ERI–Issues in Forest Restoration

Forest Restoration Treatments: Their Effect on Wildland Fire Suppression Costs

NORTHERN ARIZONA UNIVERSITY
Ecological Restoration Institute

The Ecological Restoration Institute

The Ecological Restoration Institute at Northern Arizona University is a pioneer in researching, implementing, and monitoring ecological restoration of dry, frequent-fire forests in the Intermountain West. These forests have been significantly altered during the last century, with decreased ecological and recreational values, near-elimination of natural low-intensity fire regimes, and greatly increased risk of large-scale fires. The ERI is working with public agencies and other partners to restore these forests to a more ecologically healthy condition and trajectory—in the process helping to significantly reduce the threat of catastrophic wildfire and its effects on human, animal, and plant communities.

Cover photo:

Several fire crews, comprised of more than 6,000 firefighters from across the country, fought night and day to suppress the Wallow Fire, which ignited on May 29, 2011 in eastern Arizona and burned more than 538,000 acres.

Photo: U.S. Forest Service

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Executive Summary

We modeled the effects of proposed forest restoration treatments in Arizona's Four Forest Restoration Initiative (4FRI) on fire behavior characteristics and fire suppression costs. We found two significant factors that help explain total wildfire suppression costs: 1) distance from the wildfire to the wildland-urban interface and 2) the proportion of fires with high burn severity. Given our results, we estimate a range for wildland suppression costs at $706–$825 per acre for the current conditions of the 4FRI landscape. After the proposed forest restoration treatments, the suppression costs should be reduced to $287–$327 per acre for the same size fire.

Introduction

Federal land management agencies, including the USDA Forest Service (USFS) and agencies within the Department of Interior (DOI), have experienced a significant rising trend in wildland fires and subsequent wildland fire suppression expenditures. For example, the appropriations for wildland fire management activities by these agencies rose from $1.2 billion annually from 1996–2000 to more than $2.9 billion annually during 2001–2007 (GAO 2009, Table 1). This rising trend is forecast to continue with higher frequency of wildland fire occurrences, longer durations of wildland fire seasons (Westerling et al. 2006), and the continued expansion of residential development within the vulnerable wildland-urban interface, also known as WUI (Headwaters Economics 2008).

Table 1. Forest Service and Interior Wildland Fire Appropriations, Fiscal Years 1996 through 2007

Total appropriations (millions of dollars)		
Fiscal year	Nominal	Inflation-adjusted[a]
1996	$772.4	$984.2
1997	$1,432.1	$1,793.3
1998	$1,116.7	$1,381.7
1999	$1,159.3	$1,415.9
2000	$1,598.9	$1,914.2
2001	$2,859.9	$3,344.7
2002	$2,238.8	$2,569.0
2003	$3,165.1	$3,560.2
2004	$3,230.6	$3,541.6
2005	$2,929.8	$3,144.0
2006	$2,701.4	$2,775.4
2007	$3,047.0	$3,047.0

Source: GAO analysis of Congressional Research Service data.

There have been considerable research efforts designed to understand the factors affecting the overall costs of wildland fires (Donovan and Rideout 2003, Lynch 2004, Calkin et al 2005, Gebert et al. 2007, Liang et al. 2008, Prestemon et al. 2008). These studies indicate that the increasing trend in wildland fire suppression expenditures corresponds to a trend of increasing acres burned by large, wildland fires (i.e., fires greater than 988 acres in size). While these large wildland fires are relatively small in number, they account for nearly 98 percent of the total acres burned (Calkin et al. 2005). The frequency of large fires has markedly increased since the mid-1980s with almost four times as many large fires burning nearly seven times more land between 1987 and 2003 compared to the period 1970–1986.

Total wildland fire suppression cost has also been positively correlated with various spatial factors, in addition to fire size. For example, Liang and colleagues (2008) examined 100 wildland fires greater than 300 acres in size between 1996 and 2005, and found that 58 percent of the variation in wildland fire suppression costs was attributed to fire size and percentage of private land burned. Likewise, after examining 1,550 wildland fires across the United States, Gebert and colleagues (2007) discovered that total housing value within 20 miles of the wildland fire ignition point had a positive effect on expected suppression cost. Yoder and Gebert (2012) also found that housing values and other values-at-risk positively contribute to an increase in fire suppression costs. Although total fire size (area burned) increases overall suppression cost, expected suppression cost per acre decreases as fire size increases due to the fixed nature of many fire suppression related expenditures.

