AN EVALUATION OF FUEL-REDUCTION TREATMENTS ACROSS A LANDSCAPE GRADIENT IN PIEDMONT FORESTS: PRELIMINARY RESULTS OF THE NATIONAL FIRE AND FIRE SURROGATE STUDY

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Abstract—The National Fire and Fire Surrogate (NFFS) Study is a large-scale study of the impacts of fuel-reduction treatments on ecological and economic variables. This paper examines prescribed burning and thinning as fuel-reduction treatments on one site of the national study, the southeastern Piedmont. Fuel loads were examined across a landscape gradient before and after treatment. Fuel treatments provided fairly predictable changes to the litter, duff, fine woody fuels, and large woody fuels. Prescribed burning reduced most fuels while thinning tended to increase woody fuels because logging debris was scattered throughout the thinned areas. These patterns varied by landscape position. On mesic sites, burning did not reduce the duff, and none of the treatments changed loading of woody fuels. These results suggest that fuel-reduction treatments may alter numerous components of an ecosystem and that these impacts vary according to landscape position.

INTRODUCTION

Excessive fuel loading has become a concern for forests throughout the United States, particularly in ecosystems where fires were historically frequent. In the southeastern Piedmont, most commercial forest land is in unmanaged nonindustrial private ownerships (Bechtold and Ruark 1988), where fuels are allowed to accumulate. The need for fuel reduction is apparent, but little research is available to guide management decisions. A critical finding of the Sierra Nevada Ecosystem Project (1996) is that silvicultural treatments are readily available that can reproduce the structure of historical forests, but the impacts of these treatments on ecosystem function are largely unknown.

A number of studies document fuel loads after various fuel-reduction treatments in the Piedmont (Geisinger and others 1989, Sanders and Van Lear 1988, Scholl and Waldrop 1999, Waldrop 1997). However, none has attempted to establish the interactions of fuel-reduction treatments with ecological processes and functions. The National Fire and Fire Surrogate (NFFS) Study (Weatherspoon 2000) was established to compare ecological and economic impacts of prescribed fire and mechanical fuel-reduction treatments. Thirteen independent study sites across the United States use identical treatment and measurement protocols. This paper presents preliminary results from one NFFS site in the southeastern Piedmont.

Fuel loads in the Piedmont have a strong relationship to decomposition and position on the landscape (Abbot and Crossley 1982, Ball and others 1993, Crooks and others 1997, Waldrop 1996). Impacts of fuel treatments on ecosystem functions may vary across a landscape by altering microhabitat differently at different landscape positions. However, this hypothesis has never been tested. Jones (1991) developed a Landscape Ecosystem Classification (LEC) system for the Piedmont to identify individual landscape units that primarily represent soil-moisture classes. Each class is a distinct combination of slope, aspect, exposure, and soil water-holding capacity. In this study, our specific objectives are to examine variability of fuel loading in Piedmont pine-hardwood stands across LEC classes, to determine the success of silvicultural treatments for reducing fuel loads, and to determine the interaction of silvicultural treatments and landscape position on fuel loads.

METHODS

The Piedmont site of the NFFS Study is on the Clemson Experimental Forest, managed by Clemson University, in Pickens, Oconee, and Anderson Counties of South Carolina. A wide variety of cover and site types occur on this forest. Topography is strongly a factor of past erosion and ranges from rolling hills to moderately steep slopes. Elevation ranges from 600 to 900 feet above sea level. Most soils are of the Cecil-Lloyd-Madison association, 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. Because of accelerated erosion during the row-cropping era (about 1800 through 1930), rills and gullies are common; as much as 100 percent of the surface soil layer has been removed.

Twelve study sites, one for each treatment area, were selected for size, stand age, and management history. Each site was at least 35 acres to allow for a 25-acre measurement area and a surrounding buffer. Selected sites were judged to be in danger of uncharacteristically severe wildfire due to heavy fuel loads. None had been thinned during the past 10 years, and none had been burned (wildfire or prescribed fire) in at least 5 years. Stand ages varied from 15 to 60 years, but age was used as a blocking factor to reduce variability. Each of three blocks contains four sites (one for each treatment) that

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are dominated by either pulpwood-sized trees [diameter at breast height (d.b.h.) 6 to 10 inches, block 1], sawtimber-sized trees (d.b.h. > 10 inches, block 3), or a mixture of pulpwood- and sawtimber-sized trees (block 2). All sites were dominated by either loblolly (*Pinus taeda*) or shortleaf (*P. echinata*) pines, with mixtures of oaks and other hardwoods in the understory and midstory.

