Fire and Fire Surrogate Treatments in Mixed-Oak Forests: Effects on Herbaceous Layer Vegetation

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Abstract—*Herbaceous layer vegetation responses to prescribed fire and fire surrogate treatments (thinning and understory removal) were examined. Results from 3 to 4 years following treatment are presented for the Ohio Hills Country and the Southern Appalachian Mountain sites of the National Fire and Fire Surrogate Study. At the Ohio Hills site, changes in forest structure were observed for all treatments, but areas treated with fire showed the greatest increase in herbaceous cover and species richness. These results indicate that fire effects are unique disturbances that are not mimicked by alterations of the forest structure alone. However, at the Southern Appalachian site, fire alone did not produce a response in the herbaceous layer. The combination of fire plus mechanical treatment was necessary to increase cover and species richness.*

Introduction

The herbaceous layer in oak forests typically contains the greatest number of species with perennial forbs and grasses composing the majority of diversity. Many of these species respond positively to disturbance through increased growth, sexual reproduction, and asexual propagation (Whigham 2004). With the exclusion of fire and consequently increased stand density, suitable seedbed habitat and available light become limiting factors for herbaceous species propagation and survival. Eliminating fire disturbance has allowed fire-sensitive, shade-tolerant species to become established leading to changes in forest composition and structure (Abrams 1992; Abrams and Nowacki 1992; Crow 1988; Lorimer 1984; Nowacki and Abrams 1991; Schuler and Gillespie 2000).

The use of prescribed fire in these forests has increased in recent years in efforts to reduce fuel loadings, encourage oak regeneration, and halt the conversion of these stands to forests dominated by mesophytic species. In Ohio, acreage treated with prescribed fire grew from less than 2,000 to almost 20,000 acres from 2001 to 2004 (Mike Bowden, personal communication). Thinning has also been suggested as an alternative method for creating stand structure to promote and sustain oak dominance. While oak regeneration and woody species composition have received considerable attention (for example, Abrams 1992; Albrecht and McCarthy 2006; Barnes and Van Lear 1998; Brose and others 1999, 2006; Elliott and others 2004; Lorimer 1985; Reich and others 1990), only recently has research focused on the herbaceous layer in mixed-oak forest types.

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Previous studies in oak dominated forests indicate herbaceous cover and abundance typically increase following fire (Elliott and others 1999; Hutchinson 2006; Hutchinson and others 2005), whereas fire effects on diversity vary. Burning may have little effect on diversity (Dolan and Parker 2004; Franklin and others 2003; Hutchinson and others 2005; Kuddes-Fischer and Arthur 2002), or it can significantly increase herbaceous layer diversity (Ducey and others 1996; Elliott and others 1999; Taft 2003). It should be noted the latter studies were conducted in stands that had lower basal area and/or experienced higher intensity fires, suggesting that more intense management than low-intensity burning is required (Abrams 2005; Franklin and others 2003; Ruffner and Groninger 2004).

Many herbaceous species are light limited. Therefore, changes in light availability can cause large responses in plant growth and/or reproduction (Whigham 2004). Altering the structure of oak stands through mechanical thinning increases resource availability and typically results in greater abundance and diversity of herbaceous plants (Bormann and Likens 1979; Elliott and others 1997; Gilliam and others 1995). It has also been shown that different levels of thinning affect the herbaceous layer in significantly different ways (Elliott and Knoepp 2005; Zenner and others 2006). Thus, reducing overstory and midstory stem density may provide suitable conditions for developing and maintaining diversity within mixed-oak forests.

The objective in this paper is to discuss trends resulting from fire and fire surrogate treatments in mixed-oak stands located within the Central and Southern Appalachian regions. Similarities and differences between these sites will be discussed as they relate to land management objectives.

Materials and Methods

Study Sites

Study locations are within the Central Appalachian Plateau and Southern Appalachian Mountains in Ohio and North Carolina, respectively (fig. 1). Both sites are part of the National Fire and Fire Surrogate (FFS) Study and were selected to represent Eastern forest communities that historically sustained frequent, low-intensity fire disturbances (Weatherspoon 2000).

