FINAL REPORT

Title: **Post-fire tree regeneration and fuels across the Northern Rockies following large wildfires: science meta-analyses, scenarios and manager workshops**

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Abstract

As more of the western US burns in large wildfires it is critical to managers and scientists to understand how these landscapes recovery post-fire. Tree regeneration in high severity burned landscapes determines if and how these landscapes become forested again, while changes in fuels structure influences how these landscapes may burn again. In this study we compiled two large datasets to understand region-wide patterns and drivers of tree regeneration and surface fuel accumulation post-fire. Our results demonstrated that natural tree regeneration in the Rocky Mountains is declining with increasingly hotter and drier climatic conditions and that close distance to living trees were critical for tree establishment. Additionally, surface fuel accumulation following wildfires remained low in the first few years, but peak 9-14 years post-fire, with repeated fires mitigating this accumulation of surface fuel biomass. After completing analyses, we conducted collaborative workshops to engage managers on science and work with managers to create decision support tools for post-fire landscapes. As a result of multiple workshops with managers, we co-produced a decision tree tool that managers are currently using to apply our science from this project. That decision tree tool was published as part of an invited review of post-fire tree regeneration studies recently conducted across the entire western US. The west-wide results were similar to what we found in our study region.

The objectives of this project were completed on time (with a one-year extension) and within budget, resulting in 5 publications, four focus groups, four workshops, 11 presentations to managers, the public and scientist, as well as expansive popular press interest. This project involved six young career scientists, who recently completed their PhDs and trained multiple undergraduates in field data collection methods. This project worked collaboratively with other on-going Joint Fire Science Program projects, as well as built upon the work previously funded by JFSP, NSF, and other funding agencies to create these large datasets for meta-analyses.

Key Words: Post-fire regeneration, distance to seed source, climate, post-fire fuels, manager-scientist collaboration, manager workshops.

1. Objectives

Our objectives were **1)** to understand how climate has influenced tree seedling density and species composition following wildfires in the interior northwest, **2)** Identify the relative importance of bottom-up drivers like distance to seed source, burn severity and parent material compared to the top-down drivers of climate, **3)** better understand post-fire fuel dynamics including snag fall rates that the rate of post-fire surface woody fuel accumulation in mixed conifer forests of the northern Rockies, and **4)** Incorporate the meta-analyses findings and fuels information into a planting decision tree that was coproduced with forest managers.

For objective 1 and 2 our specific questions were:

(1) Is there evidence of reduced tree regeneration following wildfires under the warmer, drier conditions of the 21st century compared to the cooler, wetter end of the 20th century, (2) what mechanisms are responsible for tree regeneration failures and (3) what forest types or regions are most vulnerable to forest loss due to the combined effects of wildfires and climate warming?

For objective 3 our specific questions were:

(1) How do canopy and surface fuels change through time following wildfires at different severities and with different site climates in mixed-conifer forests of the northern Rockies?, 2) How are woody fuel dynamics influenced by repeated wildfires in a short period of time (<20 years)?

For objective 4 our specific questions were:

(1) Does workshop participation influence land managers understanding and acceptance of local and regional climate change impacts and potential land management interventions? (2) How are workshop participants' beliefs about the credibility of current climate and tree regeneration science, perceptions of risk to forest resources, and usefulness of a post-fire planting decision tree influenced by workshop participation?

In our original proposal we also posed the question of "how does the distribution of seedlings by age class vary by time since wildfire?" This is part of Objective 2. We did not pursue this question yet because a) the presence and absence of seedlings is more important to long-term vegetation dynamics, and b) the methods for analyzing the tree seedling age data are unexpectedly challenging. Our efforts focused instead on the other objectives and questions that were successfully addressed. We plan to pursue this question in future work as University of Idaho PhD student Darcy Hammond successfully accomplished tree age analysis in her JFSP-funded Graduate Research Innovation Award, and we hope to adopt her data analysis methods with our data. We will acknowledge JFSP if and when that is completed. We did not consult with JFSP about not yet pursuing this question. Despite not yet addressing this relatively minor question, we have accomplished all of our research objectives. Further, our research is highly relevant to the JFSP Task 5 in FA-FON-16-001 "Post-fire Landscape Management" under which it was funded, both for advancing science and informing management. We worked effectively with local managers in workshops and had great success with public outreach.

2. Background and Purpose

We focused on the Rocky Mountains because it is highly vulnerable to climate-induced increases in large wildfires (Dennison et al. 2014; Westerling 2016) and reduced post-fire tree regeneration is of particular concern (Donato et al. 2016; Harvey et al. 2016; Kemp et al. 2016; Rother & Veblen 2016). In the past 60 years, mean annual temperatures in the U.S. Northern Rockies have already increased 1°C and are projected to increase by an additional 2 to 5°C by 2090 (Mote et al. 2010). Additionally, projections show the likelihood of increased drought (Dai 2011), warmer summers (Mote et al. 2010, Abatzoglou and Kolden 2011), and elevated lightning activity (IPCC 2007) making these areas prone to increased wildfire activity in dry years (Morgan et al. 2008). Although this increasing fire activity and changing climatic conditions have led to concerns about how these forests will respond and regenerate following wildfires now and in the future, researchers had yet to draw region-wide conclusions from the existing data. Prior to this project there were region-wide studies on post-fire environments across a range of conditions and time since fire. Most researchers have examined tree regeneration and fuel accumulation following a single wildfire or several wildfires in one or two time periods. In this project we compiled two large region-wide datasets. The first, was a dataset of over 62,000 tree seedlings established large wildfires in the Rocky Mountains to examine dominant drivers of natural tree regeneration. This study combined data from 12 previous studies. The second was a dataset of post-fire fuels in Idaho and Montana collected on 174 plots 1-24 years following wildfires, combining data from four previous studies.

Compiling two large datasets allowed us to examine region-wide patterns that affect region-wide landscapes and bring forward research to managers throughout the region that was applicable to specific locations. Effective action by land managers often depends on their understanding of emerging research and having open and reasoned discussions among researchers, land managers, and other relevant stakeholders (Kemp et al., 2015, Dietz, 2013). Research-management partnerships and interactive regional workshops have been effective for synthesizing, visualizing, and translating complex science, as well as coproducing management strategies to address findings of climate change and tree regeneration science (Blades et al. 2016). These interactive interdisciplinary settings may increase and reinforce participant understanding and risk perceptions related to post-wildfire climate influences on tree regeneration, regeneration failure mechanisms, forest vulnerability, and how fuels change over time post-fire, thus the focus of this study. Research-management partnerships and interactive forums will continue to be imperative in the face of increasing agency barriers (e.g., lack of time, reduced funding, dynamic politics) to using emerging science in land management decisions. The coproduction of research-management strategies and tools holds great promise for understanding, minimizing, and mitigating the effects of disturbances and rapid ecosystem change. The goals of this project were to understand forest manager perceptions of post-fire tree regeneration as it relates to climate change impacts and burn severity at local and regional scales. Further, we aimed to the improve the integration of scientific research into land management.

In the fall of 2017 and spring of 2018, our research team of biophysical and social scientists conducted a series of tree regeneration focus groups and workshops focused on conveying regionally and locally relevant information on shifts in forest ecosystems due to changing climate. The workshops facilitated the exchange of current climate change and tree regeneration knowledge across professional boundaries (academic research and land managers) in the U.S. northern Rocky Mountains. Our workshops were designed to bring abstract concepts of climate impacts and tree regeneration science to regional and local scales through the synthesis of empirical data and the coproduction of a post-fire planting decision tree. Drawing upon multiple frameworks, we evaluated the effectiveness of the boundary object (decision tree) and boundary organization (workshops). We contributed to both the social science theory and practice of boundary objects and organizations by exploring the factors posited and relationships to risk perceptions, leading to more effective outcomes. Additionally, we incorporated ideas from social learning theory to develop activities likely to enhance collective understanding in the application of science to practice, including visualization techniques and participant coproduction of a post-fire planting decision tree.

3. Methods

3.1 Study areas

Study sites for the several objectives varied but were predominantly in the Northern Rockies on both National Forest and National Park lands. Specific sites are shown in Figures 1a and 2, but ranged from eastern Washington, Montana, Idaho, Wyoming and Colorado. For objectives 1 and 2, 1485 plots worth of data were analyzed which included 62,582 individually measured seedlings. For objective 3, fuels data from 171 plots were included in the analysis. Focus groups and workshops for the manager communication focused on the areas with the most research and were therefore located in McCall ID, Boise ID, Jackson Hole WY, and Missoula MT.

3.2 Post-fire Tree Regeneration Meta-analysis (Objectives 1 and 2)

All sites were within the US Rocky Mountains, and sites range from Colorado to northern Idaho and Montana (Figure 1a). We analyzed data from over 60 wildfires that burned at mixed severity between 1988 and 2011 (Figure 1b). Elevations ranged from 692 to 2764 m above sea level, and consisted of multiple forest types from low-elevation ponderosa pine (*Pinus ponderosa*) and dry conifer forests (including Douglas-fir, *Pseudotsuga menziesii*, and ponderosa pine), to moist conifer forests that include a mix of Engelmann spruce (*Picea engelmannii*), lodgepole pine (*Pinus contorta*), various fir (*Abies*) species depending on location including white fir (*A. concolor*), subalpine fir (*A. lasiocarpa*) and/or grand fir (*A. grandis*), to forests consisting of pure lodgepole pine. Additional species found in low abundance ($\leq$ 2.5% of all seedlings) across our study sites included whitebark pine (*Pinus albicaulis*), aspen (*Populus tremuloides*) and western larch (*Larix occidentalis*). Sites spanned a range of burn severity both satellite-derived using both relativised differenced normalised burn ratio (RdNBR) and field verified burn severity methods. These sites varied climatically with

