THE NATIONAL FIRE AND FIRE SURROGATE STUDY: EARLY RESULTS AND FUTURE CHALLENGES

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Abstract—Fire-adapted ecosystems today have dense plant cover and heavy fuel loads as a result of fire exclusion and other changes in land use practices. Mechanical fuel treatments and prescribed fire are powerful tools for reducing wildfire potential, but the ecological consequences of their use is unknown. The National Fire and Fire Surrogate Study examines the effects of alternative fuel reduction techniques involving fire and mechanical "surrogate" treatments on numerous environmental and economic variables. Impacts of mechanical fuel treatments and prescribed fire on the Piedmont site are shown for several variables. However, a complete understanding of ecosystem function cannot be gained by considering each of these variables alone. Each component of the ecosystem has a distinct reaction to fuel treatment that may be caused by the treatment directly or by interactions with one or more of the other variables. The goal of the National Fire and Fire Surrogate Study is to understand the complex interactions and pathways among all components of the ecosystem.

INTRODUCTION

Several studies document fuel loads after fuel-reduction treatments. However, none has attempted to establish the interactions between fuel reduction and ecological processes. The National Fire and Fire Surrogate (NFFS) Study was established to compare ecological and economic impacts of prescribed fire and mechanical fuel-reduction treatments. Thirteen independent study sites across the United States (eight in the West and five in the East) use identical treatment and measurement protocols. All western sites are dominated by ponderosa pine (*Pinus ponderosa* Douglas ex Lawson & C. Lawson). They represent a geographical range extending from the Eastside Cascades of Washington to the Jemez Mountains of New Mexico. Eastern sites include hardwood-dominated sites in the Ohio Hill Country and Southern Appalachian Mountains of North Carolina, a pine-hardwood site in the Piedmont of South Carolina, a site dominated by longleaf pine (*P. palustris* Mill.) in Alabama, and a site dominated by slash pine (*P. elliottii* Engelm.) in Florida. This paper will focus on results from the Piedmont site and future analyses at the national level.

METHODS

The Piedmont study site is on the Clemson Experimental Forest, which is managed by Clemson University. Topography ranges from rolling hills to moderately steep slopes and is strongly influenced by past agricultural erosion. Elevation ranges from 600 to 900 feet above mean sea level. Most soils are of the Cecil-Lloyd-Madison association. These are Ultisols with moderate to extremely severe erosion. Entisols and Inceptisols are present but not abundant. Entisols occur along streams, and Inceptisols occur on steep slopes. Erosional rills and gullies are common; as much as 100 percent of the surface layer has been removed.

Twelve study sites, to accommodate three replications of each of four treatments, were selected on the basis of size, stand age, and management history. Each site had to be at least 35 acres in size to allow for a 25-acre measurement area and a buffer of at least 1 tree length (approximately 60 feet) around the measurement area. Stand ages varied from 15 to 60 years, but age was used as a blocking factor to reduce variability. Each of three blocks contained four sites dominated either by pulpwood-sized trees [diameter at breast height (d.b.h.) 6 to 10 inches, block 1], by sawtimber-sized trees (d.b.h. > 10 inches, block 3), or by a mixture of pulpwood- and sawtimber-sized trees (block 2). All sites were dominated by either loblolly (*P. taeda* L.) or shortleaf (*P. echinata* Mill.) pines with mixtures of oaks and other hardwoods in the understory and midstory.

Treatments included thinning, prescribed burning, thinning followed by prescribed burning, and an untreated control. Levels of thinning and prescribed burning are defined by NFFS protocols to reduce fuels sufficiently so that most overstory trees will survive a subsequent wildfire. At the Piedmont site, thinning was from below and left a residual basal area of 80 square feet per acre. The burn-only treatment was conducted in spring 2001 with a prescription designed to open the canopy. A combination of strip head fires and flanking fires was used. Flame heights varied from 1 foot to > 10 feet. Burning on the thin and burn treatment was delayed until the spring of 2002 to allow heavy fuel loads to partially decompose. The prescription for these fires was for intensity to be high enough to remove fuels but not high enough to damage overstory trees. Strip head fires were used with flame heights that ranged from 1 to 4 feet.

