RESEARCH ARTICLE

Repeated Prescribed Burning at Dinsmore Woods State Nature Preserve (Kentucky, USA): Responses of the Understory Community

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ABSTRACT: In 1995 we initiated a study in a nature preserve invaded by *Alliaria petiolata* (Bieb.) Cavara & Grande (garlic mustard) to determine if repeated dormant-season burns would affect *A. petiolata* abundance and understory community composition. Preburn data were collected in summer 1995 at lowland and upland sites. Mid-intensity fall burns occurred in 1995 and 1996 at the lowland site and in 1995, 1996, and 1997 at the upland site. We monitored the understory community in the summers of 1995 to1998 along permanent transects, conducted a one-time plot study of the spring understory community in 1998, and also recorded information on the populations of woody seedlings and saplings in 1995 and 1998. Mid-summer sampling showed that unburned and burned plots had similar long-term trends in *A. petiolata* populations. At both sites there was no significant effect of burning on either *A. petiolata* abundance or relative importance. In spring 1998 burned plots had significantly higher densities of *A. petiolata* flowering stems, lower densities of seedlings, and higher importance of *A. petiolata*. Although garlic mustard is not fire-tolerant, several factors contribute to population persistence under a repeated burning regimen. Our research corroborates previous studies demonstrating that dormant-season burning is not a viable approach for *A. petiolata* control. Repeated long-term monitoring of the summer plant community suggested that burning induced a directional change in lowland plots but not in the upland plots. *Eupatorium rugosum* Houtt. and *Pilea pumila* (L.) Gray responded positively to burning. Monitoring of the spring 1998 community showed that *A. petiolata* responded to burning with increased importance, whereas *Galium aparine* (L.) and *Stellaria media* (L.) Cyrillo (lowland site) responded to burning with decreased importance. Burning had no significant effect on species richness. Responses of woody seedlings and saplings to burning were site-specific. At the upland site, burning accelerated the loss of woody seedlings and saplings. The utility of dormant-season burning in deciduous forests probably will depend on a choice between management goals for understory structure and those for species composition.

Index terms: *Alliaria petiolata*, garlic mustard, herb-layer response, invasive species, prescribed burning

INTRODUCTION

There is currently widespread interest in the development of novel management strategies for small tracts of eastern deciduous forest in the United States. The desire to manage can be traced to various forest changes that are perceived as undesirable, such as invasions by nonindigenous species, failed reproduction by tree species, and declining populations of understory herbs and shrubs. Emergence of sound management practice hinges on an understanding of disturbance regimens because disturbance modifies important factors that drive community-level change or succession (White and Pickett 1985, Roberts and Gilliam 1995, Fralish 1997). However, the development of designed disturbances (sensu Luken 1990) for small preserves must also be approached by considering the broader context of the surrounding landscape, an area that determines the pool of invading species as well as the types of management practices that are feasible (Luken 1997).

Within the eastern deciduous forest, much recent research has focused on tree-fall gaps and understory development with concomitant application of management practices that mimic this form of natural disturbance (Runkle 1985, Reader and Bricker 1992, Roberts and Gilliam 1995). In many designated nature preserves it is not feasible to manipulate the tree canopy because of legal restrictions or aesthetic issues, and thus other methods of management must be explored. We present here the responses of understory species to repeated burning at Dinsmore Woods State Nature Preserve in Northern Kentucky. The impetus for this research was two-fold. First, populations of garlic mustard (*Alliaria petiolata* [Bieb.] Cavara & Grande) were common throughout the preserve, and methods of control were needed. Second, there was concern that in the absence of *A. petiolata* control, species richness of the understory community would decline. Thus our research included two fundamental goals: (1) determine if repeated burning is associated with reduced *A. petiolata* abundance, and (2) determine if repeated burning is associated with increased richness of the understory community.

Prescribed fire has long been used to manipulate structure and composition of deciduous forests (Williams 1989). There is recent heightened interest in prescribed burning for controlling invasive plant species, restoring communities of high conservation value (Naveh 1998), and encouraging regeneration of tree species that require bare mineral soil (Abrams 1992). Unfortunately, there is little information on historical fire frequencies and effects of fires in the Central Hardwood Forest region. Anecdotal evidence suggests that presettlement forests burned more frequently, had more open understories, and had fewer fire-sensitive species than present-day forests (Fralish 1997, Schwartz and Hermann 1997). Fire suppression beginning in the early 1900s has been linked to the widespread increased importance of fire-sensitive *Acer saccharum* Marsh. (sugar maple) in the understory and canopy (Vankat et al. 1975). Thus there is potential for prescribed fire to achieve several management goals in preserves where canopy manipulations are precluded. There is a need to test prescribed burning methods in sites where there is no recent history of fire, where mesotopographic gradients are associated with varying environmental conditions, and where rare indigenous species occur intermixed with invasive dominant species, so that community-level responses can be judged relative to management goals.

