Implementation of the Fire and Fire Surrogate Study—A National Research Effort to Evaluate the Consequences of Fuel Reduction Treatments

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ABSTRACT

Many fire-dependent forests today are denser, contain fewer large trees, have higher fuel loads, and greater fuel continuity than occurred under historical fire regimes. These conditions increase the probability of unnaturally severe wildfires. Silviculturists are increasingly being asked to design fuel reduction treatments to help protect existing and future forest structures from severe, damaging, and expensive wildfires. The consequences of replacing the historical role of fire with fuel reduction treatments, such as underburning with prescribed fire, cutting with mechanized equipment like a feller-buncher, or a combination of both, remain largely unknown and require innovative operational-scale experiments for improved understanding. The Fire and Fire Surrogate (FFS) study is a large manipulative experiment designed by an interdisciplinary team of federal agency and academic researchers to address ecological processes, economic viability, and operational consequences of different fuel reduction treatments. Replicated at 13 installations on federal and state lands extending from the eastern Cascade Range in Washington to the southern coastal plain in Florida, this study is likely the largest operational-scale experiment ever funded to test silvicultural treatments designed to balance ecological and economic objectives for sustaining healthy forests. This paper describes the study objectives and research approach, provides a status of work at the different sites, and presents initial results of changes in stand structure and related understory vegetation as an example of the broad comparisons that this study allows. These initial among-site comparisons highlight the potential value of network-wide meta-analyses for determining the scale at which common themes emerge.

KEYWORDS: Fire and Fire Surrogate study, fuel reduction, overstory-understory interactions, meta-analysis.

INTRODUCTION

Many fire-dependent forests—especially those with historically short-interval, low- to moderate-severity fire regimes—contain more small trees and fewer large trees, have higher fuel loads, and greater fuel continuity compared to conditions under historical fire regimes (Agee 1993, Arno et al. 1997, Barden 1997, Caprio and Swetnam 1995, Cowell 1998, Kilgore and Taylor 1979, Swetnam 1990, Taylor and Skinner 1998, Van Lear and Waldrop 1989, Waldrop et al. 1987, Yaussy and Sutherland 1994). These conditions are the result of fire exclusion and suppression, past livestock grazing and timber harvests, tree recruitment after farm abandonment (especially in the southern United States), and changes in climate (Arno et al. 1997, Skinner and Chang 1996). Collectively, these conditions contribute to a general deterioration in forest ecosystem integrity and an increase in the probability of unnaturally severe wildfires

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(Stephens 1998). Silviculturists are increasingly being asked to design fuel reduction treatments that reduce the stand basal area and the density of small trees, remove fire-sensitive trees, reduce the accumulation of woody debris, and increase the height to live crowns to help protect these forests from severe wildfire and at the same time meet a host of other resource objectives. Strategies for managing forest fuels to reduce the incidence of these expensive and damaging wildfires include underburning with prescribed fire, cutting live and dead trees and removing logs with mechanized equipment like feller-bunchers, or a combination of both. The consequences of implementing these strategies remain largely unknown. Innovative operational-scale experiments that evaluate the effects of alternative management practices involving fire and mechanical or manual surrogates for natural disturbance events are essential for improved understanding of management decisions.

A team of federal, state, university, and private scientists and land managers designed the Fire and Fire Surrogate (FFS) study, an integrated national network of long-term studies, with support from the USDA/USDI Joint Fire Science Program and the national Fire Plan. The national network currently includes 13 sites on federal and state lands extending from the Cascade Range in Washington to Florida (table 1). These 13 sites represent ecosystems with frequent, low-severity natural fire regimes. At each site, a common experimental design was used to facilitate broad comparison of treatment effects. This FFS network likely represents the largest operational-scale experiment ever funded to test silvicultural treatments designed to balance ecological and economic objectives for sustaining healthy forests. Details of the network and links to individual sites are available at the web site http://www.fs.fed.us/ffs/. In this paper, we report on the study objectives and research approach, provide a status of work at the different FFS sites, and present initial results of changes in stand structure and related understory vegetation for a subset of the sites.

STUDY OBJECTIVES OF THE FIRE AND FIRE SURROGATE STUDY

The FFS study was designed to quantify the ecological and economic consequences of fire and fire surrogate treatments across a number of forest types and conditions in the United States. Specific objectives are listed below:

1. Quantify the initial effects (first 5 years) of fire and fire surrogate treatments on specific core response variables within the disciplines of vegetation, fuel and potential fire behavior, soils and forest floor, wildlife, entomology, pathology, and treatment costs and utilization economics.

