FIRE AND FIRE SURROGATE STUDY: ANNOTATED HIGHLIGHTS FROM OAK-DOMINATED SITES

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Abstract.—The National Fire and Fire Surrogate (FFS) study was implemented to investigate the ecological impacts of prescribed fire and mechanical operations to mimic fire in restoring the structure and function of forests typically maintained by frequent, low-intensity fires. Two of the 12 sites were located in oak-dominated forests, one in Ohio and another in North Carolina. This paper summarizes results from these two sites that have been published in peer-reviewed literature, covering fire history, fuels and fire behavior, entomology, soils and belowground processes, wildlife, and vegetation. We concluded that the FFS treatments did little harm to this ecosystem, benefit many ecosystem components, and promote oak and hickory regeneration. These effects could be transient, however, and need to be studied over the long term to determine sustainability of the ecosystem.

INTRODUCTION

The National Fire and Fire Surrogate (FFS) Study was established in 2000 to compare ecological and economic impacts of prescribed fire and mechanical fuel-reduction treatments in forest types that developed under low intensity, high frequency fire regimes (Youngblood et al. 2005). These treatments were chosen to restore ecosystem structure and resiliency to forests that have experienced fire suppression for several decades. Twelve independent study sites across the United States (seven in the West and five in the East; Fig. 1) received identical treatment (prescribed fire and mechanical fuel reduction treatments) and measurement protocols. Core variables collected at each of the 12 sites encompassed several ecosystem components: vegetation composition and structure, fuel loading and fire behavior, soils and forest floor physical and chemical properties, wildlife, entomology, pathology, and utilization and economics. Five western sites are dominated by ponderosa pine (*Pinus ponderosa*) and two are classified as mixed coniferous forests. Eastern sites consist of hardwood-dominated forests in the Central Appalachian Plateau in Ohio and Southern Appalachian Mountains of North Carolina, a pine-hardwood forest in the Piedmont of South Carolina, a forest dominated by longleaf pine (*P. palustris*) in Alabama, and a site dominated by slash pine (*P. elliottii*) in Florida.

Two FFS sites—the Southern Appalachian Mountain and Central Appalachian Plateau sites—are located in oak-dominated forests. Scientific information generated by these two sites has been disseminated to more than 10,000 people during field trips. More than 50 scientific articles have been published in peer-reviewed journals or U.S. Forest Service publications. Downloadable versions of many of these publications are available through the www.treesearch.fs.fed.us Website. A listing of most FFS study articles may be found at the frames.nbii.gov website (click on the FFS link, then publications). In this paper we present an annotated reference list of some of the research highlights from these two oak-dominated sites to provide the readers with a sense of the breadth of the work conducted. Land managers may wish to use this publication as a starting point to find articles concerning the effects of fire and mechanical treatments on oak-dominated ecosystem components. In some cases, results reported in earlier articles (such as Rebbeck et al. 2004, Albrecht and McCarthy 2006, Long et al. 2006, and Phillips et al. 2007) have been included or superseded by articles annotated here. Specifically, we will show that mechanical and prescribed fire treatments can restore a more open structure to oak-dominated forests of the Appalachians without causing harm to the ecosystem.