One of four treatments, as defined by NFFS protocols, was randomly assigned to each treatment area within a block. Treatments include 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 most overstory trees will survive a wildfire. The thin-only treatment was conducted by contract and was specified as a thinning from below. Small merchantable trees and diseased or insect-infested trees were selected first. Other trees were removed as necessary to provide a residual basal area of 80 square feet per acre. Thinning operations were conducted in the winter of 2000–01. Residual slash was spread over the treatment area.

The burn-only treatment was conducted in the spring of 2001 with a prescription designed to reduce fuels and to open the canopy. A combination of strip head fires and flanking fires was used. Flame heights varied from 1 foot to > 10 feet in locations where fuels were heavy.

Thinning on the thin-and-burn treatment was conducted at the same time and with the same contract conditions as the thin-only treatment. Burning, however, was delayed 1 year to 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.

Within each treatment area, 40 permanent grid points were established on a 165-foot spacing following cardinal directions. Pre- and posttreatment data were collected at the grid points or locations specified by NFFS protocols. Woody fuel quantities, as well as litter and duff weight and depth, were measured at every grid point.

Litter and duff weight and depth were determined by destructively sampling the forest floor. Samples were randomly selected in areas that represent the full range of forest floor depth on each treatment area. A pilot study using two forest floor samples from each grid point was conducted to determine the sample size need for the remaining areas. Based on the dry weight of litter (L layer) and duff (F and H combined) samples, the sample size equation (Schaeffer and others 1979) predicted that 25 samples per treatment area would estimate the true population mean to within 2 percent. Therefore, one litter and one duff sample were collected at each of the 40 grid points in the remaining treatment areas.

A 1-foot-square wooden frame was used along with a cutter to collect each sample by layer (L and F/H), and each layer was bagged separately. After careful removal of the frame, each layer was measured on each side of the sampled area. Each sample was then washed to remove soil and rocks and dried in an oven set at 85 °C to a constant weight. Litter and duff samples were then weighed in the laboratory to develop regression equations for depth and weight. Resulting equations were used to calculate litter and duff weight on a per-acre basis.

The down dead-woody fuels were measured before and after treatment using the planar intercept method described by Brown (1974). Three 50-foot transects were established approximately 6 feet away from each grid point in a randomly selected direction. This method produced a total of 72,000 feet of fuel transects. Fuels were classified by size class: 1-hour fuels (0 to 1/4 inch), 10-hour fuels (1/4 to 1 inch), 100-hour fuels (1 to 3 inches) and 1,000-hour fuels (3+ inches). One- and ten-hour fuel intercepts were counted along the first 6 feet of the transect and 100-hour fuels were counted along the first 12 feet. Fuels in the 1,000-hour class were recorded by species, diameter, and decay class along the entire 50-foot transect. Fuel counts were converted to weights with equations given by Brown (1974). Statistical analyses of fuel loads were conducted for litter, duff, fine woody fuels (1-, 10-, and 100-hour fuels) and large woody fuels (1,000-hour fuels).

Each grid point in all 12 treatment areas was visited to determine its LEC unit. Landform index (McNab 1993), terrain-shape index (McNab 1989), and depth to the Bt soil horizon were measured. Values were entered into a discriminant function developed by Jones (1991). Equation results indicated which LEC unit best described the area around each grid point. Possible LEC units included xeric, subxeric, intermediate, submesic, and mesic. Fuel loads (litter, duff, fine woody fuels, and large woody fuels) were determined for each LEC unit within each treatment area. Differences and interactions among treatments and LEC units were tested by analysis of variance with mean separation by linear contrast. Differences were considered significant at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Accumulation of litter, duff, fine woody fuels, and large woody fuels will first be presented across LEC units before treatment. Next, treatment effects across all LEC units combined will be presented. Finally, the interactions of treatment and LEC unit will be presented.

Landscape Position Effects on Fuel Loads

Litter accumulation before treatment did not vary among LEC units and averaged 5.5 tons per acre (table 1). Duff accumulation did vary by landscape position, with the least accumulation on the driest and wettest sites. This pattern agrees with an earlier study by Ball and others (1993) who suggested that duff depth was determined by a balance of root production and decomposition rates. On moist sites, decomposition rates are higher than on dry sites, and root production is probably lower in these areas because water is readily available. On xeric sites, decomposition is slower, but root production must be lower due to the poor quality of the site. These results suggest that extra care should be taken when thinning mesic sites or when thinning or burning the xeric sites to prevent soil exposure and erosion.