Over 400 variables were measured for individual studies on the Piedmont site. Detailed methods for all measurements cannot be described here but can be found in the study proposal located at http://www.fs.fed.us/ffs/execsumm-4-17-00.htm. Measurements were made 1 year prior to treatment and 1, 3, and 5 years after treatments. Study results for selected variables for the first year following treatment are presented here.

RESULTS

Vegetation and Fuels

Fuel-reduction treatments changed vegetative structure and composition (fig. 1) (Phillips and others 2004). Burn-only plots had composition similar to that of controls but fewer trees. Thinning and thinning plus burning created distinctly different

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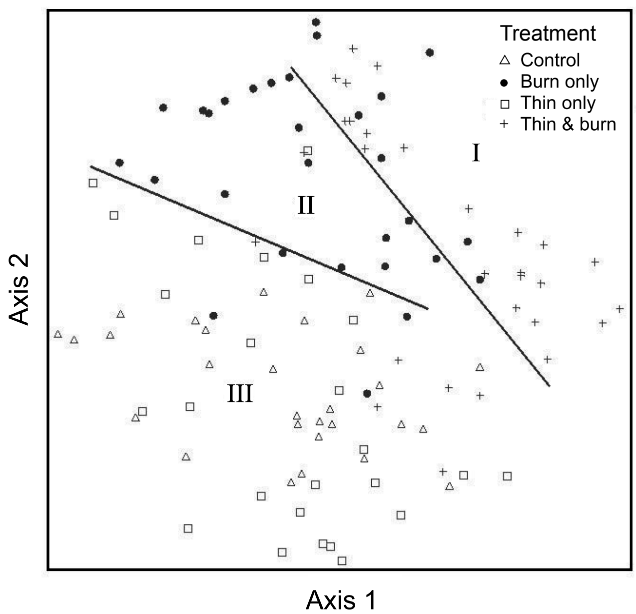

Figure 1—Nonmetric multidimensional scaling ordination for understory vegetation and shrub cover (Phillips and others 2004).

communities. The thin plus burn treatment was the only one that increased grasses and forbs. All treatments reduced litter, but the burn-only treatment reduced it most (fig. 2) (Waldrop and others 2004). Thinning increased fine woody fuels, and they remained high after burning. Treatment had no effect on loading of large woody fuels. BEHAVE predicted that wildfires would be more difficult to control after thinning until logging slash had begun to decompose (Mohr and others 2004).

Soil Properties

Thinning and thinning plus burning increased bulk density of the surface soil layer (Shelburne and others 2004). Both thinning and burning reduced total carbon (C) and nitrogen (N) in the O horizon. Thinning and burning together reduced C and N more than single treatments. In the A/Bt horizon, burning reduced total C and N. Thinning and burning together reduced C and N more than burning alone. Burning significantly reduced total exchangeable capacity relative to other treatments. Decomposition of leaf litter was slower in thinned stands than in burned or control stands (Callaham and others 2004). Nitrogen dynamics varied more over time in thinned and burned stands than in controls. Soil respiration was lower in burned stands than in control or thinned stands, possibly as a result of fire-induced reductions in potentially mineralizable C pools in the forest floor (Callaham and others 2004). These results suggest that C and N dynamics are altered by thinning and burning, but that these alterations are manifested in fundamentally different ways.

Wildlife

Thinning had a positive effect on herpetofaunal abundance, possibly because increased insolation allowed an increase in the area for thermoregulation (fig. 3) (Kilpatrick and others 2004). Small mammal trapping did not yield enough individuals for statistical analysis. Prolonged drought may have reduced the already low population of small mammals on the Piedmont. Spring counts did not indicate that there were treatment-to-treatment differences in songbird abundance and richness (Zebehazy and others 2004). Nest starts increased one season after all fuel-reduction treatments.

Insects and Diseases

The number and size of beetle-killed spots were larger the year after treatment (Boyle and others 2004). However, there were no significant treatment-to-treatment differences. Beetle activity was reduced where tree latewood was high and resin production was greater. Posttreatment *Leptographium* incidence was reduced in all areas including controls. However, incidence was apparently reduced by fuel reduction. Diseases caused by *Phytophthora* were increased by thinning alone and by burning alone but decreased by the combination of thinning and burning.

