FUEL-REDUCTION TREATMENTS FOR RESTORATION IN EASTERN HARDWOODS: IMPACTS ON MULTIPLE ECOSYSTEM COMPONENTS

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Abstract—The Southern Appalachian Mountains and Ohio Hills sites are unique within the National Fire and Fire Surrogate Study because they are in hardwood-dominated forests. The efficacy of four fuel-reduction treatments was evaluated to restore these unmanaged hardwood forests to the structure and function of open woodland habitats. Treatments included control, prescribed burning, mechanical, and a combination of burning and mechanical treatments. Overstory basal area and density of saplings and shrubs were used as measures of ecosystem structure while soil carbon and breeding bird species richness were indicators of ecosystem function. The combination of burning and mechanical treatments provided the most rapid progress toward restoration but not all goals were met. At both study sites, overstory and understory vegetation remained too dense, soils were largely unaffected, and bird species richness showed only ephemeral increases. Repeated treatments are needed to replicate historical structure and function.

INTRODUCTION

Several studies document first-order effects after fuel-reduction treatments. However, none has attempted to establish the interactions between fuel reduction and multiple ecological processes. The National Fire and Fire Surrogate (FFS) Study was established to compare ecological and economic impacts of prescribed fire and mechanical fuel-reduction treatments (Youngblood and others 2005). Thirteen independent study sites across the United States (eight in the West and five in the East) use identical treatment (prescribed fire and mechanical fuel-reduction treatments) and measurement protocols. All western sites are dominated by ponderosa pine (*Pinus ponderosa*). Eastern sites include hardwood-dominated sites in the Ohio Hills sites 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*) in Alabama, and a site dominated by slash pine (*P. elliottii*) in Florida.

The two hardwood-dominated sites of the FFS (Southern Appalachian Mountains and Ohio Hills) are substantially different from other FFS sites because of their history, plant composition, animal composition, and soils. At both sites, the primary management objective was to reduce severity of potential wildfires by reducing live and dead fuels. Secondary objectives were to increase oak regeneration by reducing competition from red maple (*Acer rubrum*) and yellow-poplar (*Liriodendron tulipifera*), to improve wildlife habitat by creating early successional habitat, and to increase cover of grasses and forbs. It may be possible to obtain each of these goals by restoring these communities to the open woodland habitats once common in these regions [described in syntheses by Stanturf and others (2002) and Van Lear and Waldrop (1989)]. Fire and mechanical treatments used at both sites were designed to restore stand structure to an open woodland condition. A number of papers have described how the fuel-reduction treatments have impacted individual components of these ecosystems such as insects (Campbell and others 2007, Greenberg and others 2010), soils (Coates and others 2008), herpetofauna (Kilpatrick and others 2010), vegetation (Schwilk and others 2009), and fuels (Waldrop and others 2010). This paper examines several types of variables at both sites as indicators of restoration success and to evaluate common patterns.

METHODS

Study Sites

Both the Southern Appalachian Mountains and Ohio Hills study sites consist of three replicate blocks, with four fuel-reduction treatments applied to a randomly chosen unit within each block. The Southern Appalachian Mountains 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 mean annual precipitation of 1638 mm and mean annual temperature of 17.6 °C (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. The most abundant species in the canopy were northern red oak (*Quercus rubra*), chestnut oak (*Q. prinus*), white oak (*Q. alba*), black oak (*Q. velutina*), pignut hickory (*Carya glabra*), mockernut hickory (*C. tomentosa*), and shortleaf pine (*P. echinata*). A relatively dense evergreen shrub assemblage was present in the understory of a majority of the study site, with mountain laurel (*Kalmia latifolia*) and rhododendron (*Rhododendron maximum*) the most common species.

The Ohio Hills FFS site is located on the unglaciated Allegheny Plateau of southern Ohio. The climate of the region is cool, temperate with mean annual precipitation of 1024 mm and mean annual temperature of 11.3 °C (Sutherland and

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others 2003). The most abundant species in the current canopy were white oak, chestnut oak, hickories (*Carya* spp.), and black oak; however, the midstory and understory are now dominated by species that have only in the last few decades become common in this community, e.g., sugar maple (*A. saccharum*), red maple, and yellow-poplar (Yaussy and others 2003). Analysis of fire scars in stems of trees that were cut as part of the establishment of the FFS experiment indicated that fires were frequent (return intervals of 8 to 15 years) from 1875 to 1930.