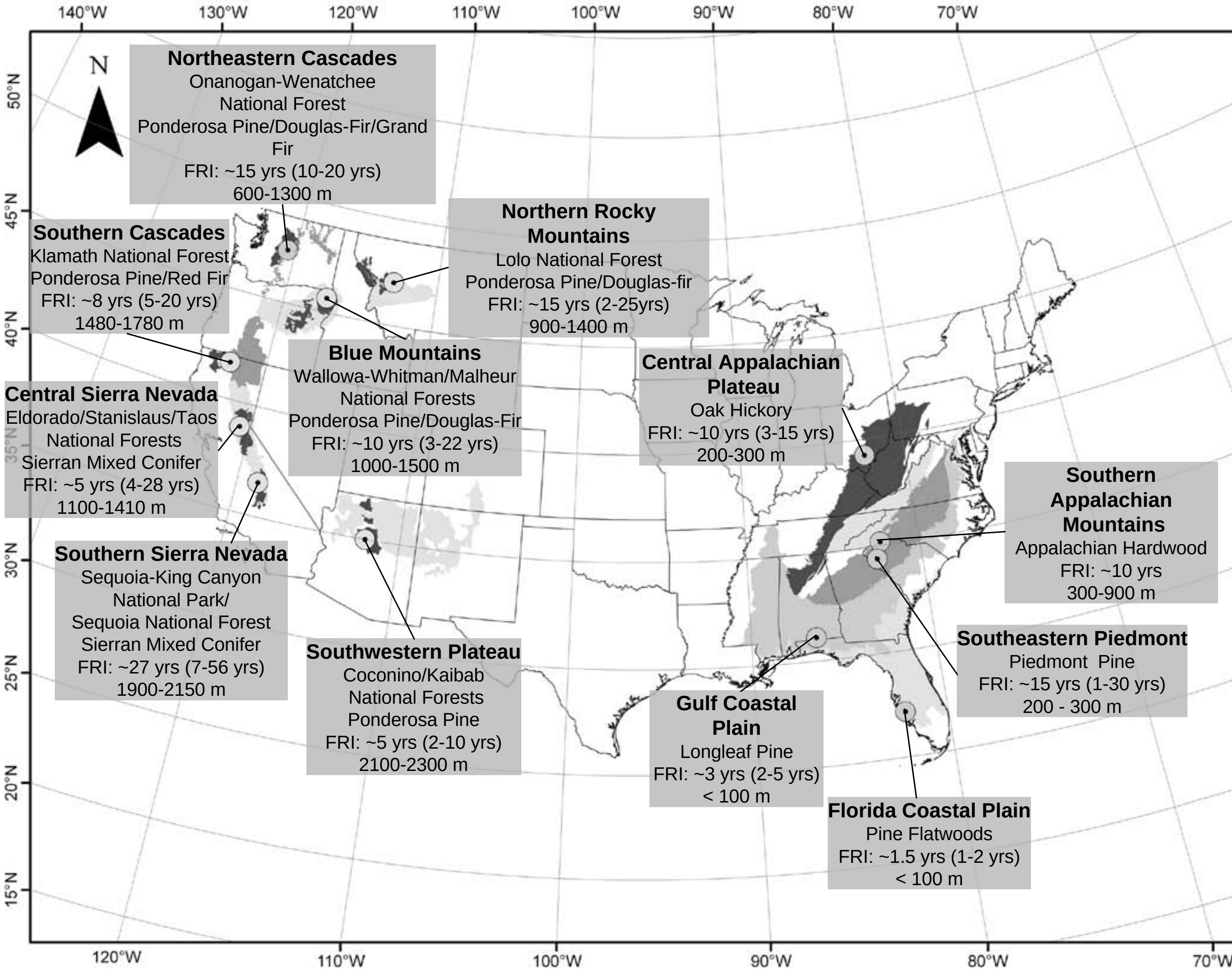

Figure 1.—Name and location of 12 Fire and Fire Surrogate (FFS) sites, showing nearest federal lands (western sites only), fire return interval (FRI), and elevational range (meters). Black shaded areas are federal lands adjacent to the western sites; lighter shading indicates 'representative land base,' or the area to which FFS results can be most directly applied for each site. Representative land bases are derived from EPA Type III Ecoregions: www.epa.gov/wed/pages/ecoregions/level_iii.htm. This paper deals specifically with the Central Appalachian Plateau and Southern Appalachian Mountain sites located in Ohio and North Carolina.

SITE LOCATIONS

The Central Appalachian and Southern Appalachian study sites each consist of three replicate blocks, with four fuel reduction treatments applied to a randomly chosen treatment unit within each block. The Central Appalachian FFS site is located on the unglaciated Allegheny Plateau of southern Ohio. The climate of the region is cool temperate with a mean annual precipitation of 40.3 in and a mean annual temperature of 52.3 °F (Sutherland et al. 2003). The forests of the region developed between 1850 and 1900, after the cessation of cutting for the charcoal and iron industries (Sutherland et al. 2003). The current canopy composition differs little from that recorded in the original land surveys of the early 1800s. The most abundant species in the current canopy were white oak (*Quercus alba*), chestnut oak (*Q. prinus*), hickories (*Carya* spp.), and black oak (*Q. velutina*); however, the midstory and understory are now dominated by species that have become common in this community only in the last few decades (e.g., sugar maple [*Acer saccharum*], red maple [*A. rubrum*], and yellow-poplar [*Liriodendron tulipifera*]) (Yaussy et al. 2003). The Central Appalachian FFS site is composed of three experimental blocks, with one each in the