Table 1—Litter and duff weight across Landscape Ecosystem Classification units before treatment

LEC unit	Litter weight	Duff weight
	- - tons per acre - -	
Xeric	5.3a[a]	5.5b
Subxeric	5.6a	7.3a
Intermediate	5.7a	7.2a
Submesic	5.7a	6.3ab
Mesic	5.3a	5.3b

LEC = Landscape ecosystem classification.

[a] Means followed by the same letter within a column are not significantly different at the 0.05 level.

Accumulation of fine woody fuels varied somewhat across LEC units (table 2). Loading of fine woody fuels tended to be greater on the more moist LEC units, which is probably a result of higher productivity on moist sites. Loading of 1-hour and 10-hour fuels was significantly greater on mesic sites. The larger 100-hour fuels were highly variable, and significant differences were not detected. For total fine fuel loading, the variability of 100-hour fuels masked the differences shown for smaller fuels, so significant differences were not detected.

The implications of these results are somewhat unclear for wildfire management and prescribed burning. Usually, extra care should be exercised in areas with heavier fuel loading. Because these heavy loads were on moist sites, however, fire behavior may not be strongly associated with these differences.

Large woody fuels (> 3 inches in diameter) correspond roughly to coarse woody debris. Loading of these fuels ranged from 4 to 6 tons per acre and did not vary among LEC units (table 2). Coarse woody debris is an important structural component of these ecosystems, contributing habitat for wildlife, insects, and microorganisms. These results suggest that differences in decomposition and productivity among LEC units balance the accumulation of large woody fuels, particularly in the absence of catastrophic disturbances.

Treatment Effects on Fuel Loads

Litter weight did not vary among treatment units prior to treatment and averaged about 5 tons per acre (table 3). After treatment, litter loads followed a fairly predictable pattern. Loading was reduced somewhat by thinning, but burning was necessary to remove the litter layer. Litter weight was significantly lower in burned plots and thin-and-burn plots when compared to controls or thin-only plots.

As with litter, the duff layer was uniform throughout treatment areas before treatment (table 3), with an average of about 7 tons per acre. After treatment, duff weights were highly variable. The only treatment with a significant decrease in duff was the combination of thinning and burning. Even though the mean duff weights for thinning alone and burning alone were not significantly different, the two treatments produced different forest floor structure. Burning removed a portion of the duff over a large area, while thinning removed larger portions of the duff in skid trails but none in undisturbed areas. These differences probably have little impact on fire behavior but may impact nutrient cycling, understory vegetation, and herpetofaunal populations, particularly on mesic sites where herpetofauna are more abundant and duff is thin.

Fine woody fuels did not vary among treatment areas before treatment (table 4). However, they changed dramatically in response to thinning. Loading increased from 2.9 to 4.0 tons per acre as tops were left throughout thinned areas. Prescribed burning did not reduce loading of these fuels. There were no significant differences when comparing the burn-only treatment to the control or when comparing the thin-and-burn treatment to the thin-only treatment. As expected, these results indicate that thinning increases fire risk and fire intensity for some period of time after treatment. A more interesting question will be how long this impact will last and what the implications will be for future fuels management and ecosystem function.

Loading of large woody fuels varied from 4.6 to 5.9 tons per acre before and after treatment, but there were no significant differences among treatments at either time (table 4). Prescribed burning of the intensities used in this study had little impact on larger fuels. Thinning was expected to increase loading in this size class, but variability may have been too high to detect the difference that is shown here.

Table 2—Weights of fine and large woody fuels across Landscape Ecosystem Classification units before treatment

LEC unit	1-hour fuels	10-hour fuels	100-hour fuels	Total fine fuels	1,000-hour fuels	Total woody fuels
	- tons per acre -					
Xeric	0.27c[a]	1.05b	0.97a	2.29a	5.8a	8.1a
Subxeric	0.30c	1.07b	1.55a	2.92a	6.0a	8.9a
Intermediate	0.33ab	1.16b	1.55a	3.04a	5.1a	8.1a
Submesic	0.30bc	1.10b	1.44a	2.84a	4.3a	7.1a
Mesic	0.41a	1.65a	1.88a	3.94a	5.1a	9.0a

LEC = landscape ecosystem classification.

[a] Means followed by the same letter within a column are not significantly different at the 0.05 level.