Treatments and Experimental Design

Each of the three replicate blocks at each site is composed of four treatment units. In the Ohio Hills site, individual treatment units were 19 to 26 ha whereas in the Southern Appalachian Mountains site they were approximately 14 ha in size. A 50- by 50-m grid was established in each treatment unit, and 10 sample plots of 0.10 ha were established randomly within each treatment unit. Treatments consisted of prescribed fire, a mechanical treatment, the combination of prescribed fire and mechanical treatments, and an untreated control. At the Southern Appalachian Mountains site, the mechanical treatment was designed to create a vertical fuel break. Chainsaw crews removed all stems >1.8 m tall and <10.2 cm diameter at breast height (d.b.h.) as well as all mountain laurel and rhododendron stems, regardless of size. In the Ohio Hills, the mechanical treatment was thinning from below to a basal area comparable to that present prior to Euro-American settlement. This was a commercial thinning operation that reduced basal area from 27.0 to 20.9 m^2/ha. All detritus generated by treatments was left on site in both areas.

Mechanical treatments were accomplished between September 2000 and April 2001 in Ohio and between December 2001 and February 2002 at the Southern Appalachian Mountains site. The prescribed fires were applied during March to April 2001 in the Ohio Hills and March 2003 at the Southern Appalachian Mountains site. These dormant season fires consumed unconsolidated leaf litter and fine woody fuels while leaving the majority of the coarse woody fuels only charred. At the Southern Appalachian Mountains site, the fire prescription was also designed to kill ericaceous shrubs. Details of fire behavior are given by Tomcho (2004) for the Southern Appalachian Mountains site and by Iverson and others (2004) for the Ohio Hills.

Measurements and Analyses

All treatment units were sampled during the pretreatment year 2000 in the Ohio Hills and 2001 in the Southern Appalachian Mountains. Additional measurements were made in Ohio 1, 2, and 4 years after treatment. The Southern Appalachian Mountains site was measured 1, 3, and 5 years after treatment. Numerous variables were measured at grid points and sample plots for many components of the FFS study. Those used for this paper are a sample of variables used to evaluate restoration success, including overstory basal area, midstory saplings and shrubs, soil organic carbon, and breeding bird species richness. Measures of overstory and midstory characteristics will allow an evaluation of how well these treatments met the goal of creating the structure of an open woodland community. Responses of soil carbon and bird diversity provide measures of ecosystem function that will provide a more complete understanding of how well fuel-reduction treatments meet restoration goals. Specific measurements and analyses followed standard protocols developed for the FFS and were described in detail by Boerner and others (2008), Greenberg and others (2007), and Waldrop and others (2008). Individual tests were considered significant at the 0.05 level.

RESULTS

Overstory Basal Area

Basal area on the Southern Appalachian Mountains site varied from 23.8 to 27.3 m^2/ha prior to treatment, but the differences were not significant (fig. 1A). After one growing season, basal area had not changed significantly from pretreatment levels except in plots treated with the mechanical+burn combination. In those plots, basal area declined from 23.8 to 21.0 m^2/ha due to mortality after hot fires. Burn-only and mechanical-only plots continued

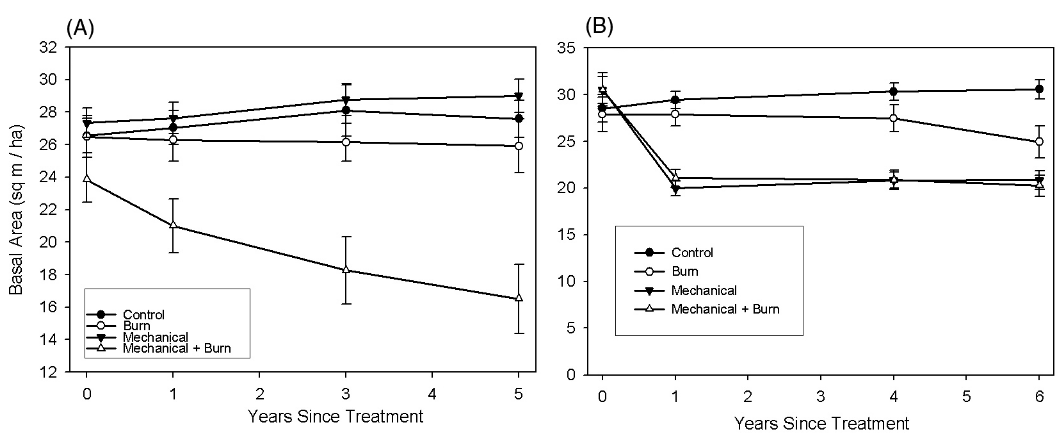

Figure 1—Change in basal area (m^2/ha) by treatment and year for the (A) Southern Appalachian Mountains and (B) Ohio Hills sites of the National Fire and Fire Surrogate Study (from Waldrop and others 2008).

to have no significant differences from control plots at measurements during years 3 and 5. However, basal area continued to decline significantly between sample years in the mechanical+burn plots, leaving only 16.5 m^2/ha of live trees after 5 years. The basal area of trees that died during the first year after treatment was significantly higher in burn-only and mechanical+burn plots than in those plots not treated with fire. Some mortality occurred in all treatment units between each sample period, but there was significantly more mortality in the mechanical+burn plots for 3 years following burning. At the end of 5 years, the only treatment that continued to have significant amounts of mortality was the mechanical+burn treatment. Species composition of the overstory was unaffected by treatment with mortality consistent among all species.

