CHAPTER 10.

The Roles of Fire, Overstory Thinning, and Understory Seeding for the Restoration of Iowa Oak Savannas (Project NC-F-07-1)

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INTRODUCTION

Savanna ecosystems historically comprised more than 10 million ha of the Midwestern United States, forming a transition zone between western prairies and eastern deciduous forest that extended from Texas into Canada (Nuzzo 1986). These ecosystems were characterized by frequent understory fires, scattered (frequently oak) overstory trees, and a dense, diverse understory layer of grasses, forbs, and shrubs (Nuzzo 1986). With fire suppression, Midwestern savannas can convert to a woodland state through encroachment by disturbance-intolerant shrubs and trees (Brudvig and Asbjornsen 2007, Karnitz and Asbjornsen 2006), leading to reductions in understory diversity (Brudvig 2010, Brudvig and Asbjornsen 2009a), oak regeneration (Brudvig and Asbjornsen 2008, 2009b), and overstory oak tree growth rates (Brudvig and others 2011). Following settlement, most Midwestern savannas were converted to agriculture or were fire suppressed and, although less than 1 percent of historic savannas remain relatively pristine, a large amount may exist in the fire-suppressed, encroached state, and these savannas may be restorable (Asbjornsen and others 2005, Nuzzo 1986). Oak savanna restoration generally involves overstory thinning (i.e., clearing of nonsavanna trees and shrubs) and reintroduction of fire (McCarty 1998); however, little is known about the impacts of such restoration activities on biotic and abiotic ecosystem attributes or the importance of reintroducing native understory species for achieving restoration goals.

In 2008, we initiated an experiment to address these research needs using fire-suppressed, encroached oak savannas in Iowa. Here, we report on the three core objectives for this project: (1) initiate a new, large-scale experiment to evaluate overstory thinning, prescribed fire, and understory species reintroductions as restoration protocols in Midwestern oak savannas; (2) evaluate the effects of these treatments on understory and overstory indicators of forest health; and (3) compare assessments of ecosystem function and restoration success obtained from the measurements in objective 2 with concurrent Forest Inventory and Analysis (FIA) plot measurements.

METHODS, RESULTS, AND DISCUSSION

Site description and study design

The study was conducted in eight 1.5- to 3.3-ha white oak (*Quercus alba*) savanna sites near Saylorville Lake in central Iowa, United States. Following decades of fire suppression, these sites were invaded by (generally native) fire-intolerant trees and shrubs (e.g., *Fraxinus americana*, *Ulmus* sp., *Ostrya virginiana*), leading to conversion of the once open-canopied savannas to closed-canopy woodlands (Asbjornsen and others 2005, Brudvig and Asbjornsen 2007).

Objective 1

To accomplish objective 1, we initiated an oak savanna restoration experiment, implementing thinning, burning, and seeding treatments at the eight study sites. In 2002–03, all nonoak woody stems greater than 1.5 m in height were cut with chainsaws and removed from four randomly selected sites; these four sites were recleared during early 2008 in preparation for the current study. The other four sites remained encroached, as controls. Within each thinned and unthinned site, a 30-by-50 m prescribed burn treatment area was established and paired with an unburned area of equal size. Prescribed fires were conducted during the spring of 2009 and 2010. Although fires historically occurred during many times of year, our approach was to match our experiment with common restoration practice, and Midwestern restoration practitioners commonly conduct prescribed fires during spring in oak savannas (Packard and Mutel 2005). Within each burned or unburned area, we established three 10-by-10 m seed-addition plots. Plots received either a diverse seed mix containing 75 percent forb seeds and 25 percent graminoid seeds by weight (high forb), 25 percent forb seeds and 75 percent graminoid seeds by weight (low forb), or an unseeded control. Seeded plots received seeds of 30 native oak savanna understory forbs and grasses (table 10.1), at a rate of 10 pounds of seed per acre, in late winter of 2008. Species for seed additions (table 10.1) were selected based on Brudvig and Mabry (2008).

