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Evaluating Post-Fire Successional Trajectories After a Large High-Severity Wildfire

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Project Title: Evaluating Post-Fire Successional Trajectories After a Large High-Severity Wildfire

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Abstract

This study took advantage of permanent plots in the then-largest severe fire in the Southwest to assess fire effects on (1) successional trajectory, (2) plant community changes, including persistence of post-fire seeding and presence of non-native species, and (3) and fuel dynamics. Each objective resulted in a separate study and publication. Abstracts summarizing each objective studied are presented below.

(1) Simulating post-wildfire forest trajectories under alternative climate and management scenarios.

Post-fire predictions of forest recovery under future climate change and management actions are necessary for forest managers to make decisions about treatments. We applied the Climate-Forest Vegetation Simulator (Climate-FVS), a new version of a widely used forest management model, to compare alternative climate and management scenarios in a severely burned multi-species forest of Arizona, U.S.A. The incorporation of seven combinations of General Circulation Models (GCM) and emissions scenarios altered long-term (100 years) predictions of future forest condition compared to a No Climate Change (NCC) scenario, which forecast a gradual increase to high levels of forest density and carbon storage. In contrast, emissions scenarios that included continued high greenhouse gas releases led to near-complete deforestation by 2111. GCM-emissions scenario combinations that were less severe reduced forest structure and carbon storage relative to NCC. Fuel reduction treatments that had been applied prior to the severe wildfire did have persistent effects, especially under NCC, but were overwhelmed by increasingly severe climate change. We tested six management strategies aimed at sustaining future forests: prescribed burning at 5, 10, or 20-year intervals, thinning 40% or 60% of stand basal area, and no-treatment. Severe climate change led to deforestation under all management regimes, but important differences emerged under the moderate scenarios: treatments that included regular prescribed burning fostered low density, wildfire-resistant forests composed of the naturally dominant species, ponderosa pine. Non-fire treatments under moderate climate change were forecast to become dense and susceptible to severe wildfire, with a shift to dominance by sprouting shrub species. Current U.S. forest management requires modeling of future scenarios but does not mandate consideration of climate change effects. However, this study showed substantial differences in model outputs depending on climate and management actions. Managers should incorporate climate change into the process of analyzing the environmental effects of alternative actions.

(2) Pre-fire fuel reduction treatments influence plant communities and exotic species 9 years after a large wildfire.

Questions: How did post-wildfire understory plant community response, including exotic species response, differ between pre-fire treated areas that were less severely burned, and pre-fire untreated areas that were more severely burned? Were these differences consistent through time?

Location: East-central Arizona, southwestern US.

Methods: We used a multi-year data set from the 2002 Rodeo–Chediski Fire to detect post-fire trends in plant community response in burned ponderosa pine forests. Within the burn perimeter, we examined the effects of pre-fire fuels treatments on post-fire vegetation by comparing paired treated and untreated sites on the Apache-Sitgreaves National Forest. We sampled these paired sites in 2004, 2005 and 2011.

Results: There were significant differences in pre-fire treated and untreated plant communities by species composition and abundance in 2004 and 2005, but these communities were beginning to converge in 2011. Total understory plant cover was significantly higher in untreated areas for all 3 yr. Plant cover generally increased between 2004 and 2005 and markedly decreased in 2011, with the exception of shrub cover, which steadily increased through time. The sharp decrease in forb and graminoid cover in 2011 is likely related to drought conditions since the fire. Annual/biennial forb and graminoid cover decreased relative to perennial cover through time, consistent with the initial floristics hypothesis. Exotic plant response was highly variable and not limited to the immediate post-fire, annual/biennial community. Despite low overall exotic forb and graminoid cover for all years (<2.5%), several exotic species increased in frequency, and the relative proportion of exotic to native cover increased through time.

Conclusions: Pre-treatment fuel reduction treatments helped maintain foundation overstory conifer species and associated native plant communities following this large wildfire. The overall low cover of exotic species on these sites supports other findings that the disturbance associated with high-severity fire does not always result in exotic species invasions. The increase in relative cover and frequency though time indicates that some species are proliferating, and continued monitoring is recommended. Patterns of exotic species invasions after severe burning are not easily predicted, and are likely more dependent on site-specific factors such as propagules, weather patterns and management.

(3) Pre-wildfire fuel reduction treatments result in more resilient forest structure a decade after wildfire.