METHODS

Study Site

Dinsmore Woods State Nature Preserve in northern Kentucky consists of 49 ha owned by the Kentucky Chapter of The Nature Conservancy and dedicated by the Kentucky State Nature Preserves Commission. The mixed mesophytic forest communities at Dinsmore Woods have developed on Illinoian glacial till capped with loess and are distributed along ridge-and-ravine topography (Held and Winstead 1976). Moist slopes are dominated by *Acer saccharum* and *Fraxinus americana* L. (white ash) with the addition of *Platanus occidentalis* L. (sycamore) and *Acer negundo* L. (boxelder) in the bottoms of ravines (nomenclature follows Fernald [1970]). The shrub layer is dominated by *Lindera benzoin* (L.) (spicebush). Held and Winstead (1976) considered Dinsmore Woods to be a "relatively undisturbed" forest based on the fact that logging was recorded only after the occurrence of chestnut blight in the 1930s and after tornado damage in the 1970s. Still, the disturbance history of Dinsmore Woods is largely undocumented. Age analysis of 10 trees indicated a maximum age of 114 years (Held and Winstead 1976). The climate is temperate humid-continental with average annual precipitation of 88 cm and average annual temperature of 10ϒC.

Virtually all communities at Dinsmore Woods have dense patches of *A. petiolata*, a European biennial herb that has successfully invaded deciduous forests throughout the eastern United States (Anderson et al. 1996, Byers and Quinn 1998). Because *A. petiolata* can dominate understory communities, much research effort has focused on germination ecology (Baskin and Baskin 1992), allelopathic potential (McCarthy and Hanson 1998), life history (Cavers et al. 1979, Anderson et al. 1996, Cruden et al. 1996, Byers and Quinn 1998), demography (Byers and Quinn 1998), and invasion history (Nuzzo 1993). Three previous studies attempted to determine if prescribed burning was a useful method of controlling the species (Nuzzo 1991, Nuzzo et al. 1996, Schwartz and Heim 1996). However, all of these studies lacked replication of the burning treatment.

Fire Treatments

Research design recommendations of Morrison (1997) were applied in an effort to assess effects of repeated burning within a single nature preserve. Repeated burning was tested because of its potential to directly kill overwintering rosettes of *A. petiolata* and because of the potential for fire to stimulate establishment of native herbs and grasses (Luken 1990). The range of environmental conditions at Dinsmore Woods was included by selecting two research sites. The "lowland" site was at the base of a series of south-facing ridges. The "upland" site was at the top of a different series of south-facing ridges. During July 1995, ten 10-m x 20-m permanent plots were established at each site with the long axes of the plots running parallel to the slope. Generally, plots were separated by 10-m x 20-m buffer areas, but these buffers were larger in some cases where downed trees precluded plot placement.

Burns were conducted in fall for two reasons. First, historical evidence suggests that this was the season when humans most frequently set fires (McClain and Elzinga 1994). Second, this was the season when fuel and moisture conditions were most conducive to fire. At each site five plots were assigned to burn treatments and five plots were designated as controls. Fire lines (ca. 1-m wide) were created in the buffer areas with a leaf blower, and fires generally burned 1–2 m beyond the plot boundaries. We assumed that plant responses in the burned plots were linked to responses of plants and seeds within the plots. However, it is possible that seeds dispersed from outside the plots also contributed to community-level responses. No fire lines were created around the control plots. Backfires were started with drip torches and plots were typically burned from upslope to downslope. At the upland site, plots were burned in the fall of 1995, 1996, and 1997. At the lowland site, plots were burned in the fall of 1995 and 1996. Wet conditions precluded burning at the lowland site in fall 1997. It was not possible to manipulate fire intensity, and it is likely that some variation in intensity occurred due to differences in fuel conditions. Still, when burning treatments were applied, fires readily carried throughout the plots and flames were generally up to 15 cm in height (a mid-intensity burn as defined by Nuzzo [1991]). The burning conditions that we tested were the same conditions that would be used on a larger scale if prescribed burning was shown to have some utility.

Monitoring

We used a modified line-intercept or transect method to generate indices of plant abundance for early summer. We chose this approach so that presumed gradients of plant abundance associated with slope would be preserved in the data, so that plant responses in the interiors of the plots could be monitored with minimal edge effects, and so that all plots within the project could be assessed in a timely manner. A single 20-m transect was established at the middle (long axis) of each plot, and the end points were permanently marked. The number of plant contacts per species along this transect (measuring tape) were recorded for each meter and then summed for the entire transect. There was no attempt to separate plant species into age- or stage-classes, and contacts of leaves and stems were treated identically. When a transect was completed, the entire plot was searched for missed species. Occasionally, rare species were found in a plot but not along the transect. These were not included in further analyses, and we are confident that the transect method accurately reflected relative importance of common species within the understory community. Monitoring of the transects began in July 1995 before burning and was repeated annually in late June or July of 1996, 1997, and 1998. Two indices of plant abundance were derived from the transects in an effort to assess response to burning. The number of contacts per transect provided a general index of plant presence. A synthetic importance value (the mean of relative number of contacts per transect + relative frequency within a transect) was calculated for each species within each plot. This provided an index of importance relative to other plant species.

Because the transects did not yield explicit information on the population structure of *A. petiolata* or information on the spring flora, a plot study was initiated during late April 1998. Five 1-m^2 plots were randomly positioned along each permanent transect. All *Alliaria petiolata* seedlings (plants germinating during spring 1998) and flowering stems were counted within the 1-m^2 plots. These were averaged for a transect and then expressed as number/m^2. The number of flowering stems in *A. petiolata* is typically indicative of the number of plants surviving to reproduction, although individual rosettes do occasionally produce more than one flowering stem. At the same time, five 20-cm x 50-cm frames were randomly positioned along each permanent transect. Coverage (5% increment cover classes) was estimated for all plant species and for bare ground. An importance value for plants in the plots was calculated as the mean of relative coverage and relative frequency.