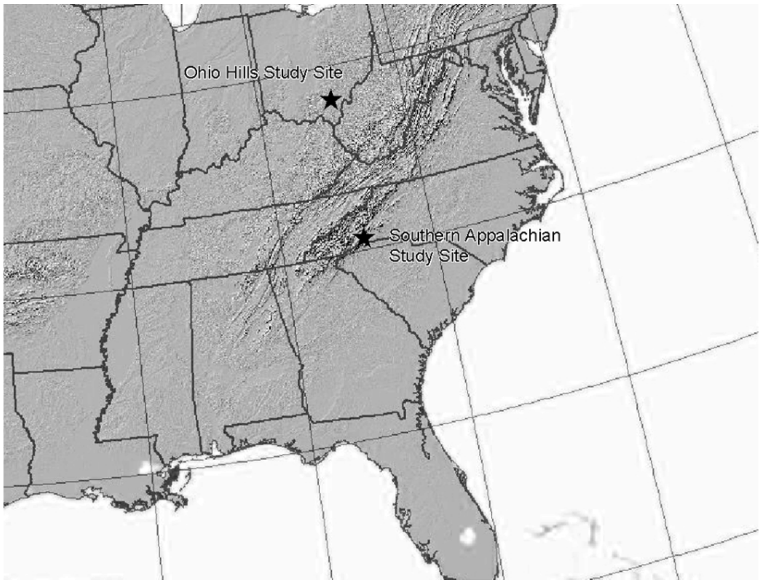

Figure 1—Site locations for the Ohio Hills Country and Southern Appalachian Mountain study sites.

The Ohio Hills Country site is on the Vinton Furnace Experimental Forest, Tar Hallow State Forest, and Zaleski State Forest in the Allegheny Plateau Province of southeastern Ohio. The overstory is dominated by oak: chestnut oak (*Quercus prinus* L.), white oak (*Q. alba* L.), northern red oak (*Q. rubra* L.), scarlet oak (*Q. coccinea* Muenchh.), and black oak (*Q. velutina* Lam.). Other common overstory species include pignut hickory (*Carya glabra* (Miller) Sweet), mockernut hickory (*C. alba* (L.) Nutt ex Ell.), bitternut hickory (*C. cordiformis* (Wangenh.) K. Koch), red maple (*Acer rubrum* L.), tulip poplar (*Liriodendron tulipifera* L.), and American beech (*Fagus grandifolia* Ehrh.). Soils are primarily of the Gilpin series (fine-loamy, mixed, mesic Typic Hapludults) with mixtures of Steinsburg (coarse-loamy, mixed, mesic Typic Dystrudepts) and Germano (coarse-loamy, mixed, mesic Typic Hapludults) soils at two replications and Latham (fine, mixed, mesic Aquic Hapludults) and Wellston (fine-silty, mixed, mesic Ultic Hapludalfs) soils at the third replication.

The Southern Appalachian site is in the Blue Ridge Province of southwestern North Carolina on the Green River Game Lands. Forest composition is mixed-oak with yellow pine on xeric ridges and white pine (*Pinus strobus* L.) in moist coves. Oaks (chestnut oak, scarlet oak, white oak, northern red oak, and black oak) dominated all sites, with other common species including: sourwood (*Oxydendrum arboreum* (L) DC.), red maple, tulip poplar, mockernut hickory, blackgum (*Nyssa sylvatica* Marsh.), and pitch pine (*Pinus rigida* P. Mill.). A dense layer of ericaceous shrubs—mountain laurel (*Kalmia latifolia* L.), rhododendron (*Rhododendron maximum* L. and *R. minus* Michx.), flame azalea (*R. calendulaceum* (Michx) Torr.), and blueberry (*Vaccinium* species L.)—is found throughout. Soils are primarily Evard series (file-loamy, oxidic, mesic Typic Hapludults) with portions of two replications (blocks 1 and 2) of the Cliffield series (loamy-skeletal, mixed, mesic Typic Hapludults). These soils are moderately deep, well drained, mountain uplands (USDA Natural Resources Conservation Service 1998). Elevations range from 366-793 m.