Increasing size and severity of wildfires has led to an interest in the effectiveness of forest fuels treatments on reducing fire severity and post-wildfire fuels. Our objective was to contrast stand structure and surface fuel loadings on treated and untreated sites within the 2002 Rodeo-Chediski Fire. Data from 140 plots on seven paired treated/untreated sites indicated that pre-wildfire treatments reduced fire severity compared to untreated sites. In 2011, coarse woody debris loading (CWD; woody material >7.62cm in diameter) was 257% higher and fine woody debris (FWD; woody material <7.62cm) was 152% higher on untreated sites than on treated sites. Yet, in spite of higher levels of CWD on untreated sites, loadings did not exceed recommended ranges based on published literature and many treated sites fell below recommendations. By 2011, basal area and stand density on treated sites and stand density on untreated sites met management guidelines for ponderosa pine forests, but untreated sites had basal areas well below recommendations. Snags declined over this period and only three plots had snags that met minimum size and density requirements for wildlife habitat by 2011. The effects of pre-wildfire treatments are long lasting and contribute to changes in both overstory and understory fuel complexes.

Background and Purpose

Managers and forest stakeholders face major challenges in dealing with the increased occurrence and severity of landscape-scale wildfires in forests adapted to surface-fire regimes. Ponderosa pine forests of the Southwest are now characterized by high densities of small trees with closed canopies (Cooper 1960, Covington and Moore 1994). These forests are at great risk of high severity, stand-replacing fires at scales that are out of the range of natural variability (Fulé et al. 2003). Compounding the effect of increased canopy fuel continuity, climate change has been linked with increasing fire severity (Miller et al. 2009), frequency and extent (Westerling et al. 2006, Littell et al. 2009). In response, land managers are applying fuel reduction treatments to restore open stand structures to significantly reduce fire severity (Finney et al. 2005). In addition, post-fire management actions such as seeding in high severity burn areas are regularly used to attempt to mitigate erosion and prevent non-native species invasions, with mixed results (Peppin et al. 2010). High-severity fires in ponderosa pine forests can result in novel species assemblages, altered stand structure and successional pathways (Savage and Mast 2005, Keane et al. 2008). Post-fire management actions such as seeding may further contribute to novel assemblages and pathways. We addressed the goal of Task 1 in the 2011 JFSP research program by taking advantage of permanent plots in the then-largest severe fire in the Southwest to assess fire effects on (1) successional trajectory, (2) plant community changes, including persistence of post-fire seeding and presence of non-native species, and (3) and fuel dynamics.

In 2002, the Rodeo-Chediski fire burned 189,658 ha (468,638 acres) in northeastern Arizona. The largest fire on record to that date in the Southwest, most of it burned with stand-replacing tree mortality. Where fire severity was reduced, it was often in areas that had received pre-fire fuels reduction treatments (Finney et al. 2005). In 2004, we established 140 permanent plots on the Rodeo-Chediski fire in the Apache-Sitgreaves National Forest, contrasting post-fire responses of stands with different pre-fire structure. As expected, virtually all trees were killed in untreated areas while higher survival occurred in treated areas (Figure 1). We used vegetation simulation modeling to compare the two alternative post-fire successional trajectories of treated and untreated stands (Strom and Fulé 2007). The study provided one of the few documented assessments in the West of the role of fuel structures in affecting fire severity as well as providing testable estimates of future stand development (Stephens et al. 2009). **Remeasurement of the permanent plots and re-assessment of successional trajectories was the first objective of this project.**

The Rodeo-Chediski fire was seeded with several herbaceous species, permitting study of the persistence of post-fire rehabilitation seeding and occurrence of non-native species. In partnership with the study by Strom and Fulé (2007), 84 of the permanent plots were measured for plant community characteristics in 2004 and 2005. The data were used in an unpublished graduate thesis (Kuenzi 2006). However, Kuenzi et al. (2008) published a companion study with data from the southern portion of the Rodeo-Chediski fire on White Mountain Apache Tribal lands. The Kuenzi et al. (2008) study showed that non-native plants were a minor component of the post-fire community and that seeded species did not persist on Tribal lands, but different management history and seed mixes characterize the National Forest lands. **The second objective of this project was to combine current remeasurement data with the previous data to assess plant community dynamics, including the fate of seeded species, in order to evaluate the burned area rehabilitation treatment of seeding.**

Finally, the post-wildfire forest also represents a fuel complex. Severely burned sites have high dead fuel loads, much of which has fallen over time to the forest floor. These fuel beds are of great concern to resource management agencies, which often propose post-fire timber salvage in part to reduce dead biomass. Such a proposal was prepared by the Apache-Sitgreaves National Forest after the Rodeo-Chediski fire. In the absence of quantitative data, the Forest estimated post-fire fuel loads, but the project was opposed by several non-governmental organizations and was not carried out. The permanent plot network we established in 2004 permits actual measurement of fuel load and arrangement after fire, an important issue for fire management and to inform activities such as salvage logging. The possibility of future severe wildfires fueled by high debris loads would substantially alter future successional trajectories, making the analysis of fuels an indispensable adjunct to the successional modeling (Objective 1). Following the methods of Passovoy and Fulé (2006), **the third objective of this project was to assess fuel dynamics (changes in snags, logs, and fine woody fuels).**