Small woody plants (stems < 5 cm dbh including seedlings) were censused in 1995 and again in 1998 by counting all stems within the 10-m x 20-m experimental plots. The only exception was *Lindera benzoin,* where multistemmed shrubs were counted as single individuals. These counts were summed by treatment and site and then multiplied by 10 to express density on a number per hectare basis. Percent change was calculated as an index of density increase or decrease during the experimental period.

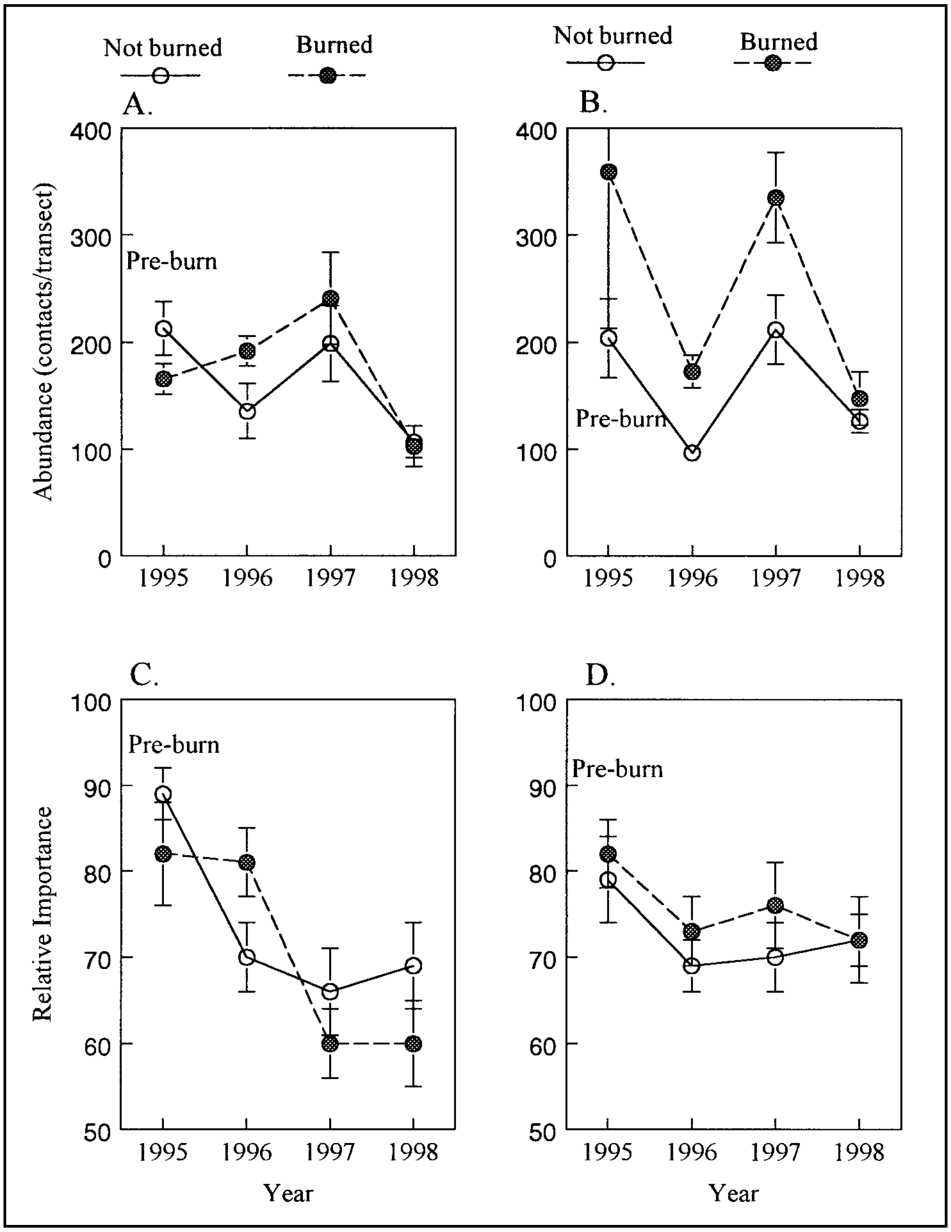

Figure 1. Trends in *A. petiolata* abundance and relative importance at the lowland site (A and C) and at the upland site (B and D) through time in burned and unburned plots, Dinsmore Woods State Nature Preserve. Means are presented with standard errors (n=5 plots).

Data Analyses of Transects

Each plot within a site was treated as an independent experimental unit. This approach was justified because each plot was separated in space from other plots and because burning treatments were applied independently. Still, there was no replication of site, and thus our results must be viewed with caution and at best represent the possible range of responses within this nature preserve.

We used repeated measures analysis of covariance (SYSTAT 7.0) to determine if burning had an effect on *A. petiolata* abundance or species richness (Wilkinson 1996). The covariate was *A. petiolata* abundance or species richness as measured in 1995 before treatments were applied. Data were square-root transformed to adjust for heterogeneity of variances, and the assumption of homogeneity of slopes was checked by examination of the treatment x covariate interaction (Wilkinson 1996). There were no such significant interactions.

