USE OF PRESCRIBED FIRE FOR MANAGEMENT OF OLD FIELDS IN THE NORTHEAST

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ABSTRACT

Prescribed fires are used to restore early successional habitat for declining grassland breeding birds by reducing the prevalence of invading shrubs and late-season perennials. In the northeastern U.S., such fires have been restricted to spring (March and April) and fall (September and October), when most vegetation is dormant and the ground is snow-free. Dormant-season fires increase the frequency of goldenrod (*Solidago* spp.) and top-kill invading shrubs, which resprout following fire. We examined the effects of alternative prescribed fire treatments in old fields in central and western New York. As predicted, dormant-season fire failed to kill shrubs, reduce shrub frequency or height, or increase cool-season grass frequency and composition. In contrast, growing-season fire preceded by growing-season mowing killed *Lonicera morrowii*, *Cornus sericea*, and *Cornus amomum*, reduced shrub frequency by about 60% and height by about 50%, and increased cool-season grass frequency and composition by about 20%. This treatment had lower *Solidago* spp. frequency and composition than the dormant-season fire. Combination treatments involving dormant-season mowing followed by dormant-season or growing-season burning reduced shrub frequency comparably to growing-season treatments, but failed to increase frequency and composition of cool-season grasses. No single-year treatments reduced shrub stem density. Two years of consecutive growing-season mowing applications, combined with a burn the following summer, reduced stem density in a resprouting shrub, gray dogwood (*Cornus racemosa*), to levels 42% lower than one summer mowing treatment. Phenological timing of treatment was more important than intensity of fires with respect to increasing the frequency and composition of cool-season grasses, and decreasing the importance of goldenrod and shrubs.

keywords: *Cornus racemosa*, cool-season grass, dormant-season fire, goldenrod, grassland bird, gray dogwood, growing-season fire, New York, old field, prescribed fire, *Solidago*.

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INTRODUCTION

Millions of acres of grasslands in the northeastern U.S. have undergone succession to shrub or forest cover, or been developed, since the middle of the 20th century. The loss of this habitat type has contributed to regional declines in several grassland breeding bird species, such as the eastern meadowlark (*Sturnella magna*), savannah sparrow (*Passerculus sandwichensis*), and grasshopper sparrow (*Ammodramus savannarum*) (Bollinger 1991, Smith 1997, Vickery and Dunwiddie 1997). Efforts to restore and maintain abandoned agricultural grasslands by mechanical conversion from shrubby fields can be labor intensive and expensive. Managers have historically resorted to dormant-season prescribed fires as an economical method of shrub control.

More recently, wildlife agencies have advocated planting native warm-season (i.e., C4) grasses to create grassland breeding bird habitat. These grasses neither establish well on the acidic and poorly drained fields often found on public wildlife management areas nor are adapted to the short growing seasons of large areas of the Northeast (Dickerson et al. 1997). Most northeastern native cool-season (i.e., C3) grasses, such as poverty grass (*Danthonia spicata*) and Canada bluejoint (*Calamagrostis canadensis*), are not commercially available. Nevertheless, studies have shown that grassland birds have adapted to, and are highly productive in, old fields populated with these cool-season grasses (Bollinger 1995, Askins 1997, Vickery and Dunwiddie 1997, Norment 1999). Consequently, many wildlife managers want to restore and increase naturalized cool-season grasses, such as Kentucky bluegrass (*Poa pratensis*) and sweet vernal grass (*Anthoxanthum odoratum*), which have historically dominated northeastern old fields since the European contact period.

Wildlife managers in the Northeast have adopted prescribed burn techniques developed in midwestern prairies for restoring and maintaining grasslands. Prescriptions typically call for dormant-season fires to increase grass and reduce woody plant biomass. Recent studies in the Midwest suggest that although dormant-season fires increase the productivity of late-season plants, such as warm-season grasses, these treatments are not beneficial to early-season plants (Howe 1994*a*,*b*). Growing-season fires may be more effective

at increasing early flowering plants (Howe 1995), such as cool-season grasses. Growing-season fires also may be more effective at reducing shrubs than dormant-season burns (Dunwiddie et al. 1997).

Growing-season fires are difficult to accomplish in northeastern grasslands. They often require additional site preparation or drought conditions. These treatments also have greater potential than dormant-season fires to disturb breeding birds during the treatment year. Nevertheless, if growing-season burns are more effective at maintaining grasses and reducing woody plant biomass in old fields than dormant-season fires, their value as a restoration tool may outweigh the costs of labor and short-term habitat loss.

The objective of this study was to test a variety of growing-season treatments, involving combinations of mowing and fire applications, in central and western New York State. Vegetation data were collected to determine the effectiveness of each treatment in increasing cool-season grass frequency and reducing shrub frequency in old fields (Mitchell 2000).

STUDY AREA

Site Descriptions

Work was conducted in central and western New York on three sites representing early and intermediate stages of shrub invasion in old fields. The early successional site was a 5-ha old field at Iroquois National Wildlife Refuge (INWR) in Alabama, western New York. Soils were well drained, strongly acidic mineral soils (Higgins et al. 1977). Shrubs invading INWR included Morrow's bush honeysuckle (*Lonicera morrowii*), gray dogwood (*Cornus racemosa*), redosier dogwood (*Cornus sericea*), and silky dogwood (*Cornus amomum*). Dominant herbaceous plants included Canada goldenrod (*Solidago canadensis*), timothy grass (*Phleum pratense*), quackgrass (*Elytrigia repens*), and Canada bluegrass (*Poa compressa*) (see Appendix 1 for vegetation data for the study sites).

An intermediate successional site was a 10-ha old field at Finger Lakes National Forest (FLNF) near Lodi, central New York. Soils were moderately well drained, slightly acidic mineral soils with a fragipan (Hutton 1972). *C. racemosa* has invaded throughout FLNF. Dominant herbaceous plants were similar to those found at INWR. FLNF was previously burned by the U.S. Forest Service in April 1995 and 1997. A second intermediate site was a 17-ha old field at Montezuma National Wildlife Refuge (MNWR) in Seneca Falls, central New York. Soils were moderately well-drained to somewhat poorly drained neutral mineral soils (Hutton 1972). The site had been mowed on a 2- to 3-year rotation for at least 10 years, resulting in a community densely populated by resprouted shrubs, mainly *C. racemosa*. Dominant herbaceous plants were similar to those found at INWR and FLNF.

Field Ages

C. racemosa, a prominent shrub at all sites, was used as an indicator of successional age at INWR and FLNF. Since neither field had been mowed since abandonment, we aged shrubs by counting growth rings of the largest diameter shrubs. Determining the date of *C. racemosa* invasion at MNWR was not possible because of historic mowing activities. *C. racemosa* invasion commenced at INWR in 1995, and between 1983 and 1985 at FLNF. Shrub invasion at MNWR commenced prior to 1989 at MNWR (Tracy Gingrich, U.S. Fish and Wildlife Service, Montezuma National Wildlife Refuge, personal communication).