Study Description and Location

The study took place in the Rodeo-Chediski fire, which burned 189,658 ha (468,638 acres) in northeastern Arizona in 2002. The largest fire on record in the Southwest to that date, most of it burned with stand-replacing tree mortality. In 2004, we established 140 permanent plots on the Rodeo-Chediski fire in the Apache-Sitgreaves National Forest, contrasting post-fire responses of stands with different pre-fire structure. The study area was dominated by ponderosa pine forest before the fire and is located in the Apache-Sitgreaves National Forest in the White Mountains of northeastern Arizona. Seven study sites were selected by USFS personnel immediately after the fire. Each site consists of one stand that was treated pre-fire by mechanical thinning (conducted within 12 years before the fire) paired with an adjacent unthinned stand. The contrasting pre-fire treatments led to different stand structures prior to the Rodeo-Chediski fire, but the paired sites did not differ in other ways (topography, fuelbreaks, etc.).

The original study design was based on seven paired sites, each pair representing a pre-fire thinned treatment and an unthinned treatment, for a total of 14 sites. Approximately 1/3 of the thinned plots had greater than 70% overstory mortality. At each site, two random points were selected to install a systematic grid of five plots each (four plots 200 meters apart in a square design and one plot in the center) for a total of 10 plots at each site. Each plot was permanently marked with a central rebar stake. All 140 plots were sampled for stand structure and fuels measurements in 2004, and the understory vegetation was measured at a subsample of 84 of these plots (6 per site) in 2004 and 2005. All 70 of the unthinned plots had greater than 70% overstory mortality (mostly 100%). In our remeasurement of the permanent plots under this project, four plots were not re-located, and so two untreated sites had five subsample plots and one site had only four, for a total of 80 plots.

Field and laboratory methods were different for each objective studies. Because the methods are lengthy, the reader is referred to the publications uploaded to the JFSP website and cited in the Deliverables Crosswalk Table.

Key findings

The key findings are organized by objective.

(1) Simulating post-wildfire forest trajectories under alternative climate and management scenarios.

The incorporation of climate change scenarios dramatically altered the conditions forecast 100 years in the future, as compared to the previous predictions presented by Strom and Fulé (2007) using the same study sites but the climate-invariant original version of FVS (Strom and Fulé 2007). The difference in predictions was not due to unexpected changes on the ground or unusual model behavior; forest conditions in 2011 were consistent with the short-term forecasts of the original study and the first decade of Climate-FVS simulation corresponded closely with field measurements. Instead, the effects of climate change on tree mortality, growth, viability, and competitiveness as simulated through the C-FVS model led to complete or nearly complete elimination of the forest in cases of severe climate change (A2 emissions scenarios) and substantial changes in structure, carbon, and composition in cases of moderate climate change.

Setting the Climate-FVS approach in a broader context, there are a number of different modeling strategies attempting to forecast future forest attributes under changing climate and disturbance regimes. Recognizing the urgency of management choices related to fire (Driscoll et al. 2010) as well as the fact that the uncertainty related to atmospheric modeling at global and regional scales is at least as important as the forest and fire modeling uncertainty (Fernandes 2013), Seidl et al. (2011) argued that practical models such as FVS were likely to play a useful role for the foreseeable future, serving to provide a range of projections to assist management decisions and playing a role in generating hypotheses for new research.

(2) Pre-fire fuel reduction treatments influence plant communities and exotic species 9 years after a large wildfire.

Plant community composition was distinct between prefire treated and untreated areas in 2004 and 2005 but was beginning to converge in 2011. We suspected that differences in the plant communities were driven by overstory structure differences, yet these overstory variables did not change much through time. Another possible explanation for this trend toward convergence may be that the close proximity of pre-fire treated areas to the untreated sites facilitated faster colonization than may have occurred in the interior of larger, high-severity burn patches (Turner et al. 1998). We detected consistently higher total understory plant cover in the more severely burned untreated areas, where the removal of most overstory trees reduced competition for light and other resources. Over time, mean total plant cover and cover by life form increased between 2004 and 2005, when higher plant cover in untreated areas was mostly forb species. The dramatic decrease in total plant, forb and graminoid cover in 2011 may be related to competitive effects from increasing shrub cover on the untreated sites. The continual increase in shrub cover may be due to the slower-growing strategy of many shrub species that are likely to become stronger competitors later in time. Whereas *Arctostaphylos pungens* dominated the 2011 shrub community, *Ceanothus fendleri* was more strongly established in the first years post-fire. In addition to competition with shrubby species, drought conditions in the years post-fire likely further suppressed herbaceous response over time.

Exotic species response was not limited to a ruderal, immediate post-fire role. In general, the exotic response was quite low, which may be due in part to the drought conditions in the post-fire years. The response was also highly variable, making the comparison of trends by life-history strategy interesting, but not definitive. One noteworthy trend, despite these limitations, was the higher proportion of mean exotic annual/biennial cover relative to native annual/biennial cover in 2011, particularly in untreated areas. This may suggest that exotic annual/biennial species are more persistent than native annual/biennial species through time.