Table 3—Weight of litter and duff before and after treatment

Treatment	Litter weight before treatment	Litter weight after treatment	Duff weight before treatment	Duff weight after treatment
	tons per acre			
Control	5.4a[a]	4.9a	7.5a	7.7a
Thin only	5.2a	3.9b	7.0a	5.3a
Burn only	5.0a	1.3c	6.7a	5.1ab
Thin and burn	4.7a	0.8c	6.5a	3.5b

Landscape ecosystem classification (LEC) units combined.
[a] Means followed by the same letter within a column are not significantly different at the 0.05 level.

Table 4—Weight of fine and large woody fuels before and after treatment

Treatment	Fine woody fuels before treatment	Fine woody fuels after treatment	Large woody fuels before treatment	Large woody fuels after treatment
	tons per acre			
Control	2.7a[a]	2.4a	4.6a	4.8a
Thin only	2.9a	4.0b	5.8a	5.9a
Burn only	3.2a	2.1a	5.4a	4.8a
Thin and burn	2.6a	3.4b	5.8a	4.9a

[a] Means followed by the same letter within a column are not significantly different at the 0.05 level.

Interaction of Landscape Position and Treatment Effects on Fuel Loads

Treatment means for litter, duff, fine fuels, and large fuels are shown in figures 1 through 4, respectively, and grouped by subxeric, intermediate, and mesic sites. Xeric sites were not included, because too few of these sites existed in burned stands for analysis. Submesic sites were not shown to improve visual clarity.

Prior to treatment, litter weights did not vary among LEC units (table 1), so an interaction between treatment and LEC unit was not anticipated. The same general pattern of treatment effects on litter loads occurred across all LEC units (fig. 1). Thinning reduced litter weights to some degree, but burning nearly removed the entire litter layer.

Responses of the duff layer to treatments did vary among LEC units (fig. 2). Duff reduction follows the same pattern on subxeric and intermediate sites, but differences occurred on mesic sites. On subxeric and intermediate sites, duff was reduced by both thinning and burning treatments. On mesic sites, however, burning had no impact on the duff layer. This suggests that the duff was too moist to burn on protected mesic sites when it would burn on more exposed drier sites. While the overall objective of treatment is to reduce fuels, protection of the duff on moist sites should

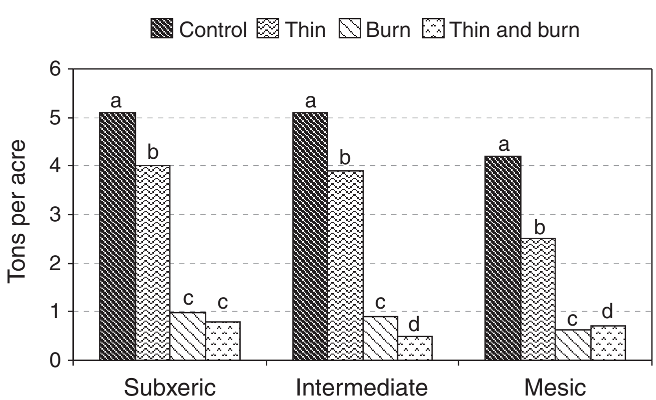

Figure 1—Posttreatment litter weights by treatment and Landscape Ecosystem Classification unit. Means followed by the same letter within a group are not significantly different at the 0.05 level.

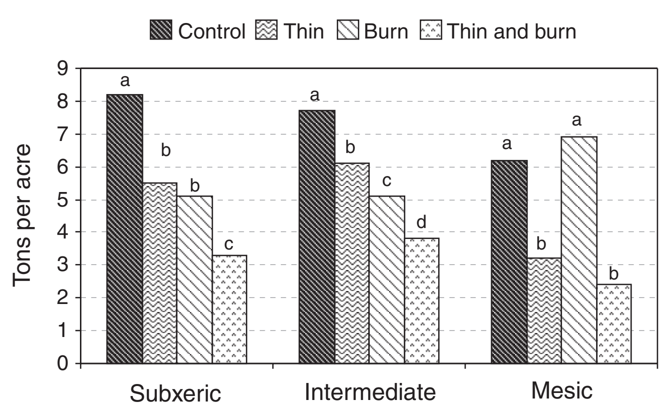

Figure 2—Posttreatment duff weights by treatment and Landscape Ecosystem Classification unit. Means followed by the same letter within a group are not significantly different at the 0.05 level.