METHODS

We compared the effect of traditional dormant-season burns to treatments involving growing-season burns preceded by mowing treatments. At all sites, treatments were randomly allocated to uniformly spaced 36 × 36-m plots. There were three treatment replicates at INWR (12 plots total) and MNWR (9 plots total), and four replicates at FLNF (16 plots total) (see Appendix 2 for a list of treatments and dates). Rotary mowers (bush-hogs) were used for most mowing applications. At INWR, a sickle-bar mower was used to treat live fuels and enhance fuel bed flammability 6 days prior to burning the spring mow–summer burn plots. Shrubs and goldenrod had not yet resprouted when fire was applied, so the sickle-bar mowing and burning application were considered one top-kill event. At MNWR, a sickle-bar mower was used 1 month prior to burning during the second year of treatment, when shrubs and goldenrod had resprouted. The sickle-bar mowing and delayed burning applications were considered two separate top-kill events.

Vegetation Data

Vegetation data were collected during March and April 1998 (pre-treatment), and June 1999 (post-treatment). Percent frequency data were collected in three general vegetation categories—Poaceae, *Solidago* spp., and shrubs—using a combined point-intercept–line-transect method (Bonham 1989). Three 36-m transects were spaced systematically per plot, 12 m apart (transect end-points and plot corners were marked with metal corner-posts). A 2-m steel rod, 0.4 cm in diameter, was dropped at 100 random points per transect to measure vegetation frequency. Occurrences in each vegetation category were denoted by contact with the rod by at least one member of a category per random point. Percent composition for two vegetation categories, Poaceae and *Solidago* spp., was collected at FLNF in June 1999, also using a combined point-intercept–line-transect method, counting contact with the steel rod by all members of each category per random point. Pre-treatment percent frequency of shrubs was used as a covariate in analyzing post-treatment shrub percent frequency and post-treatment shrub percent composition because shrubs were distributed patchily. Plant community data were collected for INWR and FLNF, using a combined point-intercept–line-transect method, sampling 100 random points per transect.

Shrub stem density data were collected prior to

mowing and burning applications at all sites. *C. racemosa* was sampled at FLNF; *L. morrowii, C. racemosa,* and a combined category of *Cornus sericea–Cornus amomum* ("stoloniferous *Cornus* spp.") were sampled at INWR. At FLNF and INWR, three shrub clones per species were randomly selected per plot. A circular 3.3-m^2 subplot was permanently marked along the outer edge of each clone. Total live shrub stems per subplot were counted. The same plots were sampled, post-treatment, in July 1999. At MNWR, *C. racemosa* stem density data were collected in June 1999 using 20 random 0.75-m^2 quadrats per plot. Post-treatment data were collected using the same method in October 1999. If shrub subplots contained no live stems in 1999, the shrub was considered dead. Height of the tallest shrub stem was measured in each *C. racemosa* subplot in October 1999.

Fire Data

Summaries of all fire behavior and site conditions are presented in Appendixes 2 and 3. Data were collected to determine if fire behavior varied by burn treatment and could be related to subsequent shrub mortality among treatments. Surface temperature was measured using aluminum tags painted with eight different Tempilaq® paints, each of which melts at one of the following temperatures: 50, 100, 150, 200, 250, 300, 350, or 400 °C. Fire intensity was determined by measuring char heights on dry pine posts placed perpendicular to the spread of flames. Intensity was calculated by $I = 259.83L^{2.174}$, where I = intensity and L = flame length (length along the flame) (Alexander 1982, Johnson and Miyanishi 1995). Rate of spread was measured by timing the flaming front as it spread from one post benchmark to the next. Percent fuel surface burned was measured along three 36-m transects, systematically spaced 12 m apart. Transects were evaluated for percentage of area charred versus area uncharred, using the combined point-intercept–line-transect method.

Fuel and site condition data were collected for each burn treatment to determine if these factors varied by fire treatment and could be related to fire intensity or percent surface burned across treatments. Fuel loading was measured 1 hour prior to the burn by clipping all vegetation, dead and live, down to the soil surface in six random 0.25-m^2 quadrats per sampling plot. Samples were bagged, air-dried in a greenhouse for 4 weeks, and weighed to estimate dry weight of total available fuels. To measure fine fuel moisture, fine fuels were clipped within 1 hour of burns, sealed in two air-tight plastic bags, kept in a cooler, and weighed within 48 h of the prescribed burn. Samples were oven-dried at 65 °C for 48 h, then re-weighed to estimate percent moisture by weight. Soils were sampled in each plot to determine soil moisture 24 h prior to each prescribed burn by clipping all vegetation, dead and live, down to the soil surface. Four random replicate cores 5 cm deep were combined into a composite sample per plot, placed in airtight soil tins, and kept refrigerated until weighed. Soil samples were weighed, dried at 105 °C for 48 h, and re-weighed to obtain volumetric soil moisture content.

Statistical Analyses

Analysis of Covariance (ANCOVA) was used to determine differences in shrub stem density among treatments after adjusting for the covariate of pre-treatment shrub stem density, using PROC GLM (SAS Institute 1998). LSMEANS was used to determine least squares treatment means after adjusting for the effect of the covariate (SAS Institute 1998). Tukey's *w* procedure (Ott 1993) was used to make pairwise comparisons among adjusted treatment means, controlling the experimentwise error rate at 0.05. Stem density data for MNWR were log-transformed to improve normality in statistical tests. Means were back-transformed for presentation. ANCOVA and Tukey's *w* were also conducted on shrub percent frequency data, for FLNF and INWR, adjusting data for the covariate of pre-treatment shrub percent frequency.

Analysis of Variance (ANOVA) and Tukey's *w* were used to test for differences between treatments for Poaceae and *Solidago* spp. percent frequency and percent composition, shrub height, fire behavior parameters, and burn site conditions (Minitab 1998, SAS Institute 1998). Fire and site condition data were combined for identical burn treatments among sites (e.g., spring burn, summer mow–burn).

Logistic regression was used to test for differences among treatments in mortality of *L. morrowii* and stoloniferous *Cornus* spp. An exact logistic regression was performed using LogXact (CYTEL Software Corporation 1996) to compare mortality differences by species and to form treatment contrasts after combining the two species. Minitab was used to develop exact binomial confidence intervals for mortality by treatments (Minitab 1998).

Combined fire behavior and site condition data from all fires at all sites were used to develop simple and multiple linear regression models. Models were developed separately for treatments involving spring burns and summer mow–burns, relating fire intensity and percent surface burned to site conditions. All subsets regression and PROC REG (SAS Institute 1998) were used to select the best predictor variables from fuel loading, soil percent moisture, fine fuel moisture, soil temperature, and relative humidity. Models were selected based upon predictive power (R^2) and significance of predictor variables ($P < 0.05$). Percentage or proportional data were normalized for analysis using an arcsine transformation (Zar 1984). Means were back-transformed for presentation.