In Ohio Hills, the overstory responded differently than at the Southern Appalachian Mountains, primarily due to the difference in mechanical treatments (commercial thinning instead of understory cutting). Plots randomly selected for mechanical treatment had significantly higher basal area prior to treatment (30.5 m^2/ha) than did plots selected for burn-only (27.9 m^2/ha) or no treatment (28.5 m^2/ha) (fig. 1B). Commercial thinning operations did not achieve the target basal area of 14 m^2/ha, leaving 20.0 and 20.1 m^2/ha in the mechanical-only and mechanical+burn plots, respectively. Basal area in both treatment units remained about the same throughout the remainder of the 6-year measurement period. Basal area in burn-only treatment units was not significantly different than in untreated control plots the first year after burning. However, basal area increased in control plots over time as trees grew but decreased over time in burn-only plots as trees died. The reduction of live basal area in burn-only plots was significant between years 4 and 6. Some mortality occurred in all treatment units the first year after treatment but the amounts were small and not significantly different. Between 2 and 4 years after treatment, mortality increased in the areas treated with fire to levels significantly higher than in the controls or mechanical-only treatments. Mortality remained significantly higher in burn-only plots through year 6. Species composition of the overstory was unaffected by treatment with mortality consistent among all species.

Midstory Saplings and Shrubs

Numbers of sapling-sized trees (>4.5 feet tall and <4 inches d.b.h.) of all species groups tended to be significantly reduced 1 year after burning at both the Southern Appalachian Mountains and Ohio Hills (fig. 2). Sapling numbers increased over time at Ohio Hills, sometimes exceeding pretreatment densities. At the Southern Appalachian Mountains, however, there was a reduction in numbers at year 5 because this was the first-growing season after the second burn. Chainsaw felling at the Southern Appalachian Mountains reduced sapling density immediately after treatment, but there were no significant differences in sapling numbers for red maple and oaks by years 3 and 5, respectively. The mechanical treatment at Ohio Hills had little impact on sapling numbers the first year after treatment. Sapling numbers increased significantly by year 4 as large numbers of small trees grew into the sapling size class (fig. 3H). The mechanical+burn treatment at the Southern Appalachian Mountains showed similar results to the mechanical treatments at Ohio Hills with large increases in sapling density as trees grew into this size category by year 3 (fig. 2G).

Recruitment of oaks is a desirable outcome for both timber and wildlife objectives. Oak sapling density was greatly increased by the mechanical treatment at Ohio Hills and the mechanical+burn treatment at both study sites (figs. 2A and 2B). However, heavy competitors such as yellow-poplar and red maple also increased in number by as many as 1.5 times the number of oaks at the Southern Appalachian Mountains (figs. 2C and 2E) and six times their number at Ohio Hills (figs. 2D and 2F). No treatment was successful at increasing oak sapling density without an equal or greater increase in the density of red maple or yellow-poplar.

Cover of the shrub layer at the Southern Appalachian Mountains was unaffected by the burn-only treatment (fig. 3). The mechanical treatment, both with and without burning, was more effective at removing this vertical fuel layer than was burning alone, primarily because burning did little to remove the rhododendrons (fig. 3B) which grew in moist areas that did not burn. Mountain laurel cover was significantly reduced the year following the mechanical-only and mechanical+burn treatments (fig. 3A). Burning again after 3 years essentially eliminated this species from the shrub layer from burn-only and mechanical+burn plots as opposed to the mechanical-only plots where mountain laurel is growing tall enough to reenter this layer. The predominant shrubs at Ohio Hills are different species from those at the Southern Appalachian Mountains, consisting of *Rubus* and *Smilax* species. *Rubus* was essentially absent from plots before mechanical or burning treatments (fig. 3A) but increased significantly by year 4 as these species responded to canopy opening and grew tall enough to reach the shrub layer. *Smilax* (fig. 3B) was reduced by all active treatments during the first year but was beginning to return to pretreatment levels by year 4 in mechanical and mechanical+burn treatment areas.

Soil Organic C

During the first posttreatment growing season, soil organic carbon (C) content was significantly affected by restoration treatment in both study sites. At the Southern Appalachian Mountains site, all three manipulative treatments resulted in reduced soil organic C content, with an average reduction of 15.6 percent relative to the control (fig. 4). At the Ohio Hills site, the only statistically significant difference was between the burned units and mechanical+burn units, with soil organic content at the latter 25.7 percent greater than the former (fig. 4). The significant effect of the restoration treatments on soil organic C persisted through the fourth posttreatment growing season at the Ohio Hills site, but not at the Southern Appalachian Mountains site. Fourth-year soil organic C content in the mechanical treatment in the Ohio Hills site was significantly greater, by an average of 28.5 percent, than that in the other three treatments (fig. 4).