We used Detrended Correspondence Analysis (DCA) as an ordination technique to assess community-level trends from 1995 to 1998 and degrees of community distinctness in spring 1998, and to determine how these community-level properties were influenced by burning. Importance values generated from transects and plots were used in the DCA. Coefficients of determination (r^2) generated from DCA represent the correlations between ordination distances and the distances in original n-dimensional space (McCune and Mefford 1997). We also used Indicator Species Analysis (ISA) to determine which species in the 1997 and 1998 data sets were significant indicators of the two treatments (Dufrene and Legendre 1997). All analyses were done within PC-ORD Version 3.0 (McCune and Mefford 1997).

Data collected in spring 1998 represented a single sample in time. We used t-tests on square-root transformed data to compare species richness of burned and unburned plots. Estimates of *A. petiolata* seedling and flowering-stem density were compared between burned and unburned plots using rank sum tests.

RESULTS

Trends in *A. petiolata* Importance

At lowland and upland sites, trends in garlic mustard abundance through time (Figures 1A and 1B) were similar in burned and unburned plots, and burning did not significantly influence garlic mustard abundance (P=0.56 at the lowland site and P=0.11 at the upland site for repeated measures analysis of covariance). The lowland site experienced gradually declining *A. petiolata* importance, whereas *A. petiolata* importance was relatively constant at the upland site (Figures 1C and 1D, respectively). Still, there were no significant effects of burning on *A. petiolata* importance at either site (P=0.98 at the lowland site and P=0.65 at the upland site for repeated measures analysis of covariance).

Sampling in spring 1998 indicated significantly (P=0.01, rank sum test) higher *A. petiolata* seedling density in control plots at the upland site and a similar but nearly significant (P=0.06, rank sum test) response at the lowland site (Figure 2A). Both lowland and upland sites had significantly (P=0.01, rank sum test) higher flowering-stem densities in burned plots (Figure 2B).

Community-Level Trends

The DCA ordination derived from summer data collected at the lowland site explained 57.9% (cumulative r^2) of the variance in DCA-1 and DCA-2 axes for unburned (Figure 3A) and burned (Figure 3B) plots. Unburned plots as a group did not share a common trend in compositional change through time (Figure 3A), while the burned plots in 1997 demonstrated similar trajectories toward higher loading scores on the DCA-1 axis (Figure 3B). When burning did not occur in 1997, 1998 trajectories were altered and three of the plots became similar to preburn communities. Of the seventeen species included in the ISA, no single species present in 1998 showed a significant ($P \leq 0.05$) maximum indicator value (Table 1). However, *Pilea pumila* (L.) Gray was a significant indicator of lowland burn plots in 1997 (Table 1). Mean herb species richness ranged from 3.2 to 6.4 species/transect in the unburned plots and from 3.6 to 7.0 species/transect in the burned plots. There was no significant effect of burning on species richness (P=0.42 for repeated measures analysis of covariance).

The DCA ordination derived from 1995–1998 data collected at the upland site explained 44.3% (cumulative r^2) of the variance in DCA-1 and DCA-2 axes, for unburned (Figure 4A) and burned (Figure

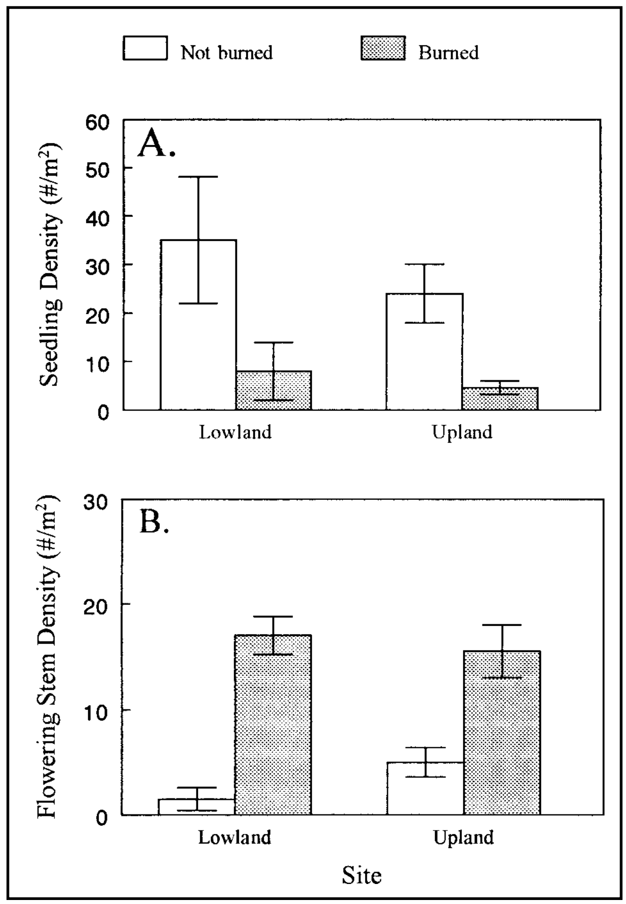

Figure 2. ***Alliaria petiolata*** **seedling density in burned and unburned plots (A), and density of *A. petiolata* flowering stems in burned and unburned plots (B), at Dinsmore Woods State Nature Preserve. Means are presented with standard errors calculated for the experimental plots (n = 5 plots).**