Table 10.1—Species added via seed addition in 2008 and number of study plots inhabited in 2011

Species	Family	Habit	Number of plots
Bromus kalmia	Poaceae	C3 grass	0
Andropogon gerardii	Poaceae	C4 grass	2
Bouteloua curtipendula	Poaceae	C4 grass	0
Schizachyrium scoparium	Poaceae	C4 grass	0
Sorghastrum nutans	Poaceae	C4 grass	5
Spartina pectinata	Poaceae	C4 grass	2
Sporobolus cryptandrus	Poaceae	C4 grass	0
Allium canadense	Liliaceae	Forb	0
Allium cernuum	Liliaceae	Forb	0
Asclepisa tuberosa	Asclepiadaceae	Forb	0
Aster laevis	Asteraceae	Forb	0
Echinacea pallida	Asteraceae	Forb	0
Eryngium yuccifolium	Apiaceae	Forb	1
Liatris pycnostachya	Asteraceae	Forb	0
L. squarrosa	Asteraceae	Forb	0
Monarda punctata	Lamiaceae	Forb	2
Parthenium integrifolium	Asteraceae	Forb	0
Penstemon digitalis	Scrophulariaceae	Forb	8
Potentilla arguta	Rosaceae	Forb	0
Ratibida pinnata	Asteraceae	Forb	0
Rudbeckia subtomentosa	Asteraceae	Forb	7
Silphium integrifolium	Asteraceae	Forb	0
Silphium laciniatum	Asteraceae	Forb	0
Solidago rigida	Asteraceae	Forb	0
Zigadenus elegans	Liliaceae	Forb	0
Baptisia lactea	Fabaceae	N-fixing forb	0
Dalea candida	Fabaceae	N-fixing forb	0
D. purpurea	Fabaceae	N-fixing forb	0
Lupinus perennis	Fabaceae	N-fixing forb	0
Tephrosia virginiana	Fabaceae	N-fixing forb	0

N = nitrogen.

Objective 2

To accomplish objective 2, we established monitoring in each seed-addition plot in 2008. Our nested experimental design enabled us to evaluate each combination of canopy thinning (thinned or unthinned), prescribed fire (burned or unburned), and seed addition (high forb, low forb, or control). In each seed-addition plot (total n = 48), we sampled understory species in four permanently marked 1-by-1 m quadrats, saplings (woody stems > 1.4 m height; < 5 cm diameter at breast height [d.b.h.]) and trees (woody stems > 5 cm d.b.h.) in the full 10-by-10 m plot, individuals of seeded species in the full 10-by-10 m plot, and fire temperature at the 10-by-10 m plot center during prescribed burns. We monitored fire temperature using three "pyrometers"—temperature-sensitive paints affixed to copper tags—per plot, which were deployed prior to prescribed fires. Because establishment of seeded individuals was relatively low, our statistical analyses focus on the effects of thinning and burning, though we qualitatively evaluate species' establishment from seed. To evaluate effects of these treatments on biotic indicators of forest health, we compared thinning and burning treatment effects on understory species richness and tree basal area using two-way analysis of variance (ANOVA). We evaluated the seeding treatments by investigating the number of 10-by-10 m plots in which each species established. To evaluate effects of these treatments on prescribed fire dynamics, we tested the effects of thinning on fire during the 2010 burns using t-tests (mean fire temperature and percent of pyrometers that burned in each burn plot).

Overstory thinning increased understory species richness by ~80 to 160 percent (fig. 10.1A; thinning effect $F_{1,6} = 38.5$, $p = 0.0008$), due to a ~20 to 60 percent reduction in overstory basal area in thinned plots (fig. 10.1B; $F_{1,6} = 3.3$, $p = 0.12$). Conversely, we found little evidence of an effect of thinning on sapling densities (thinning effect $F_{1,6} = 0.0$, $p = 0.97$) or effects of prescribed burning on understory richness (fig. 10.1A; burning effect $F_{1,6} = 0.7$, $p = 0.44$), sampling densities ($F_{1,6}$, $p = 0.32$), or overstory basal area (fig. 10.1B; $F_{1,6} = 0.06$, $p = 0.82$), in spite of the fact that 75 percent of pyrometers registered fire temperatures at greater than 121 °C during 2010 burns (mean temperature was 286 °C). There was no interaction between overstory thinning and fire on understory richness ($F_{1,6} = 1.6$, $p = 0.26$), sapling densities ($F_{1,6} = 0.0$, $p = 0.96$), basal area ($F_{1,6} = 1.3$, $p = 0.30$), or fire during burns; plots in thinned and unthinned sites burned with similar probability (t = 0.75, $p = 0.48$) and at similar temperatures (t = 0.29, $p = 0.78$). Of interest are effects of thinning and burning on oak regeneration. We recorded 7 oak saplings within our plots before prescribed fires (in 2008; of 466 total saplings) and after two prescribed fires (in 2010; of 824 total saplings). This suggests that, anecdotally, burning did not have a pronounced effect on oak sapling densities; however, we are unable to answer this hypothesis statistically with our dataset. We recorded established individuals of seven seeded species in 2011. Many species did not establish from seed (table 10.1); however, some species had become quite abundant by the final year of study (e.g., *Penstemon digitalis* and *Rudbeckia* *subtomentosa*, which we found in ~25 percent of seeded plots), suggesting successfully established populations.