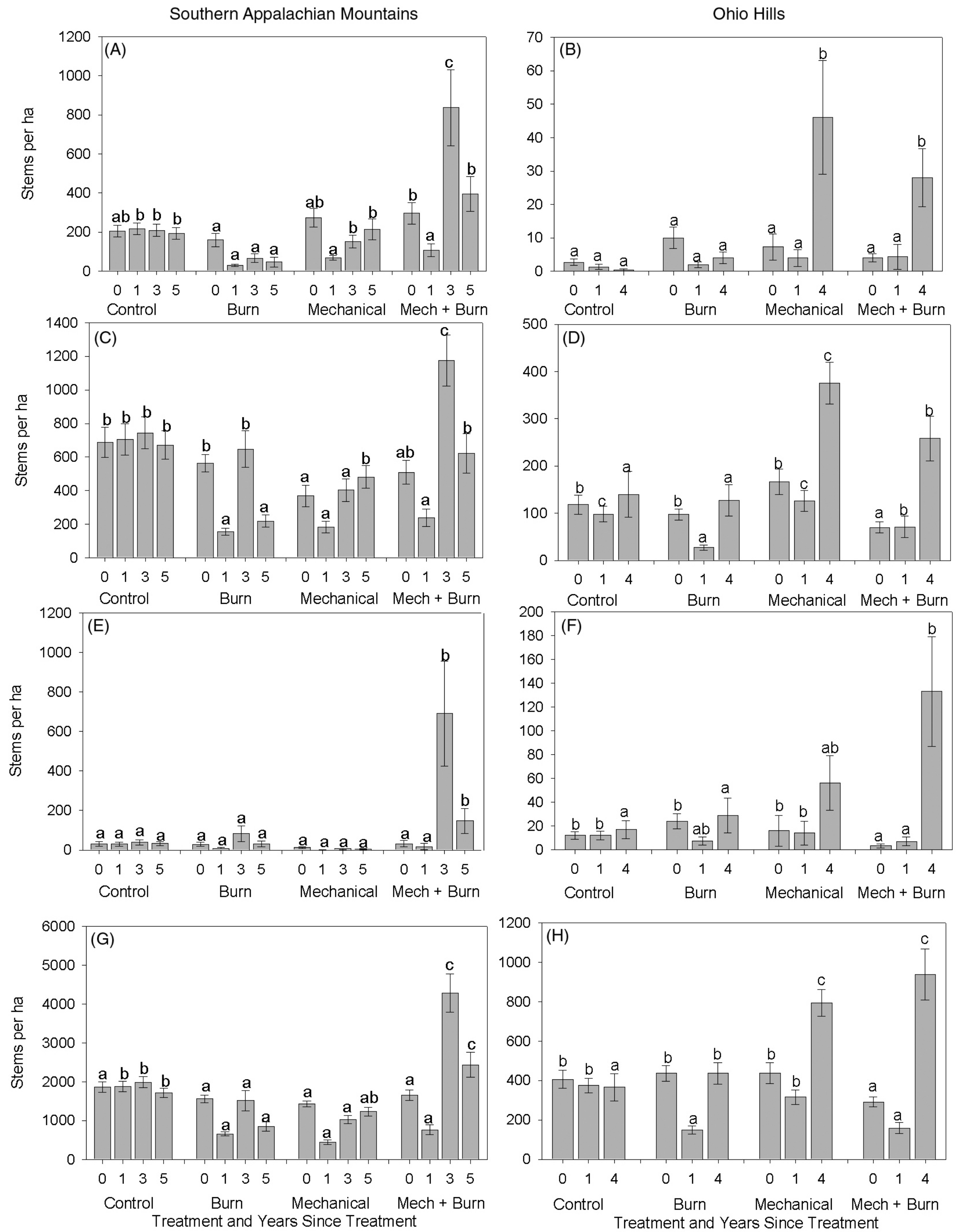

Figure 2—Density of hardwood saplings (stems/ha) by treatment and year for select species and species groups at the Southern Appalachian Mountains (A—oak, C—red maple, E—yellow-poplar, G—all species) and Ohio Hills (B—oak, D—red maple, F—yellow-poplar, H—all species) sites of the National Fire and Fire Surrogate Study. Error bars indicate differences among years within a treatment. Letters indicate differences among treatments within a year (from Waldrop and others 2008).