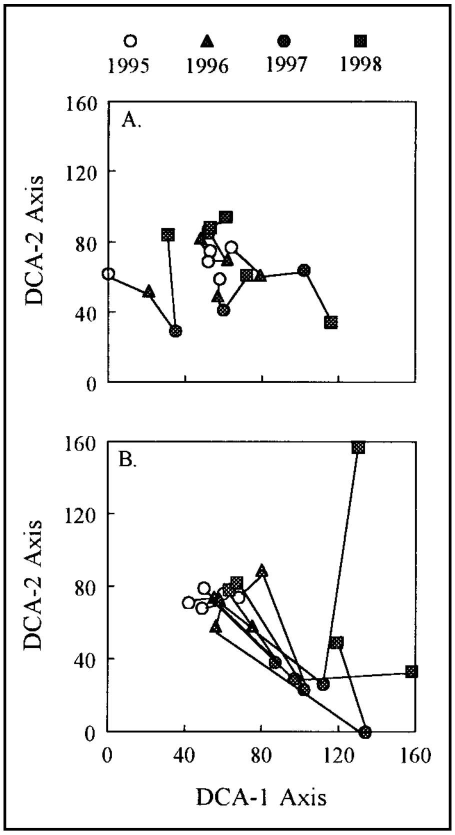

Figure 3. Detrended Correspondence Analysis (DCA) of unburned (A) and burned (B) plots at a lowland site in Dinsmore Woods State Nature Preserve. Axis scores for unburned and burned plots are presented on two separate graphs to facilitate interpretation. Individual plots are indicated by symbols connected by lines. The plots were monitored repeatedly in summer from 1995 to 1998.

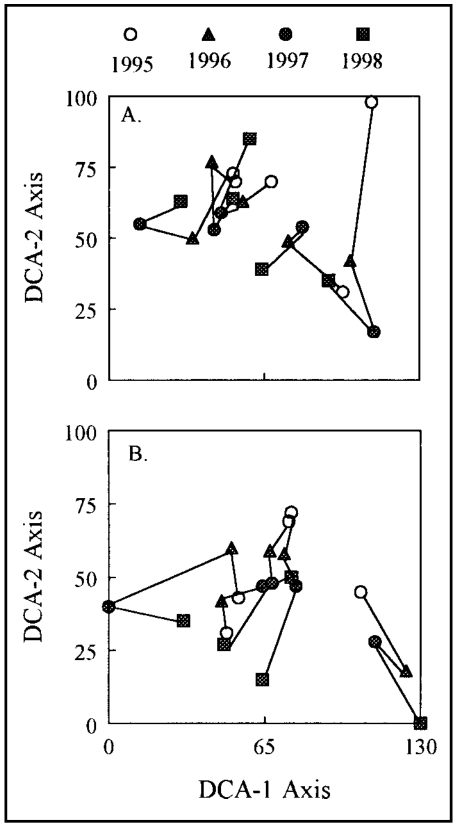

Figure 4. Detrended Correspondence Analysis (DCA) of unburned (A) and burned (B) plots at an upland site in Dinsmore Woods State Nature Preserve. Axis scores for unburned and burned plots are presented on two separate graphs to facilitate interpretation. Individual plots are indicated by symbols connected by lines. These were monitored repeatedly in summer from 1995 to 1998.

4B) plots. Again, unburned plots as a group did not share a common trend in compositional change through time (Figure 4A). Burning at the upland site also did not induce a clear universal trajectory except a weak tendency for plots to load lower on the DCA-2 axis in 1998 (Figure 4B). Of the 15 species included in the ISA for upland plots, only *Eupatorium rugosum* in 1998 had a significant (*P*=0.05) maximum indicator value (Table 1). Examination of the data indicated that this species occurred almost exclusively in the burned plots. Mean species richness ranged from 4.6 to 6.4 herb species/transect in the unburned plots and from 4.0 to 7.0 herb species/transect in the burned plots. There was no significant effect of burning on species richness (*P*=0.71 for repeated measures analysis of covariance).

The DCA ordination derived from spring 1998 data collected at the lowland site (Figure 5A) explained 65.7% (cumulative r^2) of the variance in the DCA-1 and DCA-2 axes. Burned plots loaded low on DCA-1, and unburned plots loaded high on DCA-1 (Figure 5A). Of the 12 species included in the ISA for lowland plots (Table 1), significant maximum indicator values were generated for *Alliaria petiolata* (*P*=0.004), *Stellaria media* (L.) Cyrillo (*P*=0.004), and *Galium aparine* (L.) (*P*=0.05). *Alliaria petiolata* was more important in the burned plots, whereas *Stellaria media* and *Galium aparine* were more important in the unburned plots. Similar results were found with spring 1998 data collected at the upland site (Figure 5B) with the exception that *Stellaria media* was not a significant (*P*=0.54) indicator species (Table 1). There was no significant effect of burning on species richness in either upland or lowland sites (*P*=0.40 for the lowland site and *P*=0.22 for the upland site, t-tests). Mean species richness ranged from 5.6 to 8.4 herb species/plot in the unburned plots and from 5.0 to 7.2 herb species/plot in burned plots.