2. Establish and maintain an integrated national network of long-term interdisciplinary studies using a common "core" design that facilitates broad applicability of results yet allows each site within the national network to be independent for statistical analyses and modeling, and allows flexibility for addressing locally-important issues.

3. Designate FFS research sites as demonstration areas for technology transfer to professionals and for the education of students and the public.

4. Develop an integrated and spatially-referenced database and archive data from all network sites; facilitate developing interdisciplinary and multiscale models, and integrate results across the network.

5. Over the long term, continue to monitor the results of treatments, repeat treatments where appropriate, develop and validate models of ecosystem structure and function, and refine recommendations for ecosystem management.

RESEARCH APPROACH

The FFS study is implemented on land administered by the USDA Forest Service, the USDI National Park Service, various university experimental forests and education centers, state parks, and state forests. The core experimental design for the FFS study includes common treatments, similar treatment replication and plot sizes, and common response variables for all research sites in the network. The four treatments used at 12 of the 13 sites include (1) untreated control, (2) prescribed fire only, with periodic repeated burns, (3) mechanical thinning, with periodic repeated thinning, and (4) mechanical thinning followed by prescribed fire, with this combination repeated as necessary. Treatments at the Sequoia National Park site consisted of an untreated control, an early-season burn, and a late-season burn, which are the principal landscape-scale treatment options on lands managed by the National Park Service. The FFS treatments span a range of realistic management options, and they likely will provide a range of ecological effects. Implementation of the active (noncontrol) treatments at each site was guided by a desired future condition or target stand condition uniquely defined for each site such that, if impacted by a head fire under 80th percentile weather conditions, at least 80 percent of the basal area of overstory trees would survive. Treatments were replicated at each of the sites at least three times in either a completely randomized or randomized block design. Each treatment unit was at least 10 ha and surrounded by a

Table 1—Location and current status of sites in the Fire and Fire Surrogate study network

FFS site	Forest type	Location	Treatment year
Blodgett	Ponderosa pine and white fir	Central Sierra Nevada, California	2002
Hungry Bob	Ponderosa pine and Douglas-fir	Blue Mountains, northeastern Oregon	1998-2000
Jemez Mountains	Ponderosa pine	Northern New Mexico	In progress
Lubrecht Forest	Ponderosa pine and Douglas-fir	Northern Rockies, western Montana	2002
Mission Creek	Ponderosa pine and Douglas-fir	Central Cascades, Washington	In progress
Ohio Hills	Mixed oaks	Southern Ohio	2001
Sequoia	Ponderosa and sugar pine, white fir	Southern Sierra Nevada, California	2002
Solon Dixon	Longleaf pine	South central Alabama	2003
South Carolina Piedmont	Loblolly and shortleaf pine	Northwestern South Carolina	2001-2002
Southern Appalachian	Hickory, oaks, and shortleaf pine	Southwest North Carolina	2002-2003
Southern Cascades	Ponderosa pine	Southern Cascades, northern California	2000-2002
Southern Coastal Plain	Longleaf and slash pine	Central Gulf Coast, Florida	2001
Southwest Plateau	Ponderosa pine	Northern Arizona	2003

similarly treated 50-m buffer. Assignment of treatment to each of the units was completely random. This requirement for randomization is central to the conduct of science but has not often been a part of large operational-scale studies involving land-management agencies.

Core variables encompassed several broad disciplines, including vegetation, fuel and potential fire behavior, soils and forest floor, wildlife, entomology, pathology, and treatment costs and utilization economics (FFS Study Plan 2001). Some 400 response variables were selected for monitoring, with the majority spatially referenced to a 50-m square grid of permanent sample points established and maintained in each treatment unit.

Funding for the FFS has come from home institutions and agencies, the USDA through a National Research Initiative competitive grant, the National Fire Plan, and primarily the Joint Fire Science Program.

The FFS study has three organizational tiers. The first tier is site leaders or managers who ensure uniformity of layout and implementation across all disciplines at a single site. The site managers, along with group leaders for the study disciplines (entomology, economics, fuels, pathology, soils, vegetation, and wildlife) belong to the Science and Management Integration Committee (SMIC), the second tier in the organization. The third tier is a five-member Executive Committee (a national network manager, two disciplinary group leaders, and two site managers) selected by the SMIC. Initially, the SMIC developed comprehensive study plans guiding study implementation at each site, noting any justifications for and deviations from the agreed-upon national FFS standard in implementation or monitoring. In addition, the SMIC is responsible for ensuring that (1) site-level studies are progressing according to project guidelines, (2) data collection protocols and analysis remain consistent and state-of-the-art, (3) data are properly archived and managed, and (4) integration is occurring at all levels. Site managers have responsibility for ensuring data are collected appropriately and are maintained in local databases, while the SMIC oversees the creation of a central national FFS database. The Executive Committee is responsible for project oversight, distribution of funds, and reporting to the Joint Fire Science Program Governing Board.