30-year mean annual water deficits that range from 120 to 756 mm (Figure 1c and 1d). Due to the climatically similar conditions of moist mixed conifer and lodgepole pine sites, and similarly equitable conditions between pure ponderosa pine and dry mixed conifer we combined these in our analysis, resulting in two distinct forest types for all analyses: 'dry conifer forests' and 'moist conifer forests'.
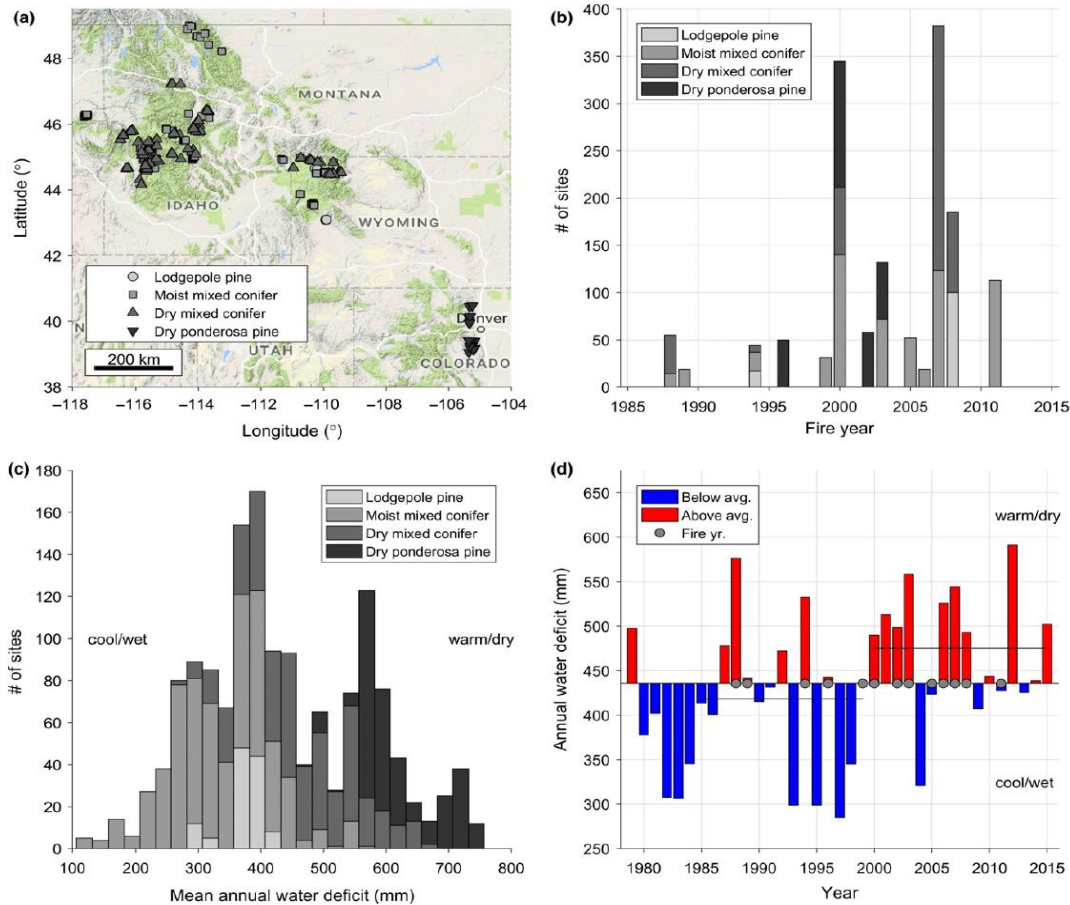

Figure 1: *(a) The geographic location of sites used in this study. Black inverted triangles indicate dry ponderosa pine forests, dark grey triangles indicate dry mixed conifer forests, lighter grey squares indicate moist conifer forests, and the lightest grey circles indicate lodgepole pine forests. (b) Sites displayed by fire year and number from each fire year, with colors indicating forest type. (c) Mean annual water deficit of all sites, again colored by forest type, with cool/wet sites on the left and warm/dry sites on the right. (d) The mean annual water deficit averaged across all sites, starting in 1979, before the period of analysis in this study (1985–2015). The black horizontal lines indicate the 1985–1999 and 2000–2015 mean values.*

As a result, field methods from the individual studies varied slightly. Full details of field

data collection methods can be found in the original studies (Harvey et al. 2013; Wells 2013; Stevens-Rumann et al. 2014; Harvey et al. 2014a,b; Harvey et al. 2015; Rother & Veblen 2016; Kemp 2015; Harvey et al. 2016; Kemp et al. 2016; Morgan et al. 2015; Stevens-Rumann & Morgan 2016; Donato et al. 2016).

All studies recorded tree seedling density by species, estimated pre-fire tree density, distance to nearest live seed source trees (m), tree mortality (%), burn severity (both RdNBR and field-verified low, moderate, or high tree mortality relative to pre-fire tree density at each site), aspect (degrees), slope (%), elevation (m) and latitude and longitude. A heat load index from direct solar radiation was calculated using slope, aspect and latitude (following McCune & Keon 2002). We calculated site-specific field burn severity as either 100% tree mortality ('stand replacing') or < 100%. This decision was made due to varying methods of determining field burn severity among the original studies. All studies in the original projects that experienced post-fire treatment such as salvage logging or planting were excluded from this analysis. Also for analysis we converted seedling densities into two variables. The first was a presence and absence variable, where a single seedling constituted a presence for that particular sites. The second was termed a "recruitment threshold", where we created a binary response variable based on the difference between pre-fire density and post-fire seedling recruitment. If seedling density equaled or exceeded pre-fire density this site was assigned a "1" to indicate seedling density exceeded the recruitment threshold. If a site had more pre-fire trees than post-fire seedlings a"0" was assigned as it did not meet this recruitment threshold. We considered many other metrics for recruitment threshold including varying the "recruitment threshold" to be half of pre-fire density or alternatively twice the recruitment threshold, however this only changed the number of sites that met the recruitment threshold by 5%. We also considered using local stocking density standards used by local national forests, but we ultimately ruled these out for multiple reasons including a lack of information from some national forests, a portion of the sites are managed by agencies without setting stocking densities (e.g., national parks or wilderness areas), and there was high variability in species and productivity across our range of sites.

We additionally acquired climate data to answer this objective. Climate data from 1979 to 2015 were compiled using 800-m PRISM data (through 2009) and ancillary wind and topographically-corrected solar radiation data from grid-MET (4 km resolution; Abatzoglou 2013). We focused on the variable climatic annual water deficit, defined as the difference between actual evapotranspiration (AET) and potential evapotranspiration (PET; AETPET, mm). Using annual water deficit we focused on two variables for this analysis: an average 30-year annual water year deficit (1985–2015) for each site (hereafter, 'average site climate'), and the Z-score of the first three years after each fire event for each site compared to the 30 year mean deficit conditions similar to Harvey et al. (2016). Using this Z -score, a 0 indicates average conditions, and positive values indicate warm/dry post-fire conditions, while negative values indicate cool/wet post-fire conditions.

We performed several analyses to answer our questions. We first split our data into to time period based on the large climatic differences observed across the 30 year study period. All analysis was performed on sites

that experienced fire between 1988-1999 and 2000-2015. We fit a binomial generalized linear mixed model (GLMM) with a logit-link using the 100% recruitment threshold as our binomial response. The models were fitted using fixed effects representing average site climate (30-year average water deficit, [AET-PET, mm]), post-fire relative water deficit (3-year post-fire average water deficit, expressed as a Z-score calculated with the 1985–2015 values) and the interaction between the two, as well as site-specific effects for heat load index, burn severity (100% tree mortality vs. 0–99%) and distance to seed source (m). We set each individual fire event as a random effect to account for potential spatial autocorrelation between sites in individual fires and variability due to burning condition, and specific post-fire conditions.

3.3 Fuels meta-analysis

Standing and downed fuels data were collected between 2008 and 2016 in Idaho and southwestern Montana (Figure 2). In all studies, fuels sampling was confined to sites identified as Middle Rocky Mountain Montane Douglas-fir Forest, Subalpine Mesic-wet Spruce Fir Forest, or Subalpine Mesic-dry Spruce Fir Forest (Rollins 2009; elevation 1000-2400 m) using Environmental Site Potential (ESP), a LANDFIRE product (landfire.gov). We verified the burn severity by considering tree mortality and seedling age in the field, and the ESP through pre-fire tree species composition at each site. We excluded all sites that had logging prior to data collection based on management action records provided from the National Forests, both through personal communications and the Forest Service Activity Tracking System FACTS database (U.S. Department of Agriculture, Forest Service 2016). are a combination of multiple initial studies and more recent unpublished field work; for full description of original studies see Hudak et al. (2011), Stevens-Rumann et al. (2014), Stevens-Rumann and Morgan (2016), and several unpublished data collection efforts (description available upon request). These original data collection efforts were funded by Joint Fire Science Program project #14-1-02-30 and 14-1-02-27.
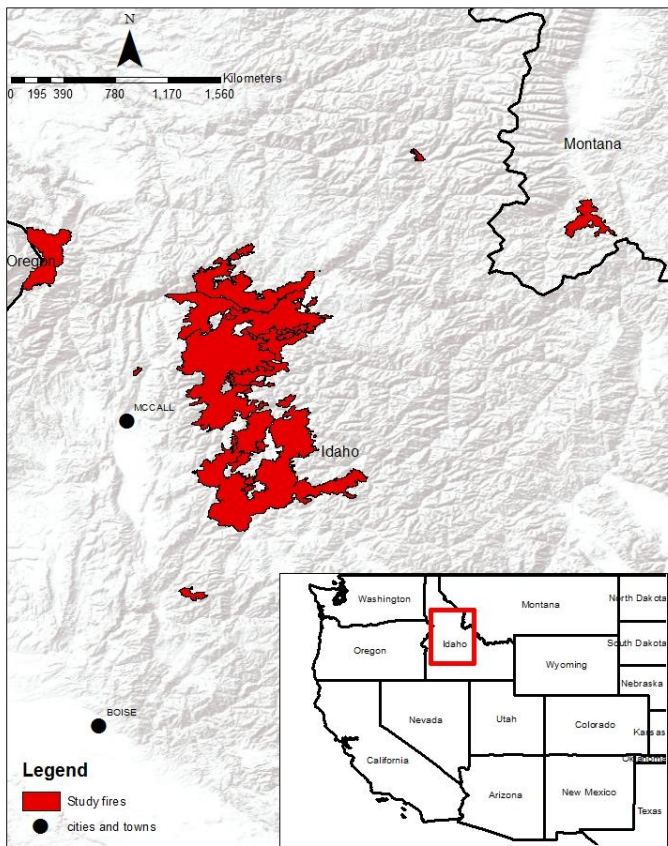
Figure 2: Red areas indicate burn areas where we sampled fuels in Idaho and Montana. These large fires burned between 1989 and 2007.

We combined data from multiple studies for the analysis to meet our objective. In all the studies, the methods were similar but not the same and so we describe them here. In all studies, researchers established a plot at each randomly located point within a stratified burn severity condition excluding sites too close to the road (> 30 m), in order to preclude edge effects. Slope, aspect, and elevation was recorded at every plot. On 195 plots, a 0.04-ha circular plot was established, while on 24 plots measured nine years post-fire, a 0.02-ha circular plot was established (Table 1). researchers tallied all trees >7.62 cm diameter at breast height (DBH, 1.37 m above the ground) as alive or dead, including fallen trees, to estimate percent tree mortality; on 40 one-year post-fire plots tallied in 2008 (also 0.04-ha), the minimum DBH was 12.7 cm. On 32 plots, including eight unburned plots in areas adjacent to burn perimeters, these plots were 0.02-ha and circular, and live and dead trees ≥10 cm were tallied. For all plots, researchers classified a "large snag" as any dead tree >30cm. They also determined burn severity based on percent tree mortality, and for the purposes of our analyses we simplified burn severity into two categories "low/moderate" severity (<90% tree mortality), and "high" severity (>90% tree mortality). While researcher identified tree species to the best of their ability, with the long time-since-fire for some sites, they were unable to determine definitively the species of long-dead trees, so we did not perform species-level analyses. Researchers measured overhead canopy closure of live and dead trees using a densiometer at the center of each plot.