Importance values presented in Table 1 show clearly that the mid-summer community at Dinsmore Woods State Nature Preserve was dominated by *A. petiolata* throughout the duration of this research. Other species such as *Parthenocissus quinquefolia* (L.) Planch. and *Podophyllum peltatum* L. maintained relatively low importance and did not respond to burning. *Asarum canadense* L. responded negatively to fire, but this response was less than the positive responses of *Eupatorium rugosum* Houtt. (upland) and *Pilea pumila* (L.) Gray (Table 1). Importance of *A. petiolata* in early spring 1998 was not as high as in the mid-summer community, in part due

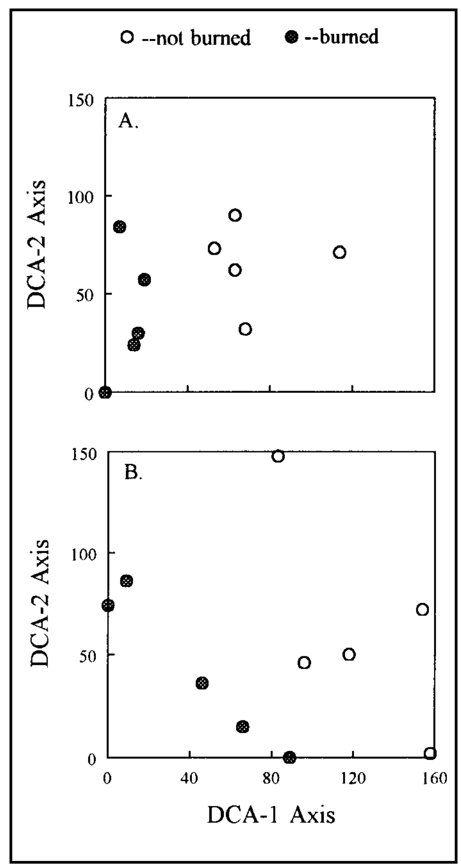

Figure 5. Detrended Correspondence Analysis (DCA) of lowland (A) and upland (B) plots sampled in spring 1998 at Dinsmore Woods State Nature Preserve.

Table 1. Mean importance values of plant species in experimental plots at Dinsmore Woods State Nature Preserve. Plant communities were sampled in mid-summer from 1995 to 1998 (95, 96, 97, 98) and in early spring 1998 (98S).

	Lowland Site Not Burned					Lowland Site Burned					Upland Site Not Burned					Upland Site Burned				
Species	**95**	**96**	**97**	**98**	**98S**	**95**	**96**	**97**	**98**	**98S**	**95**	**96**	**97**	**98**	**98S**	**95**	**96**	**97**	**98**	**98S**
Alliaria petiolata (Bieb.) Cavara & Grande	89	70	66	69	13	82	81	59	60	41*	79	69	70	72	20	82	73	76	72	48*
Asarum canadense L.	5	3	3	2	1	0	0	0	0	0	5	5	5	5	–	0	0	0	0	–
Arisaema triphyllum (L.) Schott	0	1	0	0	2	0	0	0	0	0	0	1	2	0	–	0	2	1	2	–
Campsis radicans (L.) Seem.	2	2	3	2	–	2	0	0	0	–	–	–	–	–	–	–	–	–	–	–
Carex L. spp.	–	–	–	–	–	–	–	–	–	–	0	5	7	8	2	6	4	2	5	2
Claytonia virginica L.	–	–	–	–	1	–	–	–	–	1	–	–	–	–	5	–	–	–	–	14
Corydalis flavula Raf. DC.	–	–	–	–	3	–	–	–	–	2	–	–	–	–	4	–	–	–	–	1
Dicentra Bernh. spp.	–	–	–	–	2	–	–	–	–	6	–	–	–	–	18	–	–	–	–	15
Elymus villosus Muhl.	1	4	5	3	–	1	2	0	1	–	–	–	–	–	–	–	–	–	–	–
Eupatorium rugosum Houtt.	0	0	0	3	–	1	0	0	3	–	0	0	0	0	–	0	1	0	5*	–
Festuca obtusa Biehler	–	–	–	–	–	–	–	–	–	–	2	2	0	0	–	2	3	1	0	–
Galium aparine (L.)	–	–	–	–	6*	–	–	–	–	0	–	–	–	–	24*	–	–	–	–	0
Hydrophyllum macrophyllum Nutt.	–	–	–	–	–	–	–	–	–	–	0	0	2	0	6	0	0	2	0	5
Lonicera japonica Thunb.	0	0	0	1	–	0	3	3	4	–	0	0	0	1	–	0	0	0	0	–
Onoclea sensibilis L.	1	0	0	0	–	0	0	0	0	–	–	–	–	–	–	–	–	–	–	–
Osmorhiza claytonii (Michx.)	0	0	0	0	–	0	0	0	3	–	–	–	–	–	–	–	–	–	–	–
Parthenocissus quinquefolia (L.) Planch.	2	4	4	3	–	7	4	3	0	–	5	4	2	3	–	4	3	0	0	–
Phlox divaricata L.	–	–	–	–	–	–	–	–	–	–	3	2	4	2	2	2	3	3	3	0
Phytolacca americana L.	0	0	0	0	–	0	0	0	2	–	–	–	–	–	–	–	–	–	–	–
Pilea pumila (L.) Gray	1	6	8	8	–	0	4	33*	12	–	–	–	–	–	–	–	–	–	–	–
Podophyllum peltatum L.	0	4	3	6	0	0	0	2	3	1	0	2	2	1	2	0	0	4	3	0
Polygonatum biflorum (Walt.) Ell.	–	–	–	–	–	–	–	–	–	–	0	0	0	0	2	0	0	0	0	2
Polygonum virginiana L.	–	–	–	–	0	–	–	–	–	0	0	0	0	1	–	0	0	0	0	–
Ranunculus micranthus Nutt.	–	–	–	–	0	–	–	–	–.	1	–	–	–	–	–	–	–	–	–	–
Smilax glauca Walt.	0	0	0	0	–	0	1	0	0	–	0	0	1	0	–	0	0	0	0	–
Stellaria media (L.) Cyrillo	–	–	–	–	71*	–	–	–	–	46	–	–	–	–	10	–	–	–	–	4
Toxicodendron radicans L.	0	0	1	2	–	0	2	0	0	–	–	–	–	–	–	–	–	–	–	–
Urtica dioica L.	0	0	0	0	–	0	0	0	2	–	–	–	–	–	–	–	–	–	–	–
Viola pubescens Ait.	1	2	3	0	1	0	0	0	0	0	0	4	4	2	4	1	4	3	5	5