FUTURE ANALYSES

Numerous reports from individual studies will be published as each of the 13 NFFS sites completes treatment installation

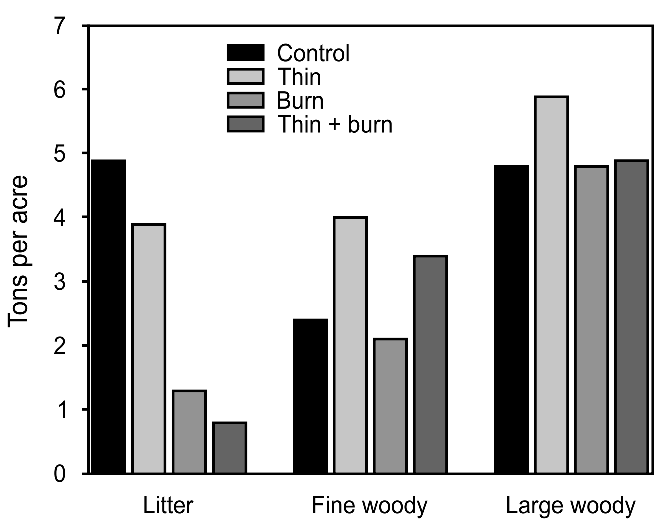

Figure 2—Loading of litter and woody fuels by treatment at the Piedmont NFFS site (Waldrop and others 2004).

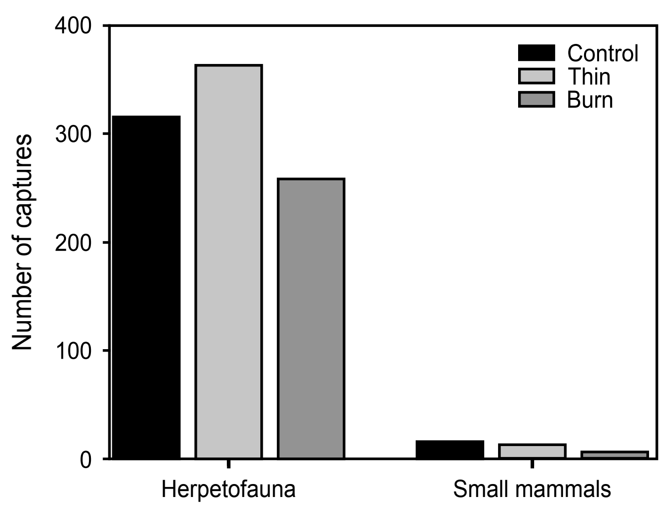

Figure 3—Number of captures of herpetofauna and small mammals during the first year after treatment at the Piedmont NFFS site (Kilpatrick and others 2004).

and posttreatment measurements. These publications will add significantly to our knowledge of multiple ecosystem components. However, the greater challenge will be to determine if fuel treatments create entirely different ecosystems and if these systems continue to function differently over time. Analyses of ecosystem-level questions are complex because they are interdisciplinary: variables may impact other variables in previously unknown ways.

An example of this complexity is the change to the forest floor (fig. 4). Each treatment produced a different forest floor structure. Burning removes the litter layer in a relatively uniform fashion throughout the treatment area. However, thinning completely removes the litter and duff in some areas but leaves other areas undisturbed. Thinning plus burning created the greatest disturbance. The problem goes far beyond identifying simple differences in forest floor structure. The forest floor affects numerous variables such as nutrient cycling, decomposition, and herpetofaunal abundance. Each of these variables in turn impacts many others. The pathways in this simple example are complex and represent only one potential analysis at one NFFS study site. Similar pathways must be investigated for all disciplines at each NFFS site and for all NFFS sites combined. Such analyses will be conducted by NFFS cooperators using a number of univariate and multivariate tools for individual study sites and multiple study sites.

Single-Site Univariate Analyses

At the site level, since experimental units are replicated and treatments assigned randomly, analyses have been and will be conducted primarily with analysis of variance and regression techniques. These techniques are flexible in the sense that independent factors can be added to models depending on the response variable in question. Although these types of analyses can be used to evaluate multivariate questions, they are most suitable for analyzing effects on individual variables. Analyses of these kinds can answer questions such as (1) how do alternative fuel-reduction treatments influence plant species diversity, and (2) how do fire-only and mechanical-plus-fire treatments compare with respect to fuel reduction?