Experimental Design and Treatments

Treatments at each study site followed national protocols (Weatherspoon 2000) with accommodations for regional differences. The four treatments included: untreated control (C); a mechanical treatment (M); prescribed burning (B); and a combination of the mechanical treatment plus burning (MB). Treatments were randomly assigned and replicated three times. Herbaceous layer vegetation (herbaceous and woody vegetation less than 1.4 m in height) was measured on 1 m^2 quadrats within larger 0.1-ha rectangular plots randomly placed throughout the treatment areas (and stratified by moisture class at the Ohio site). Within quadrats species composition and abundance were recorded using cover classes: <1, 1-10, 11-25, 26-50, 51-75, >75 percent. Plots were originally sampled in 2000 (Ohio Hills) and 2001 (Southern Appalachian). The first posttreatment sampling occurred immediately following treatment. The second posttreatment occurred 3 (Southern Appalachian) or 4 years after treatment (Ohio Hills).

The mechanical treatment at the Ohio Hills site was a commercial thinning from below whereas the Southern Appalachian site used chainsaw felling of small, suppressed trees (dbh < 10 cm) and all shrubs. Slash created from these treatments was left onsite. Mechanical treatment was completed in the winter of 2000 to 2001 in Ohio and the winter of 2001 to 2002 in North Carolina.

Prescribed burning immediately followed the mechanical treatment at the Ohio Hills site in spring 2001. Temperature and humidity (RH) during the burns ranged from 11 to 23 °C and 23 to 44 percent, respectively. Winds were generally light at 5 to 8 km/hr. Fires were patchy, with the burn-only treatment having greater coverage (acreage burned) and greater intensity than those in mechanical plus burn. Mean maximum temperatures measured by thermocouples were 152 °C in B and 133 °C in MB with flame lengths =1 m. At the Southern Appalachian site, burning was conducted in March 2003, 1 year after mechanical treatment, allowing slash to cure. Ambient temperatures during burns were 17 to 27 °C, the minimum RH was 30 percent, and southwest winds were light (3 to 5 km/hr). Fire intensity in MB was consistently greater than B, as mean maximum temperatures exceeded 370 °C as opposed to 180 °C for B.

Results

Fuel reduction treatments changed species abundance and richness within the herbaceous layer of the mixed-oak forests at both sites. Woody cover increased across all treated areas at the Ohio Hills site but changed only in MB areas at the Southern Appalachian site (fig. 2). Treatments caused a reduction in overstory basal areas for all treated areas at Ohio Hills: M decreased from 29 to 20 m^2 ha^{-1}; B declined from 27 to 24 m^2 ha^{-1}; and MB dropped from 28 to 20 m^2 ha^{-1}. Pretreatment woody cover in the herbaceous layer increased from 17 to 20 percent to greater than 53 percent by the second posttreatment measurement for M, B, and MB in Ohio. Woody cover relative to total herbaceous layer cover increased slightly for C (67 to 70 percent) and M (82 to 84 percent), whereas B and MB showed slight decreases, 77 to 71 percent and 78 to 74 percent, respectively.