0 = species included in the community analysis but with low importance that rounded to zero.

* = high importance values where Indicator Species Analysis suggested a significant (P<0.05) treatment effect

to high importance of *Dicentra* spp., *Galium aparine* (L.) (unburned plots), and *Stellaria media* (L.) Cyrillo (lowland site). Still, the early spring community developed in the burned plots emerged as one generally dominated by *A. petiolata* (Table 1).

Woody Species

Lowland and upland sites differed in densities of woody seedlings and saplings. The lowland site had higher densities of shrubs, whereas the upland site was dominated by tree seedlings and saplings (Table 2). Responses of woody species to burning were difficult to assess because of large losses of woody plants from both control and burned plots. In the lowland site, burning was associated with increased populations of *Prunus serotina* Ehrh., *Sassafras albidum* (Nutt.), and *Symphoricarpos orbiculatus* Moench. In contrast, there was nearly universal loss of woody plants at the upland site. For 9 of the 13 species, population declines in the burned plots exceeded declines in the control plots (Table 2).

DISCUSSION

Responses of *Alliaria petiolata* to Repeated Burning

Our research indicated that repeated fall burning does not reduce abundance or relative importance of garlic mustard in the understory community of a mesophytic forest in Kentucky. Two previous studies in northern Illinois (Nuzzo 1991, Schwartz and Heim 1996) reached similar conclusions when the treatment was a single fall burn. Nuzzo et al. (1996) examined effects of repeated spring burning in an Illlinois sand forest and found that garlic mustard was maintained at or near preburn levels, whereas unburned plots experienced increased *A. petiolata* importance. Although *A. petiolata* is not fire-tolerant, it can persist across a wide range of fire regimens in the eastern United States (Nuzzo 1991, Nuzzo et al. 1996, Schwartz and Heim 1996).

Alliaria petiolata plants are readily killed by mid-intensity dormant-season fires, but several factors may explain population persistence during repeated burning. First, it is impossible to ensure that every existing plant is exposed to fire. Nuzzo (1991) noted that understory fires were often patchy, thus leaving some plants unharmed. Because *A. petiolata* is self-fertile (Cruden et al. 1996), even one surviving individual may set viable seed and thus maintain the population (Anderson et al. 1996). Second, burning was associated with increased densities of flowering stems. This may be due to resprouting (Nuzzo et al. 1996) or to a release from competition (Baskin and Baskin 1992, Byers and Quinn 1998). Third, a seed bank of garlic mustard persists for up to four years (Baskin and Baskin

Table 2. Densities and percent change of small (<5 cm diameter) woody plants and seedlings from lowland and upland sites at Dinsmore Woods State Nature Preserve. Densities (expressed as #/ha) were based on the total number of plants counted in 1995 and 1998 in unburned and burned plots.

	Lowland Site						Upland Site					
	Not Burned			Burned			Not Burned			Burned		
	1995	1998	% Change	1995	1998	% Change	1995	1998	% Change	1995	1998	% Change
TREES												
Acer saccharum Marsh.	40	0	-100	30	120	+400	6920	1580	-77	8750	240	-97
Acer negundo L.	110	100	-9	110	160	+145	0	10	+100	10	0	-100
Asimina triloba (L.) Dunal	70	130	+186	730	480	-34	380	390	+102	10	0	-100
Carya Nutt. spp.	370	360	-3	370	220	-41	850	80	-91	1490	30	-98
Celtis occidentalis L.	240	50	-79	220	170	-23	3860	690	-82	3410	270	-92
Fraxinus americana L.	0	10	+100	20	50	+250	570	20	-96	700	10	-99
Morus rubra L.	30	20	-33	40	0	-100	10	0	-100	30	0	-100
Prunus serotina Ehrh.	240	310	+129	50	3860	+7700	190	0	-100	40	0	-100
Quercus L. spp.	90	10	-89	30	20	-33	100	30	-70	80	10	-88
Sassafras albidum (Nutt.) Nees	0	10	+100	520	1720	+330	0	0	0	0	0	0
Ulmus L. spp.	0	0	0	0	0	0	2790	1010	-64	2720	290	-89
Total	1190	1000	-19	2120	6800	+320	15 670	3810	-76	17 240	850	-95
SHRUBS												
Lindera benzoin (L.)	4920	7050	+143	5520	5300	-4	410	220	-46	500	0	-100
Symphoricarpos orbiculatus Moench.	1200	1640	+137	1380	2730	+197	200	130	-35	120	20	-83
Total	6120	8690	+142	6900	8030	+116	610	350	-43	620	20	-97

1992). Thus even if the extant population of *A. petiolata* was completely eradicated, treatments would need to continue until the in-situ seed bank was exhausted.