The Ecological Restoration Solution: Will it Reduce Suppression Costs?

Through the Collaborative Forest Landscape Restoration Program (CFLRP) and other measures, the USFS and its partners have plans and projects under way to restore forested landscapes that are now susceptible to large wildfires. Using ecological forest restoration principles, these projects envision returning forests to healthy ecological conditions, increasing ecosystem services, protecting forest communities from catastrophic wildfire, and providing support to local and regional economies. In terms of increasing fire safety, ecological restoration treatments are designed to change fire behavior conditions from high-severity crown fires to low-severity surface fires, largely by thinning trees using mechanical treatments and/or prescribed burning. These approaches, which have been successful at smaller scales, will be applied to hundreds of thousands acres on now fire-prone forested landscapes. The questions we sought to answer in our research were: 1) What will be the effect of restoration treatments on fire behavior at the landscape scale? 2) If these treatments are successful, what, if any, fire suppression cost savings might be realized?

Methods and Study Area

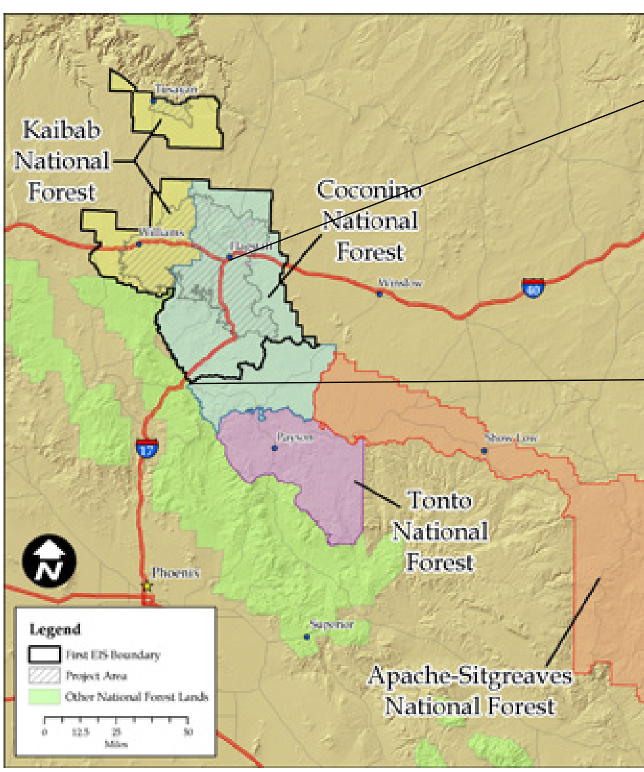
To answer our questions, we began by adopting the Cost plus Net Value Change (C+NVC) model because it provides a basis for determining the relationship between wildland fire suppression costs and fuel treatments. In the C+NVC model, costs (C) are all costs associated with wildland fire suppression and fuel treatments. Meanwhile, NVC represents all other fire-related losses, including property and facilities damage as well as other value changes in non-market ecosystem services. Theoretically, some aspects of fuel treatments can be considered substitutes for suppression costs for a given level of NVC, while some components of fuel treatments complement those in fire suppression (Donovan and Rideout 2003, Rideout et al. 2008). Thus, an increase in fuel treatments does not necessarily imply a reduction in suppression costs unless optimum NVC was set at a fixed level. Rather than viewing fuel treatments as a substitute for fire suppression, fuel treatments and fire suppression expenditures are viewed as inputs to NVC in terms of their individual marginal and joint effects.

Next, we employed wildland fire models to determine wildland fire suppression costs per acre in order to predict changes in wildland fire suppression costs. Using FlamMap via the ArcFuels extension in conjunction with ArcGIS, we selected the factors of “flame length,” “crown fire activity,” and “burn probability” to categorize the potential of severe wildfire across the landscape. We then established a baseline analysis with the fire models to show how the restoration treatments affected fire behavior on the treated landscape. Since the restoration treatments produced reductions in wildland fire probability and/or wildland fire severity potential, we were then able to estimate the changes in wildland fire suppression costs. Comparing the expected reduction in wildfire suppression costs with treatment costs will provide a metric for the cost-benefit analysis of treatment costs to avoided wildland fire suppression costs for a given NVC level.