During the first posttreatment year, soil C to nitrogen (N) ratio was significantly affected by treatment in both study sites. At the Southern Appalachian Mountains site, C to N ratio decreased (and therefore soil organic matter quality increased) in the order: mechanical > mechanical+burn = control > burn (fig. 5). At the Ohio Hills site, the magnitude of the difference among treatments was less than it was at the Southern Appalachian Mountains; however, the mechanical treatment still had significantly greater soil C to N ratio than did the other three treatments at the Ohio Hills (fig. 5). The significant effect of the treatments on soil C to N ratio persisted into the fourth posttreatment growing season at the

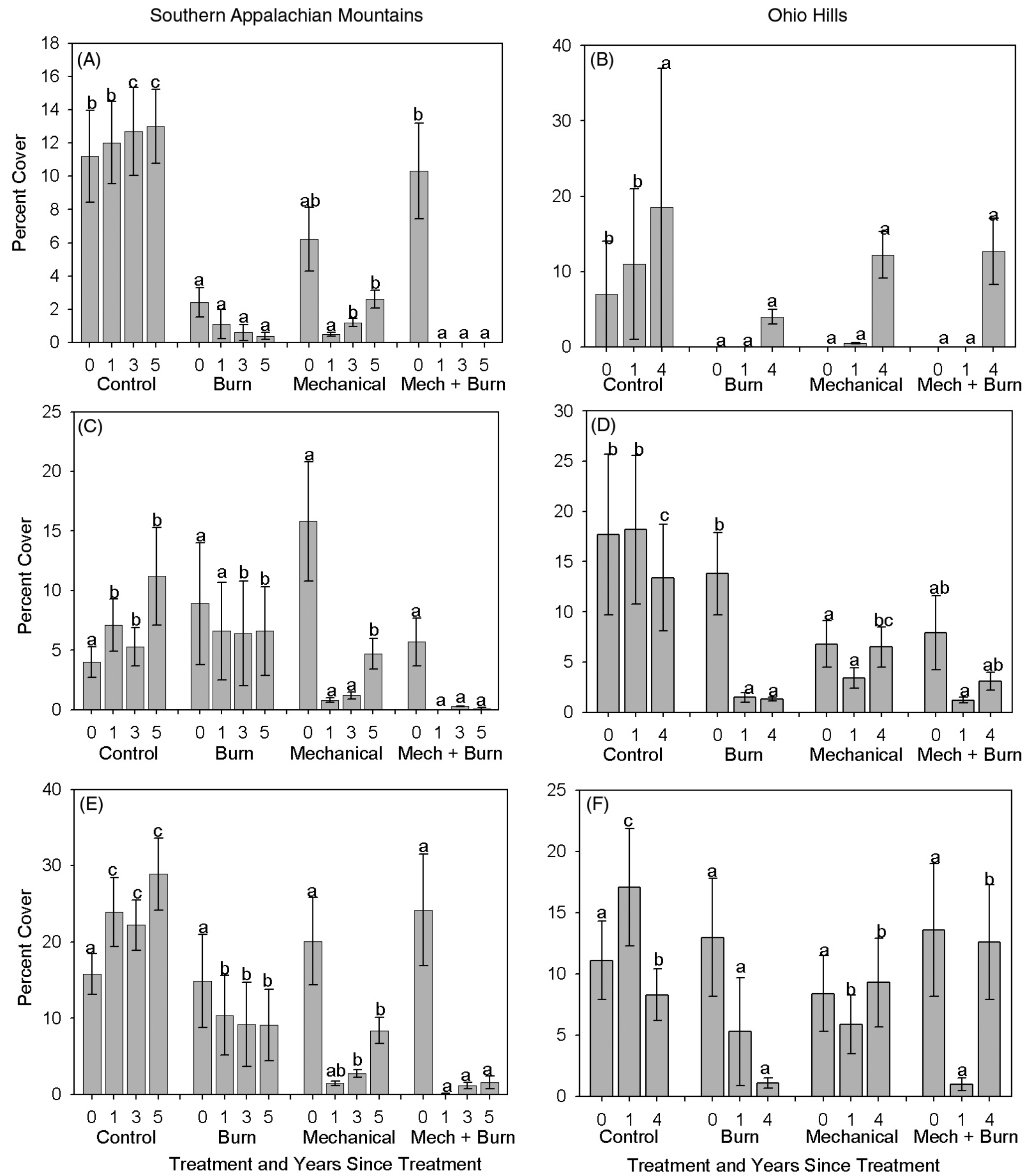

Figure 3—Percent cover of shrubs by treatment and year for select species and species groups at the Southern Appalachian Mountains (A—mountain laurel, B—rhododendron, C—all species) and Ohio Hills (A—*Rubus*, B—*Smilax*, C—all species) sites of the National Fire and Fire Surrogate Study. Error bars indicate differences among years within a treatment. Letters indicate differences among treatments within a year (from Waldrop and others 2008).