Because we did not record *A. petiolata* life stages during this study, we do not know whether burning has the capacity to disrupt the widely observed pattern of entire populations being synchronized in life stage (McCarthy 1997). It appears that burning has the potential to modify stand-level production of flowering stems and seedling density. However, this may have a relatively minor impact on the long-term population trend of *A. petiolata* (i.e., the strong dominance of *A. petiolata* that existed throughout our research). Our data indicated that long-term trends in burned and unburned plots (mid-summer community) were similar. Thus, *A. petiolata* persisted as the community dominant in all plots, and the variation in importance from 1995 to 1998 must be linked to other factors not considered in this study (e.g., climate).

Community Level Trends

Responses of understory species to repeated fire at Dinsmore Woods generally involved significant changes in the importance of a few herbs. Specifically, *Alliaria petiolata* emerged as a dominant species of the burned spring community. In contrast, unburned plots in spring had relatively low importance of *A. petiolata* and relatively high importance of *Galium aparine* and *Stellaria media*. *Eupatorium rugosum* at the upland site emerged as a positive fire-responsive species of the mid-summer community. Schwartz and Heim (1996) also found that *Galium aparine* was fire-sensitive in an Illinois woodland. Nuzzo et al. (1996) noted that much of the increased herb cover associated with burning an Illinois sand forest was due to the positive response of *Eupatorium rugosum*.

Previous research has documented a negative effect of repeated fire on the importance of woody species comprising forest communities (Tester 1989, Nuzzo et al. 1996, Schwartz and Heim 1996). Our research demonstrated that woody plants at the upland site were negatively affected by fire, while at the lowland site stem densities of some woody species showed substantial increases. Wetter conditions and perhaps less intense fire at the lowland site probably facilitated both seedling establishment and resprouting in response to burning. High natural mortality of woody seedlings is common after fire (Schwartz and Heim 1996), and indeed the upland site experienced such mortality from 1995 to 1998. However, this high background of mortality coupled with dormant-season fire has the potential of drastically reducing populations of woody seedlings and saplings.

We found that repeated dormant-season burning had no significant effect on richness of herbaceous species. This observation agrees with the results of Schwartz and Heim (1996). However, others have noted that frequent burning leads to increased richness of herbaceous species (Tester 1989, Nuzzo et al. 1996). The impact of burning on herb richness probably depends on a complex interaction among fire, extant species, and species that could potentially colonize the site. The understory communities at Dinsmore Woods expressed both resistance to change (upland site) and resilience (lowland site). Resistance could be linked to the fact that dormant-season burning had little impact on system attributes. Resilience could be linked to the fact that the response of annual species (e.g., *Pilea pumila*) to burning was transitory (see e.g., Table 1). McCarthy (1997) removed garlic mustard from understory communities and also recorded a positive response of annual species. Our results support the contention of Roberts and Gilliam (1995) that more research is needed to determine how historical and extant disturbances shape the diversity of forest understories.

Assessment of Prescribed Fire

Regardless of the underlying mechanisms that contribute to resistance of the understory community to large fire-induced compositional changes, a fundamental question remains: Is repeated dormant season burning a useful management practice in long-unburned deciduous forests that have been invaded by *Alliaria petiolata*? The answer to this question hinges on the explicit statement of various management goals. For example, if the management goal is to create a forest with a more open understory, then it is likely, at least in upland areas, that repeated burning will achieve this goal by removing small woody plants. On the other hand, burning may positively or negatively alter the performance and colonization success of indigenous and nonindigenous plant species. Indeed, Hobbs and Huenneke (1992) predicted that some management practices may actually create windows of invasion opportunity. This may be the case with *Alliaria petiolata:* previous research has suggested a positive relationship between forest disturbance and establishment of *A. petiolata* populations (Anderson et al. 1996, McCarthy 1997). Our research indicated that certain opportunistic species were ubiquitous and burning simply changed their relative importance. Thus, the value of dormant-season burning at Dinsmore Woods may depend on the choice between goals for forest structure and tree reproduction versus goals for composition of the herbaceous community.

Although the disturbance history of Dinsmore Woods is not well known (Held and Winstead 1976), data from other sites suggest that regional presettlement forests burned more frequently, had more open understories, and had fewer fire-sensitive species than present forests (Vankat et al. 1975, Fralish 1997, Schwartz and Hermann 1997). The appropriateness of repeated fire as a current management tool hinges on the potential interaction between fire (a controlled disturbance) and other uncontrolled disturbances such as wind-throw. Considering the prevalence of wind-throw as a disturbance at Dinsmore Woods (Held and Winstead 1976), a monitoring program would also need to assess how burning influences the response of plant species to canopy gaps.

Given the widespread distribution of garlic mustard throughout forest preserves in the United States, and considering that few methods have emerged for successfully eliminating the plant, it may be prudent to focus future research on *A. petiolata* and its interaction with other species. The straightforward paired-plot approach used by McCarthy (1997), wherein garlic mustard was removed by hand and then community response was monitored, provides an experimental model that could be replicated among many forest preserves. This would provide much-needed data on long-term trends in forest understory strata and would also allow a more refined assessment of impacts of invasive species.

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