RESULTS

Shrub Response

At INWR, stem densities were not significantly different among the burn treatments and the control for *L. morrowii* ($P < 0.725$) or stoloniferous *Cornus* spp. ($P < 0.353$). All burn treatments failed to reduce

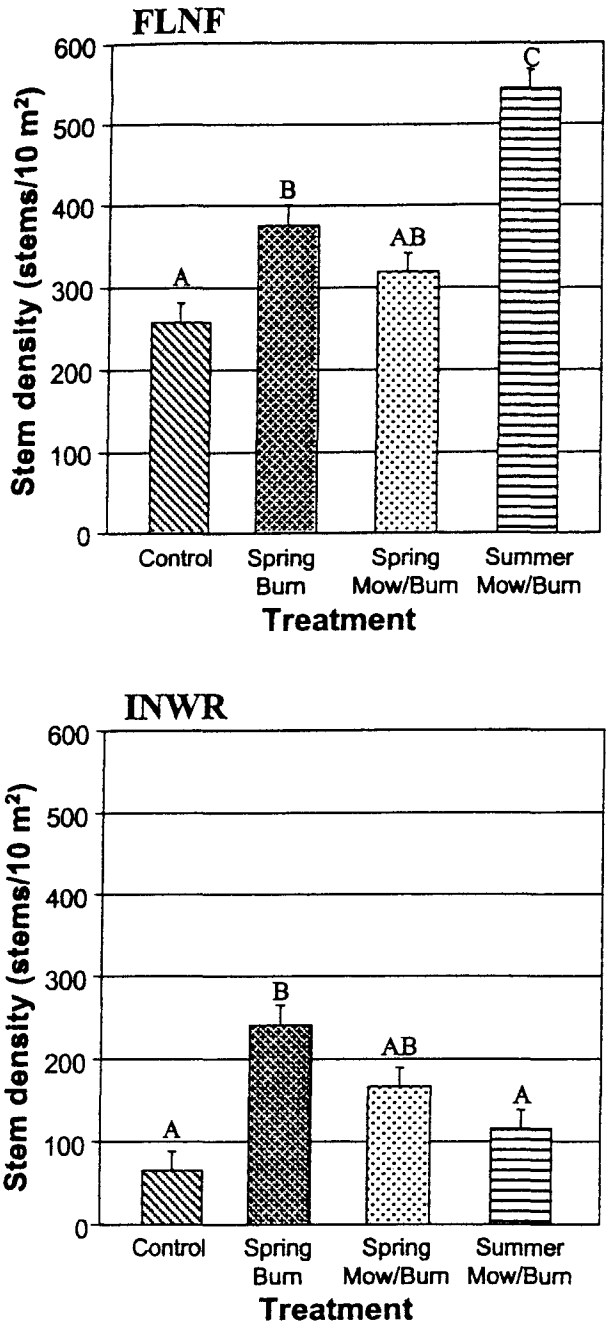


Fig. 1. Stem density of *Cornus racemosa* among prescribed fire treatments at Finger Lakes National Forest (FLNF) and Iroquois National Wildlife Refuge (INWR), New York, 1999. Densities are adjusted for the covariate of pre-treatment density. Error bars represent 1 SE from the mean. Means having dissimilar letters are significantly different ($P < 0.05$).

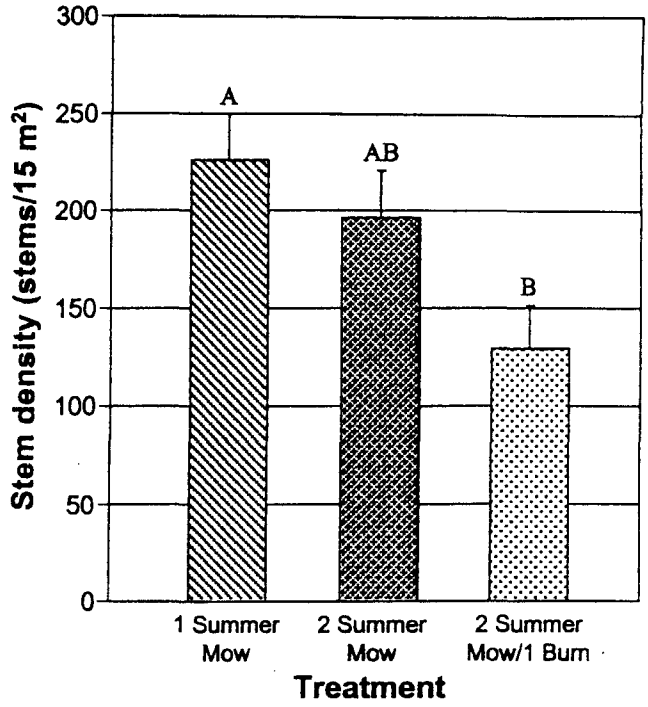


Fig. 2. Stem density of *Cornus racemosa* among prescribed fire treatments at Montezuma National Wildlife Refuge (MNWR), New York, 1999. Densities are adjusted for pre-treatment density. Error bars represent 1 SE from the mean. Means having dissimilar letters are significantly different ($P < 0.05$).

C. racemosa stem density at both INWR and FLNF. *C. racemosa* stem density was highest overall ($P < 0.05$) in the spring burn treatment at INWR ($\bar{x}$ = 241 ± 24 stems/10 m²), and in the summer mow–burn treatment at FLNF ($\bar{x}$ = 544 ± 24 stems/10 m²) (Figure 1). At MNWR, stem densities were lower ($P < 0.05$) in the two summer mow–burn treatments ($\bar{x}$ = 129 ± 1 stems/15 m²) than in the one summer mow treatment ($\bar{x}$ = 226 ± 1 stems/15 m²) (Figure 2).

Percent frequency of shrubs at both INWR and FLNF was reduced ($P < 0.05$) following the summer mow–burn treatment and the spring mow–summer burn treatment (Figure 3). As expected, spring burns did not reduce percent frequency of shrubs.

No *C. racemosa* shrubs were killed in any of the subplots at INWR or FLNF the summer following treatments. Mortality differences between *L. morrowii* and stoloniferous *Cornus* spp. were not significant. Neither of these species were killed by the spring burn treatment (Table 1). Combined mortality data of the two shrub species indicate that mortality differed by treatment ($P < 0.008$; Table 2). Summer burn treatments showed greater shrub mortality than the spring burn treatment ($P < 0.05$). Mortality did not differ ($P < 0.12$) between summer mow–burn (mortality CI = [14%, 35%]) and spring mow–burn (mortality CI = [17%, 64%]) treatments. Maximum *C. racemosa* height at FLNF was lowest overall ($P < 0.05$) for the summer mow–burn treatment ($\bar{x}$ = 0.46 ± 0.07 m) (Figure 4).