Together, these results suggest that overstory thinning elicits the largest restoration benefits for forest health during the short term, through increased understory diversity and decreased overstory density—both noted restoration goals for Midwestern oak savannas (Asbjornsen and others 2005). While prescribed fire had little impact during the course of this study, frequent burning will be critical for maintaining thinned conditions through prevention of reencroachment by fire-sensitive tree and shrub species (Brudvig and Asbjornsen 2007), and we note the success of both thinned and unthinned plots at carrying fire, producing burns of reasonably high temperature. We suggest that understanding the reestablishment of key understory species—particularly those that did not establish in this study (table 10.1)—should continue to be a priority, due to the potential for oak savannas to harbor high understory diversity (Brudvig and Mabry 2008).

Objective 3

To accomplish objective 3, we established FIA phase 2 plots at each savanna site. Plots were established between 2002 and 2006 and arranged linearly, to coincide with co-occurring sampling transects (Brudvig and Asbjornsen 2007) and to fit within savanna site boundaries. During the summer of 2008, woody species were recorded in each plot using standard FIA methodology for seedling, sapling, and tree

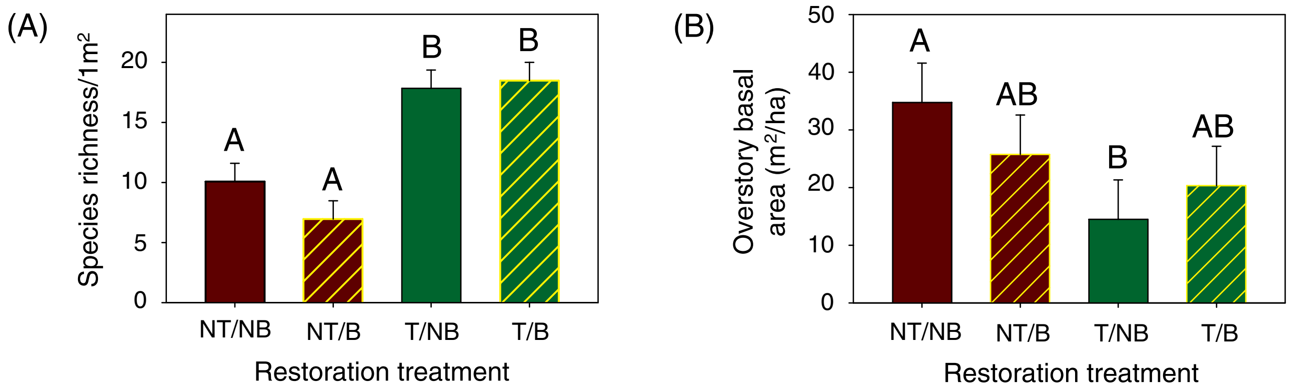

Figure 10.1—Effects of overstory thinning and prescribed fire on (A) understory species richness and (B) overstory tree basal area (stems > 5 cm). Treatments were: no thinning/no burning (NT/NB), no thinning/burning (NT/B), thinning/no burning (T/NB), and thinning and burning (T/B). Bars with different letters were statistically different ($p < 0.05$*, based on two-way analysis of variance).*

size classes. We used FIA data to evaluate the effects of mechanical encroachment removal with ANOVA.