Our initial study area for modeling fire behavior is a portion of the Coconino National Forest, which is south/southeast of the City of Flagstaff, Arizona and is designated as restoration unit 1 (RU1) as part of the CFLRP-funded Four Forest Restoration Initiative Project, or 4FRI (Figure 1).

Current analysis of the landscape is limited strictly to reducing the costs of wildland fire suppression (C). We have not incorporated treatment costs into the calculation of C, because final costs of the proposed treatment are highly uncertain at this point depending on the rate of resulting biomass utilization from the 4FRI project. For example, past estimates of similar mechanical thinning operations in the area was \$300–\$433 per acre, but the current contractor proposed to pay the USFS up to \$22 per acre for recovery of the materials. If fire suppression costs are to be mitigated, it seems appropriate to focus on the factors and treatments that relate to fires categorized as “large” in size or where the severe wildfire threat is greatest (Pollet and Omi 2002).

We used the current conditions of the entire 4FRI landscape to create the landscape files (LCPs) for the fire modeling carried out in FlamMap, version 3 (Mary Lata and Neil McCuster, personal communication). The LCP consisted of a compilation of fuel model, canopy cover, height to live crown (canopy base height), canopy bulk density, slope, aspect, and elevation raster layers. The LCP was then cropped to focus on the 4FRI treatment area, RU1. Two files—a fuel moisture file and a wind file—were created to approximate environmental conditions. Each file was based on conditions observed during the Schultz Fire, which occurred under non-extreme fire conditions. The Schultz Fire burned more than 15,000 acres north of Flagstaff in 2010,



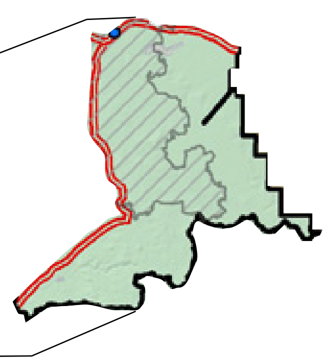


Figure 1. Study Area RU 1 within the 4FRI (Source: Four Forest Restoration Initiative Draft Proposed Action Scoping Report, June 2011).

and we assumed the fire conditions for the Schulz Fire were conservative and would be present in the RU1 area during fire season. Wind speed and direction were also based on conditions during the Schultz Fire, that is, a 20-mph wind out of the southwest (Mary Lata, personal communication). We used the Scott/Reinhardt 2001 Crown Fire Calculation Method (Scott and Reinhardt 2001) to calculate flame length and crown fire activity outputs in FlamMap.

Using a flame length categorization model (Ager et al. 2011), we categorized the flame length outputs into hauling categories (a typical categorization that corresponds directly to suppression efforts required: 0–4 feet, 4–8 feet, 8–11 feet, and 11+ feet) in order to determine the effectiveness of initial wildland fire suppression activities. Because of the various resource costs associated with more severe wildland fires, we found this categorization to be useful in assessing burn severity. A fifth flame length category, 20-foot or higher flame lengths, was included in the fire behavior analysis to show areas where we expect to observe high burn severity fire conditions.

Crown fire activity outputs from FlamMap are expressed in crown activity potential as classified by "active crown fire," "passive crown fire," "surface fire," and "unburned." Crown fire activity was used as one of the fire behavior proxies for burn severity. If a pixel was in the active crown fire category, that pixel was estimated as indicating high burn severity.

Burn probabilities were calculated from 1,000 random ignitions. Previous case studies using burn probability applied considerably higher numbers of random ignitions, but lack of computing power limited our runs. The resolution of calculations was set to 394 feet (120 meters); the maximum simulation time was one day (1,440 minutes); and the interval for minimum travel paths was 1,640 feet (500 meters).

