UNDERSTORY RESPONSE TO DISTURBANCE: AN INVESTIGATION OF PRESCRIBED BURNING AND UNDERSTORY REMOVAL TREATMENTS

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Abstract—Lack of disturbance in the Central Hardwood Region has caused a decrease in abundance of shade-intolerant species, such as oaks (*Quercus spp.*) and hickories (*Carya spp.*), while shade-tolerant species have proliferated in the understory. The goal of this research is to determine how two disturbances, prescribed fire and mechanical understory removal, affect woody species regeneration, as well as herbaceous species diversity. Preliminary analysis indicates that all treatments had little effect on herbaceous species diversity; however, prescribed burning changed the composition of woody species seedlings. While fire top-killed most seedlings, regardless of shade tolerance, shade-intolerant species responded by resprouting. As a result of the reduction in the number of shade-tolerant species, burning treatments produced greater equitability among tolerant and intolerant species seedlings. Removal treatments increased the level of photosynthetically active radiation (PAR) reaching the forest floor, while a combination of burning and removal provided both greater equitability among species and higher levels of PAR.

INTRODUCTION

Disturbances of both natural and anthropogenic origin have shaped forests in the Central Hardwood Forest Region for centuries. Human-induced disturbances, such as fire and clearing, have affected the region for approximately 10,000 years as large populations of native peoples and Europeans have passed through or settled. By choosing to burn, clear, or suppress disturbances, their actions have affected succession and forest composition.

Upland forests of this region are typified by oak-hickory (*Quercus* L.-*Carya* Nutt. *spp.*) overstories, with more shade-tolerant species, like maples (*Acer* L. *spp.*), dominating the understory. Advanced oak regeneration struggles to compete with the abundant shade-tolerant species in the understory and rarely survives long enough to grow to the overstory. Succession of plant species is similar throughout the Central Hardwoods: forests are first dominated by shade-intolerant, fast-growing species, characterized in the region by oaks and hickories, and are followed by those more tolerant of the dense shade beneath the forest canopy. The forests eventually reach a state where the overstory is composed of maples, beech (*Fagus grandifolia* Ehrh.), and other shade-tolerant species. In central and northern Indiana, where small isolated fragments of forest are dwarfed by the agricultural landscape and disturbances have been lacking, shade-tolerant species have gained in dominance over the past century. Spetich and Parker (1998) showed that the mid-story composition of an old-growth forest in east-central Indiana had changed from 14 percent oak and 12 percent sugar maple (*Acer saccharum* Marsh.) in 1926 to 1 percent oak and 43 percent sugar maple by 1992. It has been predicted that gradual replacement of the oak-hickory overstory in this forest will lead to a canopy dominated by sugar maple by the end of the twenty-first century (Spetich 1995).

Disturbances can be used to slow the succession toward shade-tolerant species dominance and encourage regeneration of early successional species. One of the greatest impacts that disturbances have on a forest is the reduction of trees in the mid- and understory layers which consequently increases the light that reaches the forest floor. Merritt and Pope (1991) have shown that the result of prescribed burning is to increase the intensity of light penetrating the forest canopy. They also found an increased density of early successional species following burning.

Burning alone, however, may not be sufficient for oak regeneration, especially if the understory is already dominated by late successional species. Research suggests that burning will have little affect on species composition and may even increase the number of shade-tolerant species that are already prolific beneath the canopy (Arthur and others 1998, Dolan 1994, Huddle and Pallardy 1996, McGee and others 1995, Merritt and Pope 1991). Furthermore, harvesting treatments can encourage the growth of shade-tolerant species by allowing light to reach seedlings which are already present in the understory prior to cutting (Abrams and Scott 1989, Jenkins and Parker 1998, Weigel and Parker 1997). Therefore, altering only the light regime may not be sufficient for increasing oak dominance in the understory.