The increase in frequency of certain exotic species through time also raises concerns. An experimental study in semi-arid sagebrush ecosystems found that *Tragopogon dubius*, a deeply tap-rooted perennial forb, could out-compete native grasses after disturbance due to its ability to access deep water resources that were available after the loss of a foundation species (Prevey et al. 2010). This species was an indicator species in 2011 and had the highest increase in frequency on our untreated sites; since drought conditions are expected to continue in the southwest US (Seager et al. 2007), this species may further proliferate in the future. Finally, the appearance of two exotic perennial bunchgrasses in 2011 may also be of concern. *Eragrostis curvula* was seeded on a nearby fire in 1993, and remained dominant (93% cover) 15 yr post-fire, suggesting it can persist on the landscape and since it is now established it may greatly increase the cover of this species on the landscape. *Festuca ovina* was seeded in 2003 and first detected in 2011. In contrast, the seeded exotic grass *L. perenne*, a sterile annual, was absent by 2011; if seeding is required, sterile annuals are recommended over perennial exotic species that are more likely to persist.

(3) Pre-wildfire fuel reduction treatments result in more resilient forest structure a decade after wildfire.

Pre-wildfire treatments reduced original fire severity and a decade later continue to have significant, persistent impacts on post-wildfire fuel complexes when compared to untreated sites. Tree mortality was high on untreated sites, which resulted in CWD loads averaging 257% higher than treated sites. However, these higher surface fuel loadings may not pose a major management or containment threat because they do not exceed recommended loadings. Higher surface fuel loads on both treated and untreated sites in 2011 compared to 2004 are a product of fire-killed trees falling over this time period. Stand structural attributes differed slightly over the study period. The observed increase in mean live basal area on treated sites was likely fostered post-wildfire by reduced overstory cover and increased available resources. However, in untreated sites the mean live basal area decreased, indicating residual tree death occurred after the 2004 sampling. In similar fashion, canopy cover increased in treated areas from 2004 to 2011, whereas it decreased in untreated areas. Thus, treated sites are recovering and the canopy is filling in the space left open by fire-killed trees. However, untreated sites continue to have a smaller overstory component with decreasing canopy cover and less basal area in 2011 than in 2004. Snag basal area and density decline was similar to that observed by Chambers and Mast (2005) and Passovoy and Fulé (2005). Both of these studies showed that by 7 years post-wildfire the majority of fire-created snags had fallen. In both years of sampling, untreated plots had more snags than treated plots. As a result of these snag fall rates, surface fuels increased from 2004 to 2011, with greater increases on untreated sites. Loadings in all fuel size classes significantly increased over the study period, illustrating the increase in fuel common in any forest without additional removal or fuel consumption from fire.

Management implications

The management implications are organized by objective.

(1) Simulating post-wildfire forest trajectories under alternative climate and management scenarios.

Management regimes were indispensable for obtaining a sustainable forest condition after 100 years. In the absence of management, all seven GCM-emissions scenarios and NCC led to either forest elimination or excessively dense conditions. In contrast, the three burning management regimes each had at least one simulation that led to forest conditions remaining within the historical range after 100 years, and several additional simulations that were fairly close. The severe A2 emissions scenario led to forest elimination, but otherwise burning at frequencies ranging from 5-20 years maintained a high proportion of ponderosa pine and kept forest densities from returning to hyperdense levels.

Managers should incorporate climate change into the process of analyzing the environmental effects of alternative actions. FVS is routinely used to support forest management decisions by the government agencies in the U.S. responsible for managing the largest forests in the nation. Logistical support and training, which already include resources supporting C-FVS, are provided to managers. It would not be difficult to switch to C-FVS or future climate-explicit simulators to provide a more thorough analysis.

Moving beyond the U.S. case, similar forest conditions, wildfire hazards, and climate change effects occur in many regions of the world. Modeling exercises should incorporate alternative future scenarios and forest managers should seek to develop conservative management strategies that best preserve future options. Adaptive management, in which management actions are monitored and findings are used to refine future actions, becomes even more important as climate changes in uncertain ways. At present, a wide range of climate scenarios may be equally likely, but 10 or 20 years into the future the actual pattern of change will become increasingly clear, allowing managers to make better choices between attempting to conserve native ecosystems or facilitate their transition to better-adapted communities.

(2) Pre-fire fuel reduction treatments influence plant communities and exotic species 9 years after a large wildfire.

There is a substantial body of research on exotic species invasions following disturbances such as wildfires. It appears that such invasions are not always strongly related to the severity of the disturbance or pre-fire management practices. Given the lack of a consistent pattern in exotic species composition and abundance across wildfires, local site-specific factors are likely stronger drivers of exotic response. Although high-severity fires can open up growing space for exotic species, the more important drivers may be on-site propagules, post-fire management practices and weather patterns. Few studies have examined longer-term exotic species trajectories following severe wildfires. Our data suggest that exotic species can increase in frequency over time, thus, longer-term monitoring following severe disturbances may be warranted.