Raccoon Ecological Management Area (REMA), Zaleski State Forest (ZAL), and Tar Hollow State Forest (TAR). Funding for the initial implementation on this site of the FFS study was through a grant from the USDA-USDI Joint Fire Sciences Program.

The Southern Appalachian FFS site is located in the Green River Game Land in the Blue Ridge Physiographic Province, Polk County, NC. The climate of the region is warm continental, with a mean annual precipitation of 64.5 in and a mean annual temperature of 63.7 °F (Keenan 1998). The forests of the study area were 80 to 120 years old, and no indication of past agriculture or recent fire was present, though the historical fire-return interval prior to 1940 was approximately 10 years (Harmon 1982). The most abundant species in the canopy were northern red oak (*Q. rubra*), chestnut oak, white oak, black oak, pignut hickory (*C. glabra*), mockernut hickory (*C. tomentosa*), and shortleaf pine (*P. echinata*). A relatively dense evergreen shrub assemblage was present in the understory of most of the study site, with mountain laurel (*Kalmia latifolia*) and rhododendron (*Rhododendron maximum*) the most common species. A grant from the National Fire Plan funds this site of the FFS study.

TREATMENTS AND EXPERIMENTAL DESIGN

Each of the three replicate blocks in each site is composed of four treatment units. At the Central Appalachian site, individual treatment units were 47 to 64 ac whereas in the Southern Appalachian site they were approximately 35 ac in size. A 164-ft x 164-ft grid was established in each treatment unit, and 10 sample plots of 0.25 ac were established randomly within each treatment unit.

Treatments were randomly allocated among treatment units at each site. Treatments consisted of prescribed fire (B), a mechanical treatment (M), the combination of prescribed fire and mechanical treatments (MB), and an untreated control (C). In the Central Appalachian site, the M treatment involved a shelterwood harvest. This commercial operation reduced basal area from 125 to 88 ft^2/ac. At the Southern Appalachian site, the M treatment was designed to create a vertical fuel break. Chainsaw crews removed all stems >6.0 ft tall and < 4.0 in d.b.h., as well as all mountain laurel and rhododendron stems, regardless of size. All detritus generated by the mechanical treatments was left on site in both areas.

M treatments were accomplished between September 2000 and April 2001 in Ohio and between December 2001 and February 2002 at the Southern Appalachian site. The prescribed fires were applied during March-April 2001 and 2005 in the Central Appalachian and March 2003 and 2006 at the Southern Appalachian site. The fires were applied on both the M and MB experimental units. These dormant-season fires consumed unconsolidated leaf litter and fine woody fuels while leaving most of the coarse woody fuels only charred. At the Southern Appalachian site, the fire prescription was also designed to kill ericaceous shrubs. Details of fire behavior are given by Iverson and others (2004a, b; 2008) for the Central Appalachian and Tomcho (2004) and Waldrop and others (2008) for the fires at the Southern Appalachian site.

SEQUENTIAL ANNOTATIONS FOR SELECTED REFERENCES

Fuels and Fire Behavior

Iverson, L.R.; Yaussy, D.A.; Rebbeck, J.; Hutchinson, T.F.; Long, R.P.; Prasad, A.M. 2004a. **A comparison of thermocouples and temperature paints to monitor spatial and temporal characteristics of landscape-scale prescribed fires. International Journal of Wildland Fire.** 13: 1-12.

> A method to monitor fire behavior using rigid steel thermocouple probes is described and compared to the use of temperature-sensitive paints at the Ohio site. Different paints melt to indicate the maximum temperature recorded. The thermocouple probes can be programmed to record temperature at set intervals, such as every 2 seconds, to indicate not only maximum temperature, but the duration of increased temperature. Readings from the two methods corresponded closely with each other. Deployed on a 55-yd x 55-yd grid, these sensors each give readings that may be used to calculate fire

behavior metrics such as rate of spread and Byram's fireline intensity. An illustration of prescribed fire movement through the ZAL burn treatments is included.