CURRENT STATUS OF WORK AT FFS RESEARCH SITES

Most of our field effort began in early 2000. The initial set of treatments has been completed at 11 of the 13 sites (table 1), and measurement of responses is ongoing. Prescribed fire for fuel reduction has been used at all sites; however, the season of application, intensity of burn, and frequency of burn varied across sites. For example, even though the Hungry Bob site in northeastern Oregon and the Lubrecht Forest site in western Montana have similar stand histories, stand structure, and vegetation composition, burns at Hungry Bob were conducted in October, whereas burns at Lubrecht Forest were conducted in May and June. Burns at the Southern Coastal Plain site in Florida were scheduled as an early-season treatment on a 3-year return interval; the second iteration of burns was completed early in the spring 2004. At most sites, mechanical fuel treatments generally consisted of removing small-diameter stems in a low thinning by using a combination of single-grip harvester and forwarder. All trees to be harvested were marked prior to harvest activities. At the Southern Coastal Plain site, the accumulation of fuels was in understory layers and consisted primarily of herbaceous matter rather than overstory layers; therefore, the mechanical treatment employed a roller drum chopper. At Blodgett in California, large stem diameters required an initial commercial thinning from below by hand-falling, with logs yarded to landings by rubber-tired skidders. Next, live and dead understory stems were masticated by using an excavator with a disk-type cutter head, with masticated material left on site. In all but the Ohio, Alabama, North and South Carolina, and Florida sites where litter decomposition occurs rapidly, the combination treatment of mechanical thinning followed by prescribed fire required waiting a full season for activity fuels to cure before burning.

Pretreatment data has been collected on all sites, as has most of the first year post-treatment data. Our first challenge within the FFS network was to portray immediate or short-term changes resulting from treatments. These short-term changes are likely of general interest to managers concerned with how conditions changed as a result of treatment. To answer this question, we used both pre- and post-treatment data and focused on the difference between pre- and post-treatment values. We also used pretreatment data as a covariate. At the site level, univariate analysis of variance for the change in each response variable was a first means of evaluating treatment differences. The second challenge is to predict longer term differences among treatments. These long-term differences are likely of general interest to managers concerned with how response variables change over time in response to the treatments; some Southern sites could also consider how the chosen variables change in response to multiple entries. To answer these longer term questions, pretreatment data is likely of little benefit. At this time, our effort in the FFS network has been confined to addressing the first challenge; over time, we will transition to considering the second challenge.

Because typical univariate analyses test a single potential causal pathway among variables through the direct effect of each predictor, our understanding of the overall system complexity is limited to the number of predictors we examine. In addition to univariate analyses, we intend to use multivariate ordination techniques such as nonmetric multidimensional scaling (NMS) and indicator species analysis (McCune and Grace 2002) for comparing species composition across treatments. A path analysis technique being considered for both site-level and network-level analysis uses indirect effects in structural equation modeling, and may help elucidate previously unrealized relationships (Quinn and Keough 2002). Finally, the SMIC recognized at the onset that the strength of the FFS network could best be realized through the calculation of effect sizes in a meta-analysis.

PRELIMINARY EVALUATION OF CORE RESPONSE VARIABLES

We began assessing the results of treatments the first growing season after full implementation of all treatments at each site. One initial question we addressed was the degree to which the active treatments (prescribed fire, mechanical thinning, and the combination of prescribed fire and mechanical thinning) resulted in similar stand structure. Based on analysis of variance, our active treatments resulted in a reduction in basal area at the Blodgett, Hungry Bob, Lubrecht Forest, Ohio Hills, and South Carolina Piedmont sites ($p < 0.05$) (table 2). The reduction was generally one-third to one-half of pretreatment basal area.

Another important indication of treatment success is the difference in height to live crown, or the height of the lower live branches, because this metric influences the transition of surface fire into tree crowns. Prescribed fire often kills small trees and prunes lower branches or scorches the lower crown of larger trees, whereas mechanical treatments can be more selective in removing only the small trees. Burning significantly increased the height to live crown ($p < 0.05$) at two sites in the western United States (Hungry Bob and Sequoia), but not in two sites in the eastern United States (Ohio Hills and South Carolina Piedmont) (table 2). Fuel types and pretreatment crown closure likely are responsible for the lack of treatment effects on lower crown heights at our southern and eastern sites. Surface fuels decay readily in the high moisture regimes of the Ohio, Alabama, North and South Carolina, and Florida sites, and a greater proportion of the material that burns is live understory compared to more western sites. In addition, the greater pretreatment height to base of live crown (table 3) suggests that self-pruning of lower branches occurs more frequently at these sites, restricting lethal heat to the lower live tree canopies

Our initial results of changes in understory (non-tree) species richness were highly variable (table 2). The lack of universally significant differences between treatments lends support to the hypothesis that sites dominated by natural high-frequency, low-severity fire regimes typically contain plant communities that undergo little floristic change after treatments modeled on historical fire disturbance (Metlen et al. 2004).