Strom & Fulé (2007) detected significant reductions in fire severity in areas treated before the Rodeo–Chediski Fire, and our data show that those treatments also had a persistent effect on vegetation response 9 yr post-fire. Since the plant communities in pre-fire treated and untreated sampling sites were beginning to converge 9 yr post-fire, the close proximity of severely burned areas to less severely burned areas may facilitate native plant community recovery. Collectively, this suggests that pre-fire treatments can help maintain native plant communities associated with an intact ponderosa pine

(3) Pre-wildfire fuel reduction treatments result in more resilient forest structure a decade after wildfire.

Pre-wildfire thinning and pile-burning treatments decreased fuel loading and increased tree survival compared with untreated areas 9 years post-wildfire. These trends persisted and the differences between treated and untreated areas were more prevalent over time. Treatments such as these can ultimately change the stand trajectory after a large wildfire. Given that most forests of the southwestern US are at high risk of severe crown fire, extensive fuel reduction treatments are needed to reduce the potential for high-severity fires. We have illustrated, as have many other studies across the western US, that pre-wildfire fuels treatments can result in reduced fire severity and long-term differences in stand recovery. Even in the face of extreme fire events that occur during severe fire weather conditions, like the Rodeo–Chediski Fire and more recent fires like the Wallow Fire of 2011 and the Whitewater–Baldy Fire of 2012, which are likely to increase owing to climate warming, there is evidence that pre-wildfire fuels treatments help maintain forest structure and reduce future surface fuel loadings compared with untreated sites.

Relationship to other recent findings and ongoing work on this topic

The proposed research links directly to other research projects as well as several important management initiatives. This project builds on previous studies by our group and others of the Rodeo-Chediski fire on Apache-Sitgreaves National Forest lands and links with our complementary work on White Mountain Apache Tribal lands (Kuenzi et al. 2008, Shive et al. 2013b).

A key management linkage is through the Southwest Fire Science Consortium sponsored by JFSP. Results from this project have been presented in several outlets sponsored by the Consortium (see the Deliverables section, below). Finally, another critical management initiative in the Southwest is the design of landscape-scale treatments intended to reduce the extent and severity of future fires. Our study offers the rare opportunity to review long-term effects of fuel treatments that were tested under the single most severe fire incident to date in the region. The data are of value to managers currently developing assessments under the Collaborative Forest Landscape Restoration Program and similar analyses.

A recent systematic review of the effects of fuel treatments on restoring natural fire behavior in dry western forests drew heavily on the studies of the Rodeo-Chediski fire and the handful of similar examples around the West that provide empirical evidence of treatment effects on fire behavior (Fulé et al. 2012). Coupled with experimental data from the Fire/Fire Surrogates Network, these studies are of great value in assessing fuel treatments and developing the best possible management strategies.

Future work needed

Future work that is suggested from this project falls into two categories. First, post-wildfire forest succession should continue to be tracked. Appropriately designed field studies with permanent plots, such as this one, provide a valuable data source. It is clear from studies around the Southwest that there are multiple alternative trajectories for burned forests (Savage and Mast 2005, Haire and McGarigal 2010). Severely burned sites provide the foundation for addressing hypotheses about the near-term and long-term changes in ecosystems. Forest tree species regulate ecosystem structure and function in broad terms, but information about two of the elements studied in this project is critical: plant community composition and dead wood structure. Data from the Rodeo-Chediski fire challenged a paradigm of exotic species irruptions following severe fire (Kuenzi et al. 2008, Shive et al. 2013a,b) but future changes are still possible. In terms of dead wood, data from the present study (Stevens-Rumann et al. 2013) and other research on the Rodeo-Chediski fire (Roccaforte et al. 2012) have quantified the dead wood biomass, snag habitat, and fuel hazard. Measuring the dynamics of dead wood biomass over time remains important for managing habitat, fire, and carbon resources.

In the broad context, estimating the long-term effects of forest management under climate change, as done in this study (Azpeleta et al., in review), is one of the most important challenges facing the conservation of forests and their adaptation to new climates. While Climate-FVS is a valuable and practical tool for simulating forest dynamics under climate change, current tools remain imprecise and depend on uncertain understanding of climate change itself. Ongoing development of simulation models, informed by empirical data from long-term studies, is critical.

Deliverables crosswalk table

In the original proposal, we said "normally it would be ambitious to propose three publications from a study with this timescale and budget. However, we believe that the fact that this research builds on previous accomplishments and the experience of the research team makes this goal feasible." We are pleased to report that we achieved the three publications and in total the actual Deliverables have exceeded those listed in the proposal.