To quantify downed woody fuels, methods varied slightly by study. Fine woody debris, litter and duff depth was tallied following methods outlined by Brown (1974) for most plots. We used Keane and Dickinson (2007) methods in 2016 for 32 plots, including the 8 unburned plots. Dead down woody debris were tallied by size classes (0– 0.64, 0.65– 2.54, 2.55– 7.62-cm diameter) to correspond with 1-, 10-, and 100-hr time-lag fuel classes, along 4-6 m, 4-6 m, and 4-10 m of the 30 m fuel transect respectively. On 20 one-year post-fire plots tallied in 2008, all three fuel size classes were tallied along the 7-9 m section of two 15-m fuel transects. These tallies were converted to biomass (Mg ha^{-1}) using Brown's (1974) allometric equations, and we additionally grouped fuels together into fine woody debris (FWD <7.62 cm). Litter and duff depths were measured 5-10 times and averaged for each site, litter and duff depths were also combined for a forest floor depth metric.

Slightly different methods also were employed between various studies for 1000-hr fuels or coarse woody debris (CWD, >7.62cm). Briefly, on 161 plots, 1000-hr fuels were tallied and diameters taken following methods outlined by Brown (1974) along either two 15-m transects (Hudak *et al.* 2011) or one 30-m transect (Stevens-Rumann and Morgan 2016). On 32 circular plots (including the 8 unburned plots) 100 m^2 in size, photoload methods (Keane and Dickinson 2007) were employed to measure 1000-hr fuels 9 years post fire.

Pre-fire density, reconstructed from standing and down trees post-fire, was tested across years since fire to understand if sites varied significantly prior to each wildfire. We ran regressions of all fuel variables with elevation, slope, and aspect to observe any relationships between snag fall rates and surface fuel accumulation and these topographic variables. To answer question one, we performed a two-way analysis of variance (ANOVA) with time since fire, severity, and the interaction of these two variables as predictor variables and fuel variables as the response variables (1-hr, 10-hr, 100-hr, FWD, CWD, litter, duff, forest floor depth, large snag density [dead trees >30 cm], standing live and dead tree basal area, and tree density including snags). Total sample size across all once burned sites was N=171, however the number of sampled sites at each year-since-fire ranged from n=19 to n=46 (Figure 3). We had additional data from 6 years post-fire (Figures 3); the trends were consistent but we did not present related analysis since fire was sampled in only high severity burned sites and no low severity sites, thus could not be included in the two-way ANOVA. To answer question two, regarding the impact of repeated fires on fuel dynamics, only sites burned in the same year as the later fire (for those sites burned twice) were used. In this case, N=94 with n=46 for once burned sites and n=48 for twice burned sites. We performed a Tukey's HSD test when significance was observed to allow for pairwise comparisons.
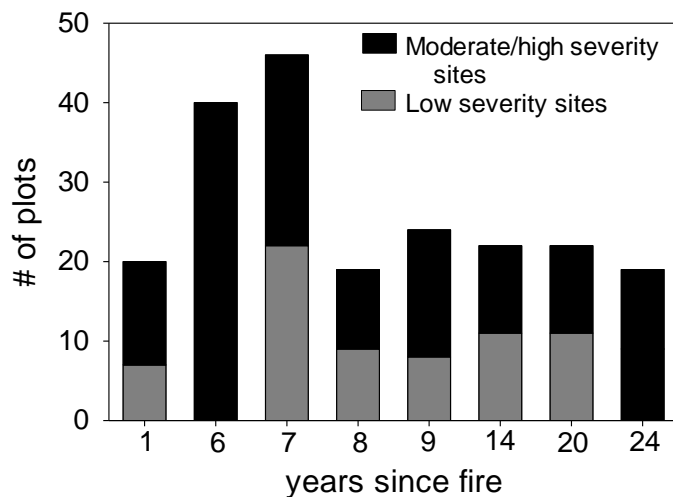
Figure 3. *Number of field plots sampled within each year-since-fire. Gray indicate "low severity" sites (tree mortality <80%) and black indicates "moderate/high" severity sites (tree mortality >90%)*

3.4 Managers and Scientists Collaborative Decision Processes Theory and Methods

Boundary Work and Risk Perceptions

The process by which research communities establish relationships with the worlds of land management and policy is commonly referred to as boundary work (Clark et al., 2010; Gieryn, 1983). Boundaries are symbolic distinctions that categorize objects, people, practices, and even time and space (Lamont & Molnár, 2002). Boundaries have been addressed in two ways: though the concept of boundary objects and as boundary organizations.

Boundary organization theory offers one approach to understanding and enhancing interactions between specific groups or organizations that lie on the boundary between worlds. Boundary organizations -- institutions or settings that facilitate knowledge and information exchange among scientists, decision-makers, and land managers -- can facilitate a multi-directional flow of information between science and management at multiple scales (Cash & Moser, 2000). The primary assumptions of boundary organizations set forth by Guston (2001) are: 1) they exist at the frontier of the science and management communities but are accountable to both; 2) they involve participation by land managers/policymakers and researchers, as well as professionals who mediate between them; and 3) they provide opportunities for the co-production of boundary objects, which are "objects that live in multiple social worlds and which has different identities in each" (Star & Griesemer, 1989, p. 409). In the context of climate change and tree regeneration science, research specific to boundary organizations and objects is relatively new.

Guston (2001) and Miller (2001) identified the importance of creating incentives for the production of boundary objects, involving key participant institutions (scientific and management communities), and maintaining lines of accountability to both scientists and managers. In a separate line of work (but related to boundary organization theory), boundary object theory originated with Star and Griesemer's (1989) study of a

museum classification system as a boundary object. Research on boundary objects describes them as hybrid, flexible, and portable tools that help people from multiple sectors negotiate knowledge transfer between the science, management, and policy realms (Cutts, White, & Kinzig, 2011; White et al., 2010). Boundary objects link different sets of diverse interests, and they can be physical or virtual entities that promote cohesive working relationships. Therefore, boundary objects can be constructed differently depending on the work or informational needs of different social groups or worlds that are creating, using, and modifying them.

Boundary objects include decision support systems, scenarios, and GIS technology (e.g., Blades et al., 2015, Girod, Wiek, Mieg, & Hulme, 2009; White et al., 2010). Transforming abstract numeric and verbal data into imagery can greatly reduce the risk of confusion while honoring the inherent human preference for visual information (Al-Kodmany, 2002). We defined our boundary organization as the workshop as a whole, and the boundary objects as the science visualizations and planting decision tree.

Despite the interest in and promise of boundary organizations and objects, the different types, natures, and effects of boundary objects in natural resource management are poorly understood (White, 2011). Their flexibility and lack of common classification have prompted efforts to create standardized sets of constructs to define and measure boundary objects (Cutts et al., 2011; White et al., 2010). Cash et al. (2003) identified two elements integral to linking knowledge and action for environmental decision-making: credibility and usefulness. ***Credibility*** involves the scientific adequacy of the technical evidence and arguments. This has been qualitatively assessed in terms of perceived scientific accuracy, validity, technical evidence, data quality, calculations, and visual display (White et al., 2010). ***Usefulness*** is the perception of whether the boundary object is able to meet the needs of decision-makers. In our study, these constructs were evaluated in terms of both the workshop effectiveness (boundary organization) and the planting decision tree (boundary object). The protection motivation theory (PMT; Rogers & Prentice-Dunn, 1997) suggests that an individual's decision to act in response to a threat (e.g., climate change effects on wildland fire and tree regeneration) results from considering the likelihood and severity of the risk (i.e., perceived vulnerability, PV, and perceived severity, PS). In this study, we hypothesized that participant perceptions of the usefulness of the workshops and coproduced decision tree will be a function of perceptions of the vulnerability and severity of threats related to climate change, wildland fire, and tree regeneration.

Workshops as Boundary Organizations

The overall workshop represented a boundary organization existing at the frontier between the science and management communities and involved participation by actors from both communities (Guston, 2001). Our workshops met the assumptions of boundary organizations because: 1) the workshops were conducted with USFS personnel (including decision-makers) and university researchers; and 2) the tools used in the workshops were developed and used by professionals from both the scientific and land management worlds. The visualization and modeling tools used during the workshops represented boundary objects and were designed to facilitate the exchange of climate change research (Figure 4).

Although there has been limited documentation of specific variables, structures, and processes of boundary organizations (Parker & Crona, 2012), the management culture (inter-personal relationships between participants and boundary organizations) has been identified as a key consideration (Crona & Parker, 2011). This was an important concern for our workshops, where the university research team made many efforts to establish and nurture relationships with potential participants. Careful planning helped to ensure that the design, organization, and convening of the workshops served both our purpose and the needs of our participants (Heierbacher, 2010; McCoy & Scully, 2002).
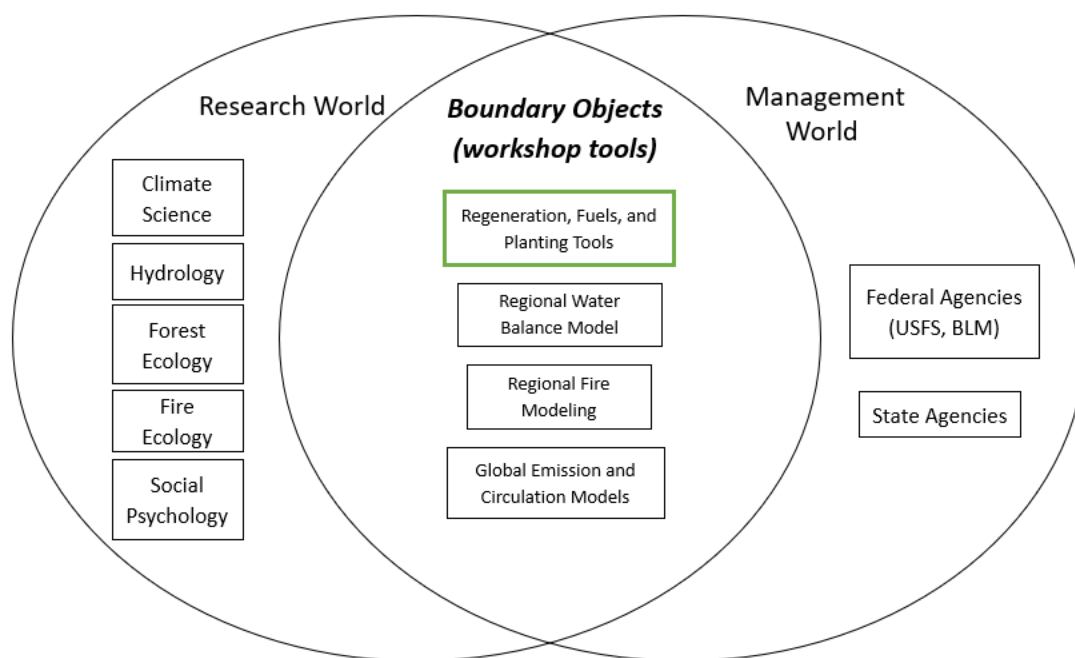

Figure 4. Conceptual diagram of the workshops as a boundary organization linking research and management worlds. The boxes on the left, academic world, are the disciplines represented by our interdisciplinary research team. The boxes on the right in the management world represent the forest managers present at the workshop. The boxes in the center represent the tools that were evaluated as boundary objects. We specifically evaluated "Regeneration, Fuels and Planting Tools"[box outlined in green] in this study).