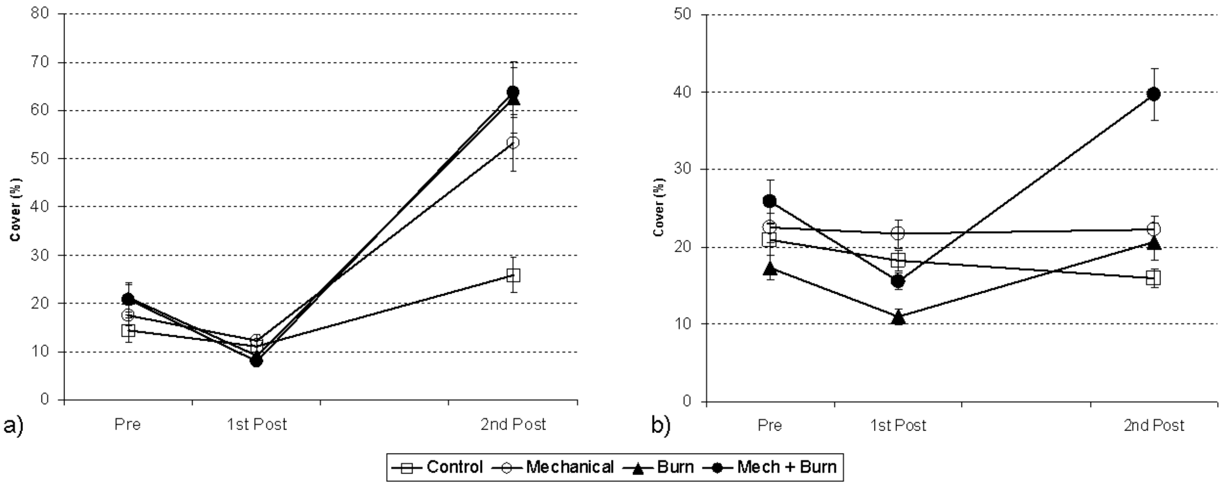

Figure 2—Woody abundance in the herbaceous layer at the Ohio Hills (a) and Southern Appalachian (b) study sites. Vegetation sampling occurred prior to treatment ("Pre"), immediately following treatment ("1st Post"), and 3 (Southern Appalachian) or 4 years (Ohio Hills) following treatment ("2nd Post").

At the Southern Appalachian site, basal area was reduced from 23 to 18 m^2 ha^{-1} in MB, whereas little effects were observed on overstory basal area for the other treatments. Pretreatment herbaceous layer woody abundance averaged 26 percent for MB, but increased to 40 percent after 3 years. Mechanical-only and burn-only were relatively unchanged from pretreatment levels after 3 years, 22 and 20 percent, respectively, while C gradually declined. Relative to total herbaceous layer cover, woody abundance decreased for all areas (C: 83 to 77 percent; M: 92 to 91 percent; B: 82 to 80 percent; and MB: 88 to 76 percent).

Forb abundance showed a positive response to burning at the Ohio Hills site with increases in B and MB from 5 percent to more than 22 and 18 percent, respectively; M differed little from the control after 4 years (fig. 3a). Graminoids followed similar trends with large increases in B and MB and twice as much graminoid cover after 4 years as compared to C and M (fig. 3b). Forbs and graminoids composed almost 30 percent of total herbaceous layer cover in C prior to treatment but cover had dropped to 24 percent after 4 years. The mechanical treatment showed little change in relative cover during the same period. The burn-only treatment increased from 20 to 25 percent in relative cover whereas herbaceous species had a relative cover of 21 percent in MB.