Brose and others (1999) have shown that the combination of burning and shelterwood cuts can have a positive effect on the composition of shade-intolerant species. While harvesting provided light for growth of shade-intolerant species like oak, fire acted to reduce competition from more abundant species like red maple and tulip-poplar. Because of physiological differences in the species, oak, which develops a strong root system as a seedling, is able to sprout quickly following a fire and take advantage of the increased light created by the harvesting and subsequent maintenance by the fire (Barnes and Van Lear 1998, Huddle and Pallardy 1999, Kelty 1999, Kolb and others 1990).

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The objective of this research is to investigate whether prescribed fire and sub-canopy removal within mid-successional forests can be used to shift the species composition of understory communities. This study examines how disturbances can be used to increase the abundance of shade-intolerant species through the control of shade-tolerant species dominance and the simultaneous modification of light conditions at the forest floor.

METHODS

Research Sites

Research was conducted on three Purdue University properties in west-central Indiana. Two properties, Martell Forest (mesic slope) and Cox-Haggerty Woodland (dry slope), are located at the break of the Tipton Till Plain and consist of several areas with 18 to 50 percent slopes. South facing slopes with oak-hickory overstories were chosen as study sites on these two properties. Soils are classified in the Strawn-Rodman complex and are well drained with moderate to low available water capacity (Ziegler and Wolf 1998). The third property, McCormick's Woods (mesic upland), is located on the till plain and has level topography. The soil is classified as Starks-Fincastle complex and is somewhat poorly drained with high available water capacity (Ziegler and Wolf 1998). The forest overstory at McCormick's Woods is also dominated by oak-hickory.

The disturbance and management history of these sites is not well documented, but recent disturbances within these woodlands have been minimal. The site at Martell Forest burned accidentally in 1981, and though the intensity was low, it completely burned the hillside of study. The understory is composed mainly of American elm and flowering dogwood, though neither is dominant. The Cox-Haggerty Woodland site was grazed until 1990 and, as a result, has an understory dominated by plant species associated with grazing, especially Amur honeysuckle (*Lonicera maackii* (Rupr.) Herder). McCormick's Woods was harvested several times in the 1960s and 1970s using group and single-tree selection cuts. The understory is dominated by sugar maple and white ash (*Fraxinus americana* L.), which often grow thick enough to prevent easy movement through the forest.

Plot Design

Study sites were divided into several 20 x 20 meter plots for study and treatment. Treatment plots were established on a grid system, oriented by cardinal directions, with a 10 meter wide buffer left between plots to reduce treatment overlap. Sampling was restricted to a 10 x 10 meter plot centered within the treatment plot, leaving a 5 meter buffer surrounding the sampling plot to reduce edge effect from adjacent, untreated areas. Twelve plots each were established at the mesic and dry slope sites, and 20 plots were established at the mesic upland site.

Sampling Design

Cover of herbaceous species and density of woody species within the understory were sampled prior to treatment during May and June 1999 and after treatment in May and June 2000 and 2001. Cover of herbaceous species was determined on a four-point scale based on percent cover: 1 = less than 1 percent cover, 2 = 1-5 percent cover, 3 = 5-15 percent cover, and 4 = greater than 15 percent cover. Woody and shrub sprouts resulting from stem top-kill were counted as seedlings; each sprouting plant was counted as one seedling. Finally each tree greater than 2 cm in diameter at breast height (d.b.h.) within the sampling plot was identified and measured at breast height.

Transmitted photosynthetically active radiation (PAR) was measured prior to treatment in July 1999, and following treatment in July 2000, for each sample plot. Measurements were not recorded in 2001. A Sunflec Ceptometer (Decagon devices, Inc., Washington, USA) was used to measure PAR at five points within each plot: one at each corner and one in the center. Measurements in full sunlight were also taken each day plot measurements were taken. All PAR measurements were made on cloudless days between 12:00 p.m. and 2:00 p.m. eastern standard time.

Treatments

One of four treatments was randomly assigned to each plot. Each treatment was replicated five times at the mesic upland site and three times at both the dry and mesic slope sites. The treatments assigned were mechanical removal of the subcanopy, prescribed burn, a combination of burning and removal, and control.