We employed a sequential mixed methods design (Leech & Onwuegbuzie, 2009) to collect quantitative and qualitative data in the evaluation of the workshops and tools. Qualitative focus groups provided depth and richness to our understanding of the post-fire restoration efforts and the utility of tree regeneration and fuels science in post-wildfire restoration activities. The quantitative surveys and activities associated with the workshops helped us to establish the magnitude of relationships among constructs, further refine our post-fire planting decision tree (boundary object) and evaluate the performance of our workshops as a boundary organization.

We purposefully selected land management individuals whom satisfied criteria to maximize our

understanding of the effectiveness of our workshops (Creswell, 2009; Onwuegbuzie & Collins, 2007; Teddlie & Yu, 2007). Using a snowball sampling approach, we asked focus group and workshop participants to recommend other participants (Creswell, 2009). The sample frame involved selecting U.S. National Forests that were located within the northern Rocky Mountains (Idaho and Montana) and contained a variety of wildland fire effects with previous research studies within them.

For each workshop location, participants were selected from these strata: forest managers and planners (e.g., fire management officers, district rangers, interdisciplinary team leaders, National Environmental Policy Act specialists), forest ecologists (e.g., silviculturists, foresters, fire ecologists), and other natural resource specialists (e.g., hydrologists, fisheries biologists, wildlife biologists). These strata represent the main topics to be presented during the workshops. A target of 25 participants at each location (100 total) was chosen.

The workshop questionnaire sections related to: participant understanding of tree regeneration science, usefulness and credibility of workshop science that were adapted from previous boundary object work (Blades et al., 2016, Cutts et al., 2011; Jacobs, Garfin, & Buizer, 2009; White et al., 2010), and risk perceptions of climate change effects in forests. An additional section asked participants to evaluate the credibility and usefulness of the workshop and coproduced tools (Blades et al., 2015). Most measures used a 7-point or 5-point Likert-type scale. Pilot testing of the items in the questionnaire were conducted for a previous study that involved three undergraduate classes at the University of Idaho in the fall of 2011, ensuring that questions were understandable, and that the response burden was not too great. The survey tool is included in Appendix D.

The quantitative analysis of the survey responses included descriptive statistics, item-reduction using exploratory factor analysis, comparison of means using T-tests and analysis of variance. Multi-item measures were investigated for multiple dimensions and reduced to scales using factor analysis and a Cronbach's alpha reliability coefficient with a cutoff level of 0.70 or greater (Field, 2005; Vogt, 2005). Maximum likelihood estimation with an oblique direct oblimin rotation was used to rotate the factors while allowing them to correlate, which is common in naturalistic and human research to determine whether a single or multiple dimension of a construct exist (Field, 2005; Raykov & Marcoulides, 2011). The pattern matrix from the rotation with pairwise deletions is reported with a description of the resulting factor(s).

4. Results and Discussion

The following sections summarize results and key findings. Findings are organized by publication. This research was completed within budget and on time (with a one-year no cost extension), there is currently two peer reviewed publications, a synthesis for the Northern Rockies Fire Science Network in press, one publication in review, and another in prep.

4.1 Tree Regeneration Meta-analysis

Stevens-Rumann, CS, Kemp, K, Higuera, P, Harvey, B, Rother, M, Donato, D, Morgan, P, Veblen T. (2018) Evidence for declining forest resilience to wildfires under climate change. Ecology Letters.

Results highlight significant decreases in tree regeneration in the 21st century. Annual moisture deficits were significantly greater from 2000 to 2015 as compared to 1985–1999, suggesting increasingly unfavorable post-fire growing conditions, corresponding to significantly lower seedling densities and increased regeneration failure. Dry forests that already occur at the edge of their climatic tolerance are most prone to conversion to non-forests after wildfires. Major climate-induced reduction in forest density and extent has important consequences for a myriad of ecosystem services now and in the future.

Climate change is already affecting multiple ecosystem properties, leading to shifts in species composition and state changes (Walther et al. 2002; Donato et al. 2016). In the US Rocky Mountains, we documented a significant trend of reduced post-fire tree regeneration, even over the relatively short period of 23 years covered in this analysis. Our findings are consistent with the expectation of reduced resilience of forest ecosystems to the combined impacts of climate warming and wildfire activity. Our results suggest that predicted shifts from forest to non-forested vegetation (e.g. Bell et al. 2014) may be underway, expedited by fire disturbances (Kemp 2015; Donato et al. 2016; Harvey et al. 2016; Johnstone et al. 2016; Rother & Veblen 2016).

Regeneration failures, as measured by both seedling presence/absence and regeneration thresholds, occurred across all forest types (Figures 5 and 6). Low-elevation forests, dominated by tree species near the warm, dry edge of their climatic tolerance may be particularly vulnerable to shifts to non-forest vegetation, because of the absence of any tree species that could reestablish under warmer, drier conditions (Harvey et al. 2016). Meanwhile, moist forest types may experience a shift in species dominance and a decrease in tree density. And while only 15% of the moist forest sites we studied lacked seedling after 21st-century fires, 35% of these sites did not meet the recruitment threshold. This represents a substantial increase (300%) relative to the 1985–1999 period, highlighting the impacts of warming in moist forests as well. Thus, unlike the potential transition from forest to non-forested cover types in low elevation, dry forests, moist forests may be more likely to experience a shift in forest structure or changes in species composition. Our study demonstrates that short postfire periods of wetter climate that have favored tree regeneration in the past may not occur frequently enough to facilitate tree regeneration in the future, across a broad region and multiple forest types in the Rocky Mountains.
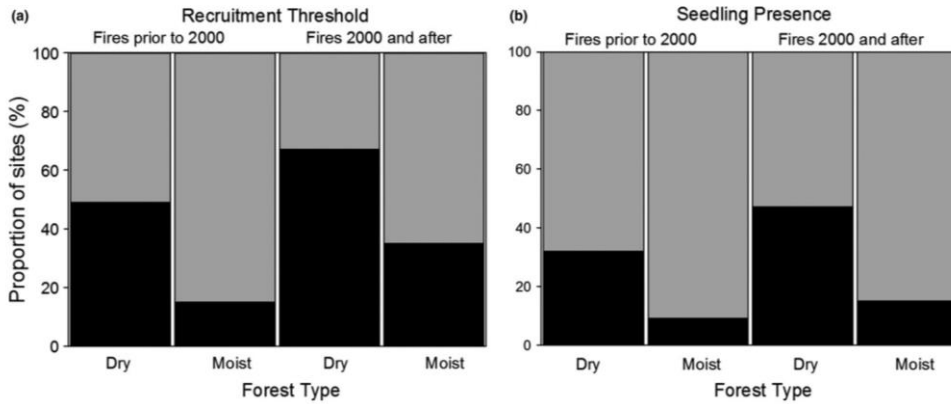
Figure 5: Displayed are the proportion of sites within each forest type [dry conifer (dry) and moist conifer (moist)] that (a) met recruitment thresholds for replacement (1; light grey) or not (0; black) and (b) had at least one conifer seedling present on a site. In both (a) and (b) we contrasted fires that occurred in the 20th century (left) and in the 21st century (right). Proportional differences between time periods (before 2000 or since 2000) were compared using a Pearson's Chi-squared test across all forest types in (a) and (b) and within dry forest and moist forests. All differences between time periods were significant ($\chi2 > 7.4$, $P < 0.001$).
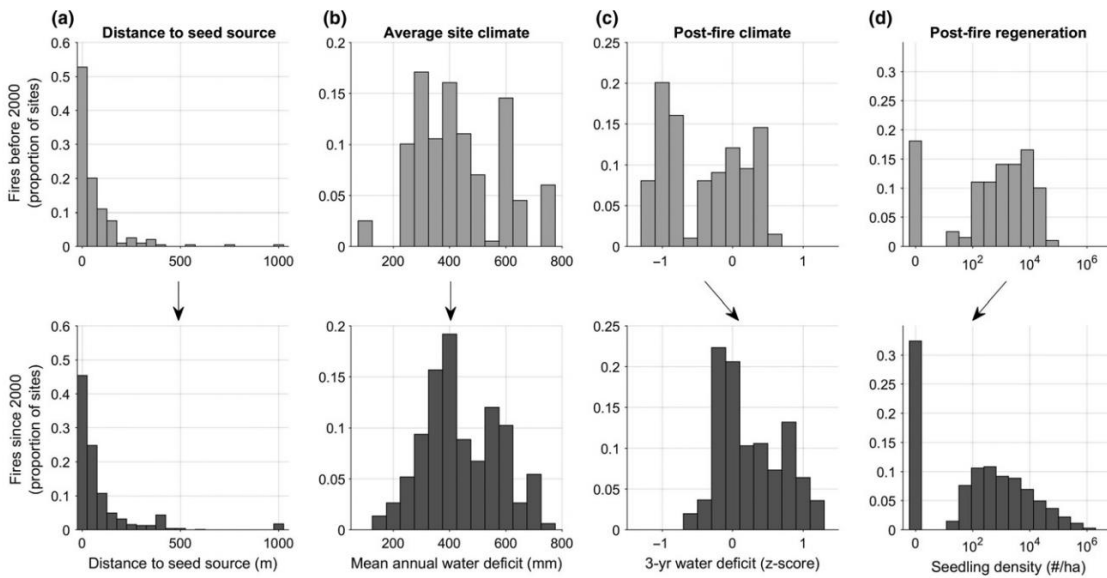
Figure 6: Displayed are site characteristics and tree seedling density from sites that burned before 2000 (light grey, top) and since 2000 (dark grey, bottom): (a) distance to seed source, (b) site climate using 30-year mean annual water deficit, (c) post-fire climate conditions using Z – scores of 3-year water deficit, and (d) post-fire regeneration as a function of seedling density. Vertical arrows indicate no general trends between time periods (before 2000 and since 2000) and diagonal arrows indicate significant directional shifts between time periods.

4.2 Fuels Meta-analysis

Stevens-Rumann CS, Hudak A, Morgan P, Arnold, A, Strand E. (in review). Fuel longevity following wildfire in the US Northern Rockies forests. Frontiers in Forests and Global Change.