Graham, J.B.; McCarthy, B.C. 2006. **Forest floor fuel dynamics in mixed-oak forests of south-eastern Ohio.** International Journal of Wildland Fire. 15: 479-488.

The authors examined fuel dynamics following the fire and thinning treatments at the Central Appalachian site to determine how these treatments influence the future fuel composition and structure in eastern mixed-oak forests. They found that the M treatment to create shelterwoods, increased 100-hr, 1000-hr sound, and coarse woody debris, and decreased 1-hr fuels 3 years after treatment, whether the units were burned or not. The M treatment without burning increased litter during this time. The B treatment increased 1000-hr sound fuels and decreased 1000-hr rotten fuels. The MB treatments decreased 10-hr fuels and the duff layer. Unlike western FFS study sites where fuels accumulate over time, fuel inputs were balanced by rapid decomposition at this site.

Phillips, R.J.; Waldrop, T.A.; Simon, D.M. 2006. **Assessment of the FARSITE model for predicting fire behavior in the Southern Appalachian Mountains.** Proceedings of the 13th biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 521-525.

The authors wished to evaluate FARSITE by comparing fire behavior from simulations to that from a prescribed burn and to test the effects of different fuel treatments on fire behavior in the Southern Appalachian Mountains. Fire behavior was monitored using thermocouple probes deployed on a 55-yd x 55-yd grid. Fire behavior simulations produced by FARSITE were not adequate for use in the Southern Appalachian region using standard fire behavior fuel models (FBFM) with or without calibrations. The FBFM used in this version of FARSITE did not account for the high fuel moistures of the heavier fuels. The irregular fire shape caused by a linear drip torch fire front (as opposed to point-source ignition) resulted in higher rates of spread than those predicted by FARSITE. The flammability of the ericaceous shrubs was not adequately modeled in the FBFM. FARSITE 4.1.0 (which was not available at the time of this evaluation) incorporates many improvements that may make the software more robust for this region.

Hutchinson, T.F.; Long, R.P.; Ford, R.D.; Sutherland, E.K. 2008. **Fire history and the establishment of oaks and maples in second-growth forests.** Canadian Journal of Forest Research. 38: 1184-1198.

To better understand how past fires were related to tree establishment, dendrochronological analysis was conducted on trees which were harvested to create the shelterwood stand structure on the Central Appalachian site. The authors found mean fire intervals (average number of years between fires) varied between 9.1 and 11.3 yrs on the six mechanical treatment units between 1870 and 1933. The oaks that were harvested originated between 1845 and 1900. Virtually no oaks established after 1925, close to the start of the fire suppression policies in Ohio. Harvested maples established after fire suppression. This finding supports the hypothesis that frequent, low-intensity surface fire was the ecosystem process that created the oak-dominated forests of today.

Soils and Belowground Processes

Iverson, L.R.; Prasad, A.M.; Hutchinson, T.F.; Rebbeck, J.; Yaussy, D.A. 2004b. **Fire and thinning in an Ohio oak forest: grid-based analyses of fire behavior, environmental conditions, and tree regeneration across a topographic moisture gradient.** In: Spetich, M.A., ed. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 190-197.

The authors present a preliminary analysis of how fire behavior, seasonal soil temperature and

moisture, canopy light penetration, and oak and hickory seedling and sapling populations vary among moisture classes and before and after the first season of treatments. Thermocouple probes were deployed on a 55-yd x 55-yd grid 1 in below the soil within the C and MB treatments located on the ZAL State Forest. These probes indicated higher soil temperatures on the MB treatments at all slopes and aspects than on the C treatment. This trend was evident from April through September. The vegetation analysis presented in this paper is included and updated in Iverson et al. 2008 (see below), and will not be commented on here.