Mechanical removal of the subcanopy occurred in August 1999 on plots designated for removal and combination treatments. Woody stems greater than 1 cm in d.b.h. but less than 15 cm in d.b.h. were cut using a chain saw and completely removed from the treatment plot. Trees greater than 10 cm in d.b.h. that would have been difficult to maneuver and could not be felled easily were double girdled and allowed to remain standing in the plot.

Prescribed burns were conducted in October and November 1999 on plots designated for burn and combination treatments. One meter wide fire break lines were constructed around each treatment plot prior to burning using fire rakes and a leaf blower. Depending on the weather and dryness of the fuel, either a strip head or ring fire technique was used to burn each plot. After ignition, the fires were allowed to burn through the plots and extinguish themselves. Any large debris left burning was extinguished using water sprayed from backpack pump sprayers.

Data Analysis

Woody seedling data were analyzed to find differences in diversity, evenness, and density between treatments at each site. The Shannon-Wiener index was used to computer diversity and evenness. To simplify results and interpretation, tree species were separated into two categories, shade-tolerant and shade-intolerant seedlings. Shade tolerance was classified by each species' ability to grow from a seedling to a sapling beneath a dense overstory. Some species typically defined as shade-intolerant, such as black cherry or white ash, were classified as shade-tolerant for this study, because their abundant seedlings often grow to sapling size and present immense competition to oaks, hickories, and other shade-intolerant species typically unable to grow beyond seedling size before mortality. The effect of treatment and time on diversity, evenness and density was analyzed with a repeated measures analysis in SAS using Wilk's Lambda to determine significance. Square-root transformations were performed on density data in order to decrease the amount of variability between plots.

Herbaceous species abundance data were analyzed with partial detrended correspondence analysis (pDCA) in CANOCO to determine the effect of treatment on herbaceous community composition. PDCA, a variation of DCA allowing for covariables, provided a graphical analysis of community composition, as well as a plot depicting the relationship between sites based on species compositions. Using plot and time as covariables, the effects of these factors were taken into account while the effect of treatment remained as a potential source of variation. Sites plotted on the graph were most similar to those plotted near it, while those farther away were dissimilar. From this method, treatment effect was evaluated by looking for clusters of sites which had the same treatment applied.

Photosynthetically active radiation data from each plot, along with measurements taken in full sunlight, were used to calculate the percent of full sunlight beneath the canopy for each plot. Comparisons and analysis of the percent full sunlight between plots and treatments were done using an ANOVA in SAS.

RESULTS

Analysis of the three forest sites with burning, mechanical removal, and combination treatments resulted in no significant difference in diversity as measured by the Shannon-Wiener index. Compared to the change over time at plots which received no treatment, the overall diversity of seedlings did not increase or decrease with treatment (fig. 1). Further, the difference between treatments at each site was not significant. In comparison to the control plots, the graphs show a decrease in diversity for burn treatments at the mesic slope site by the third year (fig. 1b). This can be attributed to an overall loss in the total number of seedlings because of burning. The loss of species was not seen however after the first year at this site or after the first or second years at the dry slope (fig. 1a) or mesic upland sites (fig. 1c).

Evenness of species distribution within each plot increased after the first year with burn treatments at each site. Both burn treatments at the dry slope site showed a dramatic increase in evenness over the change at the control site (fig. 2a). The effect was continued through the second year of treatment at which time the increase became statistically significant (p = 0.05). The increase in evenness at the mesic upland site was significant for the combination treatment (p = 0.02), but not for the burn treatment (fig. 2b). At this site, the increase in evenness after burning was apparent after only the first year of treatment. The following year saw a sharp decrease in evenness on all treatment plots. The change in evenness at the mesic slope site tended to follow that of the mesic upland; however, the results were not statistically significant (fig. 2c). All treatments showed a slight increase in evenness over the control plots, but evenness decreased after the second burn treatments. The removal treatment at all sites tended to increase evenness slightly over the control, though these changes were not significantly large.