Herbaceous Response

At FLNF, the frequency ($\bar{x}$ = 58 ± 17%) and composition ($\bar{x}$ = 57 ± 3%) of Poaceae in the summer mow–burn treatments were greater than in other treatments ($P < 0.05$) 1 year after prescribed fire (Figure 5). At INWR, the frequency ($\bar{x}$ = 53 ± 11%) of Poaceae in the summer mow–burn treatment was greater ($P < 0.05$) than in the control ($\bar{x}$ = 27 ± 4%) and spring burn ($\bar{x}$ = 29 ± 3%) treatments (Figure 6).

Solidago spp. frequency at FLNF was significantly

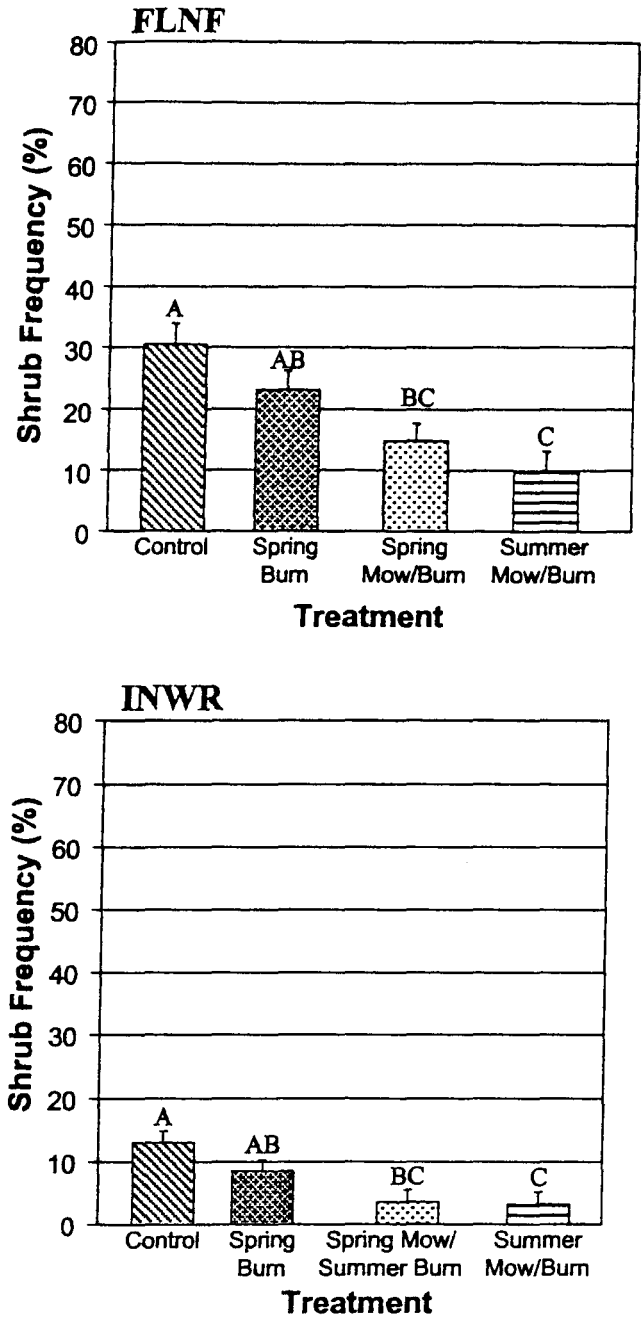


Fig. 3. Shrub percent frequency among prescribed fire treatments at Finger Lakes National Forest (FLNF) and Iroquois National Wildlife Refuge (INWR), New York, 1999. Densities are adjusted for pre-treatment density. Error bars represent 1 SE from the mean. Means having dissimilar letters are significantly different ($P < 0.05$).

Table 2. Mortality differences in shrubs following prescribed fire treatments at Iroquois National Wildlife Refuge, New York, 1999. Statistical significance of selected contrasts between treatments are shown.

Contrast	*P*-value
Treatment effect	0.0008
Burning vs. control	0.1003
Summer burn vs. spring burn	0.0467
Spring mow–burn vs. summer mow–burn	0.1212

lower ($P < 0.05$) in the summer mow–burn treatment ($\bar{x} = 17 \pm 2\%$) than in the other treatments (Figure 5). This treatment also showed less ($P < 0.05$) *Solidago* spp. percent composition ($\bar{x} = 34 \pm 4\%$) than the spring burn ($\bar{x} = 57 \pm 5\%$) and spring mow–burn ($\bar{x} = 47 \pm 4\%$) treatments (Figure 6). The frequency of *Solidago* spp. at INWR was lower ($P < 0.05$) in the summer mow–burn treatment ($\bar{x} = 11 \pm 1\%$) than in the spring burn treatment ($\bar{x} = 32 \pm 7\%$) (Figure 6).

Fire

Fuel loading did not differ among burn treatments (Appendix 4). Fine fuel moisture was lower ($P < 0.05$) in the spring mow–summer burn treatment than in any other treatment. Relative humidity was similar between summer treatments and higher than spring treatments ($P < 0.05$). Soil percent moisture was comparable between summer treatments and lower than spring treatments ($P < 0.05$). Soil temperature was comparable between summer treatments and higher than spring treatments ($P < 0.05$).

The spring mow–summer burn treatment produced more intense fires than any other treatment ($P < 0.05$) (Appendix 3). Fire rate of spread was higher for this treatment than spring mow–burn and summer mow–burn treatments. Average maximum surface temperatures for spring mow–summer burn fires were higher than spring and spring mow–burn fires ($P < 0.05$). Summer mow–burn treatments had less percent fuels surface burned than spring burn and spring mow–summer treatments ($P < 0.05$).

For treatments involving spring burns, percent fuel surface burned was positively related to soil temperature ($P < 0.02$) and negatively related to soil percent moisture ($P < 0.002$) (Figure 7). For summer mow–burn treatments, percent surface burned was positively related to fuel load ($P < 0.037$) (Figure 8). Results were suggestive of negative relationships between percent surface burned and relative humidity ($P < 0.068$)

Table 1. Mortality differences in shrubs following prescribed fire treatments at Iroquois National Wildlife Refuge, New York, 1999. Data were combined for *Lonicera morrowii* and stoloniferous *Cornus* spp. Overall treatment effect was significant ($P < 0.001$).