The proposal listed one M.S. thesis. The graduate assistant was funded separately by the Rocky Mountain Research Station but the JFSP funding provided support for data collection and analysis. Her thesis was completed in 2012 and one of her manuscripts is Manuscript 2 in the Deliverables Crosswalk Table (Table 1), Shive et al. (2013). Another graduate student from a university in Spain came to NAU to carry out her M.S. thesis research. Her thesis was completed in 2012 and her manuscript is Manuscript 1 in the Deliverables Crosswalk Table (Table 1), Azpeleta et al. (in review).

The proposal promised three manuscripts for peer-reviewed publication. We have completed all three. Two were published in 2013 (*Applied Vegetation Science*, *International Journal of Wildland Fire*) and the third is in review (*Ecological Applications*).

We carried out a webinar in the series sponsored by the Southwest Fire Science Consortium:

Azpeleta Tarancón, A., P.Z. Fulé, K.L. Shive, C.H. Sieg, A. Sánchez Meador, and B.A. Strom. How will climate change & treatments affect future forests? Webinar, Southwest Fire Science Consortium, September 25, 2013.

In addition, we carried out a field trip and numerous presentations, as cited below:

Fulé, P.Z. Climate change and wildfire in the Southwest. Southwest Fire Science Consortium Newsletter, (http://us4.campaign-archive1.com/?u=35f64585b7351c71937d858e9&id=af91103c3e&e=87eae340dd), Spring 2013.

Fulé, P.Z. Forest restoration research (field trip leader), Second American Dendrochronology Conference, May 12, 2013, Flagstaff, AZ.

Fulé, P.Z. Climate change impacts on forests. New York University program in Madrid, October 29, 2013.

Fulé, P.Z. Changement Climatique et les Forêts. CHEDD Aquitane. October 16, 2013, Pau, France.

Shive, K.L., A.M. Kuenzi, C.H. Sieg, and P.Z. Fulé. Pre-fire fuel reduction treatments influence plant communities and exotic species nine years after wildfire. 5th International Fire Ecology and Management Congress, December 3-7, 2012, Portland, Oregon.

Shive, K., Fulé, P.Z., Sieg, C.H. Successional trends in forest recovery on the 2002 Rodeo-Chediski fire of northeastern Arizona. Southwestern Association of Fire Ecology Conference 2012. Santa Fe, NM February 27-March 1, 2012.

Stevens-Rumann, C., Sieg, C.H., Hunter M.E. Ten years after wildfires: how does varying tree mortality impact fire hazard and forest resiliency? Southwestern Association of Fire Ecology Conference 2012. Santa Fe, NM February 27-March 1, 2012.

The project is described online at a Northern Arizona University website (http://nau.edu/CEFNS/Forestry/Research/Forest-Ecology/Fire-Climate-and-Forests/). Originally we intended to link this site to a database with the original data and to the publications. However, the site is not managed to permit database links and due to changed website policies at the university, it is not appropriate to link to the publications. Therefore we have uploaded the publications to the RMRS website (http://www.fs.fed.us/rm/publications/) and to the JFSP website, and we will be happy to provide the data in ASCII or Access format if JFSP has an appropriate site for storing these data.

Table 1. Deliverable, Description and Delivery Dates

Deliverable Type	Description	Delivery Dates
M.S. Thesis Completion	Original proposal: 1 M.S. thesis (K. Shive) Kristen Shive, M.S. (2012). **Pre-fire treatments have persistent effects on post-fire plant communities**. Northern Arizona University, Flagstaff, AZ. Additional M.S. thesis (A. Azpeleta Tarancón) Alicia Azpeleta Tarancón, Máster en Gestión y Restauración del Medio Natural, Universidad de Alicante, Spain (2012). **Simulando trayectorias de sucesión post-incendio bajo alternativas de clima y gestión: caso de estudio Bosque Nacional de Apache-Sitgreaves, Arizona**.	Completed, uploaded
Field tour	Field tour with southwestern fire professionals in association with JFSP Southwest Fire Science Consortium	Completed, see text
Conference presentation	Presentations to Southwest Fire Science Consortium conference and others	Completed, see text
Dataset	Plot data in accessible (ASCII) format and metadata	Completed, see text
Website	Web page hosted at NAU School of Forestry with links to online data, images, and all deliverables	Completed, see text
Manuscript 1	Azpeleta Tarancón, Alicia, Peter Z. Fulé, Kristen L. Shive, Carolyn Hull Sieg, Andrew SánchezMeador, Barbara Strom. In review. **Simulating post-wildfire forest trajectories under alternative climate and management scenarios**. Ecological Applications.	Manuscript completed, in review, uploaded
Manuscript 2	Shive, K.L., A.M. Kuenzi, C.H. Sieg, and P.Z. Fulé. 2013. **Pre-fire fuel reduction treatments influence plant communities and exotic species nine years after a large wildfire**. Applied Vegetation Science 16: 457–469. Doi:10.1111/avsc.12015.	Manuscript published, uploaded
Manuscript 3	Stevens-Rumann, C., K.L. Shive, P.Z. Fulé, and C.H. Sieg. 2013. **Pre-wildfire fuel reduction treatments result in more resilient forest structure a decade after wildfire**. International Journal of Wildland Fire http://dx.doi.org/10.1071/WF12216.	Manuscript published, uploaded
Webinar presentation	Azpeleta Tarancón, A., P.Z. Fulé, K.L. Shive, C.H. Sieg, A. Sánchez Meador, and B.A. Strom. **How will climate change & treatments affect future forests?** Webinar, Southwest Fire Science Consortium,	Presented September 25, 2013
Other Publication	Additional deliverable: Fulé, P.Z. **Climate change and wildfire in the Southwest**. Southwest Fire Science Consortium Newsletter, (http://us4.campaign-archive1.com/?u=35f64585b7351c71937d858e9&id=af91103c3e&e=87eae340dd), Spring 2013	Completed, uploaded
Final report	Final report and documentation of all deliverables (this report)	Completed, uploaded