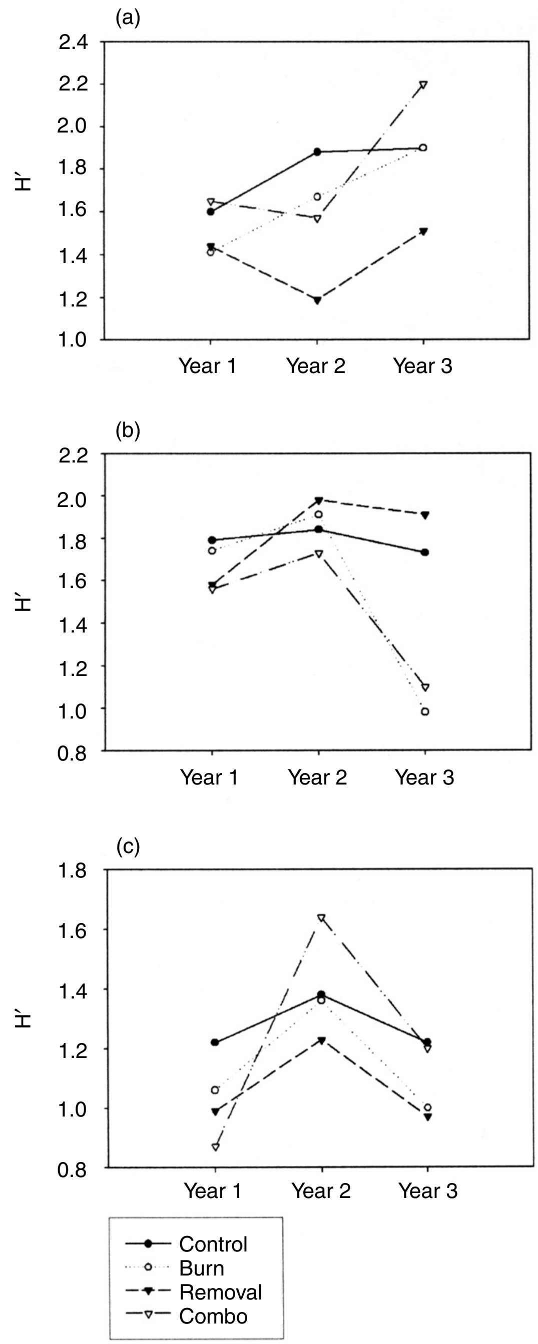

Figure 1—Plot of Shannon-Wiener index of diversity for each treatment over time at the dry slope site (a), the mesic slope site (b), and the mesic upland site (c).

Analysis of shade-tolerant seedling density reveals that only plots which received the combination treatment changed significantly (p = .10) in response to treatment. The greatest decrease was found at the dry slope site (fig. 3a) where the number of shade-tolerant seedlings was originally very high. Both burn treatments largely reduced the number of shade-tolerant seedlings at this site. The mesic slope (fig. 3b) and mesic upland sites (fig. 3c) showed similar responses to the burn treatments with a decrease in the number of shade-tolerant species, though to a lesser degree than at the dry slope site. At the mesic upland site, there was a large spike