Treatment	Total survived	Total dead	95% Binomial CI for mortality	
			Lower	Upper
Control	18	0	0	0.185
Spring burn	18	0	0	0.185
Spring mow–summer burn	16	2	0.014	0.347
Summer mow–summer burn	11	7	0.173	0.643

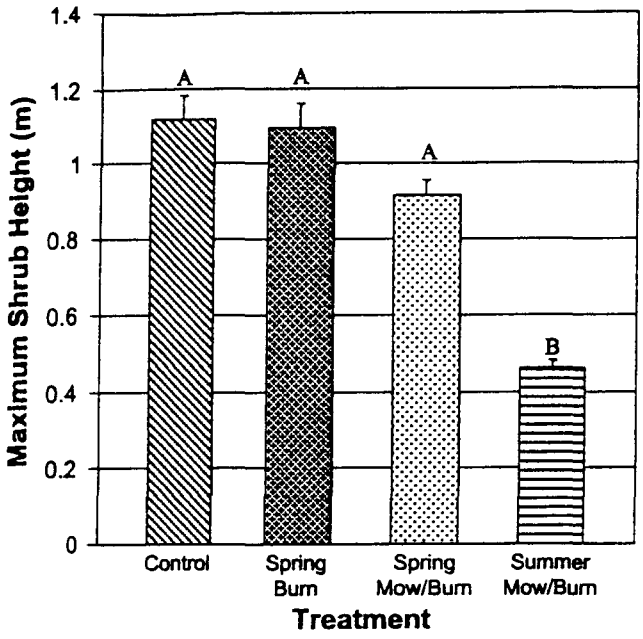


Fig. 4. Height of *Cornus racemosa* among prescribed fire treatments at Finger Lakes National Forest, New York, following the 1999 growing season. Error bars represent 1 SE from the mean. Means having dissimilar letters are significantly different ($P < 0.05$).

and soil moisture ($P < 0.089$). No good predictors for fire intensity were found for spring burn or summer mow–burn treatments using site condition variables. A larger sample of fires may be necessary to provide an adequate range of site conditions or different variables may have to be identified and measured.

DISCUSSION

Shrubs

Based on earlier work (Dunwiddie et al. 1997, Rudnicky et al. 1997), we had expected fires during the growing season to be more damaging to shrubs and to reduce shrub stem density. Contrary to our expectations, none of the growing-season combination mow–burn treatments at INWR or FLNF reduced shrub stem density for *C. racemosa, C. sericea, C. amomum,* or *L. morrowii.* Since dormant-season burns at INWR and FLNF increased *C. racemosa* stem density, annual dormant-season treatments currently used by many managers may accelerate increases in density of *C. racemosa* in old fields.

Growing-season mowing and burning treatments repeated during consecutive years may eventually reduce *C. racemosa* stem density more rapidly in younger fields than in older fields. Pre-treatment *C. racemosa* stem density was higher at FLNF than INWR, consistent with our determination that shrub invasion began at least 10 years earlier at FLNF. The older larger *C. racemosa* shrubs at FLNF likely had more below-ground biomass than shrubs at INWR. *C. racemosa* shrubs at FLNF probably had more reserves to draw upon following topkill events, including mowing

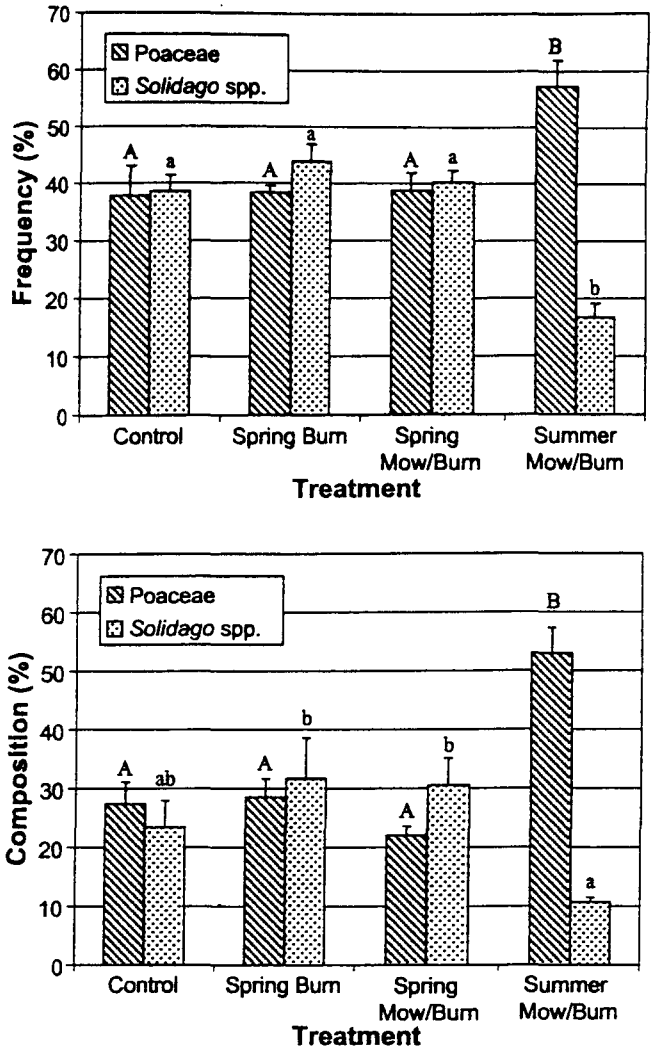


Fig. 5. Percent frequency and composition of Poaceae and *Solidago* spp. among prescribed fire treatments at Finger Lakes National Forest, New York, 1999. Error bars represent 1 SE from the mean. Means having dissimilar uppercase letters are significantly different ($P < 0.05$) for Poaceae; means having dissimilar lowercase letters are significantly different ($P < 0.05$) for *Solidago* spp.

and burning treatments during the growing season and were able to respond with multiple resprouts per top-killed stem. The younger *C. racemosa* shrubs at INWR showed fewer resprouts in response to growing-season treatments.

Results at MNWR indicate that 2 consecutive years of intensive growing-season mowing applications combined with follow-up summer fire can reduce *C. racemosa* stem density in old fields up to 57% compared with fields subjected to only one growing-season mowing application. Mowing during September 1998 may have removed above-ground *C. racemosa* organs before the plants could translocate inorganic nutrients to roots prior to fall senescence. During 1999, we allowed shrubs to expend energy in resprouting after mowing treatments before again top-killing them with a burn treatment. While conducting counts in October, we noted that many *C. racemosa* shrubs had failed to

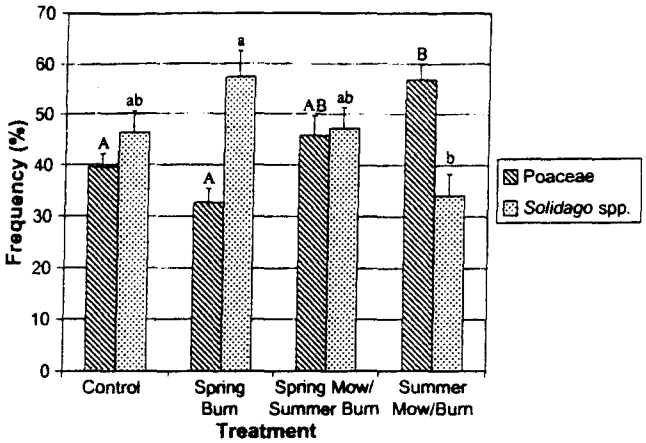


Fig. 6. Percent frequency of Poaceae and *Solidago* spp. among prescribed fire treatments at Iroquois National Wildlife Refuge, New York, 1999. Error bars represent 1 SE from the mean. Means having dissimilar uppercase letters are significantly different ($P < 0.05$) for Poaceae; means having dissimilar lowercase letters are significantly different ($P < 0.05$) for *Solidago* spp.

resprout entirely in the mow–burn treatments and were probably dead.