Large diameter woody fuels biomass peaked around 14 years post-fire while smaller woody fuel biomass peaked at 20 years post-fire (Figure 7). Surface fuel loads exceeded desired level in high burn severity sites but were within many desired ranges (from an ecological and fire fighting perspectives) at low to moderate burn severity sites. Snag density across all diameter classes generally declined after 7-9 years, but large-diameter snags were still present 24 years post-fire. Fuel loads on repeated fires had a >40% fuel reduction in surface fuels and basal area reduction of 27% compared to US northern Rockies forests burned once at the same years-since-fire (Figure 8). Burned landscapes can serve a great ecological benefit by providing an infusion of both standing and downed dead woody material. Thus, though some high severity sites exceed recommended surface fuel loadings, these ecological considerations should be weighed against concerns about reburning potential and fire fighter hazards.
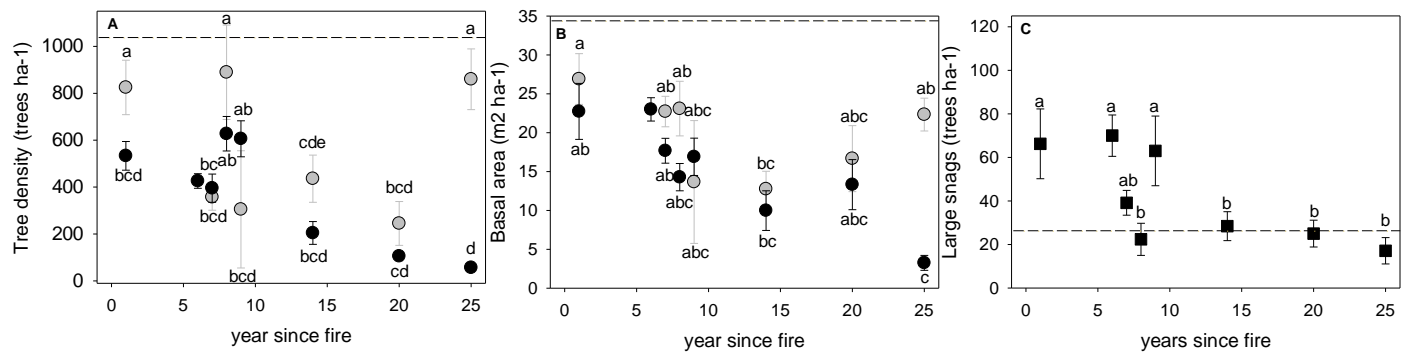
Figure 7: Effect of years since fire, burn severity, and the interaction on (A) total tree density (live and dead) and (B) total basal area (live and dead). (C) The effect of years since fire on density of large snags (>30 cm DBH). Black circles indicate lower burn severity means, gray circles indicate high burn severity means, and black squares are means across both burn severities. The highest order significant interaction are displayed (α=0.05); in the case of tree density and basal area this was the interaction between years since fire and burn severity but large snag density was only significantly influenced by years since fire. Letters indicate significant differences from Tukeys HSD pairwise comparisons on the highest order effect. Dashed line indicates means for unburned sites.
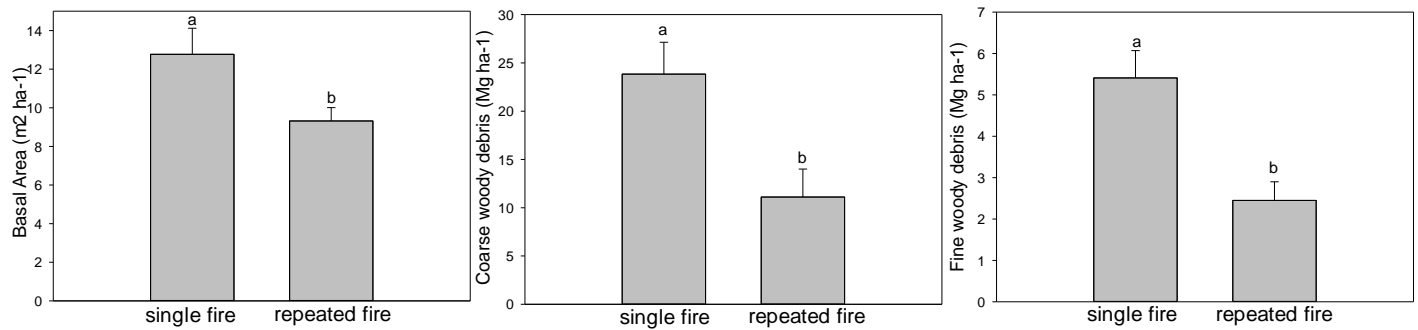
Figure 8: Effect of a single wildfire compared to repeated wildfires measured seven years following the final fire on tree basal area (includes both live and dead trees), coarse woody debris, and fine woody debris. Letters indicate significant differences at the α = 0.05 level.

4.3 Managers and Scientists Collaborative decision processes results

Blades J, Stevens-Rumann CS, Morgan P (in prep) Forest managers and fire researchers coproduce a post-fire planting decision tree.

Characteristics of the Sample

A total of four focus groups were conducted with a total 24 participants from the pacific northwest National Forests (Boise: 6, Payette: 4, Lolo and Flathead: 6, and Bridger-Teton 8). For the workshops, we had 67 total participants, but for this study we used data provided in 42 completed questionnaires following the workshops (Boise: 6, Payette: 13, Lolo and Flathead: 23). The Bridger-Teton workshop was unfortunately cancelled due to agency scheduling conflicts. Analysis revealed few differences related to participants' specific discipline and workshop location; therefore, the findings presented here combine all workshops locations and disciplines into one sample. Quantitative findings are presented in conjunction with selected focus group and workshop excerpts to provide richness and context.

Understanding of Tree Regeneration and Climate Science

We evaluated whether the workshop influenced participants understanding of how tree regeneration is influenced by post-wildfire climate, tree regeneration failure mechanisms, forest vulnerability, and how fuels change over time post-fire. Participants generally agreed to strongly agreed that the workshops helped them gain a better understanding of these topics (Table 1). A slightly higher amount of understanding was gained by

participants on the topics of tree regeneration failure mechanisms and how fuels change over time post-fire. The explanatory factor analysis (EFA) conducted for the four knowledge items revealed one distinct dimension present with good reliability ($\alpha = 0.91$) and the items were combined into a single factor.

Table 1 Summary of participants' understanding of tree regeneration and climate science, and summary of exploratory factor analysis (EFA).

The workshop helped me gain a better understanding of…	Mean (1 to 7)	SE	Factor Loadings
...how tree regeneration is influenced by post-wildfire climate.	5.33	0.36	0.96
…the mechanisms that are responsible for tree-regeneration failures.	5.43	0.36	0.94
…which forest types are most vulnerable.	5.14	0.36	0.92
…how fuels change over time in post-fire.	5.45	0.36	0.92
Factor mean (scale 1 to 7)			5.34
Standard deviation			1.28
Cronbach's alpha			0.91
Eigenvalue			3.50
% Variance explained			87.3

Credibility of the Workshop Content (Tree Regeneration and Climate Science)

To explore participant perceptions of the credibility of workshop research materials, we asked them to indicate their agreement with statements related to climate change science and scale, and defensibility if a decision is challenged or appealed (Table 2). The was moderate to strong agreement with the credibility of different spatial scales of change science, with a slight preference for the larger scales of regional and global information. This is consistent with research on similar topics using similar methods (Kemp et al., 2015, Blades et al., 2016). Participants also found the science and tools presented during the workshops to be defensible when making land management decisions. The EFA conducted for the credibility items revealed one distinct dimension present with good reliability ($\alpha = 0.88$) and the items were combined into a single factor.

Table 2 Participants' perceptions of the credibility of the tree regeneration and climate science presented, and summary of exploratory factor analysis.

Credibility items	Mean (1 to 7)	SE	Factor Loadings
Global and regional climate change science is credible.	6.00	0.19	0.82
Local (forest stand-level) climate science is credible.	5.83	0.23	0.95

	Mean (scale 1 to 7)	SE	Factor Loadings
I consider science presented in the workshops about climate impacts to be defensible if a decision is challenged or appealed.	5.81	0.207	0.65
Factor mean (scale 1 to 7)			5.89
Standard deviation			1.12
Cronbach's alpha			0.88
Eigenvalue			3.42
% Variance explained			76.5

To explore participant perceptions of the usefulness of workshop research materials and coproduced post-fire decision tree, we asked them to indicate their agreement with statements about the application of workshop materials to participants' work, the appropriateness of post-fire plantings, and intention to use the planting decision tree in the work they do (Table 3). There was moderate to strong agreement with all of the items. The EFA conducted for the usefulness items revealed one distinct dimension present with good reliability ($\alpha = 0.93$) and the items were combined into a single factor.

Table 3 Participants perceptions of the usefulness of the tree regeneration and climate science presented, the post-fire decision tree, and summary of exploratory factor analysis.

Usefulness items	Mean (1 to 7)	SE	Factor Loadings
The research findings presented are useful in my work.	5.69	0.20	0.91
Post-fire plantings are appropriate.	5.95	0.21	0.81
The decision support tools we developed are useful for my work.	5.43	0.16	0.87
I plan to use the decision support tools we developed in future work that I do.	5.81	0.15	0.96
Factor mean (scale 1 to 7)			5.64
Standard deviation			1.08
Cronbach's alpha			0.93
Eigenvalue			4.57
% Variance explained			89.1

Risk Perceptions of Climate Change Effects in Forests

We evaluated participant subjective risk perceptions (perceptions of vulnerability and severity) through

a multi-item measure focused on: changes in where plant species occur on the landscape; distances to surviving trees post-fire; amount of wildfire each year; amount of area burned by wildfire; severity of fires; and vulnerability to disease and insect outbreaks (Table 4). Perceptions of vulnerability were very high (m= 4.58), with slightly less support for perceptions of the severity of impacts (m= 3.7). The EFA conducted for the perceived vulnerability (α = 0.94) and perceived severity (α = 0.76) items revealed one distinct dimension for each with good reliability, and the items were combined into two distinct factors.

Table 4 Summary of participant perceptions of risk associated with the likelihood/vulnerability and severity of climate change impacts in the next 20 years, and summary of exploratory factor analysis.

Risk perception items	Perceived vulnerability			Perceived severity		
	Mean (1 to 5)	SE	Factor Loadings	Mean (1 to 5)	SE	Factor Loadings
Changes in where plant species occur on the landscape	4.62	0.11	0.73	3.24	0.14	0.71
Longer distances to surviving trees post-fire	4.52	0.12	0.73	3.4	0.15	0.92
More wildfire each year	4.45	0.13	0.74	3.79	0.16	0.74
Increase in the amount of area burned by wildfire	4.69	0.11	0.92	4	0.15	0.91
More severe fires	4.60	0.12	0.70	3.9	0.16	0.89
More vulnerability to disease and insect outbreaks	4.62	0.12	0.76	3.88	0.16	0.40
Factor mean (scale 1 to 5)			4.58	Factor mean		3.70
Standard deviation			0.10	Standard deviation		0.10
Cronbach's alpha			0.94	Cronbach's alpha		0.76
Eigenvalue			4.58	Eigenvalue		2.80
% Variance explained			76.2	% Variance explained		66.15

Model Testing

We used ordinary least squares linear regressions to explore relationships between the independent variables (improved understanding, perceived credibility, and risk perceptions) and the dependent variable of salience/usefulness of the workshop materials and planting decision tree. Improved understanding, credibility,

and perceptions of effects severity were significant predictors of perceived usefulness Table 5, explaining over half of the variance.

Table 5 Linear regression results for usefulness of science presented at the workshops.

	β	t	Adj. R^2	F
Model of Usefulness			0.56	18.06**
F_Knowledge	0.48	5.15		
F_CRED	0.38	2.91		
F_PS	-0.40	-2.29		

* Significant at the *p*< .01 level. α= .05

Evaluation of the Workshops and Tools

Participants were asked to rate their level of agreement with 19 statements related to the usefulness, credibility, and legitimacy of the workshop as a whole (i.e., *boundary organization* – these are different than the measures of usefulness and credibility described above for boundary objects) (**Table 6**). Participants agreed that the workshops were salient/useful overall. While high scores for the first two items were expected, given our use of models and information dissemination, it was encouraging that participants largely agreed that the workshop made science more useful for management and decision-making purposes.