Southern Appalachian Mountains, but not in the Ohio Hills. At the Southern Appalachian Mountains site, soils from the mechanical plots had significantly greater C to N ratio during the fourth year than did soils from the other treatments (fig. 5).

Breeding Bird Species Richness

Species richness of breeding birds at the Southern Appalachian Mountains site was not significantly different among treatments during the pretreatment year (2001) or for 2 years after treatments were initiated (fig. 6A). However, richness increased in the burn-only and mechanical+burn treatment areas as overstory trees continued to die and as these treatment areas became more open. Richness was significantly higher in mechanical+burn areas the third year after treatment than in other areas. By the fourth year, both burn treatment areas had significantly higher species richness than did control or mechanical treatment areas and the mechanical+burn treatment had the highest richness of all treatments. Mortality of overstory trees was slower in the burn-only areas than in the mechanical+burn areas suggesting that species richness may continue to increase if trees continue to die.

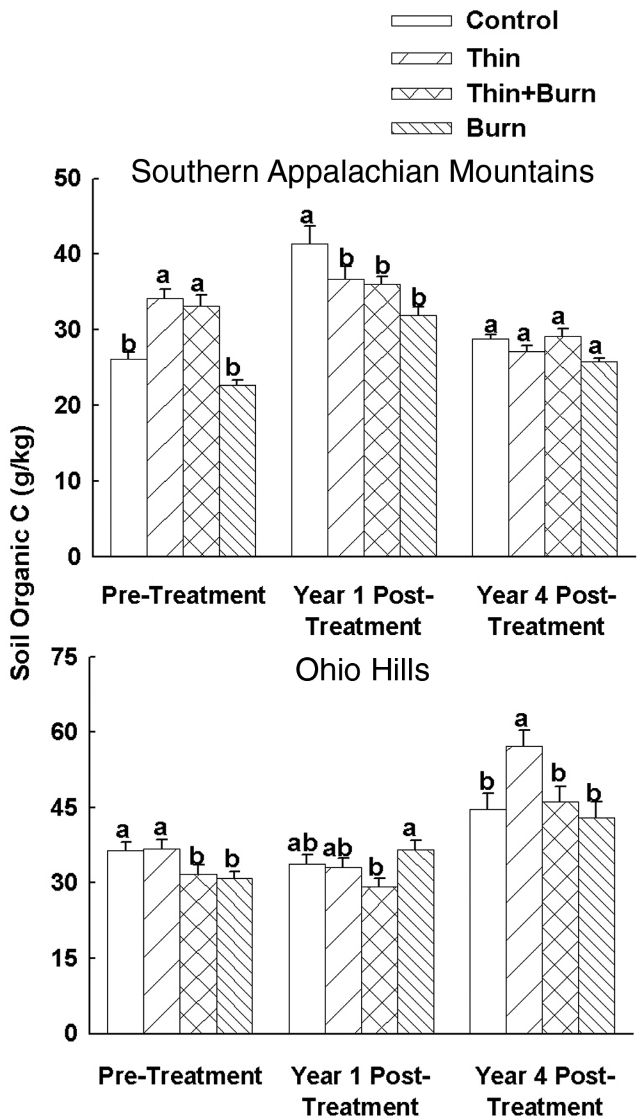

Figure 4—Changes in soil organic carbon (C) content (g C/kg) in relation to four forest restoration alternatives. Histogram bars represent means of n = 60 with standard errors of the means indicated. For site-year combinations in which there were significant treatment effects, histogram bars indicated by the same lowercase letter were not significantly different at $P < 0.05$ (from Boerner and others 2008).

