it rarely, if ever, contributes positively to ecological restoration (Lindenmayer et al. 2008).

Post-fire logging can remove large fuels but create short-term increase in surface fuels. In one study, moderate-intensity harvests generated surface fuel loads consistent with commonly prescribed levels and high-intensity logging created enough surface fuels to require follow up treatments (Donato et al. 2013). A study from Washington and Oregon found post-fire logging reduced surface fuels up to four decades following wildfire (Peterson et al. 2015). Fine fuels are likely to build up more quickly and require treatment on a shorter time scale (Campbell et al. 2016).

Post-fire logging is related to other issues such as post-fire regeneration, runoff, and nutrient retention. In one study, regeneration was 75% lower in salvaged sites because of low seed-tree retention (Keyser et al. 2009) but in another study salvage logging and planting facilitated regeneration (Collins and Roller 2013). Ground-based logging adds an additional disturbance to areas already susceptible to runoff and erosion because of fire (Wagenbrenner et al. 2015). Charred and whole woody material on-site after wildfire is a potential source of nutrients (Marañón-Jiménez et al. 2013), but nitrogen is often volatilized during the fire rather than removed by logging (Johnson et al. 2005). Other research has addressed the wildlife impacts of post-fire logging (e.g., Hutto and Gallo 2006)

Seeds and weeds

Seeding, spreading grass or other seeds across areas burned severely by wildfire, is nearly as controversial as post-fire logging. Some research points to the ability of seeding to help stabilize soils and encourage understory development after wildfire (Floyd et al. 2006, Morgan et al. 2015). However, other research highlights the lack of effectiveness of seeding (e.g., Stella et al.

2010) or negative impacts of non-native species that can be spread through seeding (Keeley 2006, Leonard et al. 2015). An evidence-based review of 94 scientific papers and agency monitoring reports found no evidence since 2000 for the ability of seeding to mitigate erosion (Peppin et al. 2010). The same review found that most studies of seeding effects on plant communities found that seeding inhibited the recovery of native plants (Peppin et al. 2010). A similar review of seeding after wildfires in range lands also identified a lack of evidence that seeding mitigated erosion (Pyke et al. 2013).

Seeding is also used as a way to limit the spread of non-native species after wildfire and reviews suggest it has mixed effectiveness in this role (Peppin et al. 2010, Pyke et al. 2013). Limiting the spread of weeds is important because wildfire, particularly high severity fire, can facilitate their invasion (Crawford et al. 2001, Symstad et al. 2014). For example, severe wildfire can promote germination and seedling growth of diffuse knapweed (Wolfson et al. 2005). Non-native weeds expanded significantly after wildfires in Mesa Verde National Park (Floyd et al. 2006). Even post-fire rehabilitation may be responsible for spreading non-native species because personnel and machines often carry seeds (Keeley 2000).

Conifer Regeneration

Fires within the range of severities to which a forest is adapted are likely to spur regeneration. However, high severity fires in forests not adapted to them can result in regeneration failure. For example, one study found that regeneration varied considerably across fires in California, but over 50 % of the patches (and approximately 80 % all plots) had no tree regeneration (Collins and Roller 2013). Similar regeneration problems have been observed after other wildfires (Lentile et al. 2005, Roccaforte et al. 2012, Yocom Kent et al. 2015). Even planting after high severity wildfires is not a guarantee of regeneration success. Only half of the projects reviewed in a study in Arizona and New Mexico produced the desired numbers of seedlings (Ouzts et al. 2015). It is worth noting that some species such as aspen regenerate well after high levels of canopy mortality (Wan et al. 2014). For example, after the 2002 Sanford Fire aspen resprouted prolifically (Smith et al. 2011).

Often, long distances to seed trees and competition with shrubs limit tree regeneration after high severity fire (Franklin and Bergman 2011, Kemp et al. 2015, Welch et al. 2016). A study of high severity wildfire patches in Colorado showed an exponential decline in conifer regeneration density with distance from surviving forest and very little regeneration beyond 600 feet (200m) from a seed source (Chambers et al. 2016). In other cases, herbivores limit regeneration, particularly where the disturbance patch size is smaller (Castro 2013, Smith et al. 2016). Drought is often an overriding factor (Savage et al. 2013, Harvey et al. 2016). As the climate gets warmer and drier, many tree species are likely to have difficulty regenerating after large, severe wildfires (Dodson and Root 2013, Feddema et al. 2013, Petrie et al. 2016).

Vegetation type change

Many forests are not adapted to large, severe wildfires and are ill suited to recover from these fires. As described previously in the section, ***Conifer Regeneration***, there is evidence that some forest types (particularly ponderosa pine and mixed conifer forests) have limited regeneration after large, severe wildfires. Without regeneration from the previous tree species, forests can change to a new set of species of trees or completely different vegetation type.