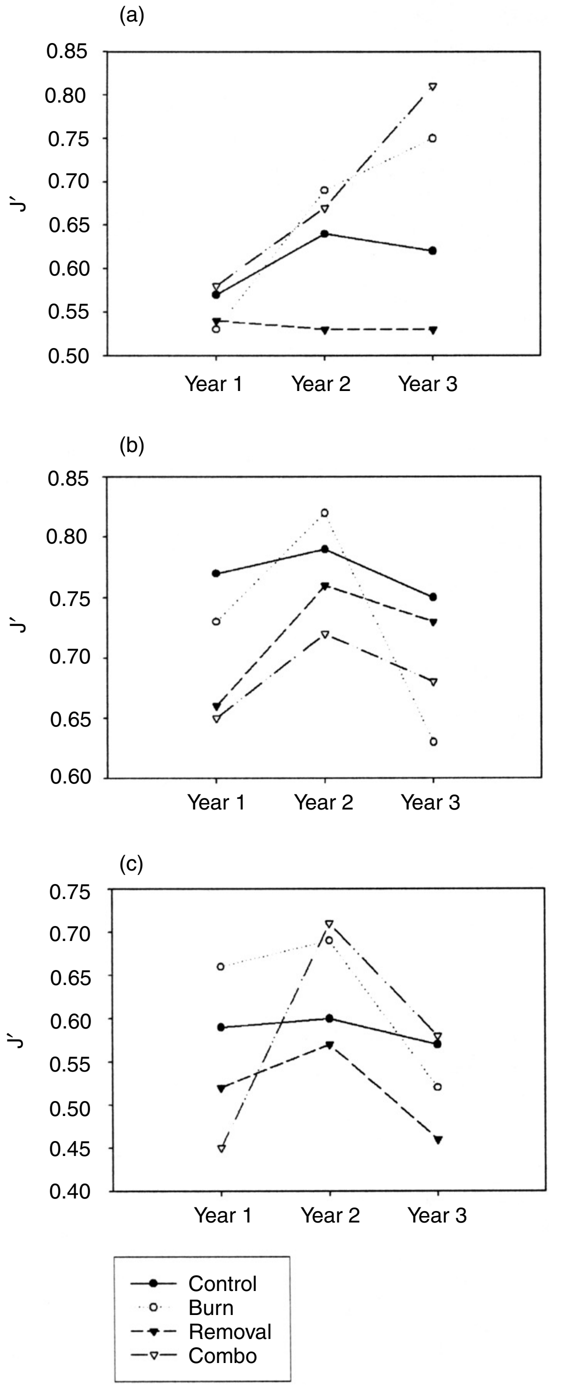

Figure 2—Plot of evenness index for each treatment over time at the dry slope site (a), the mesic slope site (b), and the mesic upland site (c).

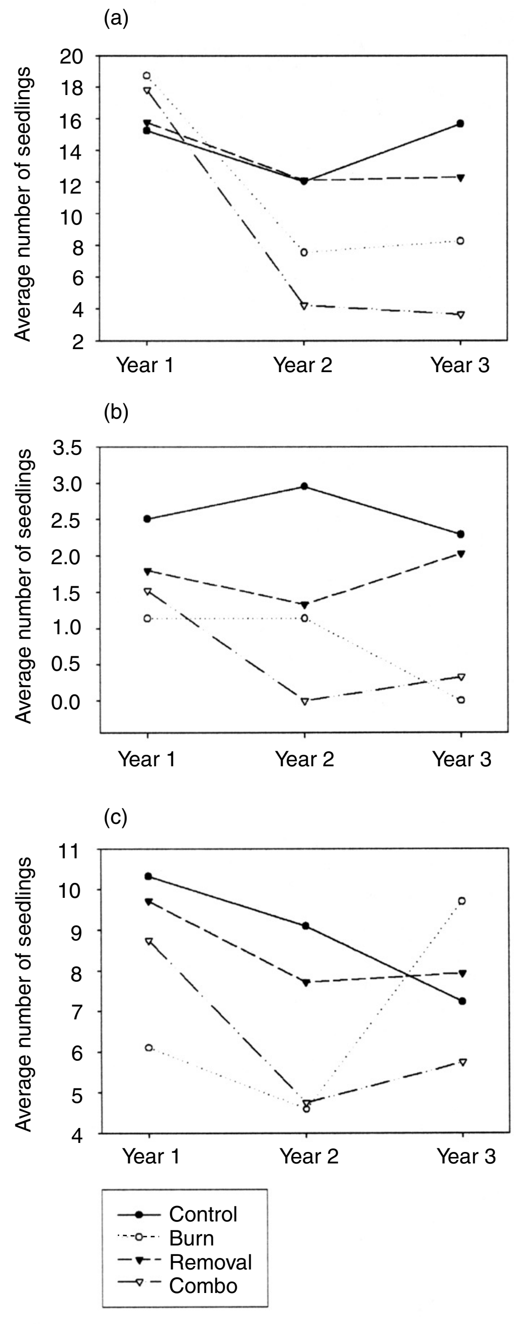

Figure 3—Plot of the average number of shade-tolerant seedlings per plot for each treatment over time at the dry slope site (a), the mesic slope site (b), and the mesic upland site (c).