As in other studies (Baker 1968), the spring fires we applied alone failed to reduce shrub frequency. Combining mowing with burning reduced shrub frequency by more than 50% in fields in both early and intermediate stages of succession. At FLNF, data suggest summer mowing–burning may have had a greater effect than spring mowing–burning, although differences were not significant.

C. racemosa was more resistant to mortality from fire than *L. morrowii* and stoloniferous *Cornus* spp. New *C. racemosa* ramets emerge from rhizomes, which may be more protected from fire effects by the insulating properties of soil. Many *C. amomum* and *C. sericea* ramets emerge from stolons; stolon bud tissue may be more directly exposed to fire. *L. morrowii* is not clonal; new buds emerge directly from the aboveground stool, which also may be more exposed to fire. As predicted, shrub mortality was higher in summer treatments.

C. racemosa height at FLNF at the completion of the 1999 growing season was about one-half that of other treatments. This difference contributed to a visual effect of a field dominated by grasses versus other treatments, which could be more attractive to grassland breeding birds (Sample and Mossman 1997).

Herbaceous Community

Summer mow–burn treatments increased Poaceae frequency at INWR and FLNF, and percent composition of Poaceae at FLNF. No treatments reduced Poaceae frequency. At FLNF, this may be because the site had been burned during the two previous dormant seasons (1996, 1997), already depressing frequency and composition of cool-season grasses. Also, grasses had not yet emerged during the FLNF dormant-season treatments and had just barely emerged at the time of

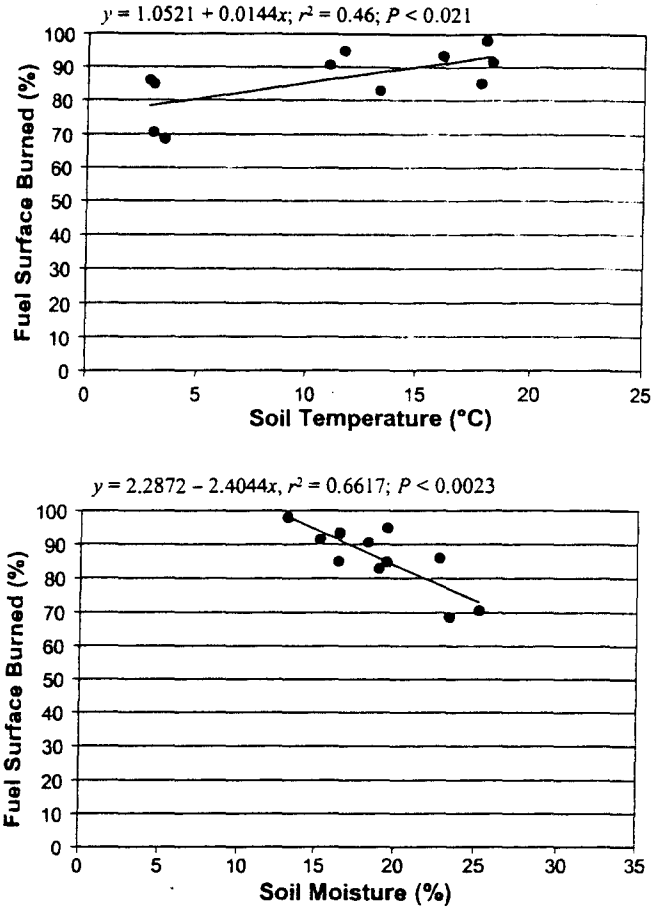


Fig. 7. Relationship between percent fuel surface burned and site conditions for prescribed fire treatments involving spring burns at Finger Lakes National Forest, Iroquois National Wildlife Refuge, and Montezuma National Wildlife Refuge, New York. Data are combined from prescribed burns at all three study sites.

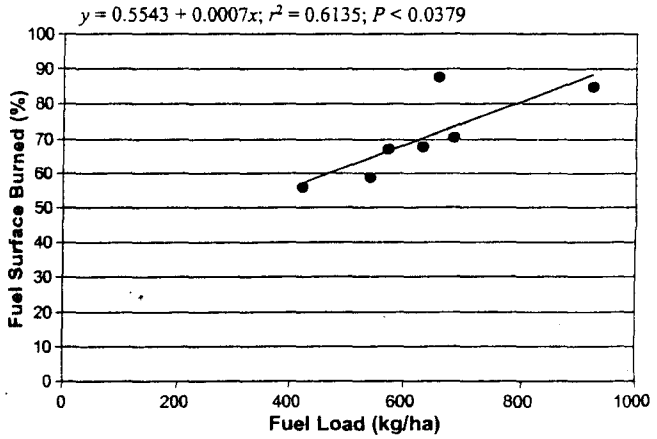


Fig. 8. Relationship between percent fuel surface burned and fuel loading for summer mow–burn treatment at Finger Lakes National Forest and Iroquois National Wildlife Refuge, New York. Data are combined from prescribed burns at both study sites.

the INWR dormant-season treatments. Burning during emergence of cool-season grasses has not been shown to affect these plants adversely. To show detrimental effects, burning must be accomplished during later stages of development, such as tiller elongation, heading, and flowering (Wilson and Stubbendieck 1997).

Summer mow–burn treatments reduced *Solidago* spp. frequency compared with all other treatments at FLNF. Our results suggested that *Solidago* spp. frequency was increased by spring burn treatments at INWR. *Solidago* spp. frequency was not increased by spring burn treatments at FLNF. This may be because FLNF had been burned previously during the spring and had already experienced increased frequency and composition of *Solidago* spp.

Our results support Howe's conclusions (1994*a*, 1995) that growing-season treatments in grasslands negatively affect late-season species while benefiting early-season species. Summer treatments reduce the ability of late-season plants to compete with early-season species during the next period of growth overlap between groups. At FLNF and INWR, early-season plants such as cool-season grasses had already flowered, seeded, and possibly stored resources at the time of summer treatments, while *Solidago* spp. had not yet completed growth or flowered. Conversely, spring fires benefited late-season species such as *Solidago* spp. by removing litter, warming soils, and allowing these species an extended growing season (Howe 1995).

McGinley and Tilman (1993) concluded that short-term changes in plant community structure following disturbance in old fields, including burning, were more strongly influenced by interspecific differences in germination and establishment than differences in growth rates. Both mechanisms may be at work at FLNF. Summer-treated plots increased in grass density, as indicated by increased Poaceae frequency. These plots also increased in plant size in grasses versus *Solidago* spp.: Poaceae composition increased while *Solidago* spp. composition decreased.