FlamMap outputs were transferred into ArcGIS 10 for geospatial referencing and further analysis. We used the spatial analyst tool, "Raster Calculator," to combine the fire behavior metrics, burn probability, and the boundaries of the suggested treatment area within the RU1 area. The "Reclassify" and "Calculate" tools were used to find the number of acres in each of the combined fire behavior metrics and burn probability categories within the treatment area. These outputs were exported to Excel 2010 to calculate the total acres of each of the fire behavior metrics and burn probability categories.

Regression Analysis and Suppression Costs

We calculated the expected wildfire suppression costs within the RU1 study area using a general linearized model output for the average cost per acre of $695 within the USDA National Forest System Region 3 (Gebert et al. 2007). In addition, we compared this cost to our results from the regression analysis. The wildland fire suppression cost estimate is also based solely on suppression costs and did not include rehabilitation and other net value changes. No consideration was given to the probability of fire spreading into the area.

We employed a regression analysis based on 39 wildland fires, each more than 1,000 acres in size, that occurred within the overall 4FRI area between 2001 and 2009 in order to estimate wildland fire suppression costs. Table 2 provides information about the variables used and information sources. Other variables of interest that were identified and collected include: vegetation cover type, proximity to the WUI area, proportion of private land burned, and total acres of the landscape being modeled. We used designated WUI areas as defined by each of the national forests within our sample. The "Euclidean Distance Tool" within the "Spatial Analyst" toolbox of ArcGIS was used to calculate this distance (Table 3).

With the fire behavior outputs available to us from the FlamMap fire modeling, we used burn severity and dominant vegetation type to represent fire behavior and distance to WUI and proportion of fire burned in private land to represent fire location. We represented other locational variables that might affect fire suppression costs by the dummy variable for each national forest where each fire occurred. This model helped us understand and forecast wildland fire suppression costs given our ability to model the impacts of proposed treatments on changes in fire behavior.

Table 2. Dependent and independent variables used in the regression analysis

Variable	Description	Source
Cost	Forest Service and DOI suppression expenditure	US Forest Service
Size (fz)	Number of acres burned	www.mtbs.gov
Distance to WUI (fl)	Shortest distance from WUI perimeter to fire perimeter	National Forest web-site
Burn Severity (fb)	Proportion of fire that burned at high, medium, and low severity	www.mtbs.gov
Private Land (fl)	Proportion of fire burned in private land	www.land.state.az.us
Dominant Vegetation Type (fb)	Vegetation type that had the highest percent cover within the fire perimeter	National Forest web-site
Forest (fl)	Dummy variable for the National Forest in which the fire occurred	National Forest web-site

Table 3. Equations from the regression analysis

Equation	P-value	R^2
C/A = 245.29664** - 0.01227* x D + 16.10641** x H	0.00	0.33
C = 406,343 - 46.9942 x D + 94,510** x H + 124.6876** x A	0.00	0.59

C = total suppression expenditure, A = acres burned, P = % private land, D = distance to WUI, and H = % high severity burn.

**, P < 0.01; *, P < 0.1

Results

Fire Behavior

In terms of fire behavior, we found several related results. They are:

1. According to the models, if fire were to occur under current conditions in the proposed treatment area we estimate 50,287 acres would burn at high severity. After restoration treatments, we project this would decrease to 4,502 acres, a reduction of 45,785 acres (see Figure 2). In other words, under the current conditions, 28.6 percent of the 175,617 acres of proposed treatment area is likely to burn at high severity while only 2.6 percent of the same area would be at high severity following the proposed restoration treatment.
2. We observed a large decrease in passive and active crowning within the boundaries of the treated areas. This resulted because the treated areas had fewer trees per acre, decreased canopy bulk density, and an increase in canopy base height compared to the current conditions.
3. The models showed a decrease in flame length within the treatment compared to the current conditions.
4. Models showed an overall increase in the probability that areas in the treated landscape will burn when compared to the current conditions. The ranges of burn probabilities are 0–27.4 percent and 0–32.8 percent for current and treated conditions, respectively. This was especially the case in the northwestern boundaries of the treatment areas and is likely due to "opening" the landscape, causing wind to have a larger impact on fire behavior.