The workshops enhanced the credibility of climate change and tree regeneration science by translating complex science and meeting management needs with data from multiple sources, and many participants commented they learned during the workshop. Many participants commented that providing the space and time to process the information in small group activities was a valuable part of the workshop experience. Participants disagreed with the statement that the presentations at the workshops were too detailed, but it was often expressed that participants desired more time to reflect on the current science presented and the tools being developed.

Table 6 Evaluation of the workshops as a boundary organization

Workshop evaluation items (agree/disagree)	Mean	SE
Scientific information and results were translated for practical use.	6.02	0.11
Information needs were connected with sources of information.	5.57	0.16
The workshop created a forum for individuals who otherwise would not have occasion to work together on these topics.	5.19	0.22
The workshop encouraged the use of models and tools for	5.79	0.15

linking science and decision making.		
Active listening took place during the Q&A and small group sessions.	6.05	0.14
The small group discussions helped me understanding the presented information.	5.76	0.19
Diverse disciplines and interests were not represented at the workshop.	3.45	0.22
The workshop promoted information exchange between scientists, agency and interested stakeholders.	5.56	0.13
The workshop added value by combining data and information from multiple sources.	5.50	0.21
The workshops helped identify the underlying assumptions of the information presented.	5.59	0.14
The workshop helped to understand how research could be used in decisions being made.	5.85	0.19
The workshop was accountable to both resource specialists and decision-maker needs and interests.	5.59	0.18
There was a clear dissemination strategy for workshop information and outcomes.	5.79	0.13
I am confident that information and outcomes from the workshop will be shared with the participants.	6.21	0.13
The presentations were too detailed – too much information was presented	2.71	0.19

Coproduction of a Post-Fire Planting Decision Tree

During the four initial focus groups, participants were presented with some of the preliminary workshop materials and asked a semi-structured series of questions related to creation of a post-fire decision tree. These conversations focused on the typical characteristics and conditions of post-fire restoration participants confront in their National Forests, seeding successes and failures, drivers of restoration efforts, climate considerations, local caveats and thresholds of local factors influencing restoration, and recommendations for the upcoming workshop series. From these conversations, the research team received local and regional perspectives on climate, distance to living trees, aspect, habitat/forest type, and soils or other microsite variables. From these perspectives we constructed a draft planting decision tree that included their information in conjunction with results of regional research, and that decision tree was further revised based on workshop participation. The

post-fire planting decision trees illustrated in Figure 9 (focus group input) and Figure 10 (workshops input), developed by researchers and managers working together (boundary object creation), suggests that on the warmest and driest sites, post-fire tree regeneration is unlikely whether trees are planted or not, and where climate is very favorable planting may not be needed either. On intermediate sites, managers could strategically target sites beyond the reach of seed sources, and also beyond the edge where reburns are more likely to occur (Stevens-Rumann and Morgan 2019). One major change in the decision tree was the modification of the first step to include forest type (habitat type to USFS), which was strongly recommended by many participants because habitat type often represents the first consideration in Forest Service post-fire planning.
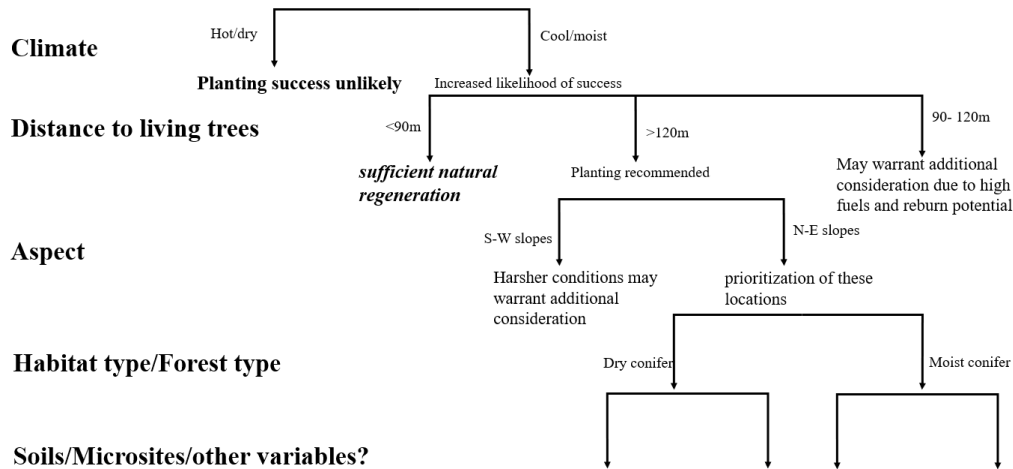
Figure 9: First attempt at a post-fire planting decision tree that was informed by focus groups (prior to workshops)
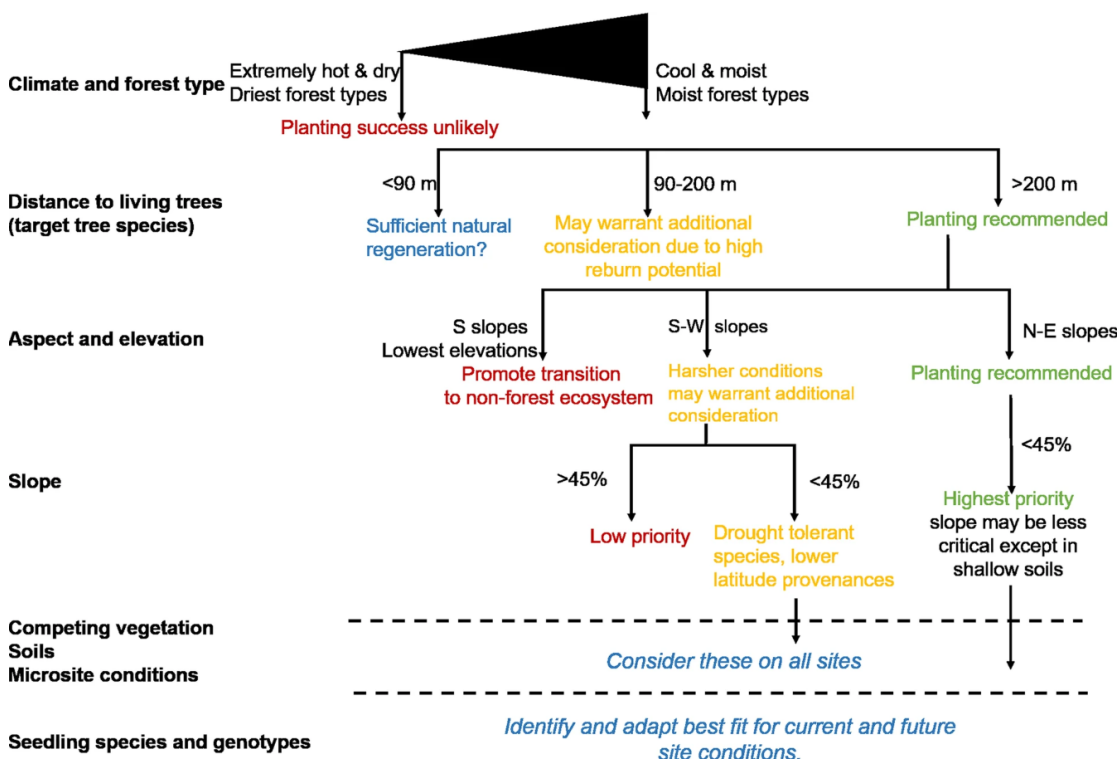
Figure 10: Final post-fire decision tree developed with land managers during workshops, informed by the pre-workshop focus groups. Published in Stevens-Rumann and Morgan 2019.

We evaluated the effectiveness of boundary objects (i.e., workshop components and decision tree) and a boundary organization (i.e., the overall workshops) for influencing workshop participants' attitudes towards the usefulness of climate change and post-fire tree regeneration science. We gained a greater understanding of boundary work variables, risk perceptions, and intention to use climate change science for management decisions at various spatial and temporal scales, using multiple methods of inquiry.

Our intent when designing this study was to address disconnects between the supply of academic research related to climate change and post-fire tree regeneration and the needs of forest managers for regional- and local-scale information pertinent for decisions. Our findings suggest that the workshops, which were less than a day in length, were effective for the rapid delivery of science in a setting that capitalized on the use of visualization and interactive participation. Perceptions of the usefulness and credibility of the workshop materials and decision tree was high. The need for ongoing research-management partnerships that synthesize and translate current science, such as the workshops and decision tool we designed, is imperative in the face of increasing agency workloads that constrain agency specialists from adequately addressing climate change in post-fire planting and management decisions.

4.4 Regeneration Patterns Across the Western US
Stevens-Rumann CS, Morgan P (2019). Understanding natural regeneration and adaptive management strategies for planted tree seedlings with climate change. Fire Ecology. 15:15

Our literature review included 49 published studies on tree regeneration post-fire (Figure 11). Overall, little to no post-fire tree regeneration was more common in low elevation, dry forest types than in high-elevation forest types. However, depending on the region and species, low tree regeneration was also observed in high elevation, moist forests. Regeneration densities varied by species and seedling densities, and were influenced by distances to a seed source, water stress or precipitation, elevation, slope, aspect, and plant competition. Our findings provide land managers with two primary considerations to offset low tree regeneration densities. First, we supply a decision support tool of where to plant tree seedling in large high severity burned patches. Second, we recommend possibilities for mitigating and limiting large high severity burned patches to increase survival of trees to be sources of seed for natural regeneration. Few or no tree seedlings are establishing on some areas of the 150+ forest fires sampled across western US, suggesting that forests may be replaced by shrublands and grasslands, especially where few seed source trees survived the wildfires. Key information gaps on how species will respond to continued climate change, repeated disturbances, and other site factors following wildfires currently limit our ability to determine future trends in forest regeneration. We provide a decision tree to assist managers in prioritizing post-fire reforestation. We emphasize prioritizing the interior of large burned patches and considering current and future climate in deciding what, when, and where to plant trees. Finally, managing fires and forests for more seed-source tree

survival will reduce large, non-forested areas following wildfires where post-fire management may be necessary.
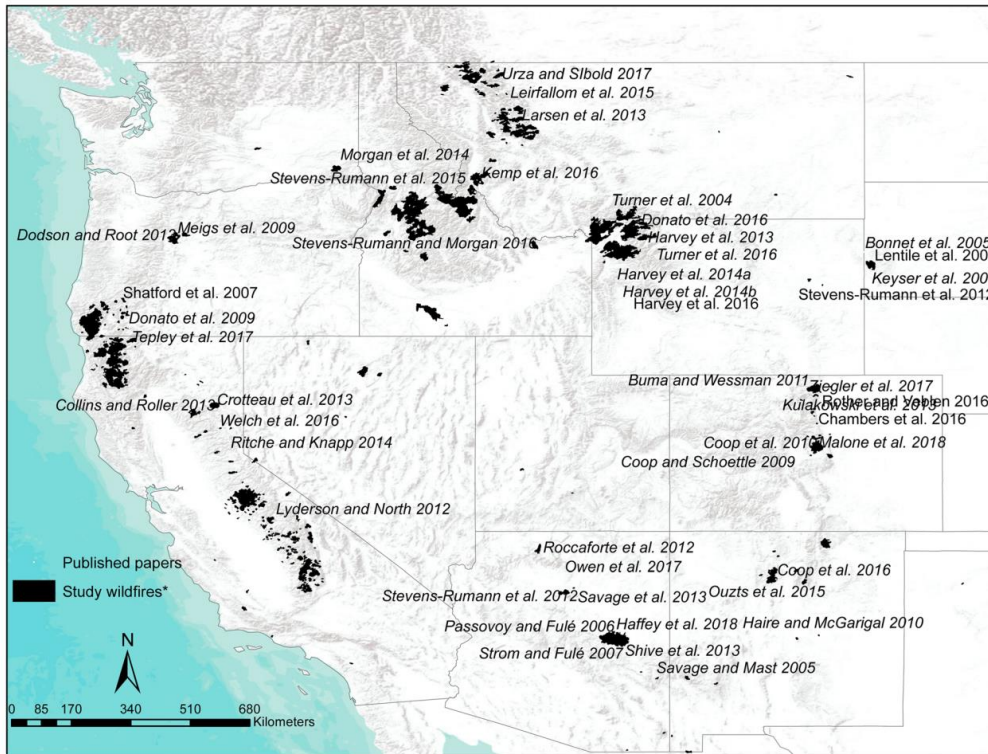