References Cited

Brown, J. K. 1974. Handbook for inventorying downed woody material. USDA Forest Service, Intermountain Research Station General Technical Report INT-16. (Ogden, UT).

Brown, J.K., Reinhardt, E.D., Kramer, K.A., 2003. Coarse Woody Debris: Managing Benefits and Fire Hazard in the Recovering Forest. USDA Forest Service General Technical Report RMRS-GTR-105. Rocky Mountain Research Station, Ogden, UT, 16 pp.

Chambers, C. L. and J. N. Mast. 2005. Ponderosa pine snag dynamics and cavity excavation following wildfire in northern Arizona. Forest Ecology and Management 216:227-240.

Cooper, C. F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. Ecological Monographs 30:130-164.

Covington, W. W. and M. M. Moore. 1994. Southwestern ponderosa forest structure - changes since Euro-American settlement. Journal of Forestry 92:39-47.

Crookston, N.L., G.E. Rehfeldt, G.E. Dixon, and A.R. Weiskittel. 2010. Addressing climate change in the forest vegetation simulator to assess impacts on landscape forest dynamics. Forest Ecology and Management 260:1198-1211.

Daubenmire, R. F. 1959. A canopy-coverage method. Northwest Science 33:43-64.

Diggins, C., P.Z. Fulé, J.P. Kaye, and W.W. Covington. 2010. Future climate affects management strategies for maintaining forest restoration treatments. International Journal of Wildland Fire 19: 903–913.

Dore, S., T. E. Kolb, M. Montes-Helu, B. W. Sullivan, W. D. Winslow, S. C. Hart, J. P. Kaye, G. W. Koch, and B. A. Hungate. 2008. Long-term impact of a stand-replacing fire on ecosystem CO2 exchange of a ponderosa pine forest. Global Change Biology 14:1801-1820.

Driscoll, D. A., D. B. Lindenmayer, A. F. Bennett, M. Bode, R.A. Bradstock, G.J. Cary, M.F. Clarke, N. Dexter, R.J. Fensham, G.R. Friend, A.M. Gill, S. James, G. Kay , D.A. Keith,C. MacGregor, J. Russell-Smith, D. Salt, J.E.M.Watson and A. York. 2010. Fire management for biodiversity conservation : key research questions and our capacity to answer the., Biological conservation 143: 1928-1939.

Dufrene, M., Legendre, P., 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol. Monogr. 67, 345–366.

Fernandes, P.M. 2013. Fire-smart management of forest landscapes in the Mediterranean basin under global change. Landscape and Urban Planning 110:175-182

Finney, M. A., C. W. McHugh, and I. C. Grenfell. 2005. Stand- and landscape-level effects of prescribed burning on two Arizona wildfires. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 35:1714-1722.

Franklin, J. 2010. Vegetation dynamics and exotic plant invasion following high severity crown fire in a southern California conifer forest. Plant Ecology 207:281-295.

Fule, P. Z., T. A. Heinlein, W. W. Covington, and M. M. Moore. 2003. Assessing fire regimes on Grand Canyon landscapes with fire-scar and fire-record data. International Journal of Wildland Fire 12:129-145.

Fulé, P.Z., J.E. Crouse, J.P. Roccaforte, and E.L. Kalies. 2012. Do thinning and/or burning treatments in western USA ponderosa or Jeffrey pine-dominated forests help restore natural fire behavior? Forest Ecology and Management 269: 68–81, doi:10.1016/j.foreco.2011.12.025.

Haire, S. L. and K. McGarigal. 2010. Effects of landscape patterns of fire severity on regenerating ponderosa pine forests (Pinus ponderosa) in New Mexico and Arizona, USA. Landscape Ecology 25:1055-1069.

Hawskworth, F. G. 1977. The 6-Class Dwarf Mistletoe Rating System. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-48. (Fort Collins, CO).