Multi-Site Univariate Analyses

Analysis of variance and regression techniques are also useful for evaluating the responses of individual variables at the network level. For example, we can ask to what extent alternative fuel reduction treatments influence plant diversity in relation to forest type across the NFFS network, or we can ask how differences among logging methods influence the relative effectiveness of fire-only and mechanical-plus-fire treatments in reducing fuels. We plan to use mixed-model analyses of variance to investigate these kinds of questions across the network. However, we will need to use meta-analyses for some questions, especially those that involve variables that respond to different degrees in different systems.

Meta-analysis has been used in medical research for decades (Cooper and Hedges 1994). One of this method's best applications is in the analysis of datasets from separate studies that evaluate the treatment response of a single variable. Typically a researcher surveys the literature for studies on the variable in question, assembles a dataset that describes response of that variable to some set of treatments, and then evaluates the commonality of response, or effect size, to treatment. With this method, the researcher can also explore the extent to

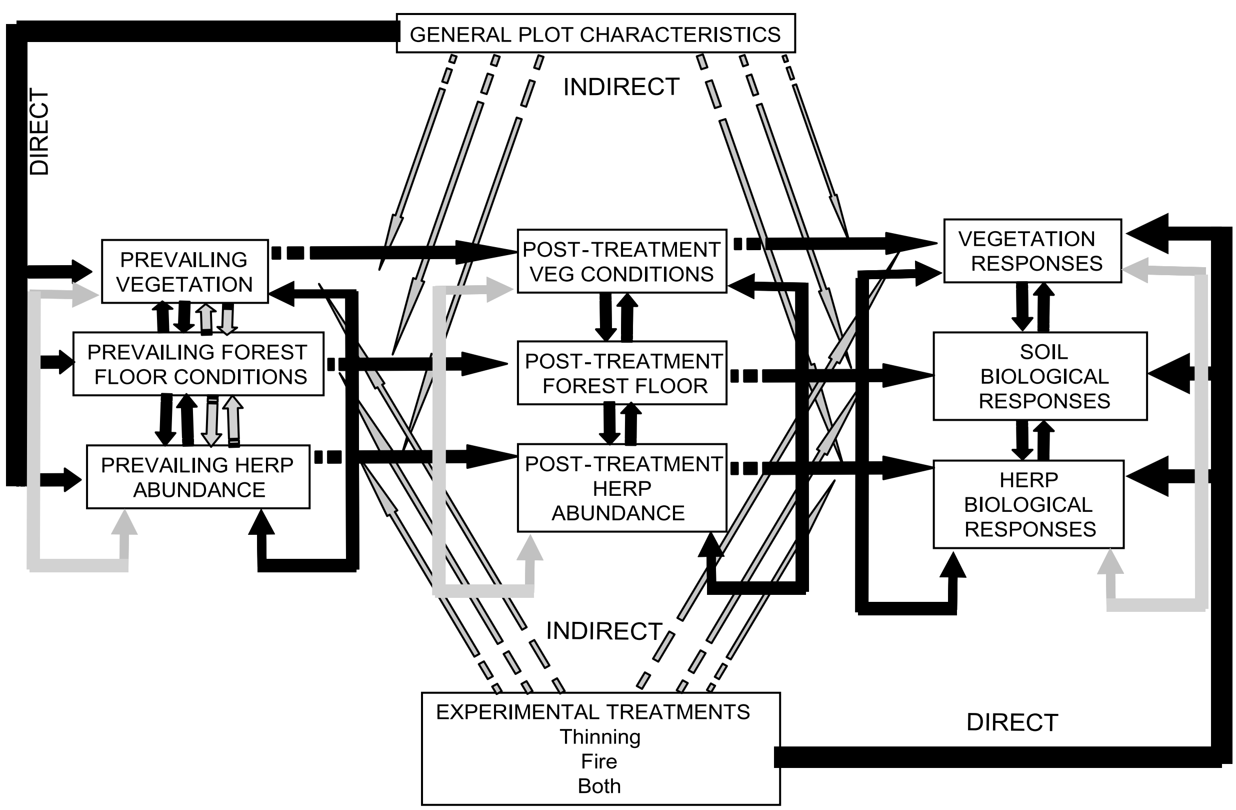

Figure 4—Hypothetical within-site path model of NFFS treatment effects on forest floor, vegetation, and herpetofauna.