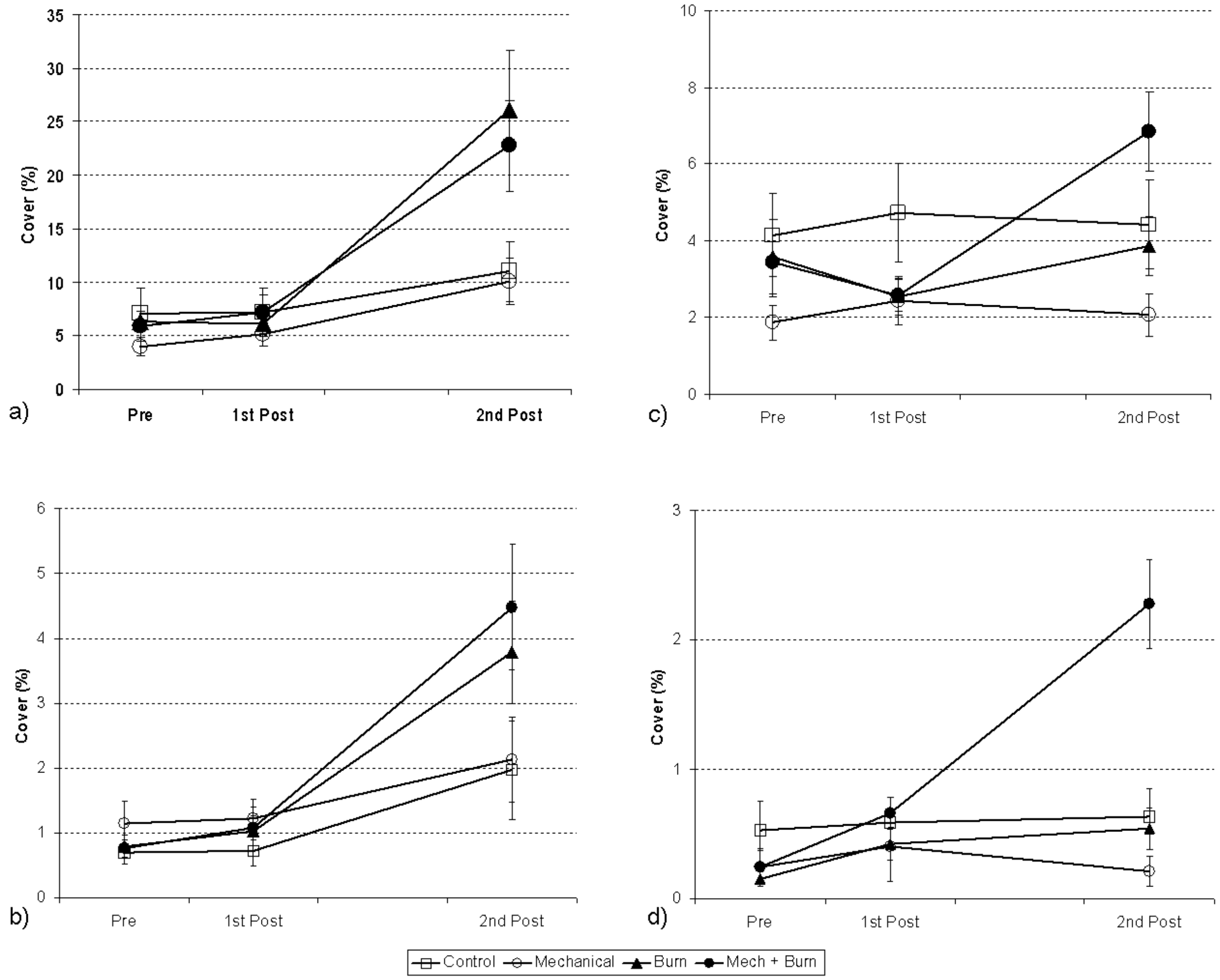

Figure 3—Cover for forbs and graminoids at Ohio Hills (a and b) and Southern Appalachian (c and d) sites.

At the Southern Appalachian site, forb and graminoid cover were higher in MB as compared to other treatments after 3 years (fig. 3c,d). Forbs recovered to almost twice the pretreatment levels in MB after declining briefly immediately after burns. Graminoids in MB increased immediately, a trend that continued into the third year. In C, M, and B, no differences from pretreatment values were observed after 3 years. Relative cover of forbs and graminoids, combined, increased from 19 to 25 percent in C, in contrast to expected results. The mechanical-only and burn-only treatments had no effect on relative cover for forbs and graminoids after 3 years (9 percent M and 18 percent B). However, relative cover of forbs and graminoids in MB increased from 13 to 20 percent.

Trends for total species richness were similar for both sites as large increases were observed in burned areas (B and MB) immediately after treatment, followed by gradual increases from the 1st to the 2nd posttreatment sampling (fig. 4a,c). The mechanical-only treatment also increased total species richness at both sites, although these areas contained considerably fewer species than B and MB areas. At the Ohio Hills site, M resulted in more species m^{-2} than the controls, but at the Southern Appalachian site, M still had lower species richness m^{-2} than C after 3 years. However, the differences between C and M lessened over time.