Boerner, R.E.J.; Brinkman, J.A.; Yaussy, D.A. 2007. **Ecosystem restoration treatments affect soil physical and chemical properties in Appalachian mixed oak forests.** In: Buckley, D.S.; Clatterbuck, W.K., eds. Proceedings, 15th central hardwood forest conference. e-Gen. Tech. Rep. SRS-101. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 107-115 [CD-ROM].

This paper assesses the effects of the treatments at the Central Appalachian site on soil physical and chemical properties measured immediately post-treatment and 3 years post-treatment (prior to the second prescribed fire) and evaluates the impact that any effects might have on decisions to implement one or more of these management approaches more broadly. Mineral soil exposure was still significantly higher in the treated areas than in the C at the time of the second measurement. Soil pH increased after burning and persisted at higher levels for at least 3 years. Phosphorus availability decreased and remained lower in the B and MB areas through the second measurement. The Ca:Al ratio increased immediately after burning, but the effect was greatly reduced by the second measurement. There was no significant effect on Ca, K, or Al availability or soil compaction.

Boerner, R.E.J.; Coates, T.A.; Yaussy, D.A.; Waldrop, T.A. 2008. **Assessing ecosystem restoration alternatives in eastern deciduous forests: the view from belowground.** Restoration Ecology. 16:3, 425-434.

The article investigates whether any or all of the treatments would move these ecosystems toward the N-limited ecosystems that preceded fire suppression and heavy atmospheric N deposition. The authors found that treatment effects differed somewhat between the Southern and Central Appalachian sites. At the North Carolina site, all manipulative treatments initially resulted in reduced soil organic carbon content, C:N ratio, and overall microbial activity; however, only the reduced microbial activity persisted into the fourth growing season. At the Ohio site, the M treatment was the only manipulation that resulted in a significant change in these properties, with an initial increase in organic carbon and a decreased C:N ratio. Four years post-treatment, all treatments at this site were similar to the C. Using evidence from soil properties, the researchers concluded that mechanical treatments and a single prescribed fire did not result in progress toward ecosystems present prior to fire suppression.

Coates, T.A.; Boerner, R.E.J.; Waldrop, T.A.; Yaussy, D.A. 2008. **Soil nitrogen transformations under alternative management strategies in Appalachian forests.** Soil Science Society of America Journal. 72(2): 558-565.

The authors wished to gain insight into the consequences of the management strategies represented by the FFS treatments to nitrogen availability. Treatment effects on available total inorganic nitrogen, nitrogen mineralization, and nitrification were measured at both the Central and Southern Appalachian sites, once pre- and twice post-treatment (prior to the second prescribed fire at each site). Changes in nitrogen transformations were modest and transient. Transformation rates were 2 to 10 times higher in Ohio than in North Carolina, which may be due to the inhibitory effects of the litter produced by the ericaceous shrubs present at the Southern Appalachian site.

Insects

Campbell, J.W.; Hanula, J.L.; Waldrop, T.A. 2007. **Effects of prescribed fire and fire surrogates on floral visiting insects of the Blue Ridge province in North Carolina.** Biological Conservation. 134: 393-404.

> This study was conducted to determine how various groups of pollinating insects vary in abundance and species richness in response to treatments at the Southern Appalachian site. The number of pollinators captured during two summers was highly correlated to change in basal area. Reduction of basal area by any of the treatments increased light to the forest floor, stimulating herbaceous plant growth and flowering. Insect pollinators, mostly bees, were captured in significantly higher numbers in MB sites than in other treatment areas.

Campbell, J.W.; Hanula, J.L.; Waldrop, T.A. 2007. **Observations of *Speyeria diana* (Diana fritillary) utilizing forested areas in North Carolina that have been mechanically thinned and burned.** Southeastern Naturalist. 6(1): 179-182.

> The authors suggest that forest management practices that include fire with other disturbances may enhance food resources for the Diana fritillary. The Diana fritillary is considered a species of concern by the U.S. Fish and Wildlife Service. This lepidoptera is thought to be indicative of undisturbed communities. During the data collection for the pollinator study above, several males of this species were observed in two consecutive years on flowering sourwood trees (*Oxydendrum arboretum*) in the MB treatment areas only. Further study of the habitat preferences of this butterfly is needed.