Table 2—Significance of pairwise orthogonal contrasts (planned a priori) after univariate analysis of variance for the change in basal area, post-treatment lower crown height, post-treatment understory vascular species richness, and log density for selected Fire and Fire Surrogate study sites

	Blodgett	Hungry Bob	Lubrecht Forest	Ohio Hills	South Carolina Piedmont	Southern Coastal Plain
Change in basal area (m^2-ha^{-1})						
Control vs. three active treatments	0.001	0.001	0.001	0.001	0.011	NS
Burn or thin vs. combined thin and burn	.115	.370	.001	.004	.053	NS
Burn vs. thin	.072	.015	.004	.001	.974	NS
Lower crown height (m)						
Control vs. three active treatments	NA	.004	.011	.899	.277	NS
Burn or thin vs. combined thin and burn	NA	.057	.015	.359	.077	NS
Burn vs. thin	NA	.017	.102	.788	.575	NS
Understory species richness (species·m^{-2})						
Control vs. three active treatments	NA	.107	.683	.001	.859	NS
Burn or thin vs. combined thin and burn	NA	.666	.044	.024	.786	NS
Burn vs. thin	NA	.748	.014	.026	.502	NS
Log density (number·ha^{-1})						
Control vs. three active treatments	NA	.003	NS	NA	.761	NS
Burn or thin vs. combined thin and burn	NA	.066	NS	NA	.383	NS
Burn vs. thin	NA	.001	NS	NA	.478	NS

• NA = Data not currently available for analysis.

• NS = Analysis of variance indicated no treatment effect, therefore contrasts unwarranted.

Finally, log density was selected as one metric for assessing the reduction in ground fuels, along with more traditional measures of volume and mass of litter and duff components, because log density has direct implications for changes in wildlife habitat values. Our first-year assessment indicated a significant reduction of log density with active treatment at Hungry Bob (p = 0.003) (table 2) with burn units containing few logs compared to thinned units. At other sites, log number did not change significantly with treatments. This likely is due to the propensity of fire to reduce the volume and mass, but not totally consume many downed logs, especially if the burns are conducted when moisture content within logs is relatively high. The number of downed logs likely will change over time at all sites as recently killed trees gradually fall to the forest floor.

Our efforts to date have focused on analyzing the individual site and building the network database to facilitate cross-site comparisons by using meta-analysis techniques. For example, we conducted a meta-analysis comparing the live crown height in first-year postburn units with live crown height in first-year control units from six sites. We used MetaWin version 2 (Rosenberg et al. 2000) with means and standard deviation data to calculate Hedges' *d* effect size and nonparametric estimates of the sampling variances for each study based on a fixed effects model. Nonparametric variances were calculated because they may be less constrained by the assumptions based on large sample sizes (Rosenbery et al. 2000). The confidence interval bounding the overall effect size was calculated based on 999 iterations of resampling. Our preliminary meta-analysis failed to indicate a significant network-wide treatment effect (an increase in height to live crown); the overall effect size was 0.4067 with a confidence interval spanning 0.0 (table 3). Yet significant and meaningful differences are anticipated by the third year post-treatment as lower crowns, once scorched by burning, continue to die back. These conflicting results from individual sites draw attention to the value of the FFS study as a large-scale experiment and suggest the value of meta-analysis across the network. Meta-analysis may be useful for determining which variables show similar response across sites, which variables require local interpretation, and the scale at which common themes emerge.

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Table 3—Results of a meta-analysis comparing the first-year post-treatment height to live crown for control and burn only treatments at selected Fire and Fire Surrogate study sites

Site	Mean height, control	Mean height, burn	Effect size (Hedges' *d*)	Nonparametric variance
Blodgett	7.5	7.4	-0.1358	0.6667
Hungry Bob	3.3	7.3	1.6667	.5000
Lubrecht Forest	8.1	7.4	-.2423	.6667
Sequoia	4.7	9.8	1.6543	.5000
South Carolina Piedmont	11.2	11.0	-.1753	.6667
Southern Coastal Plain	12.4	10.3	-1.3596	.7500

Mean effect size	95% confidence interval
0.4067	-0.413 to 1.226

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