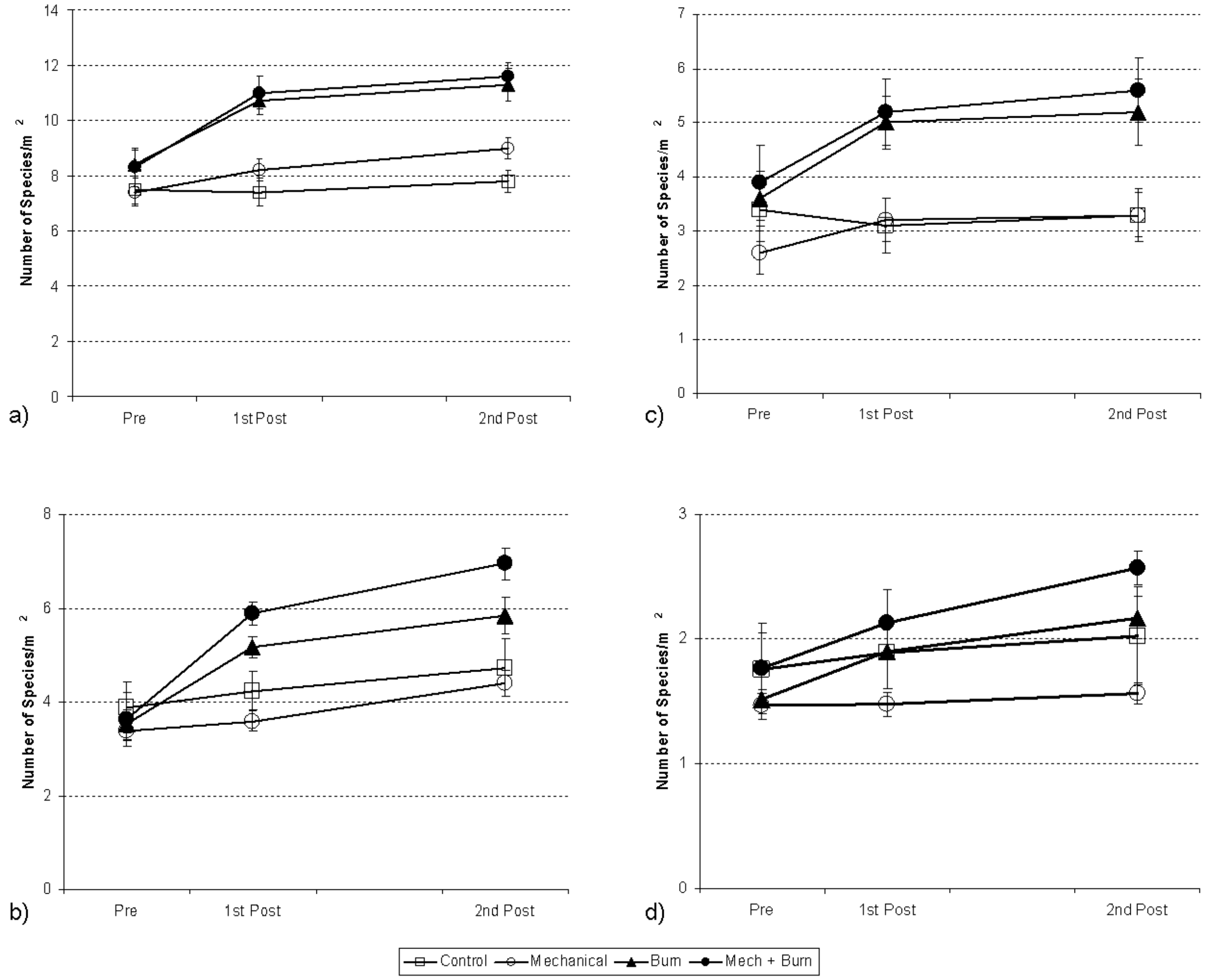

Figure 4—Total richness (a and b) and herbaceous species richness (c and d) for herbaceous layer vegetation at Ohio Hills (a and c) and Southern Appalachian (b and d) sites.

Burning increased herbaceous species richness at Ohio Hills with almost two more species m^{-2} for burned versus unburned areas (fig. 4b). The mechanical-only treatment also resulted in greater species richness, with little differences between C and M by the 2nd posttreatment measurement. At the Southern Appalachian site, burned areas (B and MB) showed similar trends as immediate increases were observed following burning, whereas unburned areas (C and M) gradually increased over time (fig. 4d). After 3 years MB contained the greatest number of herbaceous species m^{-2}; B and C were similar; and M had the least.

Discussion

Mechanical treatment alone had little effect on herbaceous species at the Ohio Hills site, but it increased woody cover and total richness. At the Southern Appalachian site, there were no significant effects for woody or herbaceous species as a result of mechanical treatment. Structural differences between the mechanical treatments for each location were distinct as basal area and density were significantly reduced at Ohio Hills (Albrecht and McCarthy 2006), whereas few changes were observed for those attributes at the Southern Appalachian site (Phillips and others, in press). Dolan and Parker (2004) reported no changes in herbaceous vegetation in an Indiana oak forest after a mechanical understory reduction treatment similar to that used in the Southern Appalachians, although they observed slight increases in shade-intolerant tree species. Other studies using more intense harvesting practices have shown increasing herbaceous layer abundance and diversity associated with greater intensity harvests (Elliott and Knoepp 2005; Zenner and others 2006). Zenner and others (2006) suggest that until certain harvest intensity thresholds are reached, few effects will be observed. The lack of response for both sites may be partially attributed to the manner in which these treatments were conducted. As specified by treatment prescriptions, all slash was scattered and left onsite. This material may have served as a physical barrier to seed germination and prevented plant growth by limiting light at the forest floor. The changes in forest structure from the mechanical treatments used at the Ohio Hills and Southern Appalachian sites did not promote herbaceous layer richness.