Lombardo, J.A.; McCarthy, B.C. 2008. **Forest management and curculionid weevil diversity in mixed oak forests of southeastern Ohio.** Natural Areas Journal. 28(4): 363-369.

> The purpose of this study was to determine whether stand level treatments affect the diversity and abundance of adult weevils at the Central Appalachian site. Weevils were collected from acorns following the second prescribed fire conducted 4 years after the first treatment. The authors found no discernable treatment effects on the number of weevils, but the manipulative treatments increased weevil species diversity over the C treatment.

Wildlife

Greenberg, C.H.; Tomcho, A.L.; Lanham, J.D.; Waldrop, T.A.; Tomcho, J.; Phillips, R.J.; Simon, D. 2007. **Short-term effects of fire and other fuel reduction treatments on breeding birds in a Southern Appalachian upland hardwood forest.** The Journal of Wildlife Management. 71(6): 1906-1916.

> The FFS study afforded the authors the opportunity to examine whether and how the treatments would affect bird communities or individual species. Breeding bird surveys were conducted annually for 5 years on the Southern Appalachian site starting 1 year pretreatment. Four years after treatment, species richness and density increased on the MB treatment, while only species richness increased on the B treatment. The decline in the density of three species was associated with decreased leaf litter and shrubs. Shrub cover was reduced on all manipulative treatments compared to the C treatment. Leaf litter depth was similar on the C and B, lowest on the MB, and highest on the M treatments.

Greenberg, C.H.; Miller, S.; Waldrop, T.A. 2007. **Short-term response of shrews to prescribed fire and mechanical fuel reduction in a Southern Appalachian upland hardwood forest.** Forest Ecology and Management. 243: 231-236.

> This study examined the FFS treatment effects on communities of shrews, an important component of the food web in southern Appalachian oak ecosystems. Shrew populations were followed the first and second years after prescribed fire at the Southern Appalachian site. During this period, the abundance of shrews was not significantly

different in the treatments than in the C; however, the MB treatment had significantly fewer shrews than the M treatment. Shrew abundance decreased significantly between the first collection and the second, which was not associated with any treatment effects. There was no difference in macroarthropods between treatments. Leaf litter depth differed, with the highest depths occurring on the M treatment and the thinnest leaf litter on the MB replications. These results imply that the difference in shrew abundance was due not to food source but to habitat structure.

Greenberg, C.H.; Otis, D.L.; Waldrop, T.A. 2006. **Response of white-footed mice (*Peromyscus leucopus*) to fire and fire surrogate fuel reduction treatments in a southern Appalachian hardwood forest.** Forest Ecology and Management. 234: 355-362.

Mice are known to be important herbivores, predators, and prey in oak ecosystems. The authors examined the effects of the FFS treatments on habitat structure and white-footed mouse populations. Seventy-nine percent of the rodents caught at the North Carolina site were white-footed mice. The number captured increased each year from pre-treatment to 2 years post-treatment on all treatments. The abundance of mice was no different on the M treatment than on the C for any year. The abundance increased on the B and MB treatments the first year after fire, but was significant only on the MB due to the high variability of collections.

Greenberg, C.H.; Waldrop, T.A. 2008. **Short-term response of reptiles and amphibians to prescribed fire and mechanical fuel reduction in a southern Appalachian upland hardwood forest.** Forest Ecology and Management. 255: 2883-2893.

Reptile populations appear to be more affected by practices which open the canopy than by prescribed fire. This study compares the effects of these two treatments, plus the combination of the two on reptile and amphibian populations. A total of 1,308 amphibians (13 species) and 335 reptiles (10 species) were captured over 4 years starting 1 year pretreatment at the Southern Appalachian site. Few significant effects were observed for families or species for the manipulative treatments. All significant effects were increases in numbers captured or in species richness; no significant negative effects were observed.

Vegetation

Huang, J.; Boerner, R.E.J. 2008. **Shifts in plant morphological traits and seed production of *Desmodium nudiflorum* following prescribed fire alone or in combination with forest canopy thinning.** Botany. 86: 376-384.