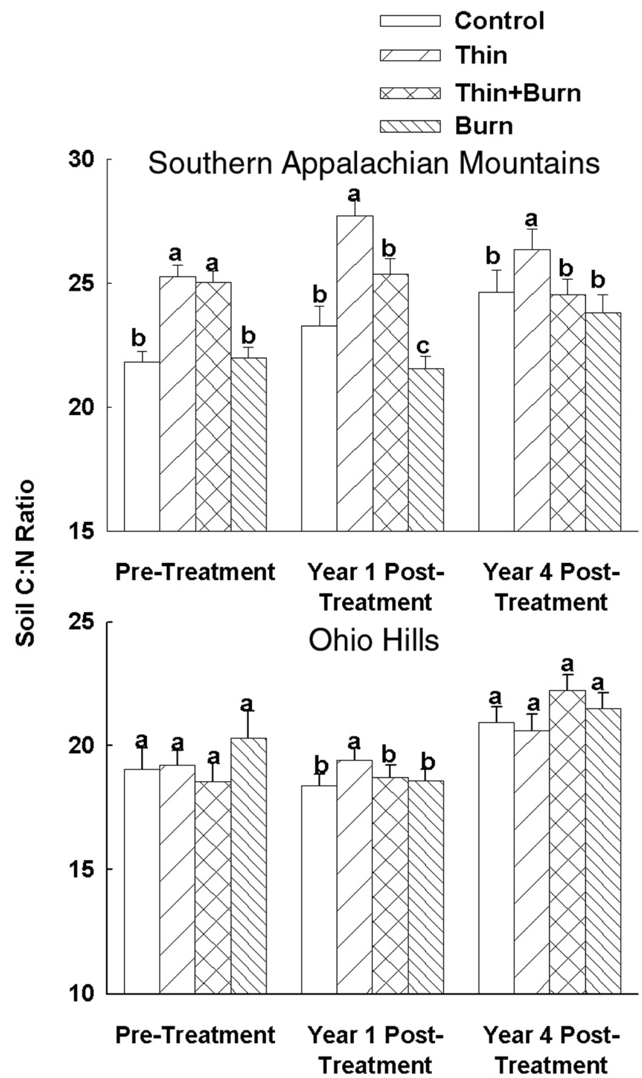

Figure 5—Changes in soil organic matter carbon to nitrogen ratio in relation to four forest restoration alternatives. Format follows figure 4 (from Boerner and others 2008).

Breeding birds responded to reductions in basal area at the Ohio Hills site is a similar manner to that of the Southern Appalachian Mountains site. However, the response to specific treatments differed because of the difference in mechanical treatments. In Ohio, richness was significantly higher in mechanical-only and mechanical+burn sites the first 3 years after treatment (2001 to 2003) (fig. 6B); differences were greatest the third year after treatment. At this site, the canopy was opened by the mechanical treatment (thinning) as opposed to prescribed burning at the Southern Appalachian Mountains site. Breeding bird richness decreased in all four treatment areas between the third and fourth years after treatment in Ohio, but differences between thinned and nonthinned plots remained significant.

DISCUSSION

Restoration of hardwood ecosystems of the Southern Appalachian Mountains and central Appalachian region is challenging because they have been protected from fire for decades, resulting in dramatic changes in stand structure. Treatments selected for the two hardwood sites of the FFS study provide a range of options for restoration which included commercial thinning at the Ohio Hills site, chainsaw felling of saplings and shrubs at the Southern Appalachian