Fire Behavior

No significant predictors were found for fire intensity. This is largely because for each burn season (spring and summer), both low- and high-intensity fires occurred under similar site conditions. Fires with the highest overall intensity were associated with the spring mow–summer burn treatment, which involved sickle-bar mower fuel treatment prior to ignition. This action produced a fuel bed of continuous pieces of dry vegetation with air spaces. In contrast, the summer mow–burn treatment used a rotary mower at least a month prior to ignition, and new green growth added to fuel moisture. The rotary mower also chopped and compacted fuel. Fine fuel moisture was significantly lower for the intense fires of the spring mow–summer burn treatment than for all other treatments. Low fuel moisture was associated with high fire intensity, consistent with fire behavior theory (Wade and Lunsford 1988).

Percent surface burned was related to soil percent moisture in spring burns. All three sites had wet soil conditions in the early growing season. In late March and early April, the study areas underwent heavy precipitation and snow-melt, making the soil–litter interface wet during spring burns. Less surface area burned where soils had higher moisture content. Soils in the same fields were dry during summer fires; therefore, fuel load became a better predictor of the amount of surface burned.

Fire Effects on Woody Plants

There is no direct contrast between the effects of dormant-season versus growing-season prescribed fire behavior on the shrubs at FLNF and INWR. Mowing preceded summer burns. Therefore, the effects of summer fire cannot be separated from the effects of combining mowing with burning. Nevertheless, treatment season was often more important than measured fire behaviors to shrub response.

At FLNF, the summer mow–burn combination was more effective at reducing shrub frequency than the spring burn treatment. Frequency for the spring mow–burn combination was intermediate between spring burn and summer mow–burn. Results were similar at INWR: summer mow–burn treatments had lower shrub frequency than spring burn treatments, while spring mow–summer burn frequencies were intermediate to these treatments. Spring burn treatments had more intense and less patchy fires than most combination treatment fires. Shrub frequency was therefore unrelated to fire intensity and patchiness, but season of mowing (summer vs. spring) may have had an effect.

At INWR, intense spring fires killed no shrubs: mortality occurred in treatments involving mowing and summer fires. Mortality did not differ significantly between the spring mow–summer burn treatment and the summer mow–burn treatment. Confidence intervals for mortality for each treatment suggest that there may have been higher mortality associated with the summer mow–burn treatment versus the spring mow–summer burn treatment. The summer mow–burn treatment had low fire intensity and high patchiness, while the spring mow–summer burn treatment had high intensity and low patchiness. Mortality appears to be unrelated to these fire behaviors. In addition to the combined effects of mowing and burning, mortality may have been related to an unanalyzed type of fire behavior, burning duration. During summer fires, we observed flaming and smoldering for several minutes in piles of mowed woody debris that had accumulated on top of shrub stumps. This behavior was not observed during spring fire treatments because woody debris was cool and wet. Prolonged burning may have facilitated heat penetration to below-ground shrub tissues, such as the root collar (Wade and Lunsford 1988).

The summer mow–burn treatment at INWR resulted in lower *C. racemosa* stem densities than the spring burn treatment and was comparable to the spring mow–summer burn treatment. The spring mow–summer burn treatment had the most intense fires of all of our treatments. Summer fires at MNWR

had low intensity, yet these summer mow–burn treatments were the only treatments that reduced stem density in *C. racemosa*. Stem density reduction appears unrelated to fire intensity and potentially related to treatment season.

Summer treatments, including mowing, shortened the growing season for resprouting shrubs versus spring treatments, reducing the shrubs' ability to accumulate and translocate inorganic nutrients and energy reserves for the following growing season. In addition, summer fire site conditions may have contributed to reduced stem density and shrub frequency. Soil moisture was lower and soil temperature was higher during summer burns. This may have exerted drought stress upon regenerating shrubs, especially because burning reduced litter levels and blackened soils for the remainder of the summer growing season. Low soil moisture may enhance the ability of prescribed fire to injure shrub tissues below ground (Wade and Lunsford 1988) because water must evaporate before heat can transfer to below-ground plant tissues (DeBano et al. 1998, Barbour et al. 1999). Higher ambient air and soil temperatures may have increased fire effects on shrubs during summer fires. Less heat is required to raise plant cells to lethal temperatures in warm summer conditions than in cool spring conditions (Wade and Lunsford 1988). This principle appears supported by the fact that average maximum temperatures were higher during summer fires, despite lower energy releases than during spring fires.

MANAGEMENT IMPLICATIONS

Recent grasslands research has suggested that the season of burn treatment may be more important than fire behavior in influencing grassland vegetation (Howe 1995, Dunwiddie et al. 1997). This appears to be the case for both shrubs and herbaceous plants in cool-season grasslands in old fields in New York. Treatment season was found to affect several factors one growing season after treatment. Growing-season burns favored early-season plants such as cool-season grasses over late-season plants such as *Solidago* spp. In contrast, dormant-season fires gave competitive advantage to late-season plants, appearing to increase frequency and composition of species such as *Solidago* spp. Second, treatment season also influenced the frequency of shrubs and may have influenced shrub stem density and mortality. Summer mow–burn treatments reduced 1) shrub frequency in both early and intermediate stages of old field shrub invasion, 2) stem density of *C. racemosa* when done following two consecutive summer mow treatments, 3) *C. racemosa* height in fields in intermediate stages of shrub invasion, and 4) numbers of live *L. morrowii* and stoloniferous *Cornus* spp. Spring mow–summer burn treatments also killed shrubs and reduced shrub frequency in fields in early stages of succession. In contrast, spring burn treatments failed to kill any shrubs or to reduce shrub frequency, stem density, or height in old fields in early and intermediate stages of succession.

Dormant-season burns alone do not appear to be effective at restoring or maintaining early successional grassland habitats in northeastern old fields and may hasten vegetation shifts to dense shrub thickets (>1 m tall) with higher frequency and composition of *Solidago* spp. than to cool-season grasses. Summer treatments were found to change vegetation structure in shrubby old fields to more closely resemble typical grassland breeding bird habitat in the Northeast one growing season after treatments. Summer mow–burn treatments maintained high ratios of grass composition and frequency to forb composition and frequency, low shrub frequency, and low shrub height. Immediate reductions in shrub frequency were about the same in fields in early stages of shrub invasion (minimum 2–4 years of invasion) as older fields (minimum 15 years of invasion). Nevertheless, summer mow–burn treatments are likely to reduce stem density of shrubs in early successional fields earlier than in older fields.

C. racemosa is a resilient shrub. One summer mow–burn application failed to kill this species and also failed to reduce stem density one growing season after treatment. Two years of consecutive growing-season treatments (late summer mow followed by a summer mow–burn application) appear to be necessary to reduce the number of resprouted *C. racemosa* stems and to kill some shrubs.

Summer fire, when augmented by dry vegetation from sickle-bar mowing, can be as intense as traditional spring fires. If a comparably intense fire were timed to destroy shrub resprouts following the mowing (about a month), this treatment could likely severely affect resilient shrubs such as *C. racemosa*.

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Appendix 1. Frequency of vegetation (percent) in grassland control plots at Finger Lakes National Forest (FLNF) and Iroquois National Wildlife Refuge (INWR), New York, 1999.