The researchers investigated the effects of the FFS treatments on *Desmodium nudiflorum*, a common perennial found across moisture and nutrient gradients of the Central Appalachian site. This long-lived perennial was chosen to represent understory herbaceous plants across the landscape. Plots were sampled during the summer on the C, B, and MB treatments at the REMA and ZAL replications four growing seasons after initial treatments and one growing season after the second prescribed fire (2004, 2005). Total plant biomass, seed mass, and seed production were significantly higher under either manipulative treatment. Specific leaf area (leaf area/leaf mass) was significantly lower under the manipulative treatments. This study found the B and MB treatments improve fitness for this species.

McCament, C.L.; McCarthy, B.C. 2005. **Two-year response of American chestnut (*Castanea dentata*) seedlings to shelterwood harvesting and fire in a mixed-oak forest ecosystem.** Canadian Journal of Forest Research. 35: 740-749.

Hybrid American chestnut seeds resistant to blight are soon to be released for outplanting to restore the species on the landscape. To quantify the forest structure most likely to produce successful plantings, 100 pure American chestnut seeds were planted in each of the replications and treatments of the Central Appalachian site prior to the second growing season after initial treatments were installed. Eleven seedling variables were measured for two growing seasons including leaf, stem, root, fine root, and total biomass; leaf area; stem height; basal diameter; and root length. All of these variables were significantly and positively affected by each of the manipulative treatments, with the exception of root length in the B treatment. The authors conclude the proper environment to reintroduce hybrid American chestnut into the Appalachian forest would include open stands, possibly with a prescribed fire regime.

Joesting, H.M.; McCarthy, B.C.; Brown, K.J. 2007. **The photosynthetic response of American chestnut seedlings to differing light conditions.** Canadian Journal of Forest Research. 37: 1714-1742.

Using a subsample of the American chestnut seedlings in the paper cited above, the authors investigated the photosynthetic capabilities of leaves in the C and M treatments of the ZAL and REMA replications of the Ohio site. The leaves of seedlings growing in the M treatment assimilated CO_2 at higher rates than leaves from seedlings in the C treatment at all but the lowest light levels. There was no significant difference in the amount of N in the leaves between treatments and the amount of N was not correlated to any photosynthetic variables or canopy openness. The authors recommend forests with higher light levels than found in undisturbed forests for successful reintroduction of hybrid American chestnut.

Schelling, L.R.; McCarthy, B.C. 2007. **Seed banks of mixed oak forest: effects of forest management on species composition and spatial pattern.** Natural Areas Journal. 27: 320-331.

Soil samples were collected 3 years following initial treatment implementation on the ZAL and REMA replications of the Central Appalachian site to investigate the effects of the FFS treatments on the soil seed bank. Species composition of the seed bank contained in these samples did not differ significantly between treatments. As other studies have found, the composition of the seed bank was significantly different from the aboveground composition on all treatments, implying that many species present aboveground do not rely on banked seeds for regeneration success.

Chiang, J.-M.; McEwan, R.W.; Yaussy, D.A.; Brown, K.J. 2008. **The effects of prescribed fire and silvicultural thinning on the aboveground carbon stocks and net primary production in an oak-hickory ecosystem in southern Ohio.** Forest Ecology and Management. 255: 1584-1594.

With the concern over the carbon sequestration potential of forests, the authors examined the potential effects of the silvicultural treatments on carbon stocks. Annual net primary production (ANPP) was calculated for the treatments of the Ohio site for the first 4 years of the study. ANPP significantly decreased in the M and MB treatments the first year following harvesting due to the reduction in basal area. However, the decrease in ANPP did not persist into the second through fourth years, implying an equivalent amount of biomass was being produced with fewer trees than on the C and B treatments. Prescribed fire had no persistent effect on ANPP.

Lombardo, J.A.; McCarthy, B.C. 2008. **Silvicultural treatment effects on oak seed production and predation by acorn weevils in southeastern Ohio.** Forest Ecology and Management. 255: 2566-2576.

To quantify the effects of the FFS treatments on mast production, acorns were collected from 72 chestnut oak and 72 black oak trees evenly distributed within the treatments of the ZAL and REMA replications of the Central Appalachian site for the five growing seasons following initial treatment implementation. Black oak acorn production did not vary among the treatments and was greater and more consistent than the masting levels of the chestnut oak. After the second prescribed fire, the chestnut oaks in the M and MB treatments produced significantly more and smaller acorns than the chestnut oaks in the C and B treatments.