Figure 11: Fires presented in all selected US studies that were reviewed as a part of this study. In many cases, a single study spanned a fairly large geographic range, thus the location of the author's name and year are centrally located among multiple fires. Some wildfires were approximated either because a map of wildfires samples was not provided in the original publication or the names of the wildfires were missing.

5. Management Implications

1. As scientists and managers plan for increasing fire activity and more post-fire burned landscapes, our results suggest a high likelihood that future wildfires will facilitate shifts to lower density forest or non-forested states under a warming climate.

2. Promoting the use of wildfires and prescribed fires to enhance the heterogeneity of forests and thus reducing the likelihood of large high severity patches will be increasingly important as fire activity continues to increase.

3. Climate and distance to seed source should be considered when making post-fire tree planting decisions to optimize the likelihood of success. Improved planting guidelines that consider current and future climate is critical for successful tree reestablishment.

4. Wildfires create high surface fuels loads, especially 9+ years after fire, but repeated burning reduced the quantity of these hazardous fuels. Managers should carefully monitor burned landscapes and reduce risk during these peak tree fall periods 9-14 years post fire. Subsequent burning may reduce fuel loads, but vegetation considerations should be considered to mitigate the effects of repeated high intensity disturbances.

5. The ecological value of both the standing and downed dead material is critical to forested ecosystems for numerous ecosystem functions and should be considered prior to any post-fire fuels reduction action.

6. Our findings suggest that the workshops were effective for the rapid delivery of science in a setting that capitalized on the use of visualization and interactive participation. Perceptions of the usefulness and credibility of the workshop materials and decision tree was high. The need for ongoing research-management partnerships that synthesize and translate current science, such as the workshops and decision tool we designed, is imperative in the face of increasing agency workloads that constrain agency specialists from adequately addressing climate change in post-fire planting and management decisions.

6. Further Research

Based upon our findings, we suggest that further research could enhance science and management:

1. Understanding species-specific tree regeneration requirements and natural regeneration patterns will be important for furthering our effectiveness in identifying areas that are likely to experience ecosystem transitions to non-forested landscapes. This will also allow managers to refine tree planting guidelines for post-fire planting.

2. As area burned continues to increase in the coming decades, it is important to consider when and where previously burned stands will aid in suppression efforts, and when and where resistance to control and potential for burning with either or both high burn severity or fire intensity reburning arises due to high surface fuel accumulation.

3. Further research around manager-science communication should focus on a deeper exploration of the deliberative conversations from the focus groups and workshops, potentially giving a richer context to our findings related to risk perceptions, boundary work, and use of current science in decisions. Further quantitative work could look closer at the mediating relationships between the constructs of this study, notably intention and actual use of the information from the workshops. We hope that a follow-up post-test later in time will document actual use of the decision tree.

7. Project Deliverables

1. Coordinated with other researchers to complete meta-analyses: Multiple meetings regarding the data management and manuscript. These meetings included 12 among Phil Higuera, Thomas Veblen, Brian Harvey, Daniel Donato, Monica Rother, Kerry Kemp, Penny Morgan, and Camille Stevens-Rumann regarding the deliverables in objectives 1 and 2. And an additional 10 meetings with Andrew Hudak, Eva Strand, Camille Stevens-Rumann and Penelope Morgan to complete objective 3. Meetings among Co-PIs were conducted both in person around the focus groups and workshops as well as remotely for planning and deliverable discussions around objective 4.

2. We completed focus group meetings in November 2017 in 4 locations with a total of 35 participants:
    - Boise, ID
    - McCall, ID
    - Missoula, MT
    - Jackson, WY

3. We completed 4 manager workshops by the spring of 2018:
    - February 2018 Missoula, MT- "Climate change, natural regeneration and adapting tree planting guidelines after large wildfires" 100 participants
    - Two in March 2018, one in McCall, ID, and one in Boise, ID - "Climate change, natural regeneration and adapting tree planting guidelines after large wildfires" 20 participants total
    - June 2018 McCall, ID- "Long-term vegetation recovery and reburn potential: central Idaho Fire and Fuels workshop" 20 participants

4. Scientific and technical publications (5, of which 3 are published and being cited and used by scientists and managers)
    - Stevens-Rumann CS, Hudak A, Morgan P, Arnold, A, Strand E. (in review). Fuel longevity following wildfire in the US Northern Rockies forests. Frontiers in Forests and Global Change.
    - Blades J, Stevens-Rumann CS, Morgan P (in prep) Forest managers and fire researchers coproduce a post-fire planting decision tree.
    - Stevens-Rumann CS, Morgan P (2019). Understanding natural regeneration and adaptive management strategies for planted tree seedlings with climate change. Fire Ecology. 15:15
    - Stevens-Rumann, CS, Kemp, K, Higuera, P, Harvey, B, Rother, M, Donato, D, Morgan, P, Veblen T. (2018) Evidence for declining forest resilience to wildfires under climate change. Ecology Letters. DOI: 10.1111/ele.12889
    - Stevens-Rumann, CS, Morgan, P, Davis, K, Kemp, K, Blades, J. (2019) Post-fire tree regeneration (or lack there of) can change ecosystems. Northern Rockies Fire Science Network, Technical Synthesis.

5. Oral Presentations(11 to scientists and managers):

- Stevens-Rumann CS, Morgan P, Blades J. 2018. Are forests regenerating after fire? I Forum on Catalan Wildfire Research. November 2018 Barcelona, Spain.

- Stevens-Rumann, C., Morgan, P., Blades, J. 2018. Wildfires and climate: ecosystem resilience and effective post-fire management. 8th International Conference on Forest Fire Research, November 2018 Coimbra, Portugal.

- Stevens-Rumann CS, Morgan P, Blades J. 2018. Fires as a catalyst for changing forests: tree regeneration success and failure post fire. University of Idaho Seminar. Fall 2018, Moscow, ID.

- Stevens-Rumann CS. Will Western Forests (As We Know Them) Survive Climate Change? 2018. Bard College National Climate Webinar at Bard's Center for Environmental Policy. Spring 2018, Annandale-on-Hudson, NY.

- Stevens-Rumann, C., Morgan, P., Blades, J. 2018. Fire Continuum Conference. May 2018, Missoula, MT.

- Stevens-Rumann CS. Climate and Wildfires: The fate of forests in the Rockies. 2018. Botany Department Seminar Series, University of Wyoming Spring 2018, Laramie, WY.

- Stevens-Rumann CS. Climate and Wildfires: The fate of forests in the Rockies. 2018 Environment & Sustainability Department Seminar Series, Western State Colorado University Spring 2018, Gunnison, CO.

- Stevens-Rumann CS, Kemp K, Higuera P, Harvey B, Rother M, Donato D, Morgan P, Veblen T. 2017. The fate of tree regeneration following wildfires: trends of the past 30 years and future outlooks for the Rocky Mountains. AFE Fire Congress, December 2017, Orlando, FL.

- Stevens-Rumann CS, Kemp K, Higuera P, Harvey B, Rother M, Donato D, Morgan P, Veblen T. 2017. Wildfires and climate facilitate ecosystem transition. Natural Areas Association Conference, October 2017, Fort Collins, CO.

- Stevens-Rumann CS, Morgan P. 2017. Mosaic landscapes: what mixed severity fires, repeated fires and the subsequent landscapes tell us about habitat. The Wildlife Society, September 2017, Albuquerque, NM.

- Stevens-Rumann CS, Kemp K, Higuera P, Harvey B, Rother M, Donato D, Morgan P, Veblen T. 2017. Evidence for declining forest resilience to wildfires under climate change. Ecological Society of America, August 2017, Portland, OR.

1) Extensive popular media coverage of our science increased the impact of our science. Below is the list of radio and written press about the post-fire tree regeneration work published by Stevens-Rumann et al. (2018):

- R*adio*

BBC World Service December 13, 2017

French Canadian Broadcasting Corporation Dec 14, 2017

National Public Radio-Science Friday Dec 15, 2017

Colorado Public Radio-Colorado Matters Dec 18, 2017

National Public Radio-On Point January 1, 2018

Jefferson Public Radio-Jefferson Exchange Jan 15, 2018

BBC World Service-Business Matters Mar 21, 2018

- *Print or online*

Canadian Broadcasting Corporation Dec 12, 2017

Phys.org Dec 12, 2017

NSF Discovery Dec 14, 2017

Science Magazine Dec 19, 2017

Coloradoan Dec 20, 2017

San Francisco Chronicler Jan 1, 2018

Science 360

Summit Daily News Mar 3, 2018

Laramie Boomerang Apr, 2018

Idaho Statesman May 27, 2018

Colorado Springs Gazette June 17, 2018

Sierra Magazine Sept 5, 2018

Colorado Sun July 25, 2019

CBC News July 28, 2019

2) Educational and Professional Development Impact

This project had tremendous impact for professional development of those involved. For example:

- Agency professionals and scientist collaborate effectively and both learned a great deal

- 10 undergraduate technicians were involved in the collection of the data

- 6 young career professionals (all recent PhD's) worked collaboratively on large data sets, had their work widely cited, improved science communication skills to both managers and the public with many popular press articles and radio interviews.

8. Literature cited

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Appendix A: Contact information for key project personnel

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Appendix B: List of Completed/Planned Scientific/Technical Publications/Science Delivery Products

Scientific and Technical Publications

1) Stevens-Rumann CS, Hudak A, Morgan P, Arnold, A, Strand E. (in review). Fuel longevity following wildfire in the US Northern Rockies forests. Frontiers in Forests and Global Change.