FIA sampling during 2008 illustrated clear effects of overstory thinning (fig. 10.2). Relative to encroached control sites, sites restored by mechanical thinning supported reduced tree density (fig. 10.2A; $F_{1,6} = 22.2$, $p = 0.003$), reduced sapling density (fig. 10.2C; $F_{1,6} = 103.7$, $p < 0.0001$), and greater seedling density (fig. 10.2D; $F_{1,6} = 9.6$, $p = 0.2$). We found no evidence of a change in overstory basal area with restoration thinning (fig. 10.2B; $F_{1,6} = 1.4$, $p = 0.29$). These FIA-derived data illustrate similar patterns to data derived from transect-based sampling for sapling and overstory components; however, the FIA plot approach was sensitive to a change in seedling densities, whereas a transect-based approach was not (Brudvig and Asbjornsen 2007). Conversely, plots related to objective 2 illustrated a reduction in overstory basal area with thinning (fig. 10.1B), whereas FIA data did not resolve this difference (fig. 10.2B).

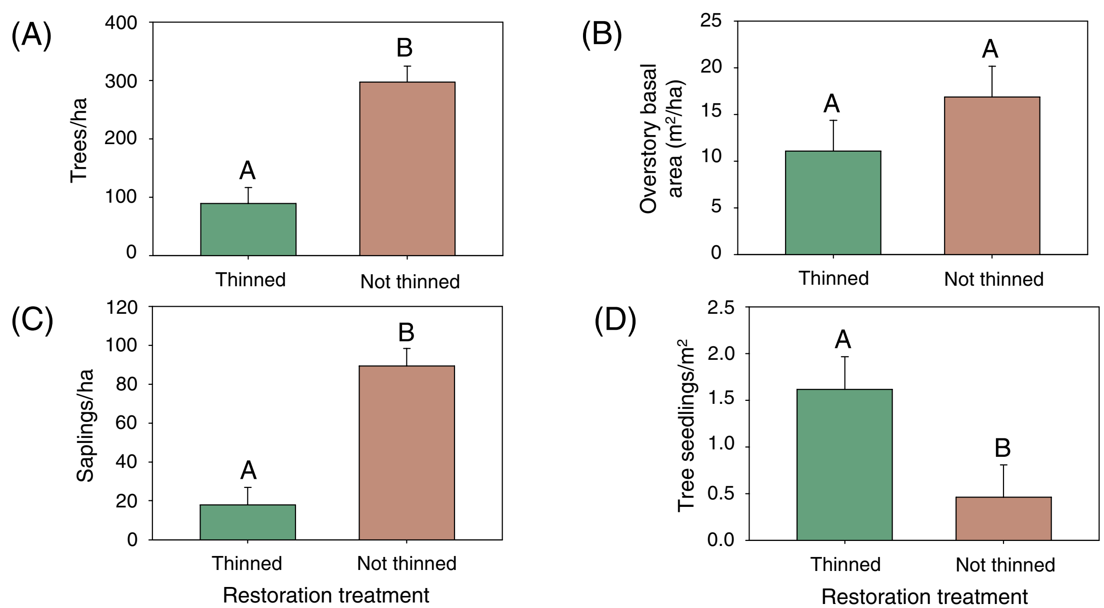

*Figure 10.2—Effects of overstory thinning on (A) overstory tree density, (B) overstory basal area, (C) sapling density, and (D) tree seedling density, as assessed by Forest Inventory and Analysis phase 2 plot data. Bars with different letters indicate statistical differences between restoration treatments (*p *< 0.05, based on two-way analysis of variance).*

Data from FIA phase 2 plots were effective at documenting changes in stand structure following oak savanna restoration. Decreased overstory tree and sapling densities, coupled with increased seedling density, illustrate positive benefits of thinning for oak savanna health through a reestablishment of scattered overstory trees and elevated understory light levels (Brudvig and Asbjornsen 2009a), decreased midstory encroachment (Brudvig and Asbjornsen 2007), and the potential for increased tree regeneration, including of oak species (Brudvig and Asbjornsen 2008, 2009b). FIA phase 2 plots may be broadly useful for documenting stand-scale changes in woody species abundance and stand structure following restoration; however, rearrangement of subplots to fit within sites may be necessary.

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