Yaussy, D.A.; Waldrop, T.A. In press. **Delayed mortality of eastern hardwoods: a function of fire behavior, site, or pathology?** In: Stanturf, J.A., ed. Proceedings, 14th biennial southern silvicultural research conference. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.

Overstory mortality was modeled using survival analysis for both Appalachian sites to investigate the effects of the FFS treatments on stand structure and composition. Mortality increased on the B and MB treatments the first growing season after prescribed fire and this increase persisted until the next fire. Mortality on the B and MB treatments increased even more after the second prescribed fire. The analysis indicated that maximum thermocouple temperature, preburn crown vigor, bark thickness, and duration of heating were the variables that explained most of the differences in mortality among treatments. Intense or slow-moving fires increase mortality of overstory trees, especially those of low vigor and thin bark, and the mortality may occur several years after burning.

Iverson, L.R.; Hutchinson, T.F.; Prasad, A.M.; Peters, M.P. 2008. **Thinning, fire, and oak regeneration across a heterogeneous landscape in the eastern U.S.: 7-year results.** Forest Ecology and Management. 255: 3035-3050.

The authors wished to evaluate the longer-term effects of the FFS treatments on canopy openness and tree regeneration. Data were collected at the grid points of the C and MB treatments at the REMA and ZAL replications of the Ohio site, pretreatment, and during the first, fourth, and sixth growing season after treatment initiation. Abundance of small trees (<4 in d.b.h.) is reported for five size classes and several species across a moisture gradient. Oak-hickory regeneration > 20 in tall, was less than 130 stems/ac on the MB grid points prior to treatment initiation. Two growing seasons after the second prescribed fire, oaks and hickories in these size classes averaged more than 930 stems/ac at dry gridpoints, and more than 685 stems/ac at intermediate gridpoints. There was little change at the mesic grid points. Each grid point was assigned an oak-hickory competition class based on density of seedlings, density of saplings, and competition. Maps are used to demonstrate the increase in oak-hickory competitiveness across the landscape as the result of moisture gradient and change in canopy openness.

Waldrop, T.A.; Yaussy, D.A.; Phillips, R.; Hutchinson, T.F.; Brudnak, L.; Boerner, R.E.J. 2008. **Fuel reduction treatments affect stand structure of hardwood forests in Western North Carolina and Southern Ohio, USA.** Forest Ecology and Management. 255: 3117-3129.

To synthesize several years of data collection, summaries of the effects of the FFS treatments on vegetation over time are reported for both the Central and Southern Appalachian sites for up to 5 years after initial study installation. Data following the second prescribed fire at the Ohio site were not available for this analysis. No attempt is made to compare the effects of treatments between the sites. The vegetation variables reported include basal area, mortality, density of regeneration and saplings (by species), shrub cover (by species), and ground layer cover (by plant type). Differences among treatments within sites can be explained by increased light availability (reduction in basal area), time since prescribed fire, and intensity of prescribed fire. Both sites indicate an increase in oak saplings on the MB treatment after the first prescribed fire.

CONCLUSIONS

The FFS study was designed as a long-term investigation of the ecosystem consequences of the reintroduction of a fire regime or its mechanical surrogate. So far, the results from these two sites have shown that the treatments do little harm to the insects, wildlife, and belowground processes and may provide some benefits to many ecosystem components such as plant biodiversity. Significant large oak regeneration has developed at both sites with the MB treatment after two prescribed fires.

Although more than 50 peer-reviewed articles have been published concerning the Southern and Central Appalachian sites of the FFS study, the results are preliminary. The treatments have changed the structure and composition of the forest, from the soils to the canopy. How long will these changes persist and what effects will a periodic burning regime have on the ecosystem? Currently, both sites are in a maintenance mode, where periodic prescribed fires are implemented every 3 to 5 years and rudimentary vegetation data are collected. Detailed fuel, wildlife, insect, and soils information will no longer be collected unless funding is obtained. The long-term effects of these restoration treatments on the ecosystem components for which the study was designed will be forfeited.

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