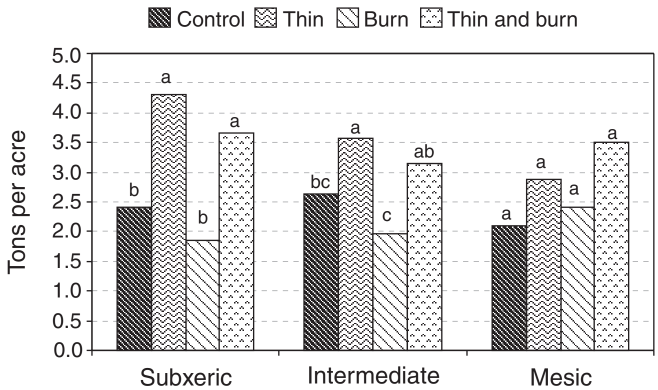

Figure 3—Posttreatment weights of fine woody fuels by treatment and Landscape Ecosystem Classification unit. Means followed by the same letter within a group are not significantly different at the 0.05 level.

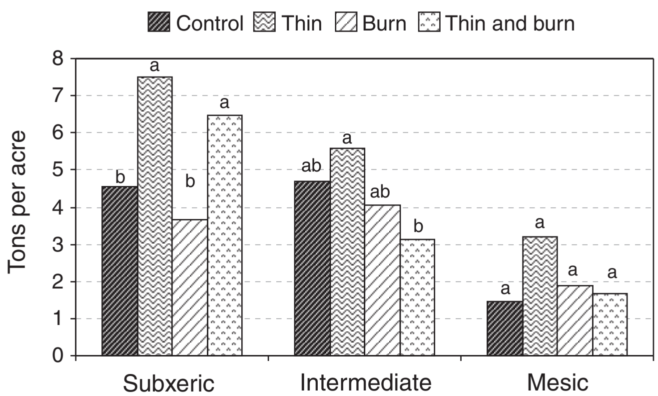

Figure 4—Posttreatment weights of large woody fuels by treatment and Landscape Ecosystem Classification unit. Means followed by the same letter within a group are not significantly different at the 0.05 level.

be considered beneficial for protecting water quality and habitat of numerous organisms.

Loading of fine woody fuels showed a significant interaction between treatment and LEC units (fig. 3). On subxeric and intermediate sites, thinning increased loading of these fuels, and burning reduced loading somewhat. Even though mesic sites had the same general pattern, the differences were not significant. It may be possible that fewer trees were harvested from mesic sites or that the results were too variable to detect differences.

Loading of large woody fuels showed an interaction between treatment and LEC (fig. 4). Fuel loading on subxeric sites followed a predictable pattern, with increases in the thinned and thin-and-burn plots. However, treatment impacts were less pronounced on intermediate and mesic sites. There is a general tendency across sites for lower loading on the more moist sites. Loading of large fuels on control plots was significantly lower on mesic sites than on subxeric or intermediate sites. This difference on mesic sites may be attributed to increased decomposition rates or lack of inputs, possibly due to better tree vigor. Lack of fuel inputs in burned areas was expected, especially on mesic sites where fire intensity would be reduced. The lack of fuel inputs on thinned mesic sites was unexpected. Casual observation of these sites suggests that fewer trees were harvested from those areas. In addition, these areas tended to be at the bottom of slopes so that trees were probably felled uphill. In this case logging slash would have accumulated in other LEC units.

SUMMARY AND CONCLUSIONS

The LEC System proved useful in understanding fuel loading across landscapes. Duff layers were thin on xeric and mesic sites, and loading of 1- and 10-hour fuels was heavier as soil moisture increased. Treatment impacts on fuels followed a fairly predictable pattern. Litter and duff were removed by the thin-only and burn-only treatments, and a greater quantity of both was removed by thinning plus burning. Fine woody fuels were increased by thinning, but burning had little impact. A better understanding of fuel accumulation was achieved by examination of the interactions of treatments and LEC units. Litter and duff were generally reduced by treatments, except that burning on mesic sites had no impact on the duff layer. Thinning generally increased loading of both fine and large woody fuels, except on mesic sites where no additions were observed. This study suggests that, in the short term, wildfire behavior on xeric through intermediate sites would be reduced by prescribed burning but increased by thinning, even in combination with prescribed burning.

Several components of these ecosystems may have been impacted by fuel-reduction treatments. Each treatment is likely to impact microsite weather conditions which will impact fire behavior, habitat for many organisms, and nutrient cycling. Differences of duff structure between thinning and burning may affect insect and herpetofaunal populations, soil fertility, and nutrient cycling. Treatment differences also impact forest structure by adding or removing coarse woody debris. These impacts are likely to impact wildlife habitat and nutrient cycling. Continued monitoring of all variables and treatment areas in the NFFS Study are needed to provide greater insight into ecosystem changes over time.

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