in the number of seedlings after the second year of treatment. This increased response in seedlings follows a large mortality of saplings 2 to 5 cm in d.b.h. after the second burn (table 1). These new sprouts were counted as seedlings and increased the total number of seedlings within each plot. The response of the shade-tolerant seedlings to the removal treatment did not differ significantly from that of the control plots at any site.

Shade-intolerant species, including oaks and hickories, showed much the same response to treatment as the shade-tolerant species (fig. 4). The removal treatment seemed to have the greatest influence on shade-intolerant species, with a slight increase at the dry slope site after the first year (fig. 4a), a slight increase at the mesic slope site after the second year (fig. 4b) and a rapid increase at the mesic upland site after the first year (fig. 4c). Response at all sites to the burn treatment was a decrease in the number of shade-intolerant seedlings.

Table 1—Average number of saplings per plot > 5 cm d.b.h. and < 1 m tall for each site and year

		Year		
Site	Treatment	1	2	3
		Average number per plot		
Dry slope	Control	5.00	5.00	5.33
	Burn	3.67	0.00	0.33
	Removal	0.67	0.00	0.33
	Combination	10.67	0.00	0.00
Mesic slope	Control	15.33	15.33	10.00
	Burn	5.33	1.33	0.33
	Removal	4.67	1.00	0.00
	Combination	12.00	0.00	0.00
Mesic upland	Control	32.40	27.00	28.60
	Burn	34.40	0.60	4.00
	Removal	59.80	14.20	1.40
	Combination	50.80	0.00	0.00

D.b.h. = diameter at breast height.

Table 2—Percent of full sunlight as measured by PAR at the forest floor taken in mid-July before and after each treatment

		Year	
Site	Treatment	1	2
		- - percent PAR - -	
Dry slope	Control	1.37	9.50
	Burn	8.92	5.40
	Removal	15.22	41.93*
	Combination	3.45	29.72*
Mesic slope	Control	3.83	2.93
	Burn	3.62	8.03*
	Removal	3.23	6.68*
	Combination	2.57	12.30*
Mesic upland	Control	4.41	2.80
	Burn	1.38	9.41*
	Removal	2.37	5.63*
	Combination	1.42	13.68*

PAR = photosynthetically active radiation.
An asterisk indicates a statistically significant change from year 1 to year 2.