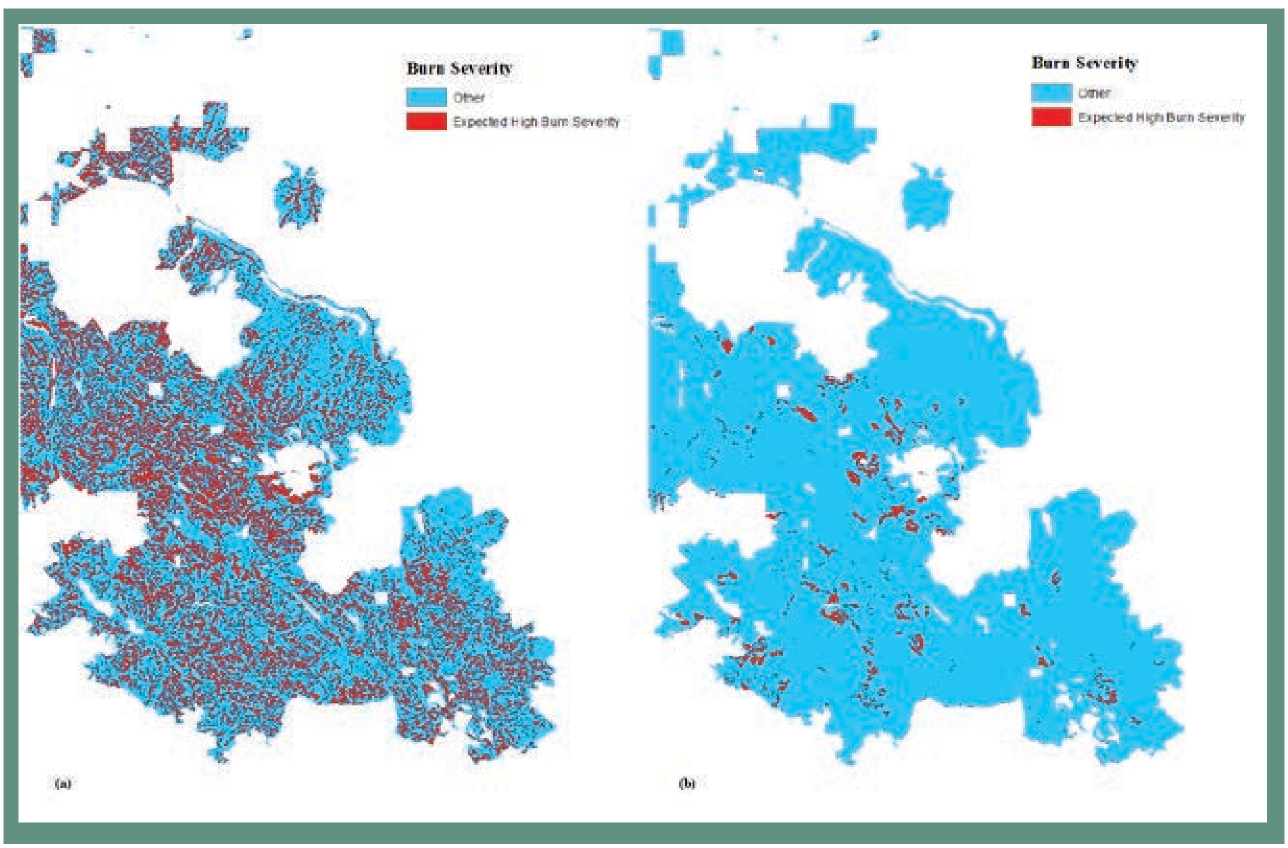


Figure 2. Distribution of estimated high burn severity from active crown fire activity and flame length greater than 20 feet. Current conditions and proposed treatment as (a) and (b), respectively.

Regression Analysis and Suppression Costs

Our results show the total acres burned was significant in predicting wildland fire suppression costs as expected, although we also found that the percent of area burned at high severity better explained the variation of suppression costs. With regards to distance from the WUI, we found a marginal (three-foot increase) decrease in suppression costs of $46.99 for total expenditures and $0.01 for cost per acre when total acres burned and proportion of high burn severity were held constant. This result is consistent with previous findings of higher wildland fire suppression costs in WUI areas (Donovan et al. 2004, Liang et al. 2008). The proportion of area with a high burn severity variable had a marginal (in terms of a 1 percent increase) increase in suppression cost of $94,510 for total expenditures and $16.11 for cost per acre when total acres burned and distance from WUI held constant.