2) Blades J, Stevens-Rumann CS, Morgan P (in prep) Forest managers and fire researchers coproduce a post-fire planting decision tree. *Expected submission date January 2020*

3) Stevens-Rumann, CS, Morgan, P, Davis, K, Kemp, K, Blades, J. (2019) Post-fire tree regeneration (or lack there of) can change ecosystems. Northern Rockies Fire Science Network, Technical Synthesis.

4) Stevens-Rumann CS, Morgan P (2019). Understanding natural regeneration and adaptive management strategies for planted tree seedlings with climate change. Fire Ecology. 15:15

5) Stevens-Rumann, CS, Kemp, K, Higuera, P, Harvey, B, Rother, M, Donato, D, Morgan, P, Veblen T. (2018) Evidence for declining forest resilience to wildfires under climate change. Ecology Letters. DOI: 10.1111/ele.12889

Oral Presentations:

1) Stevens-Rumann CS, Morgan P, Blades J. 2018. Are forests regenerating after fire? I Forum on Catalan Wildfire Research. November, 2018 Barcelona, Spain.

2) Stevens-Rumann, C., Morgan, P., Blades, J. 2018. Wildfires and climate: ecosystem resilience and effective post-fire management. 8th International Conference on Forest Fire Research, November, 2018 Coimbra, Portugal.

3) Stevens-Rumann CS, Morgan P, Blades J. 2018. Fires as a catalyst for changing forests: tree regeneration success and failure post fire. University of Idaho Seminar. Fall 2018, Moscow, ID.

4) Stevens-Rumann CS. Will Western Forests (As We Know Them) Survive Climate Change? 2018. Bard College National Climate Webinar at Bard's Center for Environmental Policy. Spring 2018, Annandale-on-Hudson, NY.

5) Stevens-Rumann, C., Morgan, P., Blades, J. 2018. Fire Continuum Conference. May 2018, Missoula, MT.

6) Stevens-Rumann CS. Climate and Wildfires: The fate of forests in the Rockies. 2018. Botany Department Seminar Series, University of Wyoming Spring 2018, Laramie, WY.

7) Stevens-Rumann CS. Climate and Wildfires: The fate of forests in the Rockies. 2018 Environment & Sustainability Department Seminar Series, Western State Colorado University Spring 2018, Gunnison, CO.

8) Stevens-Rumann CS, Kemp K, Higuera P, Harvey B, Rother M, Donato D, Morgan P, Veblen T. 2017. The fate of tree regeneration following wildfires: trends of the past 30 years and future outlooks for the Rocky Mountains. AFE Fire Congress, December 2017, Orlando, FL.

9) Stevens-Rumann CS, Kemp K, Higuera P, Harvey B, Rother M, Donato D, Morgan P, Veblen T. 2017. Wildfires and climate facilitate ecosystem transition. Natural Areas Association Conference, October 2017, Fort Collins, CO.

10) Stevens-Rumann CS, Morgan P. 2017. Mosaic landscapes: what mixed severity fires, repeated fires and the subsequent landscapes tell us about habitat. The Wildlife Society, September 2017, Albuquerque, NM.

11) Stevens-Rumann CS, Kemp K, Higuera P, Harvey B, Rother M, Donato D, Morgan P, Veblen T. 2017. Evidence for declining forest resilience to wildfires under climate change. Ecological Society of America, August 2017, Portland, OR.

Appendix C: Project metadata

We produced two large sets of data for this completed project. The data are listed by our research objective below.

Objectives 1 and 2: Post-fire tree regeneration

Meta data and data we used for all our analyses are available to people both within and outside of federal agencies on https://www.frames.gov/catalog/25470. Many of the data we used have been published by others. Note that for the west-wide review, we used already published data. All data used in this analysis were collected previously as a part of multiple collaborators PhD projects and was funded by National Science Foundation awards 1232997 and 0966472, NSF award DGE-0903479, Joint Fire Science Program projects 06-1-02-03, 12-3-1-13, and 14-1-02-27, National Aeronautics and Space Administration award NNX11A024G, the University of Idaho Stillinger Trust Forest Science Fellowship, a Joint Fire Science Program Graduate Research Innovation Award, and a George Melendez Wright Climate Change Fellowship. As a result, field methods from the individual studies varied slightly. Full details of field data collection methods can be found in the original studies (Harvey et al. 2013; Wells 2013; Stevens-Rumann et al. 2014; Harvey et al. 2014a,b; Harvey et al. 2015; Rother & Veblen 2016; Kemp 2015; Harvey et al. 2016; Kemp et al. 2016; Morgan et al. 2015; Stevens-Rumann & Morgan 2016; Donato et al. 2016).

Objectives 3: Post-fire fuels

All previously published fuels data are available through the original data collection efforts as well through the archiving of data for JFSP projects 14-1-02-30 and 14-1-02-27, and thus are available on the USDA Forest Service Rocky Mountain Research data.

Objective 4: Questionnaires

The questionnaire we used is in Appendix 4. The metadata and data for the results of the questionnaires will be published to FRAMES.gov either when the related manuscript is published or within two years after completion of this research project, whichever comes first.

Opinions about Post-fire Tree Regeneration, Fuels, Forest Management,and the Workshop

University of Idaho
College of Natural Resources

Please be assured that all answers provided are confidential. This research has been reviewed and approved by the University of Idaho Institutional Review Board.

To maintain your confidentiality, but allow us to match your questionnaire with your workshop location, **please name the workshop location you attended**.

Workshop location you attended: _____

Question 1. Please indicate your level of agreement with the following statement: *The workshop helped me gain a better understanding of....*

	Strongly Disagree		Neutral			Strongly Agree
..how tree regeneration is influenced by post-wildfire climate.	-3	-2	-1	0	1	2	3
..the mechanisms that are responsible for tree-regeneration failures.	-3	-2	-1	0	1	2	3
..which forest types are most vulnerable.	-3	-2	-1	0	1	2	3
..how fuels change over time in post-fire.	-3	-2	-1	0	1	2	3

Question 2. For this question we are interested in how credible and useful you think the climate change science presented at the workshop is. Please indicate your level of agreement with the following statements:

	Strongly Disagree		Neutral			Strongly Agree
Global and regional climate change science is credible.	-3	-2	-1	0	1	2	3
Local (forest stand-level) climate science is credible.	-3	-2	-1	0	1	2	3
The research findings presented are useful in my work.	-3	-2	-1	0	1	2	3
Post-fire plantings are appropriate.	-3	-2	-1	0	1	2	3
The decision support tools we developed are useful for my work.	-3	-2	-1	0	1	2	3
I consider science presented in the workshops about climate impacts to be defensible if a decision is challenged or appealed.	-3	-2	-1	0	1	2	3
I plan to use the decision support tools we developed in future work that I do.	-3	-2	-1	0	1	2	3

Section B: Vulnerability and adaption to climate change impacts

Based on the information we presented at the workshop, please share your opinions about the likelihood and severity of climate change impacts, and the effectiveness of potential adaptation actions.

Question 3. For this question, think about the impacts of climate in the Northern Rockies. For each item please indicate both how LIKELY (column A) you think the impact is, **and** how SEVERE (column B) you think the impact will be.

In the next 20 years, climate could
have these impacts in the Northern Rockies........

	A) How LIKELY is this impact?					B) How SEVERE will the impact be?					
	Very Unlikely	Neither		Very Likely	Don't Know	No Impact		Mod		Very Severe	Don't Know
Changes in where plant species occur on the landscape	-2	-1	0	1	2	x	0	1	2	3	4	x
Longer distances to surviving trees post-fire	-2	-1	0	1	2	x	0	1	2	3	4	x
More wildfire each year	-2	-1	0	1	2	x	0	1	2	3	4	x
Increase in the amount of area burned by wildfire	-2	-1	0	1	2	x	0	1	2	3	4	x
More severe fires	-2	-1	0	1	2	x	0	1	2	3	4	x
More vulnerability to disease and insect outbreaks	-2	-1	0	1	2	x	0	1	2	3	4	x
Other:	-2	-1	0	1	2	x	0	1	2	3	4	x
Other:	-2	-1	0	1	2	x	0	1	2	3	4	x

We are interested in your opinions about how the workshop was conducted in terms of the information presented, and workshop coordination, facilitation, and the processes.

Question 4. Please indicate your level of agreement with the following statements:

	Strongly Disagree			Neutral			Strongly Agree
Scientific information and results were translated for practical use.	-3	-2	-1	0	1	2	3
Information needs were connected with sources of information.	-3	-2	-1	0	1	2	3
The workshop created a forum for individuals who otherwise would not have occasion to work together on these topics.	-3	-2	-1	0	1	2	3
The workshop encouraged the use of models and tools for linking science and decision making.	-3	-2	-1	0	1	2	3
Active listening took place during the Q&A and small group sessions.	-3	-2	-1	0	1	2	3
The small group discussions helped me understanding the presented information.	-3	-2	-1	0	1	2	3
Diverse disciplines and interests were <u>not</u> represented at the workshop.	-3	-2	-1	0	1	2	3
The workshop promoted information exchange between scientists, agency and interested stakeholders.	-3	-2	-1	0	1	2	3
The workshop added value by combining data and information from multiple sources.	-3	-2	-1	0	1	2	3
The workshops helped identify the underlying assumptions of the information presented.	-3	-2	-1	0	1	2	3
The workshop helped to understand how research could be used in decisions being made.	-3	-2	-1	0	1	2	3
The workshop was accountable to both resource specialists and decision-maker needs and interests.	-3	-2	-1	0	1	2	3
There was a clear dissemination strategy for workshop information and outcomes.	-3	-2	-1	0	1	2	3
I am confident that information and outcomes from the workshop will be shared with the participants.	-3	-2	-1	0	1	2	3
The presentations were too detailed – too much information was presented	-3	-2	-1	0	1	2	3

Learning Environment

	Strongly Disagree			Neutral			Strongly Agree
It was easy for participants to speak openly.	-3	-2	-1	0	1	2	3
I was comfortable talking about any concerns or disagreements.	-3	-2	-1	0	1	2	3
Different opinions were welcome.	-3	-2	-1	0	1	2	3
There was adequate time to reflect on new information.	-3	-2	-1	0	1	2	3
The workshop helped participants engage in productive debate.	-3	-2	-1	0	1	2	3

To understand more about our workshop participants, we have a few questions about you. All of your answers are confidential.

5. What is your area of expertise (e.g., position title)?

_____

6. What agency or organization do you work for?

_____

7. How many years have you worked in the Northern Rockies?

- ☐ Less than 5 years
- ☐ 5 – 15 years
- ☐ More than 15 years

8. Do you have experience working in the field? (*Check all that apply*)

- ☐ Post-fire rehabilitation
- ☐ Wildland firefighting
- ☐ Other field experience
- ☐ No field experience

9. Are you   ☐ Male   or   ☐ Female?

Please provide any additional comments here. If you need more space attach a separate piece of paper.

Thank you for helping to improve post-fire forest management, communication, and its usefulness in land management. Please feel free to contact Dr. Jarod Blades if you have any concerns or additional comments regarding this survey.

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University *of* **Idaho**
College *of* Natural Resources