Keane, R. E., J. K. Agee, P. Fulé, J. E. Keeley, C. Key, S. G. Kitchen, R. Miller, and L. A. Schulte. 2008. Ecological effects of large fires on US landscapes: benefit or catastrophe? International Journal of Wildland Fire 17:696-712.

Kuenzi, A. M. 2006. Pre-fire treatment effects and understory plan community response on the Rodeo-Chediski fire, Arizona. Northern Arizona University, Flagstaff, AZ.

Kuenzi, A. M., P. Z. Fulé, and C. H. Sieg. 2008. Effects of fire severity and pre-fire stand treatment on plant community recovery after a large wildfire. Forest Ecology and Management 255:855-865.

Littell, J. S., D. McKenzie, D. L. Peterson, and A. L. Westerling. 2009. Climate and wildfire area burned in western U. S. ecoprovinces, 1916-2003. Ecological Applications 19:1003-1021.

McCune, B., Mefford, M.J., 1999. PC-ORD (Computer Program). Multivariate Analysis of Ecological Data, Version 4. MJM Software Design, Gleneden Beach, Oregon.

Miller, J.D., H.D. Safford, M. Crimmins, and A.E. Thode. 2009. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA. Ecosystems 12:16-32.

Passovoy, A. D. and P. Z. Fulé. 2006. Snag and woody debris dynamics following severe wildfires in northern Arizona ponderosa pine forests. Forest Ecology and Management 223:237-246.

Peppin, D., P. Z. Fulé, C. H. Sieg, J. L. Beyers, and M. E. Hunter. 2010. Post-wildfire seeding in forests of the western United States: An evidence-based review. Forest Ecology and Management 260:573-586.

Prevey, J.S., Germino, M.J. & Huntly, N.J. 2010. Loss of foundation species increases population growth of exotic forbs in sagebrush steppe. Ecological Applications 20: 1890–1902.

Roccaforte, J.P., P.Z. Fulé, W.W. Chancellor, and D.C. Laughlin. 2012. Woody debris and tree regeneration dynamics following severe wildfires in Arizona ponderosa pine forests. Canadian Journal of Forest Research 42:593-604.

Savage, M. and J. N. Mast. 2005. How resilient are southwestern ponderosa pine forests after crown fires? Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 35:967-977.

Seidl, R., P. M. Fernandes, T.F. Fonseca, F. Gillet, A.M. Jönsson, K. Merganičováh, S. Nethererj, A. Arpacia, J-D. Bontempsk, H. Bugmannl, J.R. González-Olabarriam, P. Laschn, C. Meredieu, F. Moreira, M-J. Schelhaasq, F. Mohrenr. 2011. Modelling natural disturbances in forest ecosystems: a review. Ecological Modelling 222:903-924.

Shive, K.L., A.M. Kuenzi, C.H. Sieg, and P.Z. Fulé. 2013a. Pre-fire fuel reduction treatments influence plant communities and exotic species 9 years after a large wildfire. Applied Vegetation Science 16: 457–469. Doi:10.1111/avsc.12015.

Shive, K.L., C.H. Sieg, and P.Z. Fulé. 2013b. Pre-wildfire management treatments interact with fire severity to have lasting effects on post-wildfire vegetation response. Forest Ecology and Management 297:75–83, http://dx.doi.org/10.1016/j.foreco.2013.02.021.

Stephens, S. L., J. J. Moghaddas, B. R. Hartsough, E. E. Y. Moghaddas, and N. E. Clinton. 2009. Fuel treatment effects on stand-level carbon pools, treatment-related emissions, and fire risk in a Sierra Nevada mixed-conifer forest. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 39:1538-1547.

Strom, B. A. 2005. Pre-fire treatment effects and post-fire forest dynamics on the Rodeo-Chediski burn area, Arizona. Northern Arizona University, Flagstaff, AZ.

Strom, B. A. and P. Z. Fulé. 2007. Pre-wildfire fuel treatments affect long-term ponderosa pine forest dynamics. International Journal of Wildland Fire 16:128-138.

Thomas, J.W., Anderson, R.G., Maser, C., Bull, E.L., 1979. Snags. In: Wildlife Habitats in Managed Forests—The Blue Mountains of Oregon and Washington. USDA Agricultural Handbook 553. U.S. Department of Agriculture, Washington, DC, pp. 60–77.USDA Forest Service. 2004. Record of Decision. Rodeo-Chediski Fire Salvage Project. Springerville, AZ.

Turner, M.G., Baker, W.L., Peterson, C.J. & Peet, R.K. 1998. Factors influencing succession: lessons from large, infrequent natural disturbances. Ecosystems 1: 511–523.

Waskiewicz, J.D., P.Z. Fulé, and P. Beier. 2007. Quantifying the deterioration of ponderosa pine snags in northern Arizona. Western Journal of Applied Forestry 22(4):233-240.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western US forest wildfire activity. Science 313:940-943.