Conversion of conifer forests to grasslands, oaks, or other shrubs has been documented across the western U.S. After the 2000 Storrie Fire in California, shrub cover in areas of high severity was more than three times the shrub cover of lower burn severities (Crotteau et al. 2013). Collins and Roller (2013) found approximately 60 percent of patches exceeding 60 percent shrub cover after a wildfire in the northern Sierra Nevada, California. High severity wildfire in Oregon enabled graminoids to dominate lower elevation sites and replace ponderosa pine (Dodson and Root 2013). Oak densities increased four times after the 1990 Dude Fire in Arizona (Leonard et al. 2015). The 2003 Cedar Fire killed conifers and oaks in the Peninsular Ranges of southern California, but the oaks were able to resprout and dominate many sites afterward (Franklin et al. 2006). Oak dominated patches within coniferous forests can persist for decades or longer (Iniguez et al. 2009, Savage et al. 2013, Guiterman et al. 2015). A study of the 2011 Las Conchas Fire in New Mexico showed high severity wildfire shifted forested sites to open savannas and meadows, oak scrub, and ruderal communities, and this shift was only reinforced by reburning (Coop et al. 2016).

In the Southwest, low elevation, dry sites are more likely convert from coniferous forest to shrub or grassland (Haffey 2014). In some cases, high severity wildfire allows non-native species to capture natural areas (Franklin et al. 2006, Keeley and Brennan 2012). Modeling suggests that if large, high severity wildfires become more common in the Southwest, sprouting species such as oak will increase in dominance in areas that are currently ponderosa pine forest (Azpeleta Tarancón et al. 2014).

Although most studies of wildfire catalyzed vegetation type conversion focus on coniferous forests, riparian forests can be similarly affected (Kaczynski and Cooper 2015).

Post fire community recovery

Wildfire impacts on people and communities can be as severe as the impacts on ecosystems. As mentioned previously (see the section ***Impacts of large, severe wildfires***), the fatalities, injuries, property losses, post-fire flooding, air and water quality damages, healthcare needs, business impacts, and infrastructure shutdowns caused by wildfire can cost as much as 30 times the initial suppression (Dale 2009). The cost of wildfires may limit community recovery. Government spending on suppression activities can translate into economic benefit for communities in the short term, but wildfire becomes a negative impact on local economies for up to two years afterward (Davis et al. 2014, Nielsen-Pincus et al. 2014).

Research suggests that many homeowners rebuild after wildfire, but that opportunities to rebuild in a manner more adaptive to future wildfire risk are easily missed. A study of three Colorado wildfires that destroyed at least 150 houses each found that local governments did not revise land-use regulations and the state did not implement new standards for building and vegetation mitigation (Mockrin et al. 2016). How people and communities experience a wildfire can drive their post-fire response (McGee et al. 2009). A study of homeowners rebuilding after wildfire found some adaptation was occurring, but not all homeowners made changes in response the wildfire (Mockrin et al. 2015). Another study found that new WUI development often occurs inside fire perimeters within five years of a fire (Alexandre et al. 2015).

Community wildfire protection plans are beginning to include planning for post-fire response (e.g., Dahl et al. 2016, Piccarello et al. 2016). New guidance in New Mexico recommends that new CWPPs and CWPP updates include post-fire response plans (EMNRD 2015). Often when communities experience wildfires they are motivated to revisit their CWPP and in some cases increasing the plan's relevance for response and recovery (Jakes and Sturtevant 2013). However, consensus or conflict over natural resource management can remain relatively unchanged after wildfire, though some conflicts may evolve (Brown et al. 2008, Carroll et al. 2011). Residents' disagreement with agencies' post-fire response is also common (Olsen and Shindler 2010). Research suggests that residents preferred action-oriented collaboration such as volunteer restoration activities and these actions helped restore community spirit and relations with local agencies (Burns et al. 2008, Ryan and Hamin 2008). Post-fire field tours are another way to build community goodwill and confidence in agencies post-fire response (Toman et al. 2008).

Conclusion

The increasing frequency of large, severe wildfires across the western U.S. is causing a range of post-fire concerns from soil stabilization treatment effectiveness to community recovery. While researchers have produced useful insights into many of these questions, there are few definitive answers. For example, there have been recent advances in modeling and mapping post-fire flooding, but a standard method for integrating these into pre or post-fire management has yet to emerge.

While all areas of post-fire research need more research, some stand out. For instance, the complex interaction of treatment, wildfire, and subsequent fires needs more study. Post-fire fuels and reburns need more research in part because it is difficult to extent studies in one ecosystem to others. Similarly, vegetation type change is likely to differ significantly between ecosystems and will require localized studies to develop a full view of the issue.

For other topics, the most important issue is the transferring knowledge from researchers to practitioners, policy makers, and the public. For example, the research on post-fire seeding indicates little ecological benefit, but the practice may continue, in part, because that research is not widely known. Another example of the disconnect between research and practice is salvage logging. Few natural resource management questions are as divisive as salvage logging and the growth of research on this topic has done little to settle the debate. In this case, social science research around the disagreement may be more useful that ecological research. The challenges of the post-fire environment require continued scientific research and active sharing of lessons learned from adaptive management.

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