Site	Scientific name	Common name	Frequency (%)
FLNF	Cornaceae		
	Cornus racemosa	Gray dogwood	30.3
	Cornus sericea	Redosier dogwood	2.5
	Rosaceae		
	Crataegus sp.	Hawthorn	1.0
	Fragaria virginiana	Wild strawberry	16.5
	Asteraceae		
	Aster lateriflorus	Calico aster	2.0
	Aster novae-angliae	New England aster	4.5
	Euthamia graminifolia	Flattop goldenrod	6.3
	Solidago canadensis var. *scabra*	Canada goldenrod	36.0
	Hieracium pratense	Hawkweed	3.5
	Solidago juncea	Early goldenrod	2.3
	Solidago rugosa	Wrinkleleaf goldenrod	8.3
	Poaceae		
	Anthoxanthum odoratum	Sweet vernal grass	4.7
	Phleum pratense	Timothy	19.5
	Poa compressa	Canada bluegrass	19.0
	Poa pratensis	Kentucky bluegrass	5.7
	Bromus inermis	Smooth brome	1.0
	Other forbs		
	Carex sp.	Unknown sedge	2.0
	Juncus tenuis	Path rush	2.0
	Lotus corniculatus	Birdsfoot trefoil	8.0
	Trifolium repens	White clover	1.0
INWR	Cornaceae		
	Cornus racemosa	Gray dogwood	3.5
	Rosaceae		
	Rubus occidentalis	Black raspberry	1.0
	Geum canadense	White avens	1.0
	Caprifoliaceae		
	Lonicera morrowii	Bush honeysuckle	7.3
	Galium aparine	Cleavers	1.0
	Poaceae		
	Agrostis gigantea	Redtop	2.0
	Elytrigia repens	Quackgrass	15.5
	Festuca elatior	Meadow fescue	1.3
	Phleum pratens	Timothy	13.0
	Poa compressa	Canada bluegrass	15.0
	Poa palustris	Fowl bluegrass	1.3
	Poa pratensis	Kentucky bluegrass	7.0
	Asteraceae		
	Unknown Asteraceae		8.0
	Chrysanthemum leucanthemum	Ox-eye daisy	1.3
	Cirsium vulgare	Bull thistle	1.3
	Euthamia graminifolia	Flattop goldenrod	3.0
	Solidago canadensis var. *scabra*	Canada goldenrod	52.0
	Solidago juncea	Early goldenrod	4.3
	Solidago rugosa	Wrinkleleaf goldenrod	5.0
	Taraxacum officinale	Dandelion	0.3
	Other forbs		
	Vicia tetrasperma	Slender vetch	23.0
	Juncus tenuis	Path rush	3.0
	Lotus corniculatus	Birdsfoot trefoil	5.0
	Stellaria graminea	Common stichwort	1.0
	Linaria vulgaris	Butter and eggs	6.0
	Ipomoea pandurata	Wild potato vine	5.0

Appendix 2. Dates of experimental prescribed fire treatments at Finger Lakes National Forest (FLNF), Iroquois National Wildlife Refuge (INWR), and Montezuma National Wildlife Refuge (MNWR), New York, 1998–1999.

Site	Treatment	1998		1999	
		Mow date	Burn date	Mow date	Burn date
FLNF	Spring burn	—	14 Apr	—	—
	Spring mow–burn	3 Apr	14 Apr	—	—
	Summer mow–burn	10 Jun	24 Aug	—	—
INWR	Spring burn	—	23 Apr	—	—
	Spring mow–burn	6 Apr	13 Aug	—	—
	Summer mow–burn	9 Jun	13 Aug	—	—
MNWR	1 summer mow	Sep	—	—	—
	2 summer mow	Sep	—	7 Jul	—
	2 summer mow–burn	Sep	—	7 Jul	3 Aug

Appendix 3. Fire behavior recorded for each prescribed fire treatment at Finger Lakes National Forest (FLNF), Iroquois National Wildlife Refuge (INWR), and Montezuma National Wildlife Refuge (MNWR), New York, 1998–1999. Results are reported ± 1 SE.

Site	Year	Variable	Treatment			
			Spring burn	Spring mow–summer burn	Spring mow–burn	Summer mow–burn
INWR	1998	Fire intensity (kW/m)	134 ± 68	263 ± 3		1 ± 0
		Rate of spread (m/h)	551 ± 123	680 ± 20		61 ± 7
		Average maximum temperature (°C)	260 ± 26	292 ± 6		262 ± 5
		Percent burned	92 ± 3	94 ± 1		80 ± 6
FLNF	1998	Fire intensity (kW/m)	119 ± 31		79 ± 43	25 ± 12
		Rate of spread (m/h)	466 ± 17		286 ± 53	21 ± 3
		Average maximum temperature (°C)	72 ± 12		78 ± 4	219 ± 20
		Percent burned	91 ± 3		80 ± 10	63 ± 4
MNWR	1999	Fire intensity (kW/m)				2 ± 0
		Rate of spread (m/h)				12 ± 1
		Average maximum temperature (°C)				208 ± 6
		Percent burned				54 ± 12

Appendix 4. Site conditions recorded during each prescribed fire treatment at Finger Lakes National Forest (FLNF), Iroquois National Wildlife Refuge (INWR), and Montezuma National Wildlife Refuge (MNWR), New York, 1998–1999. Results are reported ± 1 SE.

Site	Year	Variable	Treatment			
			Spring burn	Spring mow–summer burn	Spring mow–burn	Summer mow–burn
INWR	1998	Moisture content (%)				
		Soil	14.9 ± 0.9	8.1 ± 0.3		8.1 ± 0.2
		Fine fuel	8.9 ± 0.7	4.7 ± 0.5		11.0 ± 0.0
		Fuel loading (kg/ha)	322 ± 37	496 ± 61		299 ± 37
		Soil temperature (°C)	18 ± 2	29 ± 0		27 ± 0
		Air temperature (°C)	18 ± 0	21 ± 0		21 ± 0
		Relative humidity (%)	32 ± 0	51 ± 1		46 ± 1
FLNF	1998	Moisture content (%)				
		Soil	18.3 ± 0.6		18.9 ± 1.0	12.5 ± 0.5
		Fine fuel	11.8 ± 0.5		12.0 ± 0.6	6.6 ± 0.3
		Fuel loading (kg/ha)	161 ± 19		160 ± 10	224 ± 22
		Soil temperature (°C)	13 ± 1		12 ± 1	25 ± 1
		Air temperature (°C)	18 ± 0		18 ± 0	26 ± 1
		Relative humidity (%)	40 ± 2		37 ± 2	52 ± 1
MNWR	1999	Moisture content (%)				
		Soil				12.6 ± 0
		Fine fuel				10.3 ± 0.6
		Fuel loading (kg/ha)				208 ± 17
		Soil temperature (°C)				23 ± 0
		Air temperature (°C)				24 ± 0
		Relative humidity (%)				53 ± 0