Using the more conservative estimate of high burn severity being defined as active crown fire or flame lengths greater than 20 feet, our linear regression result estimates a wildland fire suppression cost of $706 per acre for RU1 area in its current condition. The linear regression model estimate for wildland fire suppression cost after ecological restoration treatment is $287 per acre—a significant difference of $419 per acre. Using the total cost linear regression equation, our estimates are $25 million and $22.5 million for the current conditions and post treatment, respectively. However, if other factors of wildland fire costs, including rehabilitation and ecosystem service loss, are included to suppression costs, the total cost of wildfires (C+NVC) has been estimated to be in the range of 2 to 30 times greater than the costs associated with suppression alone (Western Forestry Leadership Coalition 2010).

If we expand high burn severity to include both passive and active crown fire or flame lengths greater than 11 feet, our regression equation estimates suppression costs to be $825 per acre for current conditions and $327 per acre after restoration treatment—a difference of $498 per acre. In terms of total suppression costs, our regression estimates are $25.7 million for the current conditions and $22.8 million post treatment. These estimates are summarized in Table 4.

Table 4. Estimated wildland fire suppression costs

	Per Acre Cost	Total Cost
Current conditions with active crown fire or flame length > 20 ft.	$706	$25,006,591
Current conditions with passive and active crown fire or flame length > 11 ft.	$825	$25,706,910
Post-treatment with active crown fire or flame length > 20 ft.	$287	$22,549,331
Post-treatment with passive and active crown fire or flame length > 11 ft.	$327	$22,784,661

Discussion

Recent studies of large wildfires have repeatedly pointed to the size of the fire as the most significant factor in determining wildfire suppression costs. While recognizing the importance of fire size, we also suspected that fire behavior characteristics play an important role when modeling wildfire suppression expenditures. In this study, we used linear regression models focused on fire behavior characteristics and produced promising preliminary results. Our regionally specific regression analysis estimates a per acre suppression cost in the range of $706 to $825 under current conditions with significantly lower costs, ranging from $287 to $327 per acre, after restoration treatments. Previous research by Gebert and colleagues (2007) found that the average suppression cost for large (greater than 300 acres) wildfires was $695 per acre for the Southwest region between 1995 and 2004.

Assuming that our results are relatively accurate (and we do acknowledge that a parameter estimate bias may be present due to our relatively small sample of wildfires greater than 1,000 acres; see Yoder and Gebert 2012), what do they mean in terms of the overall costs of maintaining and restoring forest health? To determine this answer, we studied the ability of the restoration treatments to help defray wildland fire suppression costs using a cost-benefit analysis. These results suggest to us that whenever a restoration treatment costs less than $420 per acre on our conservative estimate ($498 per acre on our expanded classification), the restoration treatment will have a positive net saving with regards to suppression costs. Similarly, the treatments would produce a net saving if the treatments can be implemented over the landscape at a total cost of $2.5 million or less (less than $2.9 million as the upper end range). Of course, this is assuming a constant NVC level as discussed above.

Fire size has long been correlated with fire suppression costs. We acknowledge this association in our econometric model, but sought to predict fire suppression costs through fire behavior characteristics we can model. Our total expenditure model is largely driven by the explanatory variable "total acres burned." In both the treated and untreated landscape, we are assuming the same number of acres will burn, the area encompassed by the proposed treatments. The reduction in total expenditure is strictly due to changes in fire behavior characteristics (burn severity). The goal of restoration treatments in this area is not to mitigate fire size or prevent the occurrence of fire, but to reintroduce fire into the landscape in a socially acceptable and ecologically resilient manner.

Our ongoing research is currently expanding the use of our regression analysis by including fires from the 2010 fire season as well as fires that occurred on the Tonto National Forest. Once this modeling is completed, we will have a larger sample size to strengthen the results reported in this paper. We plan to refine the measure of burn severity that can be derived from fire behavior modeling outputs because predicting fire behavior is critical to the inputs that we have identified for estimating wildland fire suppression costs.

Firefighters perform blacklining operations, where hand drip torches are used to burn fuels along a perimeter to limit a fire's growth. *Photo courtesy of the Ecological Restoration Institute*

Management Implications

The results of this study identified several management implications and important research areas for the future.