Prescribed fire had positive effects on herbaceous layer abundance and richness at the Ohio Hills site. Abundance and species richness were considerably higher in burned areas than in unburned areas. The prescribed fires in B at Ohio Hills were of sufficient intensity to create canopy gaps, allowing enough light to elicit a response in the herbaceous layer. Changes in the understory environment (for example, consumption of the litter layer, increased available light) provided suitable conditions for seed germination and plant growth. Initial changes in composition richness are typically dominated by establishment of seed-banking, shade-intolerant species; while long-term changes result as perennial forbs and graminoids become established (Hutchinson 2005). Long-term application of fire is necessary to maintain this increased diversity (Hartman and Heumann 2003).

At the Southern Appalachian site, prescribed fire alone had little effect on herbaceous layer vegetation. No differences were observed between B and C after 3 years for herbaceous species abundance or richness, although B had higher total species richness. These results are similar to those of Kuddes-Fischer and Arthur (2002) where a single low-intensity fire produced little differences in herbaceous and shrub cover and slight, nonsignificant increases in richness after 4 years. While mean maximum fire temperatures were greater in the Southern Appalachians than in the Ohio Hills, small declines in overstory basal area and density at the Southern Appalachian site may have been offset by sprouting from ericaceous shrubs. Only minor reductions in the shrub component resulted from the burn-only treatment (Phillips and others, in press); therefore, shading may have limited the light needed for seed germination. Ducey and others (1996) and Elliott and others (1999) indicate that more intense fires are required to reduce mountain laurel abundance (*K. latifolia*) and thus increase herbaceous layer richness and diversity in the Southern Appalachians.

The combination of mechanical treatment plus burning showed similar effects as burning alone at the Ohio Hills site. Greater herbaceous layer cover in addition to increased species richness was observed with lower-intensity fires. Decreased basal area was achieved by mechanical felling of the overstory, while midstory cover and leaf litter were reduced by burning. The combination of mechanical treatment and burning may be less cost-effective than burning alone, but it provides greater control of shade-tolerant species by reducing sprouting vigor through application of multiple disturbances (Albrecht and McCarthy 2005).

In the Southern Appalachians, only a combination of mechanical treatment and burning resulted in increased herbaceous layer cover and richness. Fires within these treatment areas were considerably more intense than the burn-only treatment, resulting in greater mortality of large diameter trees (Brudnak and others, in press) increasing insolation. By using fire after mechanical treatment, sprouts from shade-tolerant species and ericaceous shrubs were further reduced (Phillips and others, in press), allowing herbaceous vegetation to become established.

The lack of response of herbaceous species to mechanical treatment compared to burning indicates that fire may promote processes (that is, nutrient cycling, seed germination, and so forth) that cannot be mimicked by structural alteration alone. Changes to forest structure in some stands, as a result of fire exclusion, may be too extreme to overcome by fire alone (Franklin and others 2003). Reducing stem densities and allowing more light to reach the forest floor, in conjunction with fire, may be necessary to restore diversity to mixed-oak forests, as evidenced at the Southern Appalachian site.

Conclusions

As oak forests decline across the Eastern landscape, prescribed fire and other treatments are being applied to encourage oak recruitment and sustain this forest type. But the intensities of fire and thinning required to restore these communities are not well understood.

These results indicate responses of herbaceous layer vegetation to fire and fire surrogate treatments vary by region and are dependant on pretreatment species composition and structure. Prescribed fire resulted in greater cover and species richness for the herbaceous layer in the Central Appalachian region in Ohio. However, in the Southern Appalachian Mountains in North Carolina, ericaceous shrubs and lack of sufficient light reaching the forest floor required both mechanical treatment and prescribed fire to increase abundance and richness in the herbaceous layer.

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