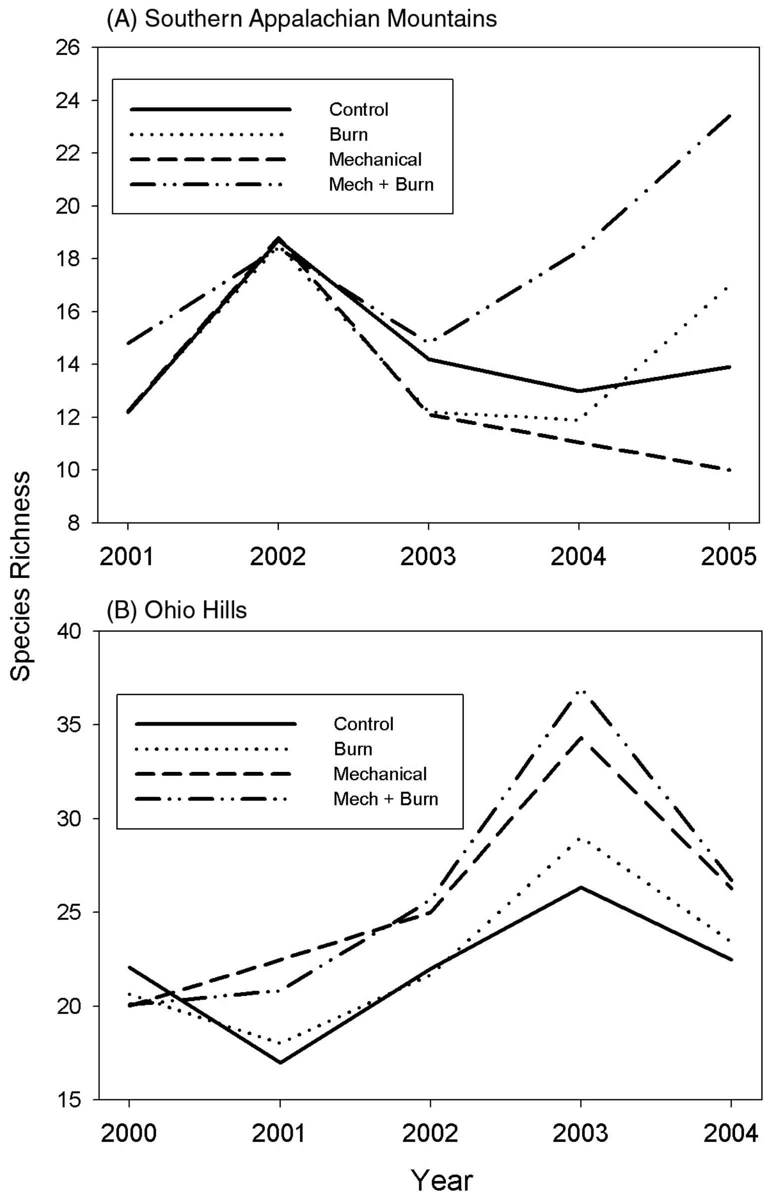

Figure 6—Species richness of breeding birds in four forest restoration alternatives: prescribed burn, mechanical understory reduction, mechanical+burn, and controls for the (A) Southern Appalachian Mountains and (B) Ohio Hills sites of the National Fire and Fire Surrogate Study [Southern Appalachian data were developed from Greenberg and others (2007)].

Mountains site, winter prescribed burning at both sites, and a combination of mechanical and burning treatments at both sites. Each treatment was designed to restore open woodland conditions by altering stand structure (mechanical treatments), reintroducing an ecosystem process (fire), or both. Historical accounts of soil characteristics lead us to postulate that the restoration goal for eastern forests would be soil subsystems that are lower in available nutrients (especially inorganic N), higher in soil organic matter, and lower in both soil organic matter quality and microbial (especially bacterial) activity (Boerner and others 2008). These systems were once driven by low rates of nutrient turnover and from a reservoir of C and N that was persistent and recalcitrant. Objectives for restoration of bird habitat are somewhat less clear. However, vegetation structure has a strong impact on the diversity and composition of bird communities. Disturbance can enhance diversity at stand and landscape scales by creating a mosaic of habitats or vegetation types. A number of bird species require habitat that has been recently disturbed by fire or by large-scale, high-intensity disturbance (Greenberg and others 2007).

None of the treatments at the Southern Appalachian Mountains or Ohio Hills was entirely successful at producing the stand structure of open woodlands, but each began the process of restoration. The burn-only treatment at both sites created some overstory mortality but stand basal area was reduced only slightly as surviving trees continued to grow. Mortality was continuing at Ohio Hills and may eventually result in more open stands. This result was unexpected as we assumed that most mortality would occur during the first year after treatment. After 6 years, the mechanical treatments were the most effective at opening the overstory but continued mortality in the burn-only plots may lower basal area to levels lower than that of the mechanical treatments. Fire reduced the sapling and shrub layer at both sites. This is especially important at the Southern Appalachian Mountains where dense mountain laurel can act as a vertical fuel. Tree regeneration was abundant at both sites including oaks, red maple, and yellow-poplar. A single burn at Ohio Hills decreased oak regeneration but increased the density of its competitors. At the Southern Appalachian Mountains, two burns seemed to favor oak regeneration by severely reducing density of red maple and yellow-poplar.

The immediate response of the organic matter complex to the restoration treatments was a reduction in soil organic matter quantity by all three treatments in the Southern Appalachian Mountains site and by the combination of thinning and burning in the Ohio Hills site. This was accompanied by a reduction in soil organic matter quality (as indicated by an increase in soil C to N ratio) in response to mechanical treatments in both sites and an improvement in soil organic matter quality as a result of fire alone at the Southern Appalachian Mountains site. By the third- or fourth-growing season after treatment, however, these effects had begun to dissipate and were limited to an elevation in soil organic matter content at the Southern Appalachian Mountains site and a reduction in soil organic matter quality at the Ohio Hills site, both of which were induced by the mechanical treatment.

Species richness of breeding birds did not increase immediately after treatment but seemed to respond positively as hardwood continued to die, especially at the Southern Appalachian Mountains site. The mechanical+burn treatment produced the quickest and largest change in species richness at both study sites. However, the open conditions created by thinning at Ohio Hills and hot prescribed fires at the Southern Appalachian Mountains are ephemeral unless either burning or mechanical fuel-reduction treatments are continued.

CONCLUSIONS

All treatments at both the Southern Appalachian Mountains and Ohio Hills sites effectively altered stand structure, but none created stands with open canopies and absent midstory. The mechanical+burn treatment showed the quickest movement toward restoration goals, but understory vegetation in eastern hardwood ecosystems regenerates and grows quickly without repeated control treatments. In addition, we saw no indication that mechanical/structural restoration actually produced changes in the desired direction for soil organic C. A single fire-based/functional treatment did offer some possibility of restoration progress repeated entries at intervals of 3 to 8 years might be necessary. Bird diversity responded positively to open canopy conditions which were best provided by the mechanical+burn treatment at both study sites, but those habitat conditions are short lived. Our results indicate that restoration of eastern hardwood forests cannot be accomplished with one or two entries. Rather, restoration is likely to be a complex, lengthy, and resource consumptive process.

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