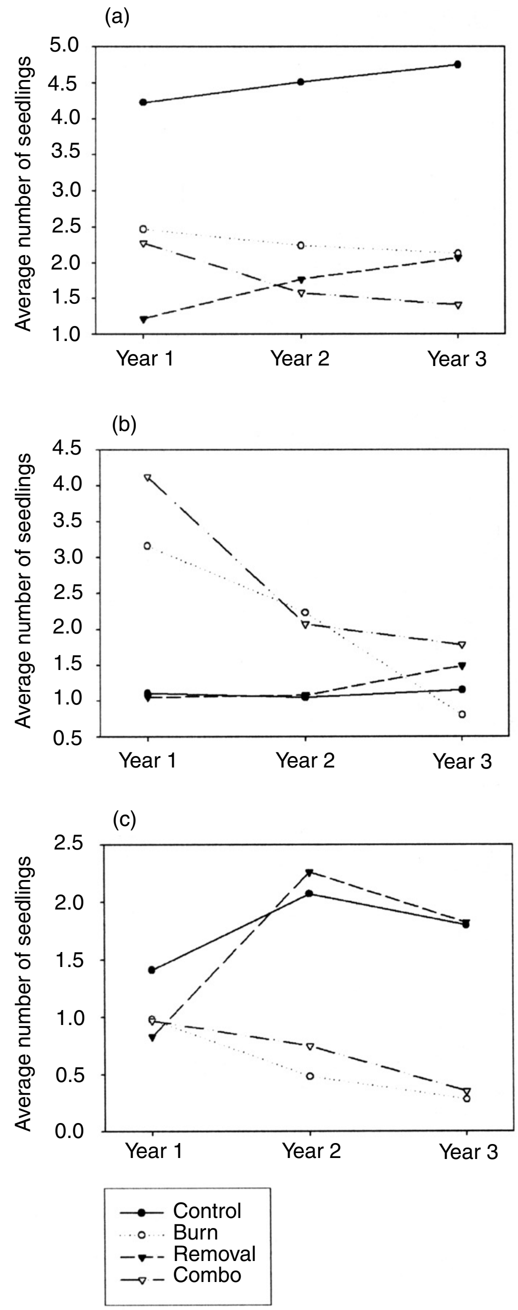

Figure 4—Plot of the average number of shade-intolerant seedlings per plot for each treatment over time at the dry slope site (a), the mesic slope site (b), and the mesic upland site (c).

Detrended correspondence analysis at each of the three sites reveals that there are no consistent changes in herbaceous communities as a result of the treatments (figs. 5a, 5b, and 5c). Site scores of the treated plots are scattered among the control plot scores and are not clustered together. A treatment effect on the herbaceous communities would result in site scores being similar; however this is not the case. Patterns based on disturbance treatment are not clearly identifiable.

The percent of full sunlight as measured by the amount of photosynthetically active radiation (PAR) increased with each treatment at all sites, except the burn treatment at the dry slope site (table 2). At this site, the abundance of Amur honeysuckle and its ability to profusely resprout, caused a decrease in PAR because of burning. Plots that were treated with understory removal increased between 3 to 25 percent full sunlight at the forest floor, while those treated with the combination treatment had an increase of 10 to 25 percent. Burn treatment plots had an increase of only 4 to 8 percent.