- As with any restoration treatment, reduction of severe wildland fires is only one of the goals and benefits. Other benefits include the enhancement of additional ecosystem services such as improved carbon storage, water yields and filtration, wildlife habitat, and recreational opportunities. All of these improved or maintained ecosystem service benefits need to be considered in the overall cost-benefit analysis of implementing restoration treatments. Further analysis of the NVC of the landscape is required to determine the true cost of wildland fire (Donovan and Rideout 2003).
- We found that restoration treatments may create unintended, negative consequences. In particular, while they reduce burn severity of the treated area, such activities may increase the burn probability of areas adjacent and outside the management boundary. To offset this tendency, managers and fire planners might examine the values and infrastructure at risk in the adjacent areas prior to treatment implementation, paying particular attention to wind direction and fire spread probabilities.
- Our models indicate that high burn severity conditions are interspersed throughout the landscape under the current conditions but change to a disconnected, spotty configuration of high burn severity following restoration treatments (Figure 2). This may affect the wildfire suppression cost estimate as areas under "severe" conditions could be allowed to burn, with suppression efforts focused on areas that exhibit lower predicted severity (i.e., have smaller flame length or surface fires). Under these circumstances, a more holistic estimate of fire suppression costs, one that includes low burn severity, could be beneficial.
- Reintroducing prescribed fires is a typical restoration goal and may be implemented instead of or as a complement to mechanical thinning. There are costs involved when using this approach that are often not included in fire suppression cost studies, including this one. A more detailed measure of wildfire suppression costs linked to differences in fire behaviors could provide a more accurate measure of the total estimated suppression costs.

Conclusion

In this paper, we applied wildfire models and an econometric regression model to predict per acre wildland fire suppression costs as well as changes in total wildland fire suppression costs within a proposed landscape-scale restoration project, the Four Forest Restoration Initiative in northern Arizona. Our results suggest that changing potential fire behavior through ecological restoration treatments can have a generally positive effect on projected wildland fire suppression costs. For instance, if the 4FRI restoration treatments can be implemented at a cost less than our estimated treatment costs of $706–$825 per acre, then, based strictly on cost savings from wildland fire suppression costs, the restoration treatments will be cost efficient. This level of cost efficiency may not reflect the true economic value, however, because our analysis does not take into account net value changes to the landscape. For example, the 4FRI ecosystem could be providing greater quantities or qualities of ecosystem services (e.g., more water, cleaner water) following restoration treatments. Additionally, the ecosystem may be more resilient to future ecosystem disturbances (e.g., wildland fire) thereby altering the net value change component of the model. Finally, our results complement the U.S. Forest Service Risk and Cost Analysis Tools Package (R-CAT), which is now required for all projects funded by the USFS Collaborative Forest Landscape Restoration Program, and are not meant to replace that procedure.

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Ecological restoration is a practice that seeks to heal degraded ecosystems by reestablishing native species, structural characteristics, and ecological processes. The Society for Ecological Restoration International defines ecological restoration as "an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability. … Restoration attempts to return an ecosystem to its historic trajectory" (Society for Ecological Restoration International 2004).

Throughout the dry forests of the western United States, most ponderosa pine forests have been degraded during the last 150 years. Many ponderosa pine areas are now dominated by dense thickets of small trees, and lack their once diverse understory of grasses, sedges, and forbs. Forests in this condition are highly susceptible to damaging, stand-replacing fires and increased insect and disease epidemics. Restoration of these forests centers on reintroducing frequent, low-intensity surface fires—often after thinning dense stands—and reestablishing productive understory plant communities.

The Ecological Restoration Institute at Northern Arizona University is a pioneer in researching, implementing, and monitoring ecological restoration of dry, frequent-fire forests in the Intermountain West. By allowing natural processes, such as fire, to resume self-sustaining patterns, we hope to reestablish healthy forests that provide ecosystem services, wildlife habitat, and recreational opportunities.

The ERI Issues in Forest Restoration series provides overviews and policy recommendations derived from research and observations by the ERI and its partner organizations. While the ERI staff recognizes that every forest restoration is site specific, we feel that the information provided in the series may help decision makers elsewhere.

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