which other variables influence the effect size of the dependent variable in question. Meta-analysis has been used sparingly in forest ecology, primarily in the past 10 years. Its use has been limited by the relative scarcity of studies that are both robust and similar enough to provide data that can be aggregated effectively. For example, Kopper (2002) found only eight major studies that had a robust enough experimental design to be included in a meta-analysis on the influence of prescribed fire on fuel reduction in ponderosa pine systems. In contrast, the NFFS project has three design features that make it uniquely suitable for meta-analytic techniques: (1) each of the 13 sites can be regarded as a separate study; (2) each site has a robust stand-alone experimental design; and (3) the experimental designs are identical among sites. With meta-analysis, we can ask not only to what extent forest types influence how plant species diversity is affected by alternative fuel reduction treatments but also how a number of other variables affect diversity, including soil type, fuel loadings, season of burn, and logging technique. Information on conditional response to treatment will allow managers to better predict how a treatment will perform given their unique sets of circumstances.

Single-Site, Multivariate Analyses

At the site level, the FFS study is a multivariate experiment and is an attempt to capture whole-system responses to fire and fire surrogate treatments. This design has great value from a management perspective, because the information we generate will allow managers to assess tradeoffs in response to treatment for different key variables. For example, we can determine how much fuel must be removed to prevent wildfire and also determine whether that level of fuel reduction will eliminate key habitat for wildlife (fig. 4). Also, we can determine the cost per ton of fuel reduction for different fire and fire surrogate treatments. From a scientific perspective, the multivariate design will allow us to better understand not only how multiple components of the system respond but also how relationships among components change when treatments are applied. Use of multivariate techniques is necessary to extract this kind of information. For example, standard multivariate techniques such as ordination and classification can help us understand how treatments influence plant species composition (fig. 1) rather than just diversity as expressed by a single measure (McCune and Grace 2002). Compositional changes are likely to be more important than diversity changes because species differ with respect to their function, e.g. nitrogen fixers, or with respect to their relative value for humans, e.g. native plants vs. invasive plants.

In order to evaluate how relationships among components within a system respond to treatment, we need multivariate techniques that go beyond simple ordination and classification. A potentially useful tool is structural equation modeling (SEM) (Pugesek and Tomer 2003). SEM has been used for many years in economics and social science, but there are relatively few examples of SEM in ecology (Grace and Pugesek 1998). One way to describe SEM is to compare it to multiple regression. Multiple regression allows one to determine simultaneously how a number of key independent variables influence one dependent variable. A typical multiple regression model identifies both the relative influence of each independent variable on the dependent variable and the correlations among independent variables. Although this technique can be useful for exploring complex relationships, it has limited applicability in modeling of real systems because possible interactions among variables are constrained: in real systems, independent variables can only be correlated to one another and can only be related to the dependent variable with a one-way cause-to-effect relationship. A typical SEM model, on the other hand, can have a much more flexible structure of relationships. The technique requires that the investigator build a hypothetical model, such as the one shown in figure 4, that includes the key variables and their causal relationships not only to the dependent variable but to one another. In essence, one builds a model of how the system is predicted to work and then tests the model with real data from the experiment. With SEM, we can answer questions about the response of key variables within the context of the whole system. For example, we can answer questions about the influence of soil type on the degree to which fire and fire surrogates affect the susceptibility of trees to bark beetles. Factors such as slope, elevation, aspect, and initial fuel loads can also be evaluated in the context of a structural equation model.

Multi-Site, Multivariate Analyses

Each of the multivariate techniques described in the previous section can also be used for among-site analyses. Ordination can be used to investigate site-to-site differences in how plant species composition changes due to treatment. For example, do invasive plants respond similarly to treatment across the network? Do fire and fire surrogate treatments tend to cause common responses in nitrogen-fixing species? Similarly, SEM can be used for multi-site analyses as well. A single structural model may be confirmed for one site but not for another, leading the investigator to identify the factors responsible for the difference. These techniques can be very useful in helping to understand the conditional response to treatment of key variables, which will allow managers to better predict how fire and fire surrogate treatments will function in systems under their care.

Current Status

Installation of treatments for the NFFS is nearing completion at all 13 sites across the country. Publications describing single-site univariate studies are becoming numerous and are listed on the NFFS web site (http://www.fs.fed.us/ffs/). Single-site multivariate analyses are underway at some locations. Multiple site analyses have begun for vegetation, fuels, and wildlife. Results of interdisciplinary studies should become available in 2006.

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