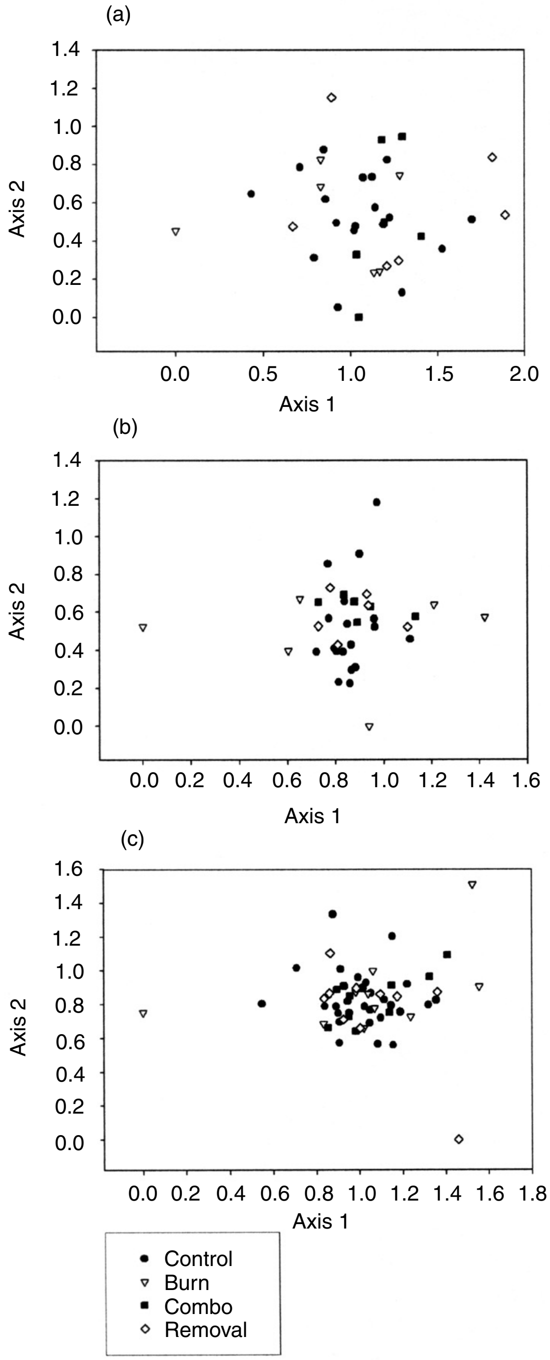

Figure 5—pDCA of herbaceous species showing site values before and after treatment at the dry slope site (a), the mesic slope site (b), and the mesic upland site (c). Axis 1 and 2 are shown in each graph with 13 and 8 percent of variation explained for graph (a), 13 and 9 percent for graph (b), and 12 and 8 percent for graph (c).

DISCUSSION

Consistent results across all three sites reveal important patterns related to the disturbance treatments. The results indicate that burning alone may not be sufficient to increase the pool of shade-intolerant species in the forest understory, especially if the forest has already transitioned into a dense understory of shade-tolerant species. It is important to provide not only an environment suitable for oak establishment, but also for sustained growth. In providing increased light through removal treatments, it may be possible for shade-intolerant seedlings to survive until an opportunity for growth to the overstory occurs, such as a tree fall or some other disturbance which affects the forest canopy.

Although the Shannon-Wiener index indicates that there is little change in diversity because of treatment, a closer look at evenness shows that burning can reduce competition between species by reducing the total number of seedlings. Further study is necessary to determine how the new and surviving seedlings will respond to the changes in environmental conditions created by the burning and removal treatments.

The response to the removal treatments is not yet clear because of the short duration of this study. Research has shown that light levels at or near 50 percent full sunlight provide the best conditions for oak establishment, while greater amounts of light are necessary for increased growth rates (Crow 1988, Gardiner and Hodges 1998, Guo and others 2001). The amount of light provided by the sub-canopy removal treatments in this study may not be sufficient for sustained growth; however, it may provide adequate light conditions for a greater amount of shade-intolerant species to establish. It will be several years before the effect of the current removal treatments on establishment and sustained growth of species like oak can be determined on these research sites.

The lack of effect of burning and removal treatments on the herbaceous species communities merits more research; however, results of this study are encouraging for the use of small disturbances to alter the composition of seedling communities without affecting the herbaceous communities. Response of the herbaceous communities was random, proving that the treatments did not greatly affect the overall composition. The effect of treatment on individual species is not clear through this research, because the sampling design was not structured for such a study. Further analysis of continued disturbance on individual species is necessary, but single disturbances do not affect individuals in such a way as to change the overall community structure.

Results of this study support existing research concerning the regeneration of oak and associated species. Low-intensity disturbances, like the combination of burning and sub-canopy removal, can be used to improve conditions for oak seedling establishment while reducing competition from shade-tolerant species. While successive burns do not dramatically alter the composition beyond that of a single burn, repeated burns every few years will be necessary to lessen competition from shade-tolerant seedlings. Through the use of burning and sub-canopy removal, oak seedlings can be maintained in the understory until they are provided with adequate light conditions for growth to the overstory that would occur with higher severity disturbances such as harvesting or wildfire.

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Appendix—List of species included in shade-tolerant and shade-intolerant species analyses

Common name	Scientific name
Shade-tolerant species	
American basswood	*Tilia americana* L.
American beech	*Fagus grandifolia* Ehrh.
American elm	*Ulmus americana* L.
Black cherry	*Prunus serotina* Ehrh.
Flowering dogwood	*Cornus florida* L.
Hackberry	*Celtis occidentalis* L.
Sugar maple	*Acer saccharum* Marsh.
White ash	*Fraxinus americana* L.
Shade-intolerant species	
Black oak	*Quercus velutina* Lam.
Black walnut	*Juglans nigra* L.
Bur oak	*Q. macrocarpa* Michx.
Chinquapin oak	*Q. muehlenbergii* Engelm.
Hickory species	*Carya spp.* Nutt.
Northern red oak	*Q. rubra* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees
Tulip-poplar	*Liriodendron tulipifera* L.
